

Plants – Pollinators – People: Wild Bees in Urban Environments

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Table of Contents

Table of Contents

LIST OF FIGURES	4
LIST OF TABLES.....	4
SUMMARY	5
ZUSAMMENFASSUNG	6
1. INTRODUCTION	8
1.1. INSECT DECLINES	8
1.1.1. <i>Global biodiversity and insect declines</i>	8
1.1.2. <i>Effects of insect declines</i>	8
1.2. WILD BEES	9
1.2.1. <i>Wild bee diversity</i>	9
1.2.2. <i>Life forms and habitat requirements of wild bees</i>	9
1.2.3. <i>Wild bee declines</i>	9
1.3. WILD BEES IN URBAN HABITATS.....	13
1.3.1. <i>Effects of urbanization on biodiversity</i>	13
1.3.2. <i>Effects of urbanization on wild bee diversity</i>	13
1.3.3. <i>Drivers of wild bee diversity and conservation strategies in urban environments</i>	14
1.4. WILD BEES AS URBAN POLLINATORS	14
1.4.1. <i>Wild bees as pollinators</i>	14
1.4.2. <i>Wild bees as pollinators in natural and agricultural ecosystems</i>	15
1.4.3. <i>Pollination in urban ecosystems</i>	15
1.4.4. <i>Interactions between wild bees and honeybees in urban habitats</i>	15
1.5. CITIZEN SCIENCE IN BEE AND POLLINATION RESEARCH	16
1.5.1. <i>Wild bee citizen science as an outreach tool</i>	16
1.5.2. <i>Examples and systematization of wild bee citizen science projects</i>	17
1.5.3. <i>Wild bee citizen science as a monitoring tool</i>	17
1.5.4. <i>Photo-based wild bee inventory methods</i>	18
1.5.5. <i>Participative research projects in urban environments</i>	19
2. OBJECTIVES AND OUTLINE.....	21
2.1. RESEARCH QUESTIONS.....	21
2.2. GRAPHICAL ABSTRACT	22
3. MATERIAL AND METHODS	23
3.1. STUDY REGION.....	23
3.2. STUDY SITES	23
3.2.1. <i>Pollinator surveys</i>	23
3.2.2. <i>Standardized bee surveys</i>	23
3.2.3. <i>Flower patches</i>	24
3.3. STUDY SPECIES.....	26
3.4. DATA SAMPLING	26
3.4.1. <i>Pollinator surveys</i>	26
3.4.2. <i>Standardized bee surveys</i>	26
3.4.3. <i>Citizen scientist bee surveys and pollinator observations</i>	27
3.4.4. <i>Bee identification</i>	28
3.4.5. <i>Species traits</i>	28
3.4.6. <i>Floral resources</i>	28
3.4.7. <i>Landscape and meteorological metrics for pollinator surveys on meadow orchards</i>	28
3.5. ANALYTICAL TOOLS	29
<i>Publication 1</i>	29
<i>Publication 2</i>	32

Table of Contents

4. SUMMARY OF PUBLICATIONS	33
PUBLICATION 1: THE IMPORTANCE OF WILD BEE COMMUNITIES AS URBAN POLLINATORS AND THE INFLUENCE OF HONEYBEE HIVE DENSITY ON WILD BEE CROP VISITATION RATES	33
PUBLICATION 2: HOLISTIC WILD BEE MANAGEMENT IN URBAN SPACES	34
PUBLICATION 3: FIELD GUIDE TO THE WILD BEES OF BAVARIA.....	35
5. GENERAL DISCUSSION.....	36
5.1. WILD BEES AS POLLINATORS IN URBAN ENVIRONMENTS	36
5.1.1. <i>Diverse pollinator communities on trees and berries from the rose family</i>	36
5.1.2. <i>Impact of honeybee hive density on wild bee flower visitation rate on orchard crops</i>	37
5.2. OPPORTUNITIES AND LIMITATIONS OF WILD BEE CONSERVATION IN URBAN ENVIRONMENTS	39
5.2.1. <i>Contextualized results</i>	39
5.2.1.1. Bee species richness	39
5.2.1.2. Conservations status	39
5.2.1.3. Floral specialization (lecty)	40
5.2.1.4. Nesting type.....	42
5.2.1.5. Nesting requisites	43
5.2.1.6. Habitat types and their management	45
5.2.1.7. Connectivity and connection to source habitats	46
5.2.1.8. Climate and overall habitat conditions	46
5.2.2. <i>Management recommendations</i>	48
5.3. METHODOLOGICAL EXPLORATIONS: CHALLENGES AND OPPORTUNITIES OF COMMUNITY-BASED SURVEY APPROACHES AND PHOTO-BASED INVENTORIES IN WILD BEE RESEARCH	50
5.3.1. <i>Participation</i>	50
5.3.2. <i>Opportunities of photo-based approaches in combination with citizen science platforms</i>	51
5.3.3. <i>Opportunities and limitations of photo-based bee identification</i>	52
6. CONCLUSION AND IMPLICATIONS FOR CONSERVATION	56
6.1. CONCEPT FOR BEE-FRIENDLY MANAGEMENT OF URBAN SPACES	56
6.2. OUTVIEW	56
ACKNOWLEDGEMENTS	58
REFERENCES.....	60
APPENDIX	86
A1 SUPPLEMENTARY DATA	
A1.1. <i>Systematization of bee- and pollination-related citizen science projects</i>	
A1.2. <i>Outreach</i>	
A1.2.1. Project website and iNaturalist project site	
A1.2.2. Flyer.....	
A1.2.3. Online forms on the project website.....	
A1.2.4. Announcements of guided talks and walks	
A1.2.5. Information boards accompanying stepping-stone flower patches	
A1.2.6. Publications in local media.....	
A1.3. <i>Extended list of the wild bee taxa recorded in Freising with links to photo-vouchers on iNaturalist, information on Red List Status (Bavaria), notes on identification, and contributions by citizen scientists</i>	
A2 PUBLICATION LIST	
<i>Peer-reviewed journal publications</i>	
<i>Conference participations</i>	

List of figures

List of figures

- Figure 1. From top left to bottom right (all females): *Anthidium oblongatum* on *Lotus corniculatus*, *Bombus sylvarum* on *Rubus idaeus*, patrolling *Sphecodes* spec., *Coelioxys aurolimbatus* on *Satureja hortensis*, *Andrena* spec. nesting, *Osmia leucomelana* nesting in *Rubus* sect. *Rubus* stem, *Osmia bicolor* nesting in a snail shell, *Anthidium manicatum* nesting in a drill hole, *Megachile* cf. *argentata* nesting in an embankment, *Anthidium manicatum* collecting plant hair on *Stachys byzantina*, *Osmia bicornis* collecting mud, *Osmia* spec. collecting pieces of *Fragaria vesca* leaves, *Dasygaster hirtipes* on *Cichorium intybus*, *Colletes hederæ* on *Hedera helix*, *Andrena agilis* on *Sinapis arvensis*, *Chelostoma campanularum/distinctum* on *Campanula* spec., *Megachile rotundata* on *Lotus corniculatus*, *Anthophora furcata* on *Nepeta grandiflora*, *Halictus subauratus* on *Ranunculus* spec., *Hylaeus nigrinus* thickening nectar on *Achillea filipendula* (pictures by Julie Weissmann). 10
- Figure 2. Examples of study sites: allotment garden (A), strawberry patch (B), flower patch with *Echium vulgare* (C), meadow orchard (D), river dike (E), wasteland (F) [pictures by Julie Weissmann (A-C), Iris Walldorf (D), Rasmus Ritz (E) and Sandra Rader (F)]. 25
- Figure 3. Location of Freising in Europe (inset) and distribution of bee-rich habitats, stepping-stone flower patches and sites for pollinator observations on straw-, rasp-, and blackberries [basemaps: Bayerische Vermessungsverwaltung (2023) (main map) & Wikimedia (inset)]. 25
- Figure 4. Some of the study species for pollinator observations: *Prunus domestica* (A), *Malus domestica* (B), *Fragaria* spec. (C), and *Rubus* spec. (D) (pictures by Julie Weissmann). 26
- Figure 5. Bee categories used for pollinator surveys: honeybee (A), bumblebee (B), large solitary bee (C) and small solitary bee (D) (pictures by Julie Weissmann). 26
- Figure 6. Standardized bee surveys in meadow orchards (A), on the river dike (B), in wastelands (C), and on flower patches (D) (pictures by Julie Weissmann). 27
- Figure 7. Excursions for citizen science projects (A) and events with elementary school children's groups in an allotment (B) [pictures by Theresia Endriß (A) and Pi Besgen (B)]. 27

