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Pollinators on Green Roofs: Diversity and Trait Analysis of Wild Bees (Hymenoptera: Anthophila) and Hoverflies (Diptera: Syrphidae) in an Urban Area (Geneva, Switzerland)

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Pollinators on Green Roofs: Diversity and Trait Analysis of Wild Bees (Hymenoptera: Anthophila) and Hoverflies (Diptera: Syrphidae) in an Urban Area (Geneva, Switzerland)

Green roofs can provide food resources to several insect groups. For pollinators found in cities, as are wild bees and hoverflies, the existence of a wide variety of green infrastructures is crucial to ensure their development and survival. In order to investigate if wild bees and hoverflies use green roofs and how local and landscape factors influence their abundance and diversity, sampling of these insects was done in 2017 using cornet traps on extensive green roofs of two types: 1) urban green roofs (30% of green spaces in a 200m radius). There were 62 wild bee species and 10 hoverfly species identified during the 22-week sampling period. For the latter, no differences in richness and abundance were found between roofs and between roof types. Most hoverfly species were associated with xero-thermophilic habitats. Regarding wild bees, no difference in abundance and richness was observed between roofs. However, urban roofs showed significantly lower abundances compared to mixed landscape roofs. Local and landscape factors influenced the pollinator communities: the percentage of attractive plant species on roofs was positively correlated with the abundance of wild bees and the percentage of green areas in a 600 m radius was positively correlated with their richness. The traits analysis showed no difference between roofs and between roof types. Our results highlight the important role of green roofs in supplying food resources for urban pollinators instead of providing suitable nesting habitats. The abundance of attractive plant species for pollinators and diversified landscape surrounding green roofs seem to be key factors in order to promote these wild pollinators in cities.

Keywords

Urban greening, Urban biodiversity, Urban landscape, Horizontal connectivity, Food resource, Syrphids

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INTRODUCTION

The urban environment is characterized by its fragmentation and contains, among others, constructed areas and open spaces of low ecological interest (Pereira-Peixoto et al., 2014). Green infrastructures, such as parks, green roofs or green walls, can mitigate this effect, by providing nesting sites and food supply patches for arthropods within the urban landscape (Braaker et al. 2014; Brenneisen 2006; Kadas 2010; Passaseo et al. 2020b; Pétremand et al. 2018a, 2018b). Green roofs are constituted by different membranes, natural or industrial substrates and vegetal assemblages (Kadas 2010). They are generally placed at the top of buildings (Sutton 2015), at variable heights and with variable slopes. The classical typology considers the substrate thickness to classify green roofs: a thickness below 15 cm corresponds to an extensive roof and a thickness above 15 cm to an intensive roof (Sutton 2015). Intensive and extensive green roofs also differ in terms of maintenance, irrigation and construction costs (Oberndorfer et al. 2007). Green roofs can host hundreds of insect species, including rare or red list species (Kadas 2006, 2010; MacIvor and Lundholm 2011; Passaseo et al. 2020a; Pétremand et al. 2018b). Despite the low number of pollinator species that can nest or develop on green roofs (Passaseo et al. 2020b), those structures can provide nectar and pollen resources for pollinating insects especially wild bees and hoverflies that can fly up to roof tops (Braaker et al. 2014; Kratchmer et al. 2018; MacIvor 2016). Wild bees on green roofs were surveyed worldwide (Hofmann and Renner 2018), e.g. in Canada and the United States (Colla et al. 2009; Tonietto et al. 2011), in France (Madre et al. 2013) and in Switzerland (Braaker et al. 2014; Pétremand et al. 2018a; Sonnay and Pellet 2016). Hoverflies visiting green roofs have been less investigated and do visit green roofs for nectar and pollen, depending upon the availability of appropriate plant taxa (Benvenuti 2014; Mecke 1996).

A green roof can be considered as a patch of a more viable habitat within a matrix of less- or non-viable habitats. It can therefore facilitate movements of individuals across the urban landscape (Blank et al. 2017). Arthropods living on green roofs are potentially influenced by local conditions (roof geometry, vegetation composition, substrate characteristics, humidity, solar radiation and wind) and landscape settings (landscape connectivity, land use around the roofs) (MacIvor and Ksiazek 2015; Fabián et al. 2021). The occurrence and composition of vegetation on the roof influences arthropods abundance and diversity, even if its relative importance varies between studies (Brenneisen 2006; Madre et al. 2013; Fabián et al. 2021). The floral characteristics of green roofs seems specially to play a key role for wild bees (Grimshaw-Surette 2020).

In heterogeneous environments, like the urban environment, the landscape is an important predictor of insect communities living on green roofs (MacIvor and Ksiazek 2015; Fabián et al. 2021). Some studies highlighted that arthropod communities on green roofs seemed to be dependent upon the location of green roofs along the rural - urban gradient (Blank et al. 2017). Two components can be distinguished in the study of movements of plant or animal propagules between green roofs and the surrounding landscape: a vertical component, related to the distance separating the ground and the roof and a horizontal component dependent upon the distance between the roof and the surrounding natural or semi-natural habitats. The relative importance of the latter upon roof arthropods is a matter of debate with opposite results being published. Tonietto et al. (2011), Braaker et al. (2014) or MacIvor (2016) showed a strong influence of the surrounding landscape upon roof assemblages, whereas Schindler et al. (2011) evidenced an absence of effect. The dispersal ability of various taxa seems to play a key role in such discrepancies, with less mobile taxa (i.e. ground beetles, spiders) more influenced by local factors, like vegetation diversity, and more mobile taxa (wild bees, hoverflies) more impacted by landscape scale characteristics, like habitat connectivity (Braaker et al. 2014).

