



Greens up: vertical greenings to promote urban pollinators – a preliminary study from a Central European City

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Received: 1 November 2024 / Accepted: 7 July 2025 / Published online: 20 September 2025
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Abstract

Urban expansion continues to impact natural landscapes and biodiversity, yet cities are implementing measures to mitigate some of these negative effects. One such measure is the use of vertical greenings, which aim to enhance urban ecosystems and support biodiversity. Given the limited knowledge of pollinators in these vertical green spaces, we conducted a pilot study in a Central European city (Vienna, Austria) focusing on butterfly and wild bee species richness and their interactions with foraging plants during the year 2022. In total, we recorded 32 wild bee species and eight butterfly species. Our results show that vertical greenings with high floral richness (i.e., comprising more than four flowering entomophilous plant species) supported significantly more wild bee ($p=0.005$) and butterfly ($p=0.002$) species compared to vertical greenings with low floral richness (i.e., comprising two or fewer flowering plant species). The majority of bee-plant interactions were observed on *Nepeta faassenii*, *Sedum* sp., and *Parthenocissus quinquefolia*, while most butterfly-plant interactions were observed on *Nepeta faassenii*. Implications for insect conservation: Our study demonstrates that vertical greenings may serve as valuable nectar and pollen sources in urban environments. However, their effectiveness most likely depends on floral diversity, which we observed to be, at least partly, influenced by the maintenance practices of the greenings.

Keywords Wild bees · Butterflies · Urban ecosystems · Species richness · Landscape management

Introduction

Cities can host a considerably high pollinator richness due to their structural richness, plant diversity and specific microclimate (Fortel et al. 2014; Llodrà-Llabrés and Cariñanos 2022). However, urban areas also negatively impact biodiversity through rapid land use change caused by soil sealing, infrastructure accumulation, and reduced occurrences of vegetation and air circulation (i.e., Urban Heat Islands; Ahrné et al. 2009; Banaszak-Cibicka and Żmihorski 2012). For example, pollinator abundance is positively affected by intermediate urbanization levels that comprise a mix of built

up area and green-patches in suburban areas, which can also reduce thermal stress (Biella et al. 2022). While the average rate of land consumption in Europe is up to 0.8% per year (between 2006 and 2012) due to the expansion of cities and is often related to the conversion of cropland to urban areas (Salvati et al. 2018), conservation actions have gained attention to counteract some of the negative consequences of biodiversity loss (Aronson et al. 2017). Besides community gardens (Matteson and Langellotto 2010) and green roofs (Kratschmer et al. 2018; Jacobs et al. 2023), vertical greenings are another example of measures intended to improve habitat quality, which are being implemented by smart, sustainably operating cities. Vertical greenings are essentially façades covered with plants where vegetation grows either directly on the building or on a structure fixed to the buildings' surface (Bustami et al. 2018). They offer energetic advantages (natural insulation and cooling), positive effects on greenhouse gas mitigation, and improvements to residents' quality of life (e.g., noise reduction; Radić et al. 2019; Oquendo-Di Cosola et al. 2022).

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In addition, it is assumed that vertical greenings provide habitat for animals, such as birds and insects (Mayrand and Clergeau 2018). However, monitoring projects or at least initial surveys to evaluate the potential of vertical greenings for local pollinator diversity have rarely been conducted (Treder et al. 2024). Therefore, we collected data on wild bee and butterfly species richness and abundance from selected vertical greenings in Vienna (Austria), a Central European city. Wild bees are one of the most important pollinators providing immense economic and nature conservation-related benefits (Klein et al. 2007; Ollerton et al. 2011). Butterflies (Lepidoptera) serve as indicators of disturbances and environmental changes and are therefore often considered useful for monitoring habitat quality (Thomas et al. 2004; Brereton et al. 2011). Further, their charismatic, recognizable appearance makes butterflies ideal flagship species for communicating conservation measures and goals to citizens (Barua et al. 2012). We surveyed urban vertical greenings with different species richness of entomophilous plants (floral diversity) to evaluate their association with pollinator diversity and abundance. Further, we assessed which plant species serve as important floral resources for bees and butterflies on vertical greenings to test whether vertical greening could be useful for supporting pollinator foraging in urban environments.