List of tables

- Table 1. Life form, nesting type, required nesting materials, pollen preference, and pollen carrying structures of all wild bee species listed for Germany by Westrich (2018). Genera are listed when at least one species of this genus can be assigned to a specific nesting, feeding, or pollen collection type. Percentages refer to the share of species belonging to a certain nesting or feeding type in relation to all species – or all nest-building species (i.e., not brood parasitic species) when applicable – documented for Germany in Westrich (2018). Calculations are based on information compiled from Westrich (2018); percentages do not necessarily add up to 100% because some (few) species belong to, e.g., more than one nesting type. 11
- Table 2. Characterization of the habitat types visited for standardized bee surveys in Freising. 23
- Table 3. Plant species selected for stepping-stone flower patches and the respective target bee species with information on nesting requisites required by them [compiled from Westrich (2018)]. 24
- Table 4. Plant species selected for stepping-stone flower patches and which of the bee specialized on those plant species we did and which we did not detect [information on oligolectic bee species compiled from Westrich (2018), information on Red List status for Bavaria (in brackets) compiled from Scheuchl et al. (2023)]. 41
- Table 5. Number of taxa, share of taxa with specific traits, and share of Bavarias taxa with the same trait for: Bavaria (Scheuchl et al., 2023), Munich since 1795 (Schuberth & Bräü, 2024), Munich since 2000 (Schuberth & Bräü, 2024), new river- and gravel-bank habitats and one area of a relocated dam in three small restored sections of the Isar river in a protected area nearby Freising [surveyed in 2015, see Mandery (2016)], and Freising city (iNaturalist Project “Wildbienen in Freising”). Red List categories are based on Scheuchl et al. (2023); traits are based on Westrich (2019). 44

Summary

In light of global bee declines and urbanization, urban bee projects are in fashion and in many European cities, different stakeholders independently work towards improving urban habitats for this important pollinator group. However, evidence-based approaches identifying conservation strategies and management practices for the conservation of wild bees at a city-wide scale are rare. The aim of this thesis is to develop and test a holistic bee and pollination research and conservation program in a medium-sized city in southern Germany integrating “pollinators, plants and people” with the main questions: 1) How relevant is bee diversity for urban fruit crop pollination? 2) What opportunities do urban habitats offer for bee conservation? 3) How can citizens be involved in urban bee research?

Publication 1 focuses on the importance of wild bees as pollinators on five common urban fruit crops from the rose family and investigates the effect of landscape variables, weather conditions, and honeybee hive density on wild bee crop visitation rates. In **Publication 2**, we combine systematic specialist surveys with photograph-based citizen science data collection to gather species lists and distribution data for a city's bees. We identify centers of bee diversity, analyze connectivity between hotspots, and implement stepping-stone flower patches to evaluate their impact for oligolectic bees. On this basis, we develop a concept for wild bee management in urban spaces. **Publication 3** – a field guide for wild bee identification based on photographs – constitutes a methodological building block for Publications 1 and 2.

Regarding pollinator management, our study suggests that species-rich wild bee communities in cities are important for continuous pollination of common fruit crops throughout the seasons and under unstable weather conditions intensified by climate change. Wild bee abundance on fruit tree flowers was negatively affected by honeybee hive density. We suggest adapting hive density to floral resources and prioritizing bee-friendly management of urban spaces for wild bees and the increasing number of honeybees. Regarding habitat management for urban bee conservation, our study supports extensive management of green spaces and highlights the importance of early succession wasteland areas. Moreover, we suggest prioritizing small-scale connectivity between foraging and nesting resources in high-value habitats over continuous connectivity between floral resources throughout the entire city. Overall, by combining systematic surveys in hotspots with citizen science data for comprehensive surveys in all parts of the city, we assessed 144 wild bee taxa for Freising 2017–2024. These included 32 Red List Species and fifteen taxa detected by citizen scientists only.

The overall discussion summarizes the findings of the three publications. It addresses opportunities and limitations of wild bee conservation in cities and of community-based bee inventories for wild bee research. On this basis, it develops practical recommendations for holistic urban bee and pollination management.

Zusammenfassung

Angesichts des globalen Rückgangs der Artenvielfalt bei Insekten und Wildbienen sowie ansteigender Urbanisierung liegen städtische Bienenprojekte im Trend. In vielen europäischen Städten arbeiten unterschiedliche Akteure unabhängig voneinander an der Aufwertung urbaner Lebensräume für diese wichtige Bestäubergruppe, doch es mangelt an ganzheitlichen Ansätzen, die die verschiedenen Bemühungen über eine gesamte Stadt hinweg bündeln. In dieser Arbeit wird ein holistischer Ansatz für die Erforschung, den Schutz und die Förderung von Wildbienen und von Bestäubungsprozessen auf der Basis empirischer Daten einer Fallstudie in einer mittelgroßen Stadt unter Einbeziehung von „Bestäubern, Pflanzen und Menschen“ entwickelt und erprobt. Folgende Fragen werden erörtert: 1) Wie bedeutend sind artenreiche Wildbienengemeinschaften für die Bestäubung von Obstgewächsen in der Stadt? 2) Welche Chancen bieten urbane Lebensräume für Wildbienenschutz? 3) Wie können städtische Bewohner*innen in Wildbienenforschung eingebunden werden?

Publikation 1 konzentriert sich auf die Bedeutung von Wildbienen als Bestäuber von fünf häufig vorkommenden städtischen Nutzpflanzen aus der Familie der Rosengewächse und untersucht die Auswirkungen von Landschaftsvariablen, Wetterbedingungen und Bienenstockdichte auf die Blütenbesuchsraten von Wildbienen. In **Publikation 2** kombinieren wir systematische Kartierungen mit fotobasierter Citizen-Science-Datenerhebung, um Artenlisten und Verbreitungsdaten für die Wildbienenarten über das Stadtgebiet hinweg zu erfassen. Wir identifizieren Zentren der Bienen Vielfalt, analysieren die Konnektivität zwischen Hotspots und schaffen Trittstein-Blühbeete, um deren Auswirkungen auf oligolektische Bienen zu bewerten. Auf dieser Grundlage entwickeln wir ein Managementkonzept zur Förderung der Wildbienen Vielfalt im urbanen Raum. **Publikation 3** – ein Feldführer zur Wildbienenbestimmung anhand von Fotos – bildet einen methodischen Baustein für die Publikationen 1 und 2.