The present study focuses on two groups of wild pollinators: bees (Hymenoptera: Anthophila) and hoverflies (Diptera: Syrphidae). It is the first to assess the diversity of these two groups on a set of six extensive green roofs in urban parts of the canton of Geneva (Switzerland). Furthermore, it appears to be one of the very few studies accounting for hoverflies on green roofs in Europe, Mecke (1996) and Bevk (2021) being the other studies found so far. The goals were i) to confront the species and functional diversities of the assemblages in the two taxa, ii) to relate them to green roofs environmental characteristics, iii) to assess the conservation value of green roofs in providing flowers to endangered pollinators in cities and iv) to provide information for future policies seeking to promote biodiversity in an urban context. The following hypotheses were set: H1: The abundance and richness of wild bees and hoverflies assemblages are lower on green roofs in an “urban environment” compared to a “mixed environment”. H2: Wild bee assemblages are influenced by local characteristics of the roof (vegetation occurrence and richness, cover of plant species potentially attractive for the target insect taxa) and by characteristics of the surrounding landscape (habitat types, occurrence of green areas and natural habitats). H3: Wild bee and hoverfly assemblages are mainly composed of generalist species (especially regarding habitat and food preferences). More generally, the capacity of green roofs to provide food resources for flying adults of the two groups was investigated and characteristic traits of the species were sought.

MATERIALS AND METHODS

Geographical Context and Selection of Green Roofs

This study was carried out in the canton of Geneva (Switzerland), located on the Swiss Central Plateau, at 375 meter above sea level and having approximately 1753 inhabitants per km^2 (SITG 2019).

Six extensive vegetated roofs were selected (Table 1) from a previous study of intensive and extensive roofs in the canton of Geneva (Pétremand et al. 2018a). An aerial picture with locations of roofs are given in Passaseo et al. (2020b). The main criterion for selection was the type of vegetation, purposely reduced to herbaceous green roofs. These are not entirely covered by a quasi-monospecific plant layer, in contrast with “muscinal” roofs (covered with less diverse bryophytes or *Sedum* spp.). Herbaceous green roofs are therefore potentially more attractive for pollinating insects like hoverflies and wild bees (Pétremand et al. 2018a). In addition, and for the same reason, green roofs with a high vegetal cover and vascular plant diversity were selected (Madre et al. 2013; Schindler et al. 2011).

Table 1. Structural, botanical and landscape characteristics of the six green roofs sampled. Main type of vegetation: main composition of plant formations on roofs, H: herbaceous plants; C: Crassulaceae; B: bryophytes. Green areas [%] and natural habitats [%]: average percentages of green areas and natural habitats in a 1000[m] radius around the roof. Roof types: types of landscape around green roofs according to the average of green areas in a 200m radius.

Characteristics		Structural				Botanical		Landscape		
Green roof number	Geographical coordinates	Height of roof [m]	Surface of roof [m^2]	Substrate height [cm]	Substrate composition	Vegetal cover [%]	Main type of vegetation on roof	Green areas [%]	Natural habitats [%]	Roof types
15	46°12'28.0"N 6°07'19.9"E	11	450	15	Topsoil	±100	H	19	2	Urban
16	46°12'28.0"N 6°07'19.9"E	11	450	15	Topsoil	±100	H	19	2	Urban
45	46°13'06.0"N 6°05'19.4"E	8	800	8	Brick	±50	C	42	6	Urban
33	46°13'43.0"N 6°07'22.7"E	13	1200	15 to 100	Brick	±95	C	44	2	Mixed
37	46°10'57.3"N 6°06'03.0"E	12	800	8	Pozzolana and brick	±60	C	47	7	Mixed
38	46°10'48.9"N 6°06'06.5"E	10	2000	8	Pozzolana and brick	±60	B ; H	63	15	Mixed

Sampling of Flying Insects

Wild bees and hoverflies were sampled from March 29th to August 21st 2017 with two cornet traps placed head to tail on each roof. The main axis of the pair of traps was orientated north - south. The traps were modified from Sarthou (2009) for use on extensive roofs to account for relatively strong wind stress and shallow soil, reducing the anchoring possibilities. The trap design is described in Passaseo et al. (2019). The trap bottles, filled out with 70° Ethanol, were retrieved approximately every fortnight. Hoverflies and wild bees were identified to species level (Hoverflies : Speight and Sarthou 2016; Van Veen 2004; wild bees: Amiet, 1994, 1996; Amiet et al. 2001, 2004, 2007, 2010, 2014). Identification of hoverflies was confirmed by Dr Martin Speight (Trinity College, Dublin) and of wild bees by Mr. Dimitri Bénon (info fauna - CSCF, Neuchâtel) and Dr Christophe Praz (University of Neuchâtel).

Vegetation Survey

A vegetation survey was carried out on roofs in June 2017. Plant species were recorded along one transect representing the median longest axis of the roof. The list of all plant species recorded and their percentage of cover calculated per roof is provided in the Appendix (Table 5). An abundance-dominance coefficient was assigned to each species (Braun-Blanquet 1928). Bryophytes were not identified to species level. The number of vascular plant species (Rich_v) and the percentage of plant species attractive for pollinators (Tax_att) were derived from the survey. As described in Tooker et al. (2014) and Woodcock et al. (2014), the latter is the percentage of the total number of plant species recorded along the survey transect, considered attractive to pollinators.

Landscape Variables

Two variables describing the landscape surrounding the roofs were extracted from a 2016 winter aerial map of the canton of Geneva (resolution 5cm) within concentric radii (100, 200, 400, 600, 800, 1000 m) using Arcgis 10.3: the percentage of green areas (Ev_) and the percentage of natural habitats (Mil_) according to Delarze et al. (2015). In order to assess the effect of the landscape on pollinator communities on green roofs, the percentages of green areas in the surrounding of roofs were calculated, allowing the classification of the six studied roofs in two categories: three were classified as “urban roofs” and three as “mixed roofs”. Considering the natural break in the data, the mixed environment was defined as containing more than 30% green areas in a 200m radius, which are mainly composed of lawns, forests, lonely trees and crops. A 200m radius falls within the lower range of foraging distances commonly recognized for wild bees (Gathmann and Tscharntke 2002) and as one of the scales at which urban planning should be focused to account for taxonomic and functional diversity in insects (González-Cèsped et al. (2021). Roofs n°15, 16 and 45 were classified as urban and roofs n°33, 37 and 38 as mixed. Roof n°33 and n°45 detained a very similar proportion of green areas at the 200m radius. The type of green areas was used to separate these two roofs. Roof n°45 was only surrounded by lawns and urban vegetation. Roof n°33 comprised a more diversified array of vegetation, including cultures and forests at the 200m radius. Roof n°45 was therefore classified as urban. The percentages of natural habitats were too low in the studied urban context and therefore discarded from the analyses.