Materials and methods

Vertical greenings in Vienna, Austria, were selected based on preliminary visits in 2021 and evaluated according to accessibility for sampling, location (all sites were located in the city center for comparability), their floral diversity (species richness of flowering plants observed in May and July 2021) and a comparable maintenance state (e.g., manual watering, seasonal pruning, façade greenery systems). Sites were considered comparable if they were watered manually (not automatically with watering systems) and pruned seasonally to maintain plant health and structure. This ensured that differences in pollinator diversity were not confounded by significant variations in maintenance practices. The maintenance practices were provided by management facilities or were based on personal observations. We selected five study areas that included 18 representative vertical greenings. One vertical greening had to be excluded as the greening was covered with a net shortly after our study started. Each study area comprised at least one vertical greening with a high species richness of flowering plants (more than four plant species, V1-V6 vertical greenings; five sites in total) and at least two vertical greenings with a single plant species or two plant species (C1-C11 sites, 12 sites in total). Species-rich vertical greenings were located at distances of

over 1 km from each other and were considered spatially independent as the mean activity range of bees is between 100 and 800 m (e.g., Gathman and Tschardt 2002).

Vertical greenings with two or fewer plant species (C1-C11) were visited when the respective flowering plants were in bloom, e.g., *Hedera helix* blooming in September; *Wisteria sinensis* blooming in June. Fieldwork was conducted during four sampling periods in 2022 from April until September on sunny, dry days (preferably cloud-free), with temperatures above 15 °C and minimal wind. In some areas, sampling was done through windows (V1) or balconies (V2, V3). Furthermore, wild bees were not sampled in study area five (V6, C10, C11) because access to conduct hand netting was not possible (Fig 1).

The sampling duration was standardized depending on the size of the greening: Wild bees and butterflies were monitored for 10 min for every 25 m² of vertical greening resulting in sampling durations ranging from 10 min to a maximum of 60 min per vertical greening site (Suppl. Information 1). This approach can be seen as a modification of a standard transect walk where sampling time and sampled area are the same across all vertical greenings, a method frequently used in pollinator studies and recommended by the EU Pollinator Monitoring Scheme (Potts et al. 2020). Butterflies were spotted using binoculars and were immediately identified in the field to species level following the nomenclature by Swaay et al. (2010). Most wild bees were sampled by hand netting with a telescopic pole, euthanized using ethyl acetate and taken to the laboratory to identify them to species level after labeling and pinning (Scheuchl 1995; Schmid-Egger and Scheuchl 1997; Amiet 2001; Amiet et al. 2004). Wild bee nomenclature followed Scheuchl and Willner (2016). Some particular wild bee species were immediately identified in the field also to species level: *Bombus* sp., *Anthophora plumipes* (Pallas, 1772), *Osmia cornuta* (Latreille, 1805), *Osmia bicornis* (L., 1758). Abundance at each vertical greening was documented and classified into categories: individual counts of up to 5 individuals, 5–10 individuals, >10 individuals, and >20 individuals. For analyses we used the most conservative count of each category (e.g., 5 individuals, 10 individuals, 20 individuals). We identified *Apis mellifera* (L., 1758) at the vertical greenings and excluded observations of this species from the wild bee data set. In addition, the taxonomic names and the total number of plant species were recorded for each vertical greening (Suppl. Information 1) and pollinator-plant interactions (i.e., when the animal was observed collecting pollen or nectar) were documented.