Unsere Studie zeigt die Bedeutung artenreicher Wildbienengemeinschaften für die Bestäubung von Obstgewächsen in der Stadt auf, insbesondere angesichts klimawandelbedingt instabiler Witterungsbedingungen. Wildbienenbesuchsraten an Obstbaumblüten wurden negativ durch steigende Honigbienenstockdichten beeinflusst. Wir empfehlen, Bienenstockdichten an die verfügbaren Blütenressourcen anzupassen und ein bienenfreundliches Management städtischer Lebensräume für Wild- und Honigbienen zu priorisieren. Diesbezüglich legt unsere Studie eine extensive Bewirtschaftung von Grünflächen nahe, verdeutlicht die Bedeutung von Brachflächen in frühen Sukzessionsstadien, und hebt die Relevanz hochwertiger Lebensräume mit kleinräumiger Konnektivität zwischen Nahrungs- und Nistressourcen hervor. Insgesamt konnten wir mit unserem kombinierten Ansatz systematischer Kartierungen in Hotspots mit umfassenden Erhebungen durch Citizen

Zusammenfassung

Scientists über das Stadtgebiet hinweg 144 Wildbientaxa inklusive 32 Rote Liste Arten für Freising (2017–2024) erfassen, fünfzehn davon allein durch Citizen Scientists.

Die übergreifende Diskussion erörtert Chancen und Grenzen von Wildbienenschutz in Städten und unseres methodischen Ansatzes fotobasierter Wildbienenerhebungen, der systematische Kartierungen mit Citizen-Science-Ansätzen kombiniert. Auf dieser Grundlage werden praktische Empfehlungen für ein ganzheitliches Bienen- und Bestäubungsmanagement in Städten artikuliert.

1. INTRODUCTION

1.1. Insect declines

1.1.1. Global biodiversity and insect declines

Global biodiversity is declining at alarming rates and scales (IPBES, 2019). More than one-quarter of more than 150,000 species assessed in the IUCN Red List of Threatened Species and 19% of more than 14,000 species assessed in European Red Lists are threatened with extinction (Hochkirch et al., 2023; IUCN, 2024). Insects constitute a major part of global biodiversity. Nearly two-thirds of the world's more than 1.5 million documented animal species are insects (Bánki et al., 2023), and large numbers are not described yet, cryptic, or not assessed regarding their conservation status (Eisenhauer et al., 2019; Hochkirch et al., 2021; Li & Wiens, 2023; Mora et al., 2011; Stork, 2018; Wiens, 2023). Meanwhile, empirical studies worldwide provide evidence for insect biodiversity declines considering biomass, abundance, and number of species throughout various habitats and bioregions. A 76 percent decline in flying insect biomass in nature protection areas in Germany (Hallmann et al., 2017), a 78–98 percent decline in ground-foraging and canopy-dwelling arthropod biomass in rainforests of Puerto Rico (Lister & Garcia, 2018), a ~47% decline in insect biomass in a protected subalpine meadow in Colorado (Dalton et al., 2023) and a 67% decline in arthropod biomass in grasslands and 41% decline in forests in Germany (Seibold et al., 2019) were recorded over 27, 36, 35 and 10 years, respectively. Decreases in abundance and species richness are identified across various taxa, affecting specialists as well as common and generalist species (Sánchez-Bayo & Wyckhuys, 2019; Van Klink et al., 2024). Moreover, a trend towards homogenization has been identified in several studies (Gossner et al., 2023; Thorn et al., 2022).

1.1.2. Effects of insect declines

Insect declines threaten whole ecosystems by affecting food webs (Bowler et al., 2019; Hallmann et al., 2014; Lister & Garcia, 2018) and pollination systems in natural and agricultural environments. For example, parallel declines in pollinators and insect-pollinated plants have been detected in Britain and the Netherlands (Biesmeijer et al., 2006), and pollinator deficits have been identified as a main driver for yield gaps (i.e., the difference in crop yield between high- and low-yielding farms of a given crop system) of pollinator-dependent crops like apple (*Malus domestica*) or cucumber (*Cucumis sativus*) in small holdings (Garibaldi et al., 2016).

1. INTRODUCTION

1.2. Wild bees

1.2.1. Wild bee diversity

More than 20,000 wild bee species have been described worldwide (Ascher & Pickering, 2020; Packer, 2023), 2,137 species belonging to 76 genera were recorded within Europe (within the geographical limits set by the ICUN, which encompass continental Europe and European Island territories such as Great Britain, Ireland, Iceland, Cyprus, Azores, Madeira, and Canary Islands) (Ghisbain et al., 2021) and 604 species belonging to 49 genera were recorded within Germany (Scheuchl et al., 2023) (all excluding *Apis*).

1.2.2. Life forms and habitat requirements of wild bees

Bees are a fascinating group of insects that come in a panoply of appearances and behaviors. Regarding their life form, nearly two-thirds of the species recorded in Germany are solitary, one-quarter are parasitic, and the rest are social or communal. They need three types of resources: nesting habitats, nesting materials, and food (pollen and nectar or plant oil). Three-quarters of all nest-building species documented in Germany build their nest in the ground either in self-excavated cavities or in pre-existing cavities like abandoned rodent nests. The remaining nest-building species nest aboveground either in pre-existing structures (in hollows in the herb layer, between stones, walls or in abandoned bird nests, in hollow plant stems, insect burrowings in deadwood, rock crevices, empty snail shells, abandoned nests of solitary Hymenoptera or reed galls), in self-excavated cavities in deadwood and pithy plant stems, or in newly built freestanding nests on stones, rocks or plant structures. Resources used as nesting materials are leaf fragments, masticated leaf tissue, plant hair, petal fragments, masticated wood and wood particles, plant pith, resin, as well as clay, sand, mineral mortar, or small stones. Regarding their pollen and nectar or oil resources, approximately one-third of all nest-building species in Germany are oligolectic. Pollen is collected with hairy scopae on the abdomen and legs (e.g., *Osmia*), in a pollen basket or corbiculum (*Bombus*), or in the crop (e.g., *Hylaeus*). Flight activity of most species encompasses only a few weeks per year and ranges from early spring to late autumn (Westrich, 2018) (see *Figure 1* and *Table 1*). Each species depends on the availability of a very specific combination of nesting habitat, nesting material, and flowering plants within foraging ranges of only a few hundred meters (Hofmann et al., 2020; Zurbuchen, Landert, et al., 2010).

1.2.3. Wild bee declines

Bees are among the taxa showing the strongest declines (Sánchez-Bayo & Wyckhuys, 2019; Zattara & Aizen, 2021). Studies using historic data sets testify reductions of abundance and diversity in the US (Burkle et al., 2013) and the UK (Biesmeijer et al., 2006; Ollerton et al., 2014). 9.2% of the 1,965 bee species assessed in Europe (Nieto et al., 2014), and half of the 557 bee species assessed in the German Red List are threatened (Westrich et al., 2011).

1. INTRODUCTION



Figure 1. From top left to bottom right (all females): *Anthidium oblongatum* on *Lotus corniculatus*, *Bombus sylvarum* on *Rubus idaeus*, patrolling *Sphecodes* spec., *Coelioxys aurolimbatus* on *Satureja hortensis*, *Andrena* spec. nesting, *Osmia leucomelana* nesting in *Rubus* sect. *Rubus* stem, *Osmia bicolor* nesting in a snail shell, *Anthidium manicatum* nesting in a drill hole, *Megachile* cf. *argentata* nesting in an embankment, *Anthidium manicatum* collecting plant hair on *Stachys byzantina*, *Osmia bicornis* collecting mud, *Osmia* spec. collecting pieces of *Fragaria vesca* leaves, *Dasygaster hirtipes* on *Cichorium intybus*, *Colletes hederæ* on *Hedera helix*, *Andrena agillissima* on *Sinapis arvensis*, *Chelostoma campanularum/distinctum* on *Campanula* spec., *Megachile rotundata* on *Lotus corniculatus*, *Anthophora furcata* on *Nepeta grandiflora*, *Halictus subauratus* on *Ranunculus* spec., *Hylaeus nigritus* thickening nectar on *Achillea filipendula* (pictures by Julie Weissmann).