Data Analysis

Differences between roofs and roof types were only tested for wild bee abundance and richness, using Wilcoxon and Kruskal-Wallis tests. Relationships between wild bee abundance and richness and both local and landscape scale variables (for local variables: number of vascular plant species (Rich_v) and the percentage of plant species attractive for pollinators (Tax_att); for landscape variables: percentages of green areas at 100m (Ev_100) and 600 m (Ev_600) radius and natural habitats at 600m (Mil_600) and 800m (Mil_800) radius were tested with Spearman rank correlations. Honey bees, *Apis mellifera*, were removed from the data, because the occurrence of the species is highly dependent on the presence of hives in the surrounding area.

Trait Analysis

Ecological and biological traits were extracted from the literature regarding 53 wild bee species:

- *Feeding range*: polylectic or oligolectic (Amiet 1994, 1996; Amiet et al. 2001, 2004, 2007, 2010, 2014; Atlas Hymenoptera 2020; Banaszak-Cibicka and Zmihorski 2012; Fründ et al. 2010);
- *Sociality*: solitary, eusocial or cleptoparasitic (Banaszak-Cibicka and Zmihorski 2012; Magnacca and Brown 2012; Yuko et al. 2009);
- *Nesting type*: ground, cavity or hive (Banaszak-Cibicka and Zmihorski 2012; Geslin et al. 2013);
- *Habitat range*: generalist or specialist (Banaszak-Cibicka and Zmihorski 2012; Geslin et al. 2013);
- *Voltinism*: univoltine, bivoltine or polyvoltine (BWARS 2020; Discoverlife 2020; Wildbiene 2020).

Differences in trait composition were tested between roofs and landscape types using chi^2 tests. The body size of sampled species was not part of the trait analysis, due to insufficient measurements of this trait. Because of the absence of trait information in the literature, the following species were removed from the trait analysis: *Bombus lapidarius*, *Halictus* *langobardicus, Lasioglossum glabriusculum, L. griseolum, L. laticeps, L. lucidulum, L. malachurum, L. politum, L. tricinctum, Osmia tridentata* and *Sphecodes puncticeps*.

A detailed trait analysis was not possible for hoverflies because of the limited number of species sampled. However, the main ecological and biological characteristics of the species were extracted from Speight et al. (2016):

- *Feeding preference of larvae*: zoophagous, phytophagous or microphagous;
- *Voltinism*: univoltine, bivoltine or polyvoltine;
- *Habitat preference of adults*: culture macrohabitats (gen.), open ground macrohabitats (gen.) and xeric / semi-arid lowland unimproved grassland (gen.);
- *Migratory status of adults*: migratory or non-migratory.

All statistical analyses and graphical displays were produced in R (version 1.1.383) (R Core Team 2013). Statistical significance is considered at a level of p value < 0.05.

RESULTS

Wild Bees

There were 2749 individuals identified, belonging to 62 species in five families of wild bees (Andrenidae, Apidae, Colletidae, Halictidae and Megachilidae) (Table 2). According to the red list of wild bees in Switzerland (Amiet 1994), fourteen species could be considered as threatened at the national level. The most abundant species, representing 85% of total catches, belonged to the genus *Lasioglossum*. Among them, *L. morio* represented approximately 47% of total catches.

Table 2. Number of individuals and total number of wild bee species captured with cornet traps (March 29th - August 21st 2017). Species considered threatened in Switzerland are highlighted in bold, all species have a status “3” in Amiet (1994) corresponding to the “V” in IUCN categories meaning “threathened”.

Species Green roof number	**15**	**16**	**33**	**37**	**38**	**45**	**Total**	**RL94**
Andrena bicolor Fabricius, 1775						1	1	
Andrena carantonica Pérez, 1902					1		1	
Andrena flavipes Panzer, 1799				1			1	
Andrena fulva (Müller, 1766)					1		1	
Andrena minutula (Kirby, 1802)		8	6	56	2	17	89	
***Andrena mitis Schmiedeknecht*, 1883**		**1**					**1**	**3**
Andrena nigroaenea (Kirby, 1802)				3			3	
Andrena subopaca Nylander, 1848			1		1		2	
Andrena wilkella (Kirby, 1802)			1				1	
Anthidium manicatum (Linnaeus, 1758)	2		1				3	
Anthidium oblongatum (Illiger, 1806)	1		18	16		3	38	
Bombus lapidarius (Linnaeus, 1758)			5	3	1	1	10	
Bombus pascuorum (Scopoli, 1763)	3	4	2	7		4	20	
Bombus terrestris aggr. (Linnaeus, 1758)	1	1	2	4			8	
Ceratina cyanea (Kirby, 1802)	1				1		2	
Chelostoma distinctum (Stoeckhert, 1929)					1		1	
Coelioxys elongata Lepeletier, 1841				1			1	