Statistical analyses were computed using RStudio (R Core Team 2021). The rank abundance distribution analysis (RADanalyses) was computed with the package 'RADanalyses' (Saeedghalati et al. 2016), to examine the evenness



Fig. 1 The five study areas consisted of vertical greenings characterized by a high entomophilous plant species richness (at least four plant species; V1–V6) and sites with fewer plant species (two or fewer

entomophilous plant species; C1–C11) within 1 km radius distributed in central Vienna (Austria, Central Europe; map: ArcGIS Desktop V. 10.8.1; <https://maps.wien.gv.at/basemap>)

of species within the sampled assemblage (Saeedghalati et al. 2016). Boxplots comparing species richness between vertical greening types with high (V1–V6 sites) and low (C1–C11 sites) plant species richness and network plots assessing important foraging plant species were generated with the package ‘bipartite’ (Dormann et al. 2008). Data management was performed with the package ‘tidyverse’ (Wickham et al. 2019). Differences in wild bee and butterfly species richness between vertical greening types were analyzed using Wilcoxon rank-sum tests.

Results

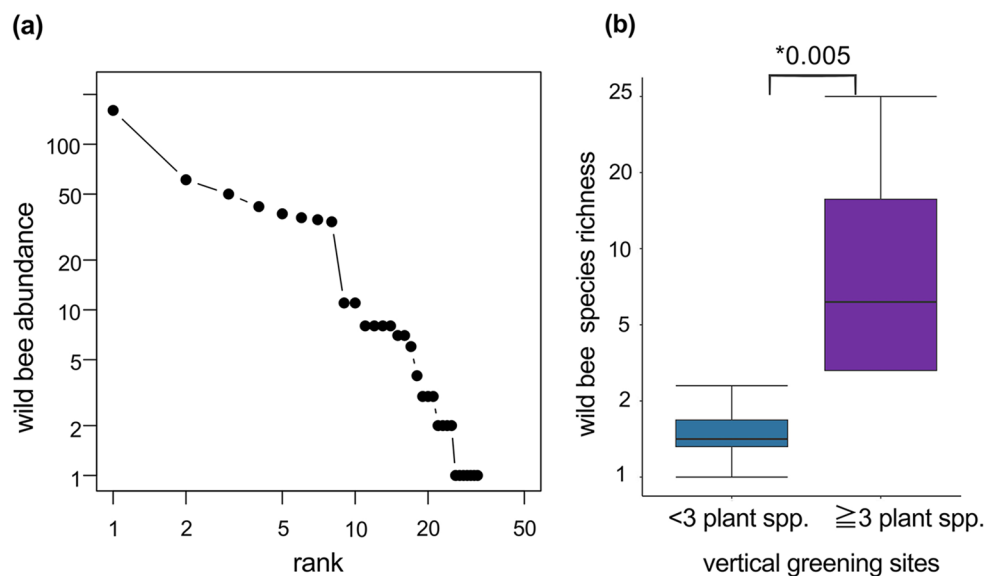
Wild bees

In total, 558 individuals from 32 wild bee species belonging to 12 genera were recorded, representing approximately

7% of the wild bee species documented in Vienna (Zettl et al. 2022; Suppl. Information 2a). The RADanalysis showed that the most abundant species were *Lasioglossum pauxillum* (Schenk, 1853), *Colletes hederæ* (Schmidt & Westrich, 1993) and *Halictus subauratus* (Rossi, 1792; Fig. 2a). The wild bee species richness differed significantly (Wilcoxon rank-sum test: $W=0$; $p=0.005$) between vertical greening with <2 flowering plant species and vertical greenings with >4 plant species (Fig. 2b).

Eleven species (34%), such as *H. subauratus* and *Lasioglossum politum* (Schenk, 1853), were primitive eusocial species, while 19 species (59%) were solitary. A single parasitic bee species (*Coelioxys elongata* (Lepelletier, 1841)) was documented on the studied vertical greenings. The majority, comprising 19 species (60%), nested below ground in burrows, 10 species (28%) were above-ground cavity nesters including *Xylocopa violacea*, which utilizes dead-wood for nesting. No nesting activity was discovered.