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life form	solitary	communal	social	parasitic	unknown
genera	<i>Andrena, Anthidium, Anthidiellum, Anthophora, Camptopoeum, Ceratina, Chelostoma, Colletes, Dasypoda, Dufourea, Eucera, Halictus, Heriades, Hylaeus, Lasioglossum, Lithurgus, Macropis, Megachile, Melitta, Melitturga, Nomia, Nomioides, Hoplitis, Osmia, Panurginus, Panurgus, Rhophitoides, Rhophites, Systropha, Xylocopa</i>	<i>Andrena, Panurgus, Osmia</i>	<i>Bombus, Halictus, Lasioglossum</i>	<i>Ammobates, Ammobatooides, Biastes, Bombus/Psithyrus, Coelioxys, Dioxys, Epeoloides, Epeolus, Melecta, Nomada, Sphecodes, Stelis, Thyreus</i>	<i>Lasioglossum</i>
% of all species	62%	1%	8%	24%	4%

nesting type	endogeic (belowground)		hypogeic (aboveground)										parasitic
	self-excavated cavities	pre-existing cavities	pre-existing structures (between stones/walls/in abandoned bird nests)	self-excavated cavities in deadwood	surface-nesting (nests in the herb layer/hollows)	hollow plant stems, insect burrowings in deadwood	pithy plant stems	rock crevices / masonry joints	empty snail shells	free-standing nests on stones, rocks or plant structures	abandoned nests of solitary Hymenoptera	reed galls	n.a.
genera	<i>Andrena, Anthidium, Anthophora, Camptopoeum, Colletes, Dasypoda, Dufourea, Eucera, Halictus, Lasioglossum, Macropis, Megachile, Melitta, Melitturga, Nomia, Nomioides, Osmia, Hoplitis, Panurginus, Panurgus, Rhophites, Rhophitoides, Systropha</i>	<i>Anthidium, Bombus, Hylaeus, Megachile</i>	<i>Anthidium, Bombus, Hylaeus, Osmia, Hoplitis, Megachile</i>	<i>Anthophora, Lithurgus, Megachile, Osmia, Xylocopa</i>	<i>Bombus, Osmia, Hoplitis, Megachile</i>	<i>Chelostoma, Halictus, Heriades, Megachile, Osmia, Hoplitis</i>	<i>Ceratina, Megachile, Hoplitis, Hylaeus</i>	<i>Megachile, Hylaeus, Osmia</i>	<i>Osmia</i>	<i>Anthidiellum, Megachile, Hoplitis</i>	<i>Osmia, Hylaeus</i>	<i>Hylaeus, Heriades, Osmia</i>	<i>Ammobates, Ammobatooides, Biastes, Bombus/Psithyrus, Coelioxys, Dioxys, Epeoloides, Epeolus, Melecta, Nomada, Sphecodes, Stelis, Thyreus</i>
% of all species	50%	6%	10%	1%	2%	6%	2%	2%	1%	1%	1%	1%	24%
% of all species	56%		24%										24%
% of nest building species	74%		31%										n.a.

1. INTRODUCTION

required nesting materials	leaf fragments	masticated leaf tissue	plant hair	petal fragments	masticated wood / wood particles	plant pith	resin	clay / clayey sand / sand mineral mortar / small stones
genera	<i>Megachile, Anthidium</i>	<i>Osmia, Hoplitis</i>	<i>Anthidium</i>	<i>Hoplitis</i>	<i>Xylocopa, Hoplitis</i>	<i>Xylocopa</i>	<i>Anthidium, Anthidiellum, Megachile</i>	<i>Megachile, Osmia, Hoplitis</i>
% of all species	4%	4%	1%	<1%	1%	<1%	1%	2%

pollen preference	polylectic	oligolectic	parasitic
genera	<i>Andrena, Anthidium, Anthidiellum, Anthophora, Bombus, Cnecropoem, Ceratina, Colletes, Dufourea, Halictus, Hylaeus, Lasioglossum, Megachile, Nomia, Nomioidea, Osmia, Hoplitis, Panurginus, Xylocopa, Andrena, Lasioglossum, Osmia</i>	<i>Andrena, Anthidium, Anthophora, Bombus, Chelostoma, Colletes, Dasypoda, Dufourea, Eucera, Heriades, Hylaeus, Lasioglossum, Lithurgus, Macropis, Megachile, Melitta, Melitturga, Osmia, Hoplitis, Panurginus, Panurgus, Rhophites, Rhophitoides, Systropha</i>	<i>Ammobates, Ammobatoides, Biastes, Bombus/Psithyrus, Coelioxys, Dioxys, Epeoloides, Epeolus, Melecta, Nomada, Sphecodes, Stelis, Thyreus</i>
% of all species	51%	24%	24%
% of all nest building species	68%	32%	n.a.

pollen carrying structures	corbicula	scopa on the abdomen	scopa on the legs	crop	parasitic
genera	<i>Bombus</i>	<i>Anthidium, Chelostoma, Heriades, Lithurgus, Megachile, Osmia, Systropha</i>	<i>Andrena, Anthophora, Colletes, Dasypoda, Dufourea, Eucera, Halictus, Lasioglossum, Macropis, Melitta, Nomioidea, Panurginus, Panurgus, Rophites, Rophitoides, Ceratina, Systropha, Xylocopa</i>	<i>Hylaeus, Ceratina, Xylocopa</i>	<i>Ammobates, Ammobatoides, Biastes, Bombus/Psithyrus, Coelioxys, Dioxys, Epeoloides, Epeolus, Melecta, Nomada, Sphecodes, Stelis, Thyreus</i>

A non-exhaustive list of resources suitable for wild bees (recorded in Germany) with particular nesting requirements compiled according to Westrich (2018) and Westrich (n.d.) (additional sources are specified when applicable):

- Plant species used by wild bees nesting in pithy plant stems: *Artemisia campestris* and other *Artemisia* spp., *Carduus nutans*, *Cirsium vulgare*, *Dipsacus* spp., *Onopordum* spp., *Rosa corymbifera*, *Rubus idaeus*, *Rubus* sect. *Rubus*, *Verbascum densiflorum* and other *Verbascum* spp.
- Tree species preferred by wild bees nesting in self-excavated cavities in dead wood: hardwood, fruit trees
- Wood species preferred by wild bees nesting in pre-existing cavities in deadwood: hardwoods, e.g., *Fraxinus excelsior*, *Fagus sylvatica*, *Carpinus betulus*, *Quercus robur*
- Plant species suitable for wild bees nesting in hollow plant stems: bamboo, reeds
- Snail species whose shells are used by wild bees nesting in empty snail shells: *Helix pomatia*, *Cepaea nemoralis*, *Cepaea hortensis*, *Arianta arbustorum*, *Bradybaena fruticum*, *Helicella itala*, *Zebrina detrita*
- Plant species used by wild bees requiring leaf fragments to build their nests: hardwoods (e.g. *Acer platanoidea*, *Acer pseudoplatanus*, *Betula* spp., *Carpinus betulus*, *Fagus sylvatica*, *Quercus* spp., *Robinia* spp.), *Epilobium angustifolium*, *Rosa canina* and other *Rosa* spp., *Symphoricarpos* spp., *Wisteria sinensis* [see also Maclvor (2016) and Sinu et al. (2022)]
- Plant species used by wild bees requiring petal fragments to build their nests: *Campanula* spp., *Geranium pratense*, *Geranium sylvaticum*, *Helianthemum* spp., *Linum flavum*, *Malva* spp., *Papaver* spp., *Potentilla* spp., *Ranunculus* spp., *Rosa* spp.
- Plant species used by wild bees requiring plant hair to build their nests: *Anaphalis margaritacea*, *Carlina vulgaris*, *Centaurea spec.*, *Cydonia*, *Echinops ritro*, *Helichrysum arenarium*, *Helichrysum thianshanicum*, *Lychnis coronaria*, *Populus*-seeds, *Senecio bicolor*, *Stachys byzantina*, *Stachys germanica*, *Verbascum* spp., *Vitis vinifera*
- Resources on substrate requirements of ground-nesting bees: https://www.wildbienen.info/artenschutz/nisthilfen_05.php, https://www.wildbienen.info/artenschutz/nisthilfen_06.php, <https://ebooks.wildbee.ch/erdnister/mobile/index.html>
- Suitable plants for oligolectic bees: <https://www.wildbienen.info/bluetenbesuch/oligolektie.php>, https://www.wildbienen.info/bluetenbesuch/oligolektische_arten.php, <https://www.nature.uni-freiburg.de/ressourcen/publikationen-pdfs/oligolektie.pdf>

