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We assessed bee diversity and abundance in a botanical garden in the city of Buenos Aires during two consecutive spring–summer periods. Every 15 days, we collected by hand-netting bee specimens seen foraging on flowers during five-minute censuses at every entomophilous herbaceous plant. A total of 66 bee species (Hymenoptera: Apoidea) were recorded. Richness and abundance of native, generalist, and above-ground nesting (cavities) species were higher than that of exotic, specialist, and below-ground (soil) nesting ones, respectively. Social bees were more abundant, while the richness of solitary species was higher than that of social bees. Cleptoparasitic species were represented by a high number of species, even though only a few individuals were captured. Our results suggest that the studied area is an important bee reservoir within the city.

Keywords: urban ecology; bee diversity; bee community; Apoidea; biological aspects

Introduction

Bees are major pollinators in natural and anthropogenic ecosystems, facilitating sexual reproduction of almost 50% of world's angiosperms (Kearns & Inouye 1997; Roig Alsina 2008; Brown & Paxton 2009; Murray et al. 2009). Besides their role as pollinators, natural populations of bee species are declining in different world regions, mainly due to habitat loss and ecosystem fragmentation (Rasmont et al. 2006; Garibaldi et al. 2011). However, it is very difficult to know the rate of decline given that, in some regions, there is not enough knowledge about their taxonomy, nor their abundance and/or diversity.

Growth and development of large cities is increasingly overtaking the landscape. Urbanization is one of the activities responsible for habitat alteration (Goddard et al. 2009; van Rossum 2010). Consequently, cities cannot be excluded from the areas to be considered for conservation strategies (van Rossum 2010).

In urban and natural environments, native bee species offer important benefits for plants and possibilities for environmental education (Cane 2005; Frankie et al. 2009). However, to achieve these benefits it is important for people to know how many and which species are present in the place where they live (McKinney 2002). Urban bee ecology is an emerging field that will reveal more about the biology of bees and their conservation in these highly modified environments (Tommasi et al. 2004; Matteson et al. 2008;

Frankie et al. 2009; Hernandez et al. 2009; Banaszak-Cibicka & Żmihorski 2012; Martins et al. 2013).

Based on 59 works on urban bee ecology, the following patterns have been observed in urban areas: (1) a negative correlation between bee species richness and urban development; (2) an increase in abundance of cavity nesting species; and (3) a scarcity of floral specialists (Hernandez et al. 2009). Transformation from rural to urban areas benefits generalist (polylectic) bee species, given that urban development replaces the native flora, and floral diversity tends to decrease and/or be replaced by a combination of native and non-native flora. Generalist bee species are favored in these urban areas while specialists suffer from the absence of their host plants and diminish in number (Cane 2005; Frankie et al. 2005; Hernandez et al. 2009; Kearns & Oliveras 2009). Also, due to their ability to store food, social bees tend to be more abundant than solitary bees (Zanette et al. 2005; Fetridge et al. 2008; Banaszak-Cibicka & Żmihorski 2012). Cleptoparasitic species would also be less common as their host populations decrease or disappear (Cane 2005). On the other hand, abundance of below-ground nesting species tends to decrease in relation to above-ground (i.e. different types of cavities) nesting bees, perhaps due to soil compaction or low availability of bare soil (Fetridge et al. 2008; Hernandez et al. 2009; Dalmazzo 2010). All these factors produce important changes in the composition of urban bee communities.

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Some authors reported that urban areas, such as managed habitats (Matteson et al. 2008; Wojcik et al. 2008; Santiago et al. 2009; Pawelek et al. 2009; Banaszak-Cibicka & Żmihorski 2012), cemeteries (Nates-Parra et al. 2006a) and residential and/or botanical gardens (Bembé et al. 2001; Dötterl & Harmann 2003; Walge & Lunau 2003; Tommasi et al. 2004; Diestelhorst & Lunau 2007) are important places to maintain and conserve wild bee populations (Cane 2005). It was reported that the diversity of bees (and other pollinating animals) increased with green space size within urban areas (McIntyre 2000; Cornelis & Hermy 2004, Zanette et al. 2005; Hennig & Ghazoul 2012) and it was also found that the surrounding matrix was positively related to some bee species abundances (McFrederick & LeBuhn 2006).

In Argentina, the knowledge about urban bee ecology is virtually null and there is only one recent study that was carried out in a small town in the province of Santa Fe (Dalmazzo 2010). In her work, Dalmazzo (2010) compared the diversity and biological aspects of bee communities in two different environments (urban area versus nature reserve) in the same town. In the urban area, she found a high proportion of generalist and cavity nesting species, but did not find significant differences in relation to social structure.

In Buenos Aires, one of the largest cities in the world, studies on urban bees have not been performed. For that reason, the main objective of this study was to assess the diversity and abundance of bee species present in "Lucien Hauman" Botanical Garden, Buenos Aires University, Agronomy School, a green space in the city center. This analysis also intends to recognize phenological patterns and the biological aspects of the bee community. Bee data over two years from standardized net sampling on entomophilous flowers in the botanical garden allowed us to test the hypothesis that changes brought about by urbanization have different effects on distinct bee species. We hypothesized that in our urban site, we would find a higher richness and/or abundance of (1) generalist (polylectic) than specialist (oligolectic/monolectic) species; (2) social than solitary and cleptoparasitic species; and (3) above-ground nesting than below-ground nesting species.