Fig. 2 (a) The RADanalysis shows that 8 wild bee species (25%) were represented with >20 individuals, 2 species (6%) with >10 individuals, 6 species (19%) with 5–10 individuals and another 16 species (50%) with 1–5 individuals. (b) The Wilcoxon rank-sum test between vertical greenings with more than four plant species (V1–V4 sites) and one or two plant species (C1–C9 sites) was significant for wild bee species richness (V1–4: mean: 13.75 ± 8.62 SE; C1–9: 2.7 ± 1.70 SE; $p=0.005$)



In total, 28 species (88%) exhibited a polylectic pollen-collecting behavior, while only three oligolectic species (*C. hederæ*, *Colletes succinctus* (L., 1758), *Hylaeus signatus* (Panzer, 1798)) were documented. The most frequently visited plant species by bees were *Nepeta faassenii*, *Sedum* sp. and *Parthenocissus quinquefolia* (Fig. 3). *Colletes hederæ* was collected in high abundance (>20 individuals) of both sexes at the main pollen source *Hedera helix* at several sites in September. For *C. succinctus* and *H. signatus*, a single male was collected during nectar feeding.

Butterflies

In total, 48 individuals from eight butterfly species and three genera were recorded, which corresponds to 6% of the 137 butterfly species documented in Vienna (Höttinger et al. 2003; Suppl. Information 3b). As with wild bees, butterfly species richness also differed significantly (Wilcoxon rank-sum test: $W=3$; $p=0.002$, Fig. 4b) between vertical greenings with <2 flowering plant species and vertical greenings comprising >4 plant species. The most abundant species was *Pieris rapae* (L., 1758) followed by *Vanessa atalanta* (L., 1758) and *Pieris brassicae* (L., 1758; Fig. 4a). Seven species are categorized as Least Concern (LC) in the Red List of Butterflies in Austria (Höttinger and Pennerstorfer, 2005) and Vienna's Red List (Höttinger et al., 2013), including *Celastrina argiolus* (L., 1758), *Polygonia c-album* (L., 1758), *Vanessa atalanta*, *Gonepteryx rhamni* (L., 1758), *Pieris brassicae*, *Pieris napi* (L., 1758), and *Pieris rapae*. One species, *Vanessa cardui* (L., 1758), is classified as Not Evaluated (NE).

We documented the highest species richness for one south-exposed vertical greening (V6), with six documented species and 15 individuals. Two species (*Gonepteryx*

rhamni, *Pieris napi*) were observed exclusively at this site. Vertical greening V1, with 21 individuals from five species, had the highest butterfly abundance, where most nectar-sucking individuals were registered on the south-exposed side of the building.

Discussion

The present study provides valuable insights into flower-rich vertical greenings, which can increase pollinator species richness and abundance in urban areas by providing pollen and nectar resources. Although direct comparisons are hampered by different study designs, the total species richness of this study is relatively low compared with the results from other local studies (32 wild bee species; no comparable data for butterflies are available), such as green roofs (90 bee species; Kratschmer et al. 2018) or urban gardening projects (113 bee species; Lanner et al. 2020). Vertical greenings appeared to be relatively species-poor in wild bee richness. A likely explanation for these differences is that entomophilous plant species richness and nesting opportunities were considerably higher on the green roofs and in urban gardens. The high proportion of ground-nesting bee species on vertical greenings combined with the absence of observed nesting activity indicates that suitable nesting habitats may have been close to the study sites (Tonietto et al. 2011). Isolation due to low connectivity between habitats can negatively affect highly mobile insect diversity and abundance (Braaker et al. 2014). For example, green roofs located close to public gardens supported more insect species compared to more isolated green roofs (Husain et al. 2023). In addition, low maintenance frequency (for example, mosaic mowing) of lawns or green roofs in