1. INTRODUCTION

1.3. Wild bees in urban habitats

1.3.1. Effects of urbanization on biodiversity

Land use changes have been identified as a main driver of insect and bee declines (Cardoso et al., 2020; Goulson et al., 2015; Sánchez-Bayo & Wyckhuys, 2019; Uhler et al., 2021; Wagner et al., 2021). One key agent of land-use change (besides agricultural intensification) is urbanization, which refers to the growth and densification of urban areas in terms of population and size (United Nations, 2018). The share of the world's population living in urban areas increased from less than one-third in 1950 to more than one-half in 2018 and is projected to reach more than two-thirds by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2019). This growth leads to urban expansion (Gao & O'Neill, 2020; Seto et al., 2011, 2012; Simkin et al., 2022; van Vliet, 2019) and densification (Haaland & Van Den Bosch, 2015; McDonald et al., 2023), which in turn alters biogeochemical cycles [e.g., climate (e.g., urban heat island effect), soils (e.g., an increase of impervious surfaces), hydrology (e.g., pollution)], affects habitats (e.g., habitat fragmentation, habitat disturbance, loss of natural habitats) (Grimm et al., 2008; Kowarik, 2011; Moll et al., 2019), and impacts species richness, community composition, and functional diversity, with a tendency towards biotic homogenization (Deguines et al., 2016; Fenoglio et al., 2020; Fournier et al., 2020; Hahs et al., 2023; McKinney, 2006, 2008). At the same time, there is evidence that urban habitats can be important for biodiversity conservation, including rare species (Buchholz et al., 2020; Hofmann & Renner, 2020). Thus, the urgency to address environmental issues in cities is increasingly taken into account in global policy frameworks like the UN Sustainable Development Goals and the UN Decade on Ecosystem Restoration 2021–2030 (Neuenkamp et al., 2021; United Nations, n.d., 2015).

1.3.2. Effects of urbanization on wild bee diversity

The occurrence of bees in a given habitat depends on the availability of nesting sites, nesting materials, and food plants within flight range, as well as on landscape connectivity (Westrich, 2018). Soil sealing (Geslin et al., 2016), habitat fragmentation (Theodorou, Herbst, et al., 2020), flight barriers (Fitch & Vaidya, 2021), high levels of disturbance (Sattler et al., 2010), pesticides and pollution (Baldock, 2020), reduced floral resources, and shifts in plant community composition (Theodorou, Herbst, et al., 2020) caused by urbanization have been found to negatively affect bee diversity and abundance. Nonetheless, Hymenoptera prove to be less affected by urbanization when compared to other insect taxa (Deguines et al., 2012; Theodorou, Radzevičiūtė, et al., 2020). Some effects of urbanization can be conducive to bees: networks of parks, gardens, and other green spaces can offer a diversity of plants flowering throughout the season, small-scale structural diversity can positively impact the availability of nesting sites, and a moderately warmer microclimate is largely beneficial for bees (Zurbuchen & Müller, 2012).

1. INTRODUCTION

A growing corpus of studies examines urban bee diversity and community composition in comparison to farmland, nature reserves, and rural grasslands (Baldock et al., 2015; Zaninotto et al., 2021), along urban gradients (Banaszak-Cibicka & Żmihorski, 2012; Fortel et al., 2014), across different urban habitat types (Baldock et al., 2019; Normandin et al., 2017; Threlfall et al., 2015), and within selected sites like parks (Geslin et al., 2015), community gardens (Felderhoff et al., 2022), residential gardens (Fetridge et al., 2008), green roofs (Hofmann & Renner, 2018), roadsides (Dietzel et al., 2024), and wastelands (Twerd & Banaszak-Cibicka, 2019). Overall, a more complex picture of urbanization generating “winners” (e.g., cavity-nesting, polylectic, and small species) and “losers” (e.g., ground-nesters and oligolectic species) becomes apparent (Ayers & Rehan, 2021; Buchholz & Egerer, 2020; Fauvau et al., 2022; Hernandez et al., 2009).

1.3.3. Drivers of wild bee diversity and conservation strategies in urban environments

Although some studies identify urban wild bee hotspots [e.g., community gardens (Baldock et al., 2019)] and environmental features driving wild bee taxonomic and functional diversity [e.g., green space size and connectivity (Zaninotto et al., 2023)], highlight potentials for the protection of rare species (Hall et al., 2017), or evaluate the effects of habitat management interventions [e.g., improvement of floral resources (Dietzel et al., 2024; Hofmann & Renner, 2020; Wojcik et al., 2008)], evidence-based approaches identifying conservation strategies and management practices for the conservation of wild bees at a city-wide scale are rare.

1.4. Wild bees as urban pollinators

1.4.1. Wild bees as pollinators

An estimated 85-90% of all flowering plants, 76% of the leading global food crops, and 35% of global food production are animal-pollinated (Klein et al., 2007; Ollerton et al., 2011; Tong et al., 2023). Regarding their importance as pollinators, which results from their ability to touch anthers, contact stigmas, carry pollen, and move to a flower of the same species, bees are high performers. They are the only animal pollinating group where both adults and larvae rely on floral resources. They cover a large spectrum of tongue lengths, body sizes, and collecting behaviors matching different corolla shapes and sizes. Many species have relatively large and hairy bodies and pollen-carrying structures. Moreover, many species attain high flower visitation frequency as a result of large population sizes (e.g., *Bombus*), high numbers of flower visitations per time unit (e.g., *Osmia*), and/or are flower consistent (one-third of all nest-building species recorded in Germany are oligolectic, see *Table 1*). Concordantly, bees have been identified as the most important pollinating taxon for various habitat types, plant species, and communities (Ballantyne et al., 2017; Ollerton, 2017; Silva et al., 2023; Willmer et al., 2017), although the importance of other pollinating groups should not be overlooked (Rader et al., 2016, 2020; Requier et al., 2023; Schmack & Egerer, 2023).