Materials and methods

Study site

Bee capture was carried out in the "Lucien Hauman" Botanical Garden (LHBG), Buenos Aires, Argentina (34°46′ S, 58°30′ W). This garden occupies approximately 2 ha (Botanic Gardens Conservation International 2010). The LHBG is situated at the School of Agronomy of the University of Buenos Aires, an ample green space in the center of Buenos Aires. The area surrounding the LHBG is part of the Agronomy School Campus and has a similar structure, although with less diversity and abundance of entomophilous plants.

Buenos Aires has an area of 203.3 km^2 and more than 2.9 million inhabitants, but considering the metropolitan area these quantities become 2590 km^2 and 12.8 million respectively (INDEC 2010). The city is characterized by a subtropical climate with cold winters (mean temperature of 11°C) and hot, rainy summers (mean temperature of 25°C). Mean minimum and maximum monthly temperatures during the sampling period in 2009–2010 and 2010–2011 were similar to those of the preceding 32 years (1980–2011).

Sampling methods

We selected two sampling sites within the LHBG with high diversity of herbaceous plants with entomophilous flowers. Sampling was carried out every 15 days during two consecutive spring–summer periods: September 2009 to April 2010 and October 2010 to April 2011. Sampling methods consisted of hand-netting bee specimens seen foraging on flowers (Sakagami et al. 1967). Netting was done by one or two collectors, with similar sampling effort in both sampled periods. We took 5-min censuses at every entomophilous plant. Insect captures were carried out between 10 and 16 h, on sunny days, with temperatures higher than 20°C and little wind. Insects were sacrificed *in situ* and preserved to be identified later.

Identification was carried out at the lowest possible taxonomic level (i.e. species or genus), and in some cases with the assistance of specialists (see Acknowledgements). Individuals that could not be identified at the species level were assigned to morpho-species groups. Specimens are preserved in the Entomological Collection of the General Botany Unit, at the School of Agronomy of the University of Buenos Aires.

Data analysis

Abundance and species richness of bees were counted separately for the two sampling periods. To study bee phenology, we analyzed the proportion of individuals and of species classified as solitary, social and cleptoparasitic for each sampling month in both periods. In our study, all collected cleptoparasitic species were solitaries, but due to their particular biological traits, we preferred to analyze them separately.

Species composition was compared between months in both periods using Jaccard similarity index, J = c /(a + b − c), where a = number of species/month i in the first sample, b = number of species/month i in the second sample, and c = number of shared species (Jost et al. 2011).

Rarefaction curves for each sampling period and for both periods together were constructed to show the accumulation trend of new species and to estimate if the sampling effort was sufficient. We used individual-based rarefaction to estimate total species richness of bee community (Banaszak-Cibicka & Żmihorski 2012). Rarefaction curves were calculated using 500 simulations using the computer program InfoStat (Di Rienzo et al. 2008).

Ecological information about all the species was compiled from primary literature, catalogues, revisions and personal observations. Bee species were classified into the following categories: origin (native versus exotic), floral specificity (generalist or polylectic versus specialist or oligolectic/monolectic), nesting substrate (above-ground nesting versus below-ground nesting), and social behavior (social, solitary or parasitic).

Regarding their origin, during both periods, we caught three males of *Lithurgus* (*Lithurgus*) *huberi*. This subgenus is present in the Old World whereas New World species of *Lithurgus* belong to the subgenus *Lithurgopsis* (Snelling 1983). According to Snelling (1983) *L. huberi* belongs to the Indo-Australian group of *Lithurgus atratus* and is probably adventitious in the Neotropical Region. In Argentina this species occurs in Misiones (Roig Alsina 2006), but recently, Gonzalez et al. (2013) provided new records in La Plata, Province of Buenos Aires, Argentina. These authors document distinctive differences between *L. huberi* and *L. atratus*, and suggest they be treated as separate species (Gonzalez et al. 2013). Therefore, we considered this species as native. Also, we captured one worker of the meliponine *Scaptotrigona jujuyensis*, which is native to Argentina, but in northernmost areas (Roig Alsina 2010). Colonies of this species are being studied in the Apicultural Unit of the School of Agronomy, and possibly the captured specimen came from those hived colonies. Nevertheless, we considered this species native as well.

The category "above-ground nesting" included species that nest in pre-existing cavities (e.g. many species of *Megachile*) and species which make the burrows themselves (e.g. *Xylocopa, Lithurgus*). In the absence of species specific ecological data, ecological categories were inferred based on the habits of closely related taxa. Finally, the honey bee (*Apis mellifera*), a very abundant species at the study site, was not captured randomly. One or few individuals were captured just to record the presence of this species and therefore they were only considered in the richness analysis.

Results

In total, 895 bees from five families, 32 genera and 66 species were captured during our survey (Tables 1, 2). During the period 2009–2010 we collected 472 individuals from 49 species (or morpho-species) from five families and 27 genera, while during 2010–2011 we captured 423 specimens from 52 species (or morpho-species), from five families and 30 genera (Tables 1, 2). We identified 43 taxa to the species level, 13 to the subgenus level, and 10 to the genus level (Table 1).