Species **Green roof number**	**15**	**16**	**33**	**37**	**38**	**45**	**Total**	**RL94**
Halictus langobardicus Blüthgen, 1944			3				3	
Halictus maculatus Smith, 1848			2		5		7	
***Halictus scabiosae* (Rossi, 1790)**			**7**	**16**	**2**	**1**	**26**	**3**
Halictus simplex aggr. Blüthgen, 1923				2	1		3	
***Halictus subauratus* (Rossi, 1792)**	**4**	**2**	**30**	**11**	**14**	**14**	**75**	**3**
Halictus tumulorum (Linnaeus, 1798)		1	5			2	8	
Heriades truncorum (Linnaeus, 1758)			5	1	6	5	17	
***Hoplitis tridentata* (Dufour and Perris, 1840)**			**1**				**1**	**3**
Hylaeus brevicornis Nylander, 1852					1		1	
Hylaeus gredleri Förster, 1871			1	1		1	3	
Hylaeus hyalinatus Smith, 1842			4	3			7	
Hylaeus lephtocephalus (Morawitz, 1870)	2		1				3	
Hylaeus nigritus (Fabricius, 1798)					1		1	
***Hylaeus pictipes* Nylander, 1852**			**1**	**2**			**3**	**3**
Hylaeus punctatus (Brullé, 1832)		1	2	1			4	
Hylaeus sinuatus (Schenck, 1873)	2			4			6	
Lasioglossum calceatum (Scopoli, 1763)			1	1	4	4	10	
***Lasioglossum glabriusculum* (Morawitz, 1872)**					**2**		**2**	**3**
***Lasioglossum griseolum* (Morawitz, 1872)**						**1**	**1**	**3**
Lasioglossum laticeps (Schenck, 1868)	15	17	80	7	14	4	137	
Lasioglossum leucozonium (Schrank, 1781)			3	1	1		5	
Lasioglossum lucidulum (Schenck, 1861)					1		1	
Lasioglossum malachurum (Kirby, 1802)	16	7	30	67	143	93	356	
Lasioglossum morio (Fabricius, 1793)	114	30	587	197	150	213	1291	
Lasioglossum nitidulum (Fabricius, 1804)	4	1	31	8	9	8	61	
***Lasioglossum parvulum* (Schenck, 1853)**			**2**	**1**			**3**	**3**
Lasioglossum pauxillum (Schenck, 1853)	5	1	48	125	80	68	327	
Lasioglossum politum (Schenck, 1853)	4	2	53	28	10	36	133	
Lasioglossum punctatissimum (Schenck, 1853)					3		3	
***Lasioglossum tricinctum* (Schenck, 1874)**					**1**	**5**	**6**	**3**
Lasioglossum villosulum (Kirby, 1802)					3		3	
Megachile ericetorum Lepeletier, 1841	3			1	2		6	
***Megachile maritima* (Kirby, 1802)**	**1**		**1**			**1**	**3**	**3**
***Megachile pilidens* Alfken, 1924**			**2**				**2**	**3**
***Megachile rotundata* (Fabricius, 1787)**	**9**	**1**	**4**		**2**	**1**	**17**	**3**
Megachile willughbiella (Kirby, 1802)		1	1				2	
Osmia adunca (Panzer, 1796)	1		1				2	
Osmia bicornis (Linnaeus, 1758)				2			2	
Osmia caerulescens (Linnaeus, 1758)	1		1		1		3	
***Osmia submicans* Morawitz, 1870**				**1**			**1**	**3**
***Sphecodes albilabris* (Fabricius 1793)**					**1**		**1**	**3**
Sphecodes ephippius (Linnaeus, 1767)		1	2		2	1	6	
Sphecodes gibbus (Linnaeus, 1798)	1		3		2		6	

Species **Green roof number**	**15**	**16**	**33**	**37**	**38**	**45**	**Total**	**RL94**
Sphecodes monilicornis (Kirby, 1802)	1		5				6	
Sphecodes puncticeps Thomson, 1870			1	1			2	
Number of individuals per roof	191	79	954	572	469	484	2749	
Total number species per roof	21	16	39	30	33	22	62	

Abundance and Richness of Wild Bees

Abundance and richness showed a high heterogeneity between roofs and roof area types. While abundance and richness were never significantly different between green roofs (Abundance: Kruskal Wallis chi^2: 6.12, p-value > 0.05; Richness: Kruskal Wallis chi^2: 7.27, p-value > 0.05), the abundance varied significantly between roof types (Wilcoxon test: w = 63; p-value < 0.05). The median abundance of species on mixed landscape roofs was higher than on urban roofs (Fig. 1).

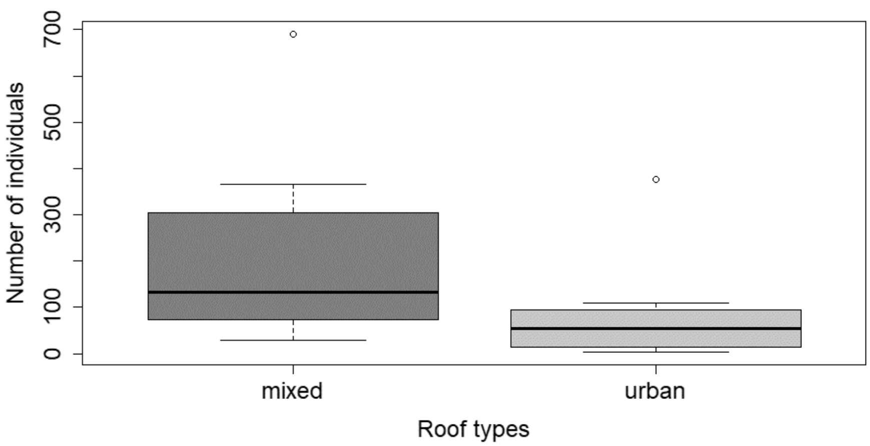

Fig. 1. Number of individuals of wild bees between mixed (N=3) and urban (N=3) green roofs. The two cornet traps and periods were aggregated per roof.

Influence of Local and Landscape Scale Variables on Wild Bee Communities

The percentage of plant species attractive for pollinators was significantly correlated with the abundance of wild bees (Spearman correlation: s = 0.89 p-value < 0.05) but not with richness (Table 3). The percentage of green areas in a 600m radius was significantly correlated with wild bee richness (Spearman correlation: s = 0.81 p-value < 0.05). The number of natural habitats was neither correlated with abundance nor with richness.