1. INTRODUCTION

1.4.2. Wild bees as pollinators in natural and agricultural ecosystems

Studies in natural and agricultural ecosystems have investigated how pollination efficiency is affected by bee diversity, bee community composition, and landscape variables. The effectiveness of managed honeybees is related to their large numbers (20,000–70,000 worker bees per colony), social organization (scout bees communicate pollen sources), their qualities as super-generalists while also showing flower constancy, their large flight range (reaching over 10 km), and the fact that they can be active at relatively low morning temperatures (Aslan et al., 2016; Zurbuchen & Müller, 2012). Nevertheless, it has been shown for a range of plant species [e.g., sweet cherry (Eeraerts et al., 2020)] and ecosystems [e.g., natural habitats (Hung et al., 2018)] that honeybees are less efficient than some wild bee species. Furthermore, bee species diversity has been found to positively influence pollination efficiency and stability by ensuring complementarity in within-flower behavior (influenced by morphological variations regarding size, pollen-collecting structures or tongue length, and particular pollen-collecting techniques like buzz pollination) and flower visitation traits characterized by spatial variations (e.g., preferred flower height), temporal variations (e.g., differing activity periods depending on time of day or phenology), and differing responses to environmental variables (e.g., temperature, wind) (Albrecht et al., 2012; Bartomeus et al., 2013; Brittain et al., 2013; De Luca et al., 2013; Hoehn et al., 2008; Rogers et al., 2014; Vasiliev & Greenwood, 2020). Therefore, extensive research interest has been devoted to identifying management factors at the local and landscape scale affecting bee diversity in agroecosystems, e.g., floral and nesting resource availability, local plant diversity, or occurrence of (semi-)natural habitat (Eeraerts et al., 2019; Eeraerts & Isaacs, 2023; Martins et al., 2015).

1.4.3. Pollination in urban ecosystems

Meanwhile, a number of studies on wild plants document altered pollinator abundances and traits as well as changes in plant-pollinator networks in urban compared to other environments (Baldock et al., 2019; Fisogni et al., 2020; Geslin et al., 2013; Sirohi et al., 2022; Udy et al., 2020; Youngsteadt & Keighron, 2023; Zaninotto et al., 2021). Although some studies account for increased wild bee flower visitation rates and/or plant reproductive success in urban compared to other environments (Liang et al., 2023; Theodorou et al., 2016; Theodorou, Radzevičiūtė, et al., 2020), a large meta-analysis based on over 2,200 experimental studies across the globe and more than 1,200 wild plants reports that pollen-limitation in animal-pollinated wild plants is higher in urban settings than in other landscapes (Bennett et al., 2020). Against this background, generating knowledge about pollination on urban crops seems highly relevant.

1.4.4. Interactions between wild bees and honeybees in urban habitats

In light of the evidence for negative effects of high honeybee abundances on wild bee flower-visitation rate and abundance in agricultural and natural habitats (Geldmann & González-Varo,

1. INTRODUCTION

2018; Geslin et al., 2017; Mallinger et al., 2017; Schwenninger et al., 2024), competition from increased numbers of honey bee hives has been identified as one of the main threats for urban pollinator conservation (Baldock, 2020). Indeed, urban beekeeping is increasingly popular (Moore & Kosut, 2020), leading to high colony densities [e.g., an increase from an average of 6.48 hives per km² to 10.14 hives per km² has been documented in 14 Swiss Cities between 2012 and 2018 (Casanelles-Abella & Moretti, 2022)]. In Vienna (Austria), Lanner et al. (2025) found areas of high apiary densities and wild bee hotspots to significantly overlap. Meanwhile, studies examining the effect of honeybee hive densities on wild bee species richness and flower visitation rates in urban environments are rare. Regarding the impact on wild bee species richness, increased honey bee abundances correlated with decreases in species richness and functional diversity in green spaces in Toronto (MacKell et al., 2023) and on the island of Montréal (MacInnis et al., 2023). Regarding the impact on plant-pollinator interactions on wild and cultivated plants, negative effects on wild pollinator visitation rates were recorded at average hive densities of 6.5 hives/km² in Paris (France) (Ropars et al. 2019) and 16 to 22 hives/km² in Munich (Germany) (Renner et al., 2021). Wild bee species traits, urban habitat types (Prendergast et al., 2021), and resource availability (Casanelles-Abella et al., 2023) have been found to influence patterns between honeybee density and wild bee species richness in Perth (Australia) and Zurich (Switzerland), respectively.

1.5. Citizen science in bee and pollination research

1.5.1. Wild bee citizen science as an outreach tool

In light of dramatic global insect declines, developing effective outreach and education strategies and measures has been identified as one key building block for research and the implementation of insect and plant-pollinator interaction conservation (Basset & Lamarre, 2019; European Commission: Directorate-General for Environment. et al., 2020; Hall & Martins, 2020; Mayer et al., 2011; Wagner et al., 2021).

While scientific bee research has highly increased in the last ten years, a survey to measure public understanding of bee diversity in the US has identified a huge discrepancy between strong support of bee conservation on the one hand and very limited understanding of bee diversity on the other (J. S. Wilson et al., 2017). Researchers and nature conservation associations are concerned about the decline of taxonomists, species experts, and nature observers in both the scientific community and the general public (Frobel & Schlumprecht, 2016; Hochkirch et al., 2022; Schulte et al., n.d.). Researchers therefore explore different media to reach a wider audience: e.g., booklets (S. MacIvor et al., 2016), podcasts (Melathopoulos, n.d.), practical tools like the “Encyclopedia of life bee observer cards” (Rykken, n.d.), simplified identification keys (e.g., (SAPOLL, 2018), and identification apps (e.g., BienABest, n.d.; NABU & LBV, n.d.; Pollinator Partnership & Border Free Bees, n.d.) designed to encourage pollinator observations. In that vein, the potential of citizen science

1. INTRODUCTION

approaches as a tool to increase civic engagement is increasingly being explored (Deguines et al., 2018; Sharma et al., 2019; Toomey & Domroese, 2013; Von Gönner et al., 2023).

1.5.2. Examples and systematization of wild bee citizen science projects

The last ten years have witnessed a rise of citizen science projects relating to bees and pollination (Koffler et al., 2021), and the existing initiatives can be roughly systematized as follows:

- I. Focus
 1. Projects studying bee species diversity and distribution by:
 - a. recording bee species diversity in a particular area;
 - b. mapping the geographical distribution of selected target species;
 - c. studying the behavior of selected bee species.
 2. Projects focusing on pollination ecology by:
 - a. recording flower visitors and/or visitation frequency on focal plant species;
 - b. measuring pollination efficiency through manipulative/experimental methods.
- II. Methods
 1. observation (photography);
 2. capture (specimen);
 3. manipulative/experimental methods.
- III. Resolution of species identification
 1. identification up to species level;
 2. identification at the level of pre-defined parataxonomic groups.
- IV. Approach
 1. opportunistic: observations do not follow a particular protocol (e.g., records of bee species at any time or location within an area);
 2. systematic: following a precise protocol (e.g., defined observation period, transect).

Appendix A1.1. lists some examples of bee- and pollination-related citizen science projects according to the abovementioned systematization. The list is non-exhaustive and biased towards English-, French-, and German-speaking projects in Europe, North America, and Australia.