Bee abundance in the LHBG exhibited a bimodal pattern with abundance peaks in December (167 individuals) and March (129 individuals) during the 2009–2010 period; however, during 2010–2011 a unimodal pattern was found with a peak in December (105 individuals) (Figure 1A). In both sampling periods, most bee species were represented by a few individuals (47 taxa comprised fewer than 10 individuals, and 41 taxa comprised five or less individuals; Table 1). Moreover, many species were captured only in one of the periods (Table 1). In total, the most abundant species were *Plebeia droryana* (178 individuals), *Lasioglossum* (*Dialictus*) sp. (67), *Melissoptila bonariensis* (63), *Augochlora amphitrite* (63), *A. iphigenia* (54), *Bombus pauloensis* (54), and the exotic *Hylaeus punctatus* (54) (Table 1). Bees from the family Apidae were most abundant (437 individuals, 48.8%), followed by Halictidae (256, 28.6%), Megachilidae (129, 14.4%), Colletidae (64, 7.2%) and Andrenidae (nine, 1.0%). This pattern was the same in both sampling periods (Table 2).

Richness also showed a bimodal distribution in the first period, with more species captured in December (38 species) and March (29), whereas in the second period the greatest richness was captured in December (30) and January (28), conforming a unimodal distribution (Figure 1B). For both periods, bee richness was highest in Apidae (24 species, 36.4% of total) and Megachilidae (22 species, 33.8%), followed by Halictidae (11 species, 16.9%), Colletidae (seven species, 10.8%) and Andrenidae (two species, 3.1%). The richness pattern was the same in the two sampling periods (Table 2).

Regarding bee phenology, social species were present during all months, reaching high proportions in September (100% of captured individuals and species) and October (90% of captured individuals and c.70%

Table 1. Species of bees captured in the "Lucien Hauman" Botanical Garden in Buenos Aires city, Argentina, during two consecutive spring–summer periods (2009–2010 and 2010–2011).

Bee species	Number of individuals captured in each period		Sex ratio[a]	Origin[b]	Floral specificity[c]	Nesting substrate[d]	Social structure[e]	References
	2009–2010	2010–2011	f/m					
Andrenidae								
Panurginae								
Protandrenini								
1 *Anthrenoides* sp. 1	6	2	7/1	n	?	bg	sol	Michener (2007)
2 *Parapsaenythia serripes* (Ducke)	—	1	0/1	n	s	bg	sol	Ramos & Melo (2010)
Apidae								
Apinae								
Apini								
3 *Apis mellifera* L.	nd	nd	nd	e	g	ag	soc	Michener (2007)
Bombini								
4 *Bombus pauloensis* (Friese)	39	15	50/4	n	g	bg	soc	Torretta pers. obs.
Centridini								
5 *Centris trigonoides* Lepeletier	14	6	18/2	n	g	ag	sol	Williams et al. (1984)
Emphorini								
6 *Diadasia distincta* (Holmberg)	—	1	1/0	n	s	bg	sol	Martins & Borges (1999)
7 *Melitoma segmentaria* (Fabricius)	9	9	0/18	n	s	bg	sol	Pick & Schlindwein (2011)
8 *Ptilothrix relata* (Holmberg)	6	2	1/7	n	s	bg	sol	Tellería (2003)
Eucerini								
9 *Melissodes rufithorax* Brèthes	13	—	0/13	n	g	bg	sol	Cilla et al. (2012)
10 *Melissodes tintinnans* (Holmberg)	23	4	5/22	n	g	bg	sol	Cilla et al. (2012)
11 *Melissoptila bonaerensis* Holmberg	48	15	27/36	n	g	bg	sol	
12 *Melissoptila desiderata* (Holmberg)	2	1	1/2	n	g	bg	sol	
13 *Melissoptila* sp. 1	—	1	1/0	n	g	bg	sol	
Exomalopsini								
14 *Exomalopsis* sp. 1	1	—	1/0	n	?	bg	sol	Rozen (1984)
Meliponini								
15 *Plebeia droryana* (Friese)	74	104	177/1	n	g	ag	soc	Michener (2007)
16 *Scaptotrigona jujuyensis* Schrottky	—	1	1/0	n	g	ag	soc	Michener (2007)
Protepeolini								
17 *Leiopodus lacertinus* Smith	5	1	1/5	n			cle	Roig-Alsina & Rozen (1994)
Tetrapediini								
18 *Tetrapedia* sp. 1	8	3	3/8	n	g		sol	Michener (2007)
Nomadinae								
Epeolini								
19 *Doeringiella (Triepeolus) nobilis* (Friese)	2	—	0/2	n			cle	Roig-Alsina (1989)
20 *Epeolus (Trophocleptria) variolosa* (Holmberg)	—	1	0/1	n			cle	Michener (2007)
Xylocopinae								
Ceratinini								
21 *Ceratina (Ceratinula)* sp. 1	1	11	11/1	n	?	ag	sol	Sakagami & Laroca (1971)

(Continued)

Table 1. (Continued).