Table 3. Spearman's ranks correlation coefficients between local and environmental variables and wild bee abundance (Ab) and richness (Rich). Tax_att = percentage of plant species attractive for pollinators; Rich_v = number of vascular plant species; Ev_100 = percentage of green areas in a 100 m radius; Ev_600 = percentage of green areas in a 600 m radius; Mil_600 = percentage of natural habitats in a 600 m radius; Mil_800 = percentage of natural habitats in a 800 m radius. Bold coefficients are statistically significant at p-value < 0.05.

	Ab	Rich
Ab		
Rich	0.83	
Tax_att	**0.89**	0.60
Rich_v	-0.26	-0.03
Ev_100	0.41	0.58
Ev_600	0.58	**0.81**
Mil_600	-0.06	0.12
Mil_800	-0.06	0.12

Biological Trait Analysis of Wild Bees

The 99% of the wild bee individuals collected belonged to ground-nesting, eusocial and univoltine species (Fig. 2). One species nests in hives (*B. terrestris*) and only six are cleptoparasites, accounting for 1% of all individuals. Less than 3% of individuals were specialists regarding feeding behaviour. There were no significant differences in functional composition, neither between roofs, nor between roof types (all p-values > 0.05).

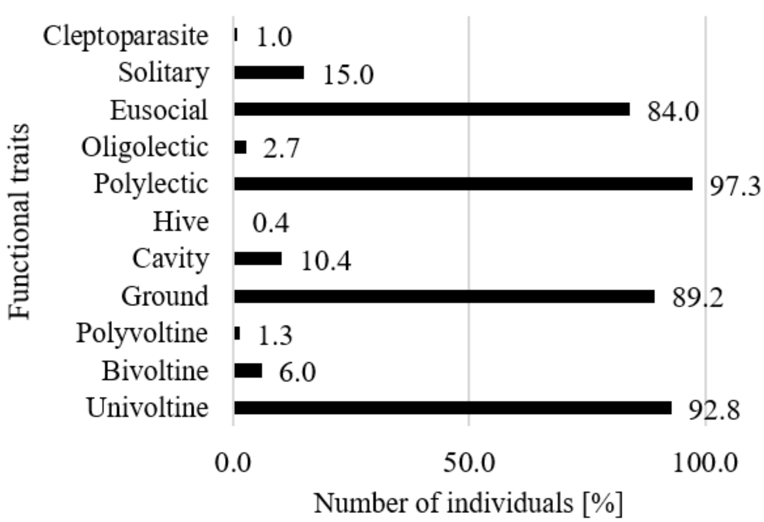

Fig. 2. Percentage of wild bee individuals according to four functional traits related to social behaviour (cleptoparasite / solitary / eusocial), feeding preferences (oligolectic / polylectic), habitat type regarding nesting (hive, cavity, ground) and voltinism (polyvoltine / bivoltine / univoltine).

Hoverflies

There were 36 individuals of hoverflies, belonging to seven genera and ten species sampled (Table 4). Two species could be considered as threatened in Switzerland, *Paragus quadrifasciatus* and *Cheilosia soror,* and one as potentially threatened, *Eumerus amoenus*

(Speight et al. 2016). *Sphaerophoria scripta* was the most abundant species, representing 61% of total catches.

Table 4. Number of individuals and total number of hoverfly species captured with cornet traps. Threatened species are highlighted in bold. Information regarding biological traits and habitats are given. Mig: migrant; Phyto: phytophagous larvae; Zoo: zoophagous larvae; Pl: larvae active on plants; H.l.: larvae active in herbaceous layer. Xeric: species associated with lowland unimproved xeric grassland; +: strong association with biological trait; +: preferred macrohabitat; ++: maximally preferred macrohabitat.

Species **Green roof number**	**15**	**16**	**45**	**33**	**37**	**38**	**Total**	**Mig**	**Phyto**	**Zoo**	**Pl**	**H.l.**	**Xeric**
***Cheilosia soror* (Zetterstedt, 1843)**					**1**		**1**		**+**		**+**	**+**	
***Eumerus amoenus* Loew, 1843**				**2**			**2**		**+**		**+**	**+**	**+**
Eumerus funeralis Meigen, 1822					1		1		+		+	+	
Eupeodes luniger (Meigen, 1822)					1		1	+	+		+		+
Melanostoma mellinum (Loew, 1758)					1		1	+	+				++
Paragus haemorrhous Meigen, 1822		1		1			2			+	+	+	++
***Paragus quadrifasciatus* Meigen, 1822**						**2**	**2**			**+**	**+**	**+**	**+**
Paragus tibialis (Fallen, 1817)					1		1			+	+		+
Pipizella viduata (Loew, 1758)				1		1	2			+	+		+
Pipizella sp.						1	1						
Sphaerophoria scripta (Linnaeus, 1758)	1	3	2	3	7	6	22	+		+	+	+	+
Number of individuals per roof	**1**	**4**	**2**	**7**	**12**	**10**	**36**						
Total number species per roof	**1**	**2**	**1**	**4**	**6**	**4**	**10**						

Biological Traits of Hoverflies

While seven hoverfly species sampled weres not migratory (Table 4), 3 of the collected species *Eupeodes luniger, Melanostoma mellinum* and *S. scripta* were identified as strong migrators, capable of flying long distances. All adult species recorded collect nectar from small to tall herbaceous plants. Two species are strictly univoltine (*Eumerus funeralis* and *Pipizella viduata*) and two strictly plurivoltine (*M. mellinum* and *P. quadrifasciatus*). The seven remaining species are considered bivoltine.

Out of the ten collected species, 8 had larvae developing on or in plants of the herbaceous layer. No species sampled develop in stony habitats. Regarding feeding preferences, half of the species were phytophagous in the larval stage, feeding on living plants and half were zoophagous feeding on aphids (*Paragus* spp., *P. viduata, M. mellinum* and *S. scripta*).