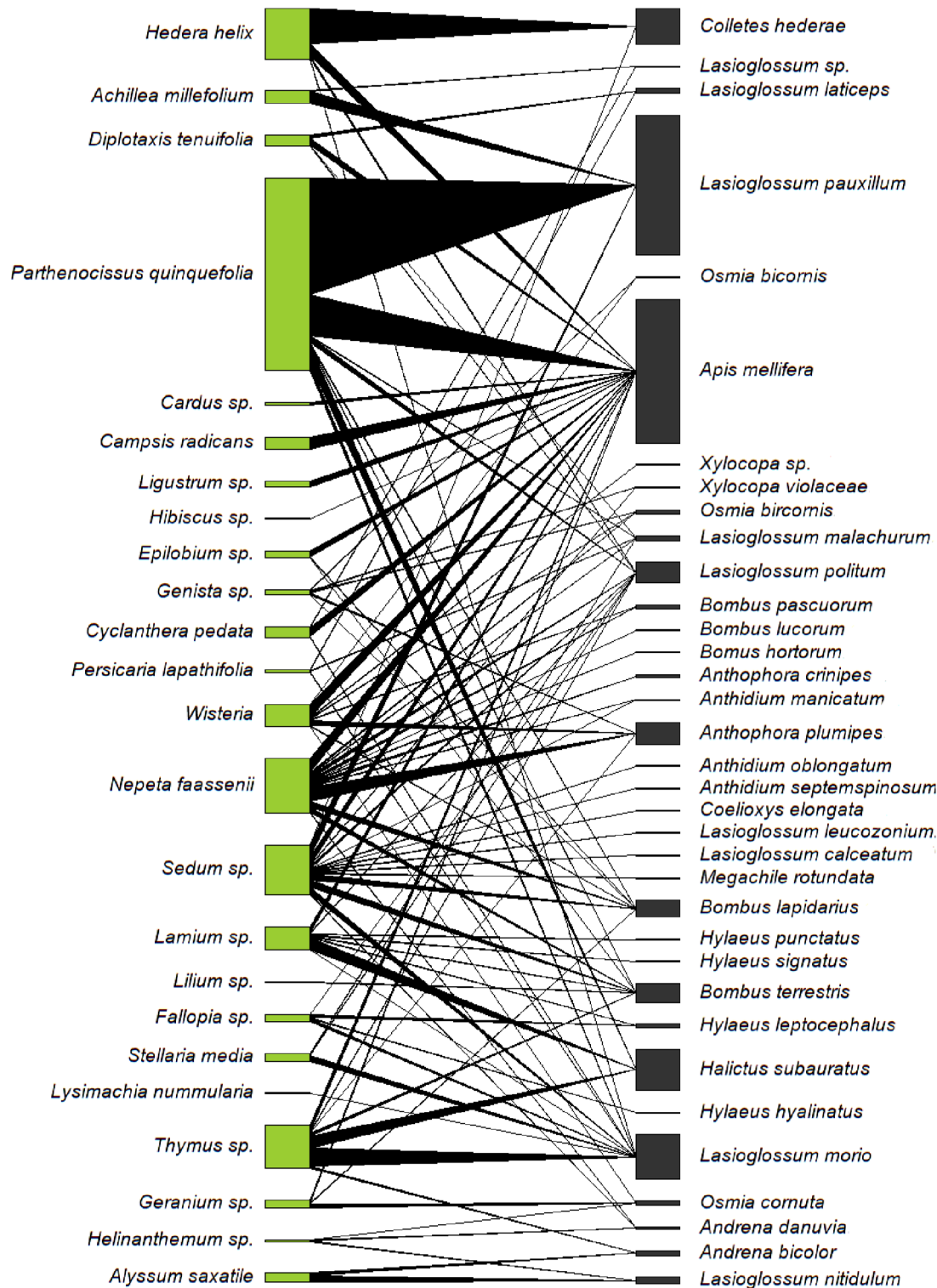


Fig. 3 Most bee-plant interactions on vertical greenings were recorded on *Nepeta faassenii*, *Sedum* sp., and *Parthenocissus quinquefolia*

general positively affected pollinator diversity (Rada et al. 2024; Kratschmer et al. 2018).