Bee species	Number of individuals captured in each period		Sex ratio[a]	Origin[b]	Floral specificity[c]	Nesting substrate[d]	Social structure[e]	References
	2009–2010	2010–2011	f/m					
Xylocopini								
22 *Xylocopa (Neoxylocopa) augusti* Lepeletier	1	1	2/0	n	g	ag	sol	Lucia et al. (2014)
23 *Xylocopa (Neoxylocopa) frontalis* (Olivier)	2	—	2/0	n	g	ag	sol	Lucia et al. (2014)
24 *Xylocopa (Schoennherria) splendidula* Lepeletier	2	—	1/1	n	g	ag	sol	Dalmazzo (2010)
25 *Xylocopa (Schoennherria) subcyanea* Pérez	6	—	6/0	n	g	ag	sol	Torretta pers.obs.
26 *Xylocopa (Stenoxylocopa) artifex* Smith	4	1	5/0	n	g	ag	sol	Torretta pers.obs.
Colletidae								
Colletinae								
27 *Colletes rugicollis* (Friese)	—	2	0/2	n	s	bg	sol	Michener et al. (1958)
Hyleinae								
28 *Hylaeus punctatus* (Brullé)	24	30	44/10	e	g	ag	sol	Sheffield et al. (2011)
29 *Hylaeus* sp. 2	—	1	1/0	n	g	ag	sol	Michener 2007
30 *Hylaeus* sp. 3	—	1	1/0	n	g	ag	sol	Michener (2007)
31 *Hylaeus* sp. 4	—	1	0/1	n	g	ag	sol	Michener (2007)
32 *Hylaeus* sp. 5	—	1	0/1	n	g	ag	sol	Michener (2007)
Xeromelissinae								
Chilicolini								
33 *Chilicola* sp. 1	4	—	3/1	n	?	ag	sol	Michener (2007)
Halictidae								
Halicitnae								
Augochlorini								
34 *Augochlora (Augochlora) amphitrite* (Schrottky)	25	38	25/38	n	g	ag	soc	Dalmazzo & Roig-Alsina (2011)
35 *Augochlora (Augochlora) phoenonoe* (Schrottky)	9	6	8/7	n	g	ag	soc	Dalmazzo & Roig-Alsina (2011)
36 *Augochlora (Oxystoglossella) iphigenia* Holmberg	29	25	48/6	n	g	bg	soc	Michener & Lange (1958)
37 *Augochlorella ephyra* (Schrottky)	16	17	21/12	n	g	bg	soc	Coelho (2004)
38 *Augochloropsis euterpe* (Holmberg)	—	2	1/1	n	g	bg	sol	Dalmazzo (2010)
39 *Augochloropsis multiplex* (Vachal)	—	2	2/0	n	g	bg	sol	Dalmazzo (2010)
40 *Augochloropsis tupacamaru* (Holmberg)	5	7	12/0	n	g	bg	sol	Dalmazzo (2010)
41 *Temnosoma* sp. 1	3	3	5/1	n			cle	Michener (2007)
42 *Temnosoma* sp. 2	—	1	0/1	n			cle	Michener (2007)
Halictini								
43 *Lasioglossum (Dialictus)* sp. 1	22	45	56/11	n	g	bg	soc	Michener (2007)
44 *Pseudagapostemon* sp. 1	—	1	1/0	n	?	bg	soc	Michener (2007)
Megachilidae								
Megachilinae								
Anthidini								
45 *Anthodioctes megachiloides* Holmberg	19	26	12/33	n	g	ag	sol	Alves-dos-Santos (2004)
46 *Epanthidium bicoloratum* (Smith)	3	2	2/3	n	?	ag	sol	Torretta pers.obs.

(*Continued*)

Table 1. (Continued).