Considering the macrohabitat type “lowland unimproved xeric grassland” (Speight and Castella 2016) as the closest to the one studied on green roofs, eight out of the ten species collected are associated with this macrohabitat type (Tab. 4). At the regional level, 26 species known from the canton of Geneva (Speight et al. 2019) can be associated with the same habitat (Speight et al. 2016). Therefore, the six green roofs considered collectively proved to be used by 30% (8/26) of the regional species pool for that habitat.

DISCUSSION

Limitations of the Study

The single sampling method used, together with the reduced ground coverage of the traps, the limited number of roofs and the spatial overlap of 4 of the radii, represent limitations to statistical treatments of the results, which we nonetheless consider as providing valuable information. The availability of a robust sampling device (Passaseo et al. 2019) allows for further studies of the same type incorporating a larger sample size and accounting for annual variations in meteorological conditions.

Wild Bees

Urban areas are fragmented, and green roofs may provide additional corridors for pollinator conservation. Our results highlighted that green roofs were visited by a diverse community of wild bees. The number of wild bee species (62) found is in accordance with results of other studies (Brenneisen 2006; Colla et al. 2009; Kratschmer et al. 2018; Pétremand et al. 2018a). According to the Swiss red list of wild bee species (Amiet 1994), fourteen species could be considered as threatened at the Swiss level. Nevertheless, the swiss red list is currently updating, and considerably changing the species status following today's knowledge.

Green roof location along the urban / rural gradient impacts the diversity and composition of the associated insect communities (Blank et al. 2017). We showed that the abundance of wild bees was influenced by the surrounding landscape; wild bee abundance being lower in urban environments. This result is coherent with previous studies, showing that urbanisation leads to a decrease in wild bee abundance (Banaszak-Cibicka and Zmihorski 2012; Bates et al. 2011; Hernandez et al. 2009). This decrease can be explained by the loss of vegetal cover and nesting sites in urban environment (Zanette et al. 2005). Our first hypothesis, assuming an increase of abundance and richness with increasing percentages of green spaces in the landscape could therefore only partly be accepted, as the trend could not be confirmed for species richness.

The positive relationship we established between the percentage of attractive plant species and wild bee abundance is also consistent with other studies, who demonstrated that abundance and diversity of wild bees are highly correlated with the number of attractive plants on green roofs (Kratschmer et al. 2018; Wu 2019; Dusza et al. 2020). It suggests that vertical movement occur between ground and green roofs and that horizontal movements also occur between green roofs and green areas in the surrounding landscape (Braaker et al. 2014). We also confirmed that vegetation richness exerts only a minor effect on the diversity of wild bees of green roofs (Kruess and Tscharntke 2002; Madre et al. 2013).

Regarding landscape variables, the percentage of green areas within a 600 m radius proved to be positively correlated with wild bee richness, in line with results of previous studies (MacIvor 2016; Madre et al. 2013; Tonietto et al. 2011). Wild bees are highly mobile and capable of flying 0.1 to 1.5 km away from their nesting site to reach foraging sites (Gathmann and Tscharntke 2002). Wild bees are therefore strongly influenced by landscape characteristics and by the connectivity between habitats. This is probably especially true in the case of insects reaching green roofs (Braaker et al. 2014). Regarding our second hypothesis, we evidenced both local (amount of attractive plants) and landscape (coverage by green areas) variables correlating with wild bee community characteristics.

More than half (57.8%) of the species we found are shared with the study of Kratschmer et al. (2018). This author and Pétremand et al. (2018a) also found *A. nigroaenea, B. lapidarius, B. pascuorum, B. terrestris, H. hyalinatus, L. laticeps, L. malachurum, L. morio* and *L. politum* occurring on green roofs. This suggests that a pool of species, with particular functional traits, can take advantage of the simplified and harsh conditions of green roofs (Braaker et al. 2017), independently of roof location and environmental variables. The species collected in this research and the ones found in Kratschmer et al. (2018) shared similar functional traits: they are all eurytopic, ubiquitous regarding nesting sites and highly synanthropic (Amiet et al. 1996; Normandin et al. 2017). They can also be tolerant and opportunistic for varied food resources (Normandin et al. 2017). The dominance of generalist species supports our third hypothesis.

As exposed in Tonietto et al. (2011) or Braaker et al. (2017), we also showed that wild bee communities were dominated by ground-nesting species. The fact that the roof substrate composition appears to potentially support a few species of ground-nesting bees is particularly encouraging (Passaseo et al. 2020b), because they are less frequent in urban environments compared to cavity-nesting species (Cane et al. 2006). Indeed, ground-nesting species are known to be limited by the availability of nesting sites, human disturbance and their high sensitivity to landscape fragmentation (Cane et al. 2006). Only few individuals belonging to cleptoparasitic species were caught in this study, following the same trend as in Braaker et al. (2017). Cleptoparasites are good indicators of ecosystem health, because they play a stabilisation role in ecosystems and are sensitive to perturbations (Braaker et al. 2017). Except one species (*A. mitis*), all oligolectic species were specialised on plant families existing on green roofs (mainly *Crassulaceae*, *Asteraceae* and *Apiaceae*), reinforcing the idea of food supply provided by these structures. Nevertheless, regarding the passive catching method used in this study, it does not allow us to argue if the species collected where foraging or just passing over the roofs. In the case of *A. mitis,* in the absence of suitable flowers to visit, it is likely to conclude that the specimen caught was just passing over the roof. For other species collected, even for singletons, the presence of suitable plant families on roofs suggests that these species are able to reach roof top and forage on green roofs.