However, our findings are preliminary results as we did not include any landscape characteristics into the planning

of the study design. This limits the interpretation of our findings, as does the coverage of a single season, which also affected the results and conclusions due to e.g., annual variations of weather conditions influencing insect populations

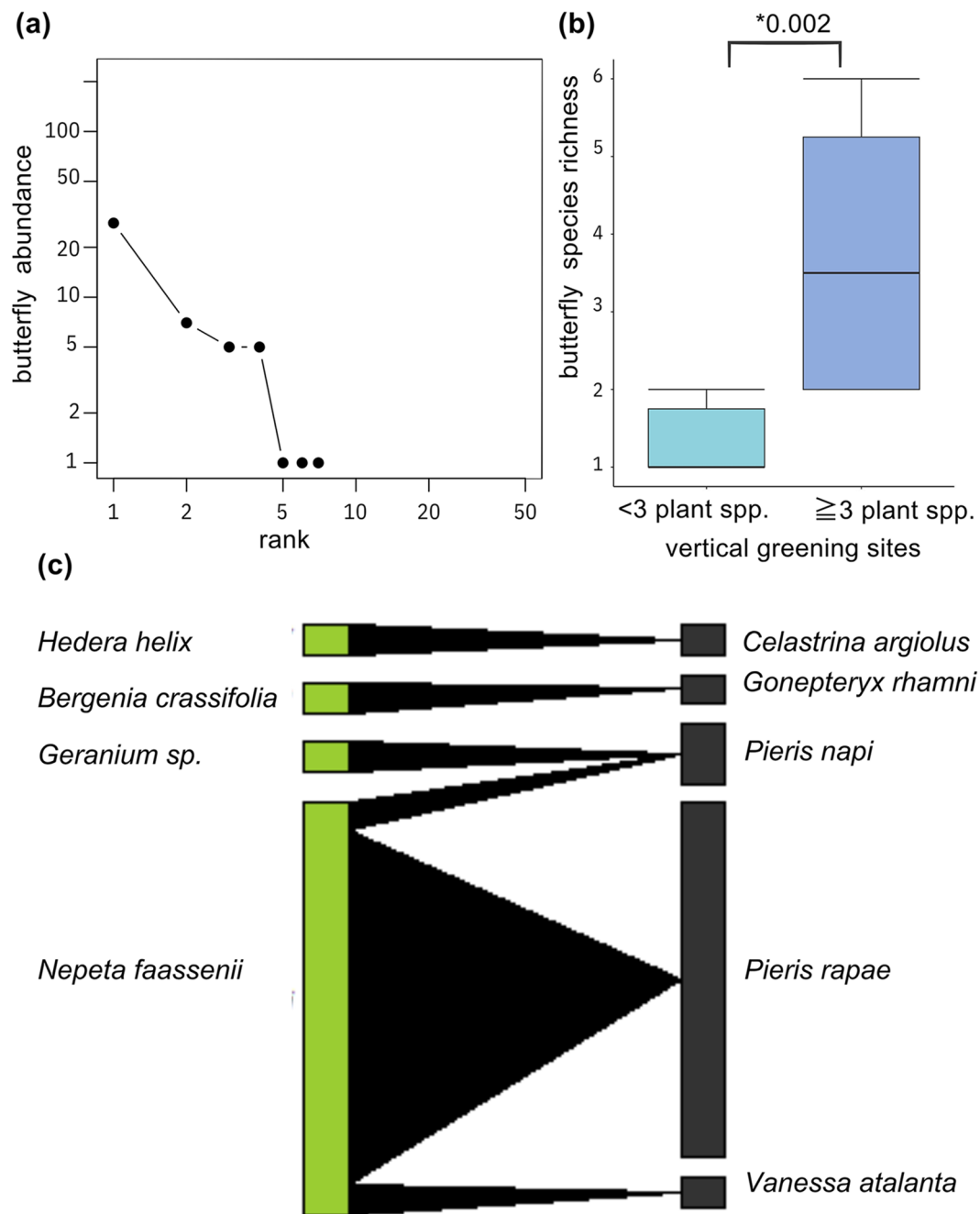


Fig. 4 (a) The RADanalysis plot on the left shows that *P. rapae* was the most abundant species observed on vertical greenings, with 28 individuals followed by *Vanessa atalanta*, *Pieris brassicae* and *Celastrina argiolus*. Species with only one individual documented are listed in Suppl. Information 2b (b) We found significantly ($p=0.002$; Wilcoxon

rank-sum test) more species at plant-diverse vertical greenings (V1-V6 sites, mean: 2.75 ± 2.06 SE) compared to vertical greenings with few plant species (C1-C11 sites, mean 0.3 ± 0.48 SE). (c) Most plant-butterfly interactions were recorded on *Nepeta faassenii*

between years (Papanikolaou et al. 2017). Further investigations are necessary, also considering landscape variables (e.g., community gardens, parks, distance to the city center, etc.) to obtain a more comprehensive picture of the ecological value of vertical greens for pollinators.

Based on our preliminary findings, we carefully conclude that the benefits for the local pollinator biodiversity

on vertical greenings depend on several factors: (1) Vertical greenings with a rich plant diversity provide foraging resources for a variety of bee and butterfly species. Even though we did not observe any nesting activity during our survey period, structures already implemented (e.g., artificial nesting aids made of dead wood) in vertical greening systems and specific vegetation material (e.g., stems from

raspberries) may provide valuable nesting habitat mainly for above-ground nesting species, such as masked bees (*Hylaeus* sp.). (2) Another important factor is the maintenance of vertical greenings. We qualitatively observed that vertical greenings with a well-maintained state (frequent watering, extensive pruning) appeared to have higher species richness and species exhibiting more diverse ecological traits (e.g., V1, V3). In contrast, we observed fewer species at vertical greenings with a poorly maintained state (V2). (3) Inflorescences providing foraging resources throughout the vegetation period, from April until September, support a variety of different pollinator species. We qualitatively observed this pattern on vertical greenings: Across the vertical greenings with high floral diversity, we observed an expected peak of flowering plants during June, and an overall stable supply of nectar-providing plants until early September. We documented most plant-pollinator interactions with *Nepeta faassenii* and *Sedum* sp. – both plants having an exceptionally long flowering period. (4) Lastly, we recommend establishing plant species, which are attractive foraging resources for pollinators but also aesthetically pleasing for humans living with vertical greens (Ranalli et al. 2025). Plants, such as lavender or raspberry, may reduce conflict potential between residents and conservationists (personal observation from vertical greening V2) and may motivate residents to keep the vertical greening in a well-maintained state.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10841-025-00695-3>.

Acknowledgements We wish to thank Josef Mikocki, and our colleagues Christina Rupprecht, Bärbel Pachinger for the support in designing the study. Further we thank the facility managements for giving us access to the green walls and all the owners of the properties for allowing us to collect data.

Author contributions Study conception, fieldwork and species identification were performed by JL and EH. Analysis were conducted by JL and SK. The first draft of the manuscript was written by JL and SK. All authors commented and approved the final manuscript.

Funding Open access funding provided by Paris Lodron University of Salzburg. Financial support was granted to JL and EH by the city of Vienna – Department for Nature Conservation (MA 22).

Data availability All data generated or analysed during this study are included in this published article.

Code availability Not applicable.

Declarations

Ethical approval No approval of research ethics committees was required to accomplish the goals of this study because experimental work was conducted with an unregulated invertebrate species.

Consent to participate Not applicable.

Competing interests The authors declare no competing interests.

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