	Bee species	Number of individuals captured in each period		Sex ratio[a]	Origin[b]	Floral specificity[c]	Nesting substrate[d]	Social structure[e]	References
		2009–2010	2010–2011	f/m					
	Lithurgini								
47	*Lithurgus (Lithurgus) huberi* Ducke	2	1	0/3	n	s	ag	sol	Camillo et al. (1994)
	Megachilini								
48	*Coelioxys (Acrocoelioxys)* sp. 1	—	2	2/0	n			cle	Durante et al. (2008)
49	*Coelioxys (Acrocoelioxys) tolteca* Cresson	1	3	2/2	n			cle	Durante et al. (2008)
50	*Coelioxys (Cyrtocoelioxys) missionum* Holmberg	1	—	0/1	n			cle	Durante et al. 2008
51	*Coelioxys (Cyrtocoelioxys)* sp. 1	3	1	0/4	n			cle	Durante et al. (2008)
52	*Coelioxys (Glyptocoelioxys)* sp. 1	4	—	4/0	n			cle	Durante et al. (2008)
53	*Coelioxys (Rhinocoelioxys) mesopotamica* Holmberg	1	2	3/0	n			cle	Durante et al. 2008
54	*Coelioxys* sp. 1	—	1	1/0	n			cle	Durante et al. (2008)
55	*Megachile (Austromegachile) anomala* Schrottky	11	12	15/8	n	?	ag	sol	Torretta pers. obs.
56	*Megachile (Austromegachile)* sp. 1	2	3	5/0	n	?	ag	sol	Durante pers. comm.
57	*Megachile (Chrysosarus) guaranitica* Schrottky	—	1	1/0	n	?	ag	sol	Torretta pers.obs.
58	*Megachile (Dactylomegachile)* sp. 1	1	—	1/0	n	?	ag	sol	Torretta pers.obs.
59	*Megachile (Dactylomegachile)* sp. 2	2	—	2/0	n	?	ag	sol	Torretta pers.obs.
60	*Megachile (Dactylomegachile)* sp. 3	2	—	0/2	n	?	ag	sol	Torretta pers.obs.
61	*Megachile (Eutricharaea) rotundata* (Fabricius)	3	2	4/1	e	g	ag	sol	Pitts-Singer and Cane (2011), O'Neill and O'Neill (2011)
62	*Megachile (Leptorachis)* sp. 1	4	—	4/0	n	?	ag	sol	Durante pers. comm.
63	*Megachile (Pseudocentron) gomphrenae* Holmberg	4	2	4/2	n	?	bg	sol	Torretta et al. (2010)
64	*Megachile (Pseudocentron) gomphrenoides* Vachal	1	1	2/0	n	s	ag	sol	Torretta et al. (2012)
65	*Megachile (Sayapis) bomplandensis* Durante	3	—	3/0	n	?	ag	sol	Durante pers. comm.
66	*Megachile (Sayapis) dentipes* Vachal	2	1	0/3	n	?	ag	sol	Durante pers. comm.
	Species richness	49	52						
	Abundance	472	423	895					

[a]f = female, m = male; [b]n = native, e = exotic; [c]s = specialist, g = generalist; [d]bg = below ground, ag = above ground; [e]sol = solitary, soc = social, cle = cleptoparasite. ? = unknown. nd = no data.

Table 2. Abundance (number of individuals) and richness (number of species) of wild bees captured in the "Lucien Hauman" Botanical Garden in Buenos Aires city, during two consecutive spring–summer periods (2009–2010 and 2010–2011). Number in parentheses indicates percentage.

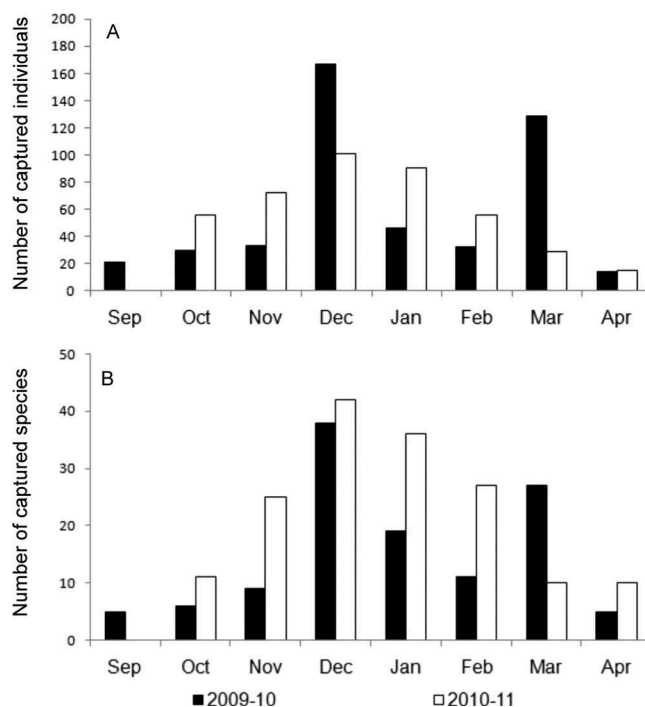|	Total		2009–2010		2010–2011	
	Abundance	Richness	Abundance	Richness	Abundance	Richness
Andrenidae	9 (1)	2 (3.0)	6 (1.3)	1 (2.0)	3 (0.7)	2 (3.8)
Apidae	437 (48.8)	24 (36.4)	260 (55.1)	20 (40.8)	177 (41.8)	18 (34.6)
Colletidae	64 (7.2)	7 (10.6)	28 (5.9)	2 (4.1)	36 (8.5)	6 (11.5)
Halictidae	256 (28.6)	11 (16.7)	109 (23.1)	7 (14.3)	147 (34.8)	11 (21.2)
Megachilidae	129 (14.4)	22 (33.3)	69 (14.6)	19 (38.8)	60 (14.2)	15 (28.9)
	895 (100)	66 (100)	472 (100)	49 (100)	423 (100)	52 (100)

Figure 1. Abundance (A) and richness (B) of bees captured in the "Lucien Hauman" Botanical Garden in Buenos Aires city, during two consecutive spring–summer periods (2009–2010 and 2010–2011).

of species) (Figure 2A, B). Solitary species were captured during all months except in September 2009. These species reached highest proportions in December and January with 50–70% of captured individuals. However, the highest values of richness varied between sampling periods (Figure 2A, B). The few individuals of cleptoparasitic species were only recorded in the months of high abundance and richness of solitary species (Figure 2A, B).