Hoverflies

Compared to wild bees, few hoverfly species (10) seemed to visit the studied roofs. As far as we know, this result is coherent with the only two studies led on this topic in Europe (Mecke 1996; Bevk 2021). The poor number of individuals caught in this study is presumably related to the negative impact of the urban landscape on hoverflies, preventing trends from being drawn. Several researches highlighted the poor diversity of hoverflies in urban and suburban environments (Hennig and Ghazoul 2012; Verboven et al. 2014), due notably to the limited availability of larval feeding resources: plants, aphids and decomposing vegetal material are less frequent in urban environments than in natural environments (Verboven et al. 2014). The homogeneous landscape of urban environment also does not provide optimal egg-laying sites for females (Hennig and Ghazou 2012; Verboven et al. 2014). Abundance and richness did not show any significative variations with roof types, although they were higher in mixed than in urban environments. These results could become significative with a higher number of sampling points. The first hypothesis, postulating that abundance and richness values are higher in mixed environment is therefore rejected for hoverflies.

The functional analysis of hoverflies caught on green roofs provided useful information. We could confirm that a majority of species were associated with xerothermophilic conditions, a condition generally observed for roof arthropods (MacIvor and Ksiazek 2015). This exemplifies the potential role of green roofs as surrogates for natural xeric grassland. The fact that the six roofs investigated could host one third of the potential species associated with xeric grassland in the canton of Geneva is worth noticing.

In terms of abundance, hoverfly assemblages were however dominated by a very ubiquitous species, *S. scripta.* This species was also mentioned by Hennig and Ghazoul (2012) as dominant in the city of Zurich. Indeed, *S. scripta* is present in almost all environments along the urban-rural gradient (Hennig and Ghazoul 2012; Speight et al. 2016; Verboven et al. 2014). It is bivoltine and therefore, less sensitive to environmental disturbances (Biesmeijer et al. 2006). *S. scripta* larvae lives on a wide variety of plants of any size (on or in parts of living plants) in the herb layer (Speight 2016). Its generalist requirements in terms of habitat and ecology supports our third hypothesis.

Because highly mobile species are expected on green roofs, due to vertical and horizontal habitat isolation (Braaker et al. 2017; Brenneisen 2006), we could have expected syrphid species with a high migratory capability to dominate the assemblages. This tendency was not totally supported by our results, as only three species out of ten could be considered as migratory (Speight et al. 2016). We showed therefore that the studied roof could harbour syrphid species with low dispersal ability. Equally, phytophagous insects could be expected to dominate in urban environment, compared to rural and natural habitats, due to prey dispersion linked to the habitat fragmentation (MacIntyre 2000). The fact that half of the species found were zoophagous at larval stage, implies that such hoverflies larvae can find sufficient feeding resources on green roofs (Kadas 2010).

As suggested in some studies (Colla et al. 2009; Tonietto et al. 2011; Grimshaw-Surette 2020; Passaseo et al. 2020b), some pollinators can find suitable habitats on green roofs: one species of wild bees, *L. morio*, and two of hoverflies, *S. scripta* and *P. quadrifasciatus*, were identified as the only species spending their whole life cycle on the studied roofs (Passaseo et al. 2020b). Regarding wild bees, it was highlighted that larger species nest in the ground and fly up to the green roof when foraging (Tonietto et al. 2011). It appears therefore that green roofs are more efficient in providing potential food resources than nesting sites for these two groups of pollinators.

Considering the results drawn by this study, the following Take-Home messages could be addressed to urban policymakers, who are planning biodiverse green roofs that are effective towards the promotion of wild bees and hoverflies:

- To allow pollinators access to green roofs, a good landscape connectivity should be ensured with the implementation of various types of green spaces surrounding green roofs, such as lawns, rows of trees or patches of urban farming.
- The floral diversity and abundance is a key driver of attractiveness of green roofs for pollinators. The design of green roofs comprising a set of floral species that i) attracts diverse pollinator communities and ii) provides foraging resources for oligolectic species, is therefore essential.
- Finally, as wild bees and hoverflies are sensitive towards anthropogenic disturbances in their habitat, the level of maintenance should be kept as low as possible on green roofs.

APPENDICES

Table 5. Vegetation survey: list of sampled taxa per roof in percent cover [%], corresponding to the abundance-dominance coefficient according to Braun-Blanquet (1928). Plant species were recorded along one transect representing the median longest axis of the roof ; "+" means that species is present on the green roof without significant cover. Status: species were attributed the status "N" for native or "NN" for non-native according to their classification in InfloFlora (2021); "-" means that no data were found.

Taxa **Green roof number**	**15**	**16**	**45**	**33**	**37**	**38**	**Status**
Acer sp.					+	+	N
Achillea millefolium (Linnaeus, 1753)	3	+					N
Allium schoenoprasum (Linnaeus, 1753)	+	14		14			N
Anthemis tinctoria (Linnaeus, 1753)						0.3	N
Anthyllis vulneraria (Linnaeus, 1753)	3						N
Arenaria serpyllifolia (Linnaeus, 1753)					0.3		N
Bromus erectus (Hudson, 1762)						0.3	N
Bromus tectorum (Linnaeus, 1753)			0.3				N
Campanula bertolae (Colla, 1835)	+						N
Campanula rotundifolia (Linnaeus, 1753)	+						N
Cerastium fontanum (Baumgarten, 1816)						0.3	N
Cerastium glomeratum (Thuillier, 1799)	+						N
Conyza canadensis (L.) Cronquist, 1943			3				NN
Cornus sanguinea (Linnaeus, 1753)				+			N
Dactylis glomerata (Linnaeus, 1753)	0.3						N
Daucus carota (Linnaeus, 1753)	32						N
Dianthus armeria (Linnaeus, 1753)	+						N
Dianthus carthusianorum (Linnaeus, 1753)	+	+		+			N
Dianthus sylvestris (Wulfen, 1787)	+						N
Echium vulgare (Linnaeus, 1753)	14	14	3	3	3		N
Erigeron annuus (L.) Desfontaines, 1804	32		0.3	14		3	NN
Erodium ciconium (L.) L'Héritier de Brutelle ex Aiton, 1789	14	32				0.3	NN