1.5.3. Wild bee citizen science as a monitoring tool

In the course of much-needed data on wild bees and other pollinators' distribution, ecology, and population trends, citizen science approaches are increasingly considered as an important element of monitoring schemes (Cardoso et al., 2020; Graham et al., 2023; IPBES, 2016; Klaus et al., 2024; Luke et al., 2023; L. Marshall et al., 2024; Potts et al., 2021). Noticeably, one of the studies that had the strongest impact regarding reception in major international media and policy-level repercussions was based on volunteer naturalists' data (Fontaine et al.,

1. INTRODUCTION

2021; Hallmann et al., 2017). Citizen science data provide unique contributions to the study of processes occurring on broad temporal and geographical scales as well as on private lands (Callaghan et al., 2021; Dickinson et al., 2010; Theobald et al., 2015). Nevertheless, systematic analysis of data collected by citizen scientists has particular challenges (e.g., variation in observer quality and heterogeneity of sampling efforts in space and time) (Altwegg & Nichols, 2019; Dickinson et al., 2010), and the study of bees as a species group characterized by their small size, mobility, and taxonomic difficulty is particularly challenging. Studies evaluating the data collected by citizen scientists show that despite challenges regarding species-level identification (Le Féon et al., 2016; Ward, 2014) and occurrence counts (Kremen et al., 2011; Leocadio et al., 2021), high levels of accuracy can be attained.

Photographs are an established tool for evidence support and data validation in citizen science projects. They rapidly gain in potential through the availability of good quality cameras and recording devices, the development of online social networks like iNaturalist and Observation.org (Callaghan et al., 2022; Kaufmann & Lindner, 2021), and automated species identification (Høye et al., 2021; Saoud et al., 2020; Suzuki-Ohno et al., 2022; Van Klink et al., 2022). This goes hand in hand with developments in sampling and documentation methods for inventories by specialists.

1.5.4. Photo-based wild bee inventory methods

In parallel to the abovementioned technological developments, arguments are increasingly raised for the use of high-resolution photographs by experts to minimize specimen collection (Herrera-Mesías et al., 2022; Minter et al., 2014; Montero-Castaño et al., 2022). Moreover, methods and tools facilitating species identification of bees in the field are increasingly being explored. The German Ministry for Education and Research (BMBF) funded the development of the software tool ABIS (Automatic Bee Identification System) for the identification of bees from images of the bees' wings (Arbuckle et al., 2001; Buschbacher et al., 2020; Rebelo et al., 2021; Steinhage et al., 2005) and the "BienABest" project (Verein Deutscher Ingenieure e.V. & Universität Ulm, n.d.) funded by the German Federal Agency for Nature Conservation (BfN) develops survey methods and online image-based identification tools to support non-lethal species identification in the field. Increasingly, bee specialists make online image collections available to support species identification (Droege, n.d.; Falk, n.d.; Fritzsche & Fritzsche, n.d.; Université de Mons & Gembloux Agro Bio Tech, n.d.). Natural History Museums digitize their collections through high-resolution imaging technology (Holovachov et al., 2014; Mantle et al., 2012; Mathys et al., 2015) and provide multi-entry keys that facilitate species identification with high-resolution images (Polaszek, n.d.). Advancements in imaging technology (e.g., the development of in-camera focus stacking) increase the technical capabilities to enhance the resolution of macrophotographs in the field (Brecko et al., 2014; Mertens et al., 2017). In addition, methods to immobilize the insects and improve image capture are being developed,

1. INTRODUCTION

tested, and applied, e.g., temporarily chilling down the insects (Hofmann et al., 2018; Steinhage et al., 2005), CO₂ anesthesia (Toulzac et al., 2022), and restraining devices (Thomson & Zung, 2015). Increasingly, studies examine the accuracy of identification of bee photographs by experts, non-experts, and computer vision and identify best practices (e.g., diagnostic morphological characters to include on photographs, camera quality, exposure/light) (Austen et al., 2016; Colgan et al., 2024; Spiesman et al., 2021; Stafford et al., 2010). Nevertheless, case studies systematically working with photographs are still rare [but see Hofmann & Fleischmann (2020) and McCullough et al. (2013)].

The main challenge with regard to photo-based inventories lies in developing a systematic approach for a species group where identification is not always possible up to species level when one relies on features visible in pictures. The existing identification keys are based on features distinctly visible on mounted specimens only. For example, the fifth of eighty-five steps of the taxonomic key for female *Lasioglossum* by Amiet et al. (2001) already requires to differentiate between the options “tergite one smooth apart from the punctuation” and “tergite one chagrinated at least on the arch at 20x magnification” (Amiet et al., 2001, translation by JW). This puts an end very early on in the identification process to attempts to identify a bee up to species level in the field or on pictures (or to systematically narrow down to as few similar species as possible). On the other hand, resources aiming to encourage the identification of bees in the field tend to be restricted to un-systemized portraits of relatively easily recognizable species (e.g., Amiet & Krebs, 2019; Arbeitskreis Entomologie im NABU Landesverband Sachsen e. V. et al., n.d.; Scheuchl & Willner, 2024). Steven Falk’s Field Guide to the Bees of Great Britain and Ireland (Falk & Lewington, 2015) and the Field Guide to the Bumblebees of Austria, Germany and Switzerland by Gokcezade et al. (2010) are some of the very rare systematic field guides available for bees in Europe.

1.5.5. Participative research projects in urban environments

As more than half of the world’s population currently resides in urban areas (United Nations, Department of Economic and Social Affairs, Population Division, 2019), focusing people’s attention on urban wildlife provides opportunities to influence public support for conservation goals, environmental policies, public and private space management, and consumer choices that link up to agricultural practices (McKinney, 2002; Stevenson et al., 2020; Underwood et al., 2017). Nonetheless, Hall et al. (2017) warn against reducing urban bee conservation to outreach and education and call upon initiatives to actively engage urban citizens and city planners in practical conservation, including high-priority insect species. Such efforts require case studies that provide empirical data for evidence-based urban conservation practices. The EU Pollinators Initiative adopted by the European Commission in 2018 and revised in 2021 frames the enhancement of pollinator habitats in urban areas and the promotion of citizen science as objectives (European Commission, 2018, 2023; European Commission:

1. INTRODUCTION

Directorate-General for Environment. et al., 2020; European Commission. Directorate-General for Environment. et al., 2020). Initiatives combining habitat-creation, awareness-rising, and research have been initiated in some cities, including Berlin, Hamburg, Munich (Deutsche Wildtier Stiftung, n.d.; Green City e.V. & Technische Universität München, Lehrstuhl für Renaturierungsökologie, n.d.; Museum für Naturkunde Berlin & Technische Universität München, n.d.), Crailsheim (Stadtverwaltung Crailsheim, n.d.), Vienna (Stadt Wien, n.d.), Lyon (Urbanbees, n.d.), Bristol, Leeds, Reading, and Edinburgh (University of Bristol, n.d.). In this effervescent context, it seems important to evaluate opportunities and limitations of wild bee conservation and of participative bee research in urban environments.

2. OBJECTIVES AND OUTLINE

2.1. Research questions

This study aims to develop a holistic approach in bee and pollination management in medium-sized city integrating “pollinators, plants and people” with the main questions:

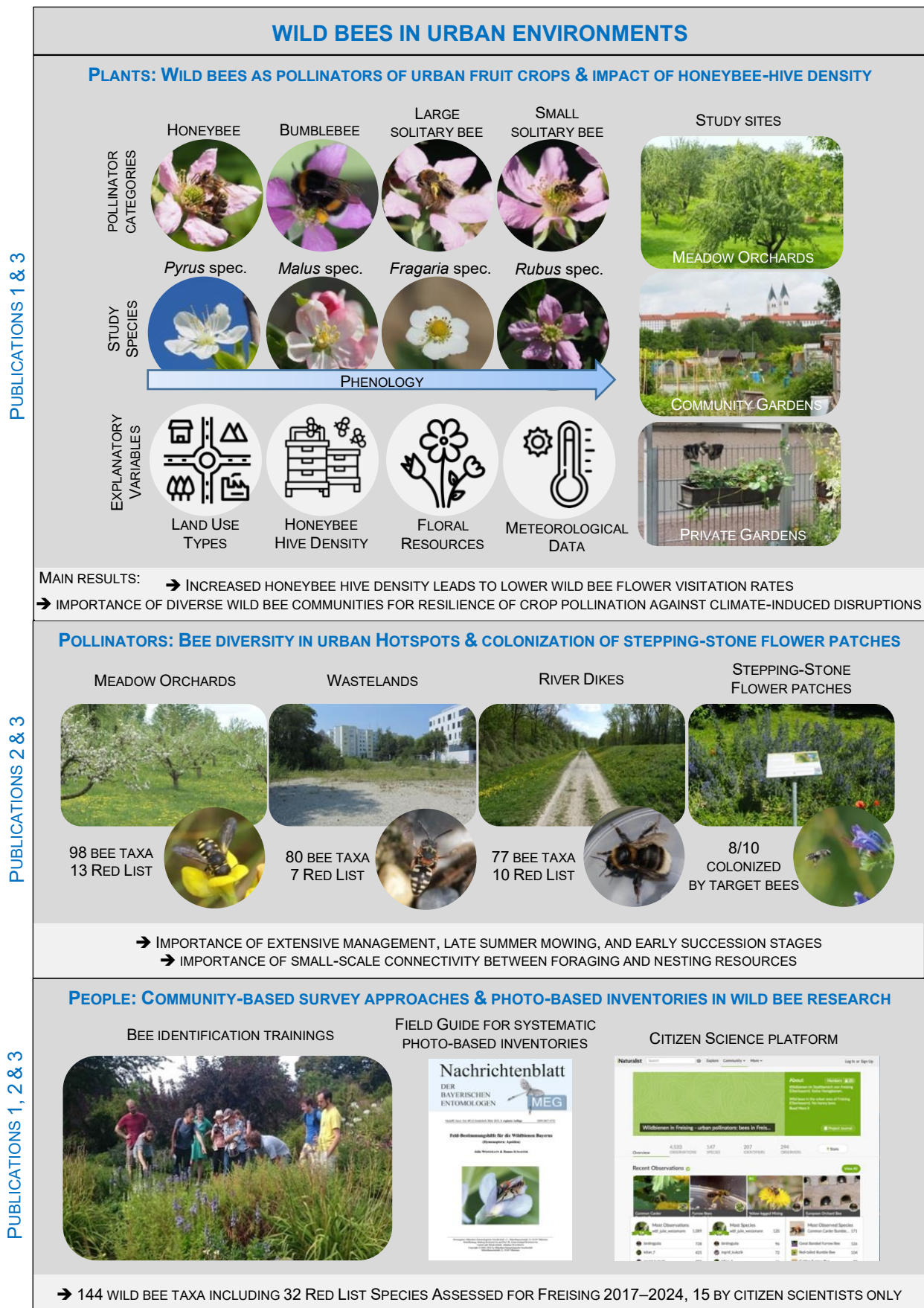
- 1) How relevant is bee diversity for urban fruit crop pollination?
- 2) What opportunities do urban habitats offer for bee conservation?
- 3) How can urban citizens be involved in urban bee research?

Publication 1 focuses on the importance of wild bees as pollinators on five common urban crops from the rose family and investigates the effect of landscape variables, weather conditions, and honeybee hive density on wild bee crop visitation rates. In **Publication 2**, we develop a holistic management concept to promote wild bee diversity in urban spaces based on empirical data from a case study in a medium-sized city. **Publication 3** – a field guide for wild bee identification based on photographs – constitutes a methodological building block for Publications 1 and 2.

The overall **discussion** summarizes the findings of the three publications, addresses opportunities and limitations of wild bee conservation in cities and community-based bee inventories for wild bee research, and develops practical recommendations for holistic urban bee and pollination management.

2. OBJECTIVES AND OUTLINE

2.2. Graphical abstract¹



¹ Icons made by MindWorlds, imaginationlol, Freepik and Fusion5085 from www.flaticon.com; pictures by Iris Walldorf, Sandra Dedolf, Rasmus Ritz, Theresia Endriß, and Julie Weissmann.

3. MATERIAL AND METHODS

3.1. Study region

The study was carried out in the city of Freising in southern Bavaria, Germany. The large district city (“Große Kreisstadt”) has a total area of c. 89 km² and a population of about 50,000 inhabitants (Bayerisches Landesamt für Statistik, 2024a). The urbanized area [according to the geographical limits set in the Urban Development Plan for Freising 2030 (Stadt Freising, n.d.) and in *Figure 3*] extends over c. 17 km². Freising is situated in the lower Isar valley at an altitude of c. 460 m asl. and has a temperate climate with annual rainfall of c. 800 mm and temperatures ranging from –14 °C to +33 °C (summarized in Publication 1). In a small area, this study site provides some of the characteristics relevant for bee research in larger cities like a) different habitat types (e.g., sealed, semi-natural, fallow, and garden areas coexist on a small scale), b) a heterogeneous landscape matrix (an urban core with a suburban area with small gardens is surrounded by large agricultural and forested landscape elements and traversed by a river-dike providing a semi-natural corridor), c) a diversity of stakeholders like urban planners, environmental NGOs, educational establishments.

3.2. Study sites

3.2.1. Pollinator surveys

Pollinator surveys on fruit trees were performed in five meadow orchards distributed all over the city, each with 50–216 fruit trees of ten different species (*Malus*, *Prunus*, *Pyrus*) ranging in age between 10 to >50 years (*Figure 2D* and *Figure 3*, orange sites). Observations on berry patches (*Rubus*, *Fragaria*) were performed in 23 private gardens, community gardens, and fallow land sites throughout the city (*Figure 2A,B* and *Figure 3*, pink and red dots). (summarized in Publication 1)

3.2.2. Standardized bee surveys

Systematic wild bee and flowering plant surveys were performed in 22 sites representative of different management types or succession stages of river dikes (*Figure 2E* and *Figure 3*, green sites), meadow orchards (*Figure 2D* and *Figure 3*, orange sites), and wastelands (*Figure 2F* and *Figure 3*, brown sites, see also *Table 2*). (summarized in Publication 2)

Table 2. Characterization of the habitat types visited for standardized bee surveys in Freising.

habitat type	river dikes	meadow orchards	wastelands
total area	16.25 ha	8.14 ha	9.37 ha
number of sites	3 sections	5 sites	14 sites
criterion for sub-categories	mowing time	management intensity	succession stage
sub-categories	• mown in September • mown in August/September • mown in July	• fallow • mixed • grazed • mowed • mulched	• early succession stage • medium succession stage • late succession stage

3. MATERIAL AND METHODS

3.2.3. Flower patches

In 2019, we planted ten flower patches as stepping-stones between flower-rich parts of the city with a minimum of 30 individuals per patch of a plant species chosen to provide pollen and nectar for specific oligolectic bee species (*Table 3*, *Figure 2C* and *Figure 3*, blue squares). Accompanying information boards provided information on the respective plant and target bee species (see Appendix A1.2.5.). (summarized in Publication 2)

Table 3. Plant species selected for stepping-stone flower patches and the respective target bee species with information on nesting requisites required by them [compiled from Westrich (2018)].

plant species	target bee species	nesting site	nesting materials
<i>Campanula persicifolia</i> , <i>C. rotundifolia</i> , <i>C. rapunculoides</i> , <i>C. trachelium</i> , <i>C. latifolia</i> var. <i>macrantha</i> , and <i>C. poscharskyana</i>	<i>Chelostoma rapunculi</i>	preexisting cavities in dead wood or nesting aids (boreholes in wood, bamboo canes, reed with inner diameter of c. 3.5 mm)	