Bee diversity and abundance varied along the sampled period, and this was reflected in the Jaccard's similarity index, which had values below 0.50 when comparing the months of the two sampling periods (Table 3). Considering that the Jaccard index takes values between 0 (samples totally different) and

1 (samples identical), values reached in this study are low.

Species accumulation curves reached asymptotic values in both sampling periods as well as for both periods combined (Figure 3A, B, C). These curves suggest that sampling effort in each sample period was sufficient and that the sampling reliably represents the bee community in the LHBG. However, when data from both periods were analyzed together, the number of species increased markedly (Figure 3C).

Due to lack of information (taxonomy and/or of natural history), some recorded species were not taken into account in many of the biological aspects considered in this study (origin, floral specificity, nesting
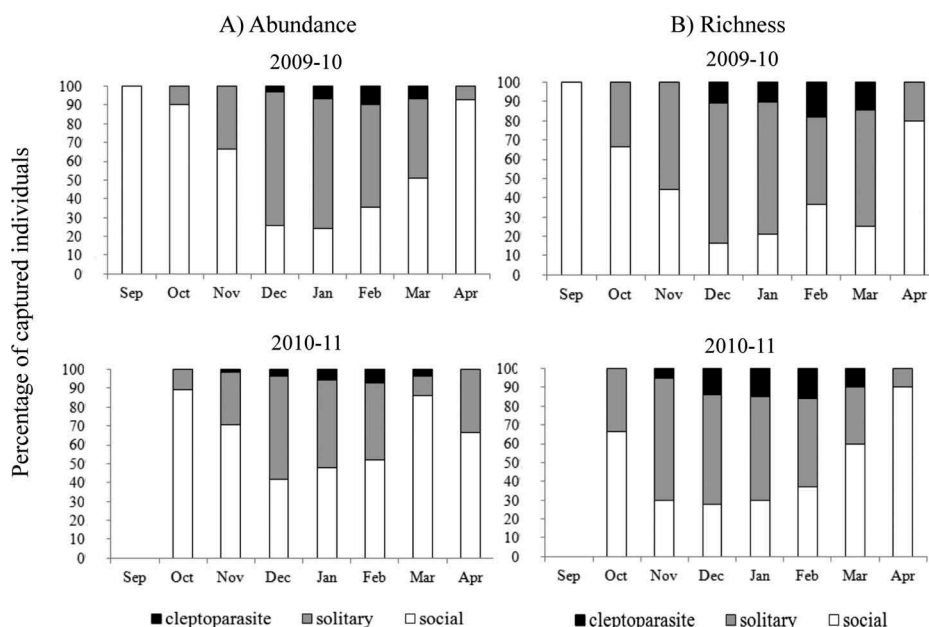
Figure 2. Percentage of individuals (A) and species (B) of monthly captured bees in the "Lucien Hauman" Botanical Garden in Buenos Aires city, during two consecutive spring–summer periods (2009–2010 and 2010–2011), according to their social structure.

Table 3. Monthly comparison of species composition (Jaccard's similitude index) of wild bees captured in the "Lucien Hauman" Botanical Garden in Buenos Aires city, Argentina, during two consecutive spring–summer periods (2009–2010 and 2010–2011).

Month	Period	Richness	Jaccard index
October	2009–2010	6	0.50
	2010–2011	9	
November	2009–2010	9	0.26
	2010–2011	20	
December	2009–2010	37	0.40
	2010–2011	29	
January	2009–2010	19	0.39
	2010–2011	27	
February	2009–2010	11	0.30
	2010–2011	19	
March	2009–2010	28	0.27
	2010–2011	10	
April	2009–2010	5	0.25
	2010–2011	10	

substrate and social behavior); therefore the species number varies for each tested trait (Table 4). Most species (63 species, 96.9%) were native (Table 4), while only three species were exotic: *Apis mellifera* L., *Hylaeus punctatus* (Brullé) and *Megachile rotundata* (Fabricius) (Table 1).

Regarding floral specificity, most species analyzed (30 species, 81%) were generalists (Table 4). Only seven species were specialists: *Lithurgus huberi, Megachile gomphrenoides, Melitoma segmentaria* and

Ptilothrix relata captured in both periods, and *Colletes rugicollis, Diadasia distincta* and *Parapsaenythia serripes* only captured during 2010–2011 period.

On the subject of nesting substrate, 34 species (62.9%) were above-ground nesting (28 species, 68.2% in 2009–2010 and 24 species, 57.1% in 2010–2011), while 20 species (37.1%) were below-ground nesting (13 species, 32.8% and 18 species, 42.9% respectively, Table 4).

Finally, solitary bees were predominant with 44 species (66.6%) in both periods (33 species, 67.4% in 2009–2010 and 33 species, 63.4% in 2010–2011), followed by 12 (18.5%) cleptoparasitic species (eight species, 16.7% in 2009–2010 and nine species, 17.6% in 2010–2011) and 10 (15.2%) social species (eight species, 16.3% in 2009–2010 and 10 species, 19.2% in 2010–2011). On the other hand, regarding the total number of captured individuals, social species were most abundant (466 individuals, 52%), followed by solitary (394 individuals, 44%) and cleptoparasitic species (35 individuals, 4%). Abundance of social and solitary species varied between sampling periods (Table 4).

Discussion

Phenology and composition of the bee assemblage

The phenology of bee species in the LHBG was related to their life cycle patterns. Social bees were present during all sampling months as they have
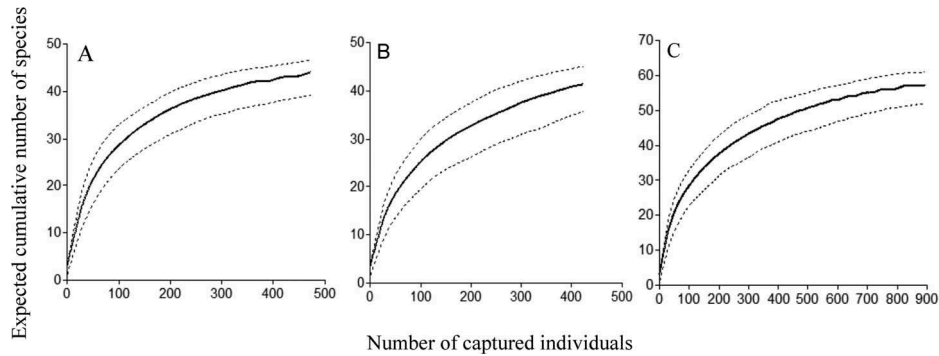
Figure 3. Expected cumulative number of bees species as a function of number of captured individuals in the "Lucien Hauman" Botanical Garden in Buenos Aires city, during two consecutive spring–summer periods (2009–2010 and 2010–2011). These curves compare the species richness levels in (A) period 2009–2010, (B) period 2010–2011, and (C) all species captured for both periods. Dashed lines indicate confidence intervals (95%). Curves are averaged over 500 simulations and are based in number of individuals captured.

Table 4. Comparison of the biological aspects of the community of wild bees occurring in the "Lucien Hauman" Botanical Garden in Buenos Aires city, during two consecutive spring–summer periods (2009–2010 and 2010–2011).

	Total		2009–2010		2010–2011	
	Abundance	Richness	Abundance	Richness	Abundance	Richness
Origin						
Natives	836 (93.4)	63 (95.5)	446 (94.3)	46 (93.8)	391 (92.4)	49 (94.2)
Exotic	59 (6.6)	3 (4.5)	26 (5.7)	3 (6.2)	32 (7.6)	3 (5.8)
	$\chi^2 = 678.09^*$	$\chi^2 = 43.12^*$	$\chi^2 = 373.73^*$	$\chi^2 = 37.02^*$	$\chi^2 = 304.68^*$	$\chi^2 = 39.21^*$
Floral specificity						
Generalist	739 (96.1)	30 (83.3)	385 (95.8)	22 (88.0)	354 (95.7)	26 (81.3)
Specialist	33 (3.9)	6 (17.1)	17 (4.2)	3 (12.0)	16 (4.3)	6 (18.7)
	$\chi^2 = 653.68^*$	$\chi^2 = 19.53^*$	$\chi^2 = 336.88^*$	$\chi^2 = 16.25^{****}$	$\chi^2 = 308.77^*$	$\chi^2 = 13.27^{***}$
Nesting substrate						
Cavities	488 (56.8)	34 (62.9)	233 (51.5)	28 (68.2)	255 (62.0)	24 (57.1)
Soil	371 (43.2)	20 (37.1)	219 (48.5)	13 (32.8)	152 (38.0)	18 (42.9)
	$\chi^2 = 10.27^{**}$	$\chi^2 = 4.87$ ns	$\chi^2 = 0.04$ ns	$\chi^2 = 5.97^{*****}$	$\chi^2 = 23.54^*$	$\chi^2 = 0.61$ ns
Social structure						
Solitary	394 (44.0)	44 (66.6)	238 (50.4)	33 (67.4)	156 (36.9)	33 (63.4)
Social	466 (52.0)	10 (15.2)	214 (45.3)	8 (16.3)	252 (59.5)	10 (19.2)
Cleptoparasitic	35 (4.0)	12 (18.2)	20 (4.3)	8 (16.3)	15 (3.6)	9 (17.4)
	$\chi^2 = 356.87^*$	$\chi^2 = 31.65^*$	$\chi^2 = 181.96^*$	$\chi^2 = 24.63^*$	$\chi^2 = 201.53^*$	$\chi^2 = 20.05^*$

Significance of chi-square values: * $p < 0.0001$, ** $p < 0.001$, *** $p < 0.0009$; **** $p < 0.0007$; ***** $p < 0.02$, ns = not significant.

multivoltine life cycles, with individuals developing and emerging continuously over several months (Michener 2007). On the other hand, many solitary bees in temperate climates, such as in our study site, are active and reproduce only during the warmer seasons, producing one (univoltine) or two (bivoltine) generations per year only. For example, in two sites of the Pampean region (similar latitudes to our sample site) *Megachile* (*Chrysosarus*) *catamarcensis* exhibits an univoltine life cycle (Torretta et al. 2014) while *M.* (*Pseudocentron*) *gomphrenoides* shows facultative bivoltinism (Torretta et al. 2012). However, we cannot exclude the possibility of the existence of solitary species with multivoltine life

cycles. Most cleptoparasitic species collected in both periods are known to attack solitary bee species. Accordingly, the individuals of these species were captured in months with high presence of solitary bees. However, the hosts of *Temnosoma* spp. are thought to be augochlorine bees (Halictidae), but this has not been confirmed yet (Michener 2007), and this taxon comprises solitary and social species (Danforth & Eickwort 1997).

Bee diversity encountered in this study was variable from one sampling period to the other; this was demonstrated by low values of the Jaccard similarity index and by the increasing tendency shown when accumulation curves were analyzed together.

However, this variability could be due to the way of sampling. A high number of singletons means that many species are either quite rare (low population densities) or visit other species of flowers, not observed in our sampling. Long-term studies or complementary methods of sampling (see Kamke et al. 2011) would be useful to determine if this variability is extended in time and if there are more species in the study site that have not yet been sampled. Also, starting the bee sampling earlier (around 07.00 h) could allow capture of nocturnal and crepuscular species that are unlikely to be collected at 10.00 h.

Biological traits of bees

Because we did not collect honeybees, in our sample native species were more abundant than exotic ones. Of the exotic species only honeybee is social, whereas the other two species captured in LHBG are solitary (Roig Alsina 2006) and the few captured individuals suggest that they have low population densities.

Generalist bees were the most abundant in this community, in agreement with data reported by others (review in Hernandez et al. 2009). This fact could be due to: (a) the replacement of native flowering plants by a mix of native and non-native plant species, where some specialist bee species cannot find the food resources they need (Frankie et al. 2009); or (b) the greater extinction risk that specialist (oligolectic) bees face for genetic or demographic reasons and their lower adaptation capacity to the new environmental conditions (Packer et al. 2005). However, the two causes do not mutually exclude each other.

Solitary bees had higher species richness than social and cleptoparasitic bees, as was shown in other studies about urban bees (Nates-Parra et al. 2006b; Fetridge et al. 2008; Matteson et al. 2008; Wojcik et al. 2008; Dalmazzo 2010). A possible explanation for this is the fact that there are more solitary than social bee species overall (Danforth 2007; Michener 2007), and that the richness of social species declines towards higher latitudes (Roubik 1992). Moreover, possibly the management of LHBG (e.g. grass cutting and leaf litter removal) is detrimental for social species that nest in ground (during our study, we did not observe nests of *Bombus pauloensis* or halictid species). Low availability of nesting sites was a limiting factor for several bee species found in a highly urbanized area in Brazil (Laroca et al. 1982). Long-term studies could help to better understand the presence/absence and phenology of the bees found in urban environments.

The presence of numerous cleptoparasitic species shows a complex bee community in the LHBG. The diversity and abundance of these species in relation to all bees is indicative of the status of the total bee community (Sheffield et al. 2013). Species of the highest trophic level are the first to disappear in adverse host availability and/or environmental conditions (Sheffield et al. 2013). The number of species of cleptoparasitic bees was high in comparison with other urban parks (Fetridge et al. 2008; Matteson et al. 2008; Dalmazzo 2010; Banaszak-Cibicka & Żmihorski 2012).

Our results that most of the species with known nesting biology used cavities as substrate agree with studies in other cities (review in Hernandez et al. 2009; but see Fetridge et al. 2008; Banaszak-Cibicka & Żmihorski 2012). In the urban environment, conditions for soil nesting bees might be quite poor due to increased runoff, erosion, low availability of bare soil, and compaction of soil (Cane 2005; Cane et al. 2006) whereas cavity nesting bees might benefit from man-made structures such as fences, posts, and houses which may offer new nesting places (Cane 2005; Matteson et al. 2008).

Importance of green areas in bee ecology

This is the first work about urban bees in the city of Buenos Aires. We captured a great diversity of bees along the two sampled periods suggesting that LHGB is an important bee reservoir within this city. Our study site is immersed in a bigger green space (Agronomy School Campus) which may provide nesting spaces or refuge for some bee species. These urban parks can behave as islands of useable habitat surrounded by an inhospitable landscape (McFrederick & LeBuhn 2006).

Botanical gardens that include a high diversity and abundance of plant species that provide extended periods of bloom are preferred by a diverse pollinator community and are critical for bee biodiversity conservation (Winfree 2010). Hennig and Ghazoul (2012) reported that bee abundance increased with plant diversity and floral abundance. The botanical gardens offer an abundant and (more or less) constant floral supply (Mazzeo 2011). This resource supply may allow for an increase in the abundance and richness of native wild bees in these gardens compared to surrounding areas (including residential gardens, with lower abundance of flowers).

Considering the high diversity found at the "Lucien Hauman" Botanic Garden, as well as the cleptoparasitic species richness encountered, we highlight the importance of boosting studies like this one in other urban parks. In this way comparisons and bee diversity estimations can be done. It may also be useful to identify which factors in urban environments positively affect bee abundance and richness, information that will be necessary to establish bee conservation programs.

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Disclosure statement

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