Taxa **Green roof number**	**15**	**16**	**45**	**33**	**37**	**38**	**Status**
Euphorbia amygdaloides (Linnaeus, 1753)		0.3					N
Festuca arundinacea (Schreb.) Darbyshire, 1993		0.3					N
Festuca marginata ssp *gallica* (Hack. Ex Charrel) Breistroffer, 1966						57	-
Festuca rubra s. str. (Linnaeus, 1753)					+		N
Festuca rubra aggr.	3	3					N
Festuca rubra Linnaeus, 1753			+				N
Festuca stricta ssp *trachyphylla* (Hack.) Patzke ex Pilz, 1984		57					-
Geranium pusillum (Linnaeus, 1753)	3						N
Geranium pyrenaicum (Burman, 1759)				+			N
Geranium rotundifolium (Linnaeus, 1753)		3				0.3	N
Helianthemum nummularium sst (L.) Miller, 1768	0.3						N
Hieracium cymosum (Linnaeus, 1753)	3	0.3			0.3		N
Hieracium pilosella (Linnaeus, 1753)	3	14	14	14	0.3		N
Holcus lanatus (Linnaeus, 1753)	0.3				0.3	0.3	N
Hypericum perforatum (Linnaeus, 1753)	3	3		3		0.3	N
Hypochaeris radicata (Linnaeus, 1753)	3	0.3		32		3	N
Koeleria pyramidata (Lam.) Palisot de Beauvois, 1812						3	N
Lactuca serriola (Linnaeus, 1753)		0.3	0.3			0.3	N
Leontodon hispidus (Linnaeus, 1753)			14				N
Leucanthemum vulgare (Lamarck, 1779)			0.3				N
Linaria vulgaris (Miller, 1768)				+			N
Linum alpinum (Jacquin, 1762)		+					N
Linum austriacum (Linnaeus, 1753)		+					N
Lolium multiflorum (Lamarck, 1779)			+		+		NN
Lotus corniculatus (Linnaeus, 1753)	+	0.3		0.3			N
Medicago lupulina (Linnaeus, 1753)	0.3	14	0.3	0.3			N
Medicago minima (L.) Linnaeus, 1754						0.3	N
Medicago sativa (Linnaeus, 1753)	0.3						N
Melilotus officinalis (Lamarck, 1779)			0.3				N
Nigella arvensis (Linnaeus, 1753)			3				N
Origanum vulgare (Linnaeus, 1753)	3	3	57	3			N
Oxalis corniculata (Linnaeus, 1753)				3			N
Papaver rhoeas (Linnaeus, 1753)					3		N
Petrorhagia saxifraga (L.) Link, 1829			3	0.3	3	0.3	N
Picris hieracioides (Linnaeus, 1753)				32		3	N
Pimpinella saxifraga (Linnaeus, 1753)		+					N
Plantago lanceolata (Linnaeus, 1753)	3	14		3		0.3	N
Poa compressa (Linnaeus, 1753)				0.3			N

Taxa Green roof number	15	16	45	33	37	38	Status
Poa pratensis (Linnaeus, 1753)	+			0.3			N
Populus alba (Linnaeus, 1753)	0.3	+					N
Potentilla argentea (Linnaeus, 1753)	3						N
Potentilla sp.		3					N
Salvia pratensis (Linnaeus, 1753)	0.3	0.3					N
Sanguisorba minor (Scopoli, 1771)				0.3			N
Sanguisorba minor ssp *polygama* Waldstein and Kitaibel, 1978	3	+	3		+		N
Saponaria ocymoides (Linnaeus, 1753)					0.3		N
Sedum acre (Linnaeus, 1753)			3		14		N
Sedum album (Linnaeus, 1753)			3	3	14	+	N
Sedum floriferum (Praeger, 1918)				57	32		-
Sedum hybridum (Linnaeus, 1753)			0.3				NN
Sedum reflexum (Linnaeus, 1762)				32			-
Sedum rupestre (Linnaeus, 1753)					+	0.3	N
Sedum rupestre aggr.			32	32	14		N
Sedum sexangulare (Linnaeus, 1753)			3	0.3	14		N
Sedum spurium (Von Bieberstein, 1808)		0.3	0.3	3	32		NN
Senecio inaequidens (De Candolle, 1837)				0.3			NN
Silene flos-cuculi (L.) Greuter and Burdet, 1982						+	N
Silene nutans (Linnaeus, 1753)	+	0.3	3		0.3		N
Silene vulgaris sstr (Moench) Garcke, 1869	0.3						N
Sonchus asper (L.) Hill, 1769		3	3	0.3	0.3	3	N
Sonchus oleraceus (Linnaeus, 1753)						14	N
Stachys recta s. str. (Linnaeus, 1753)	0.3						N
Taraxacum officinale (Weber ex Wiggins, 1780)				0.3		0.3	N
Teucrium botrys (Linnaeus, 1753)	14	0.3					N
Thymus pulegioides (Linnaeus, 1753)		3		0.3	0.3		N
Thymus serpyllum (Linnaeus, 1753)	3						N
Thymus vulgaris (Linnaeus, 1753)			3	0.3			N
Tragopogon pratensis (Linnaeus, 1753)			0.3				N
Trifolium arvense (Linnaeus, 1753)				32			N
Trifolium dubium (Sibthorp, 1794)				0.3			N
Trifolium pratense (Linnaeus, 1753)				0.3			N
Trifolium pratense sstr (Linnaeus, 1753)	14	0.3					N
Trifolium repens (Linnaeus, 1753)	3			3			N
Vicia hirsuta (L.) Gray, 1821				+		0.3	N
Vicia orobus (De Candolle, 1837)				+			N
Vicia sativa ssp *nigra* (L.) Ehrhart, 1780		0.3					N
Viola arvensis Murray, 1770		0.3		3		+	N
Vulpia myuros (L.) Gmelin, 1805	57	57		32		0.3	N

Taxa Green roof number	15	16	45	33	37	38	Status
Total taxa per roof	**40**	**36**	**26**	**39**	**22**	**26**	
Total coverage per roof [%]	**221.7**	**240.9**	**152.7**	**321.9**	**131.7**	**90.5**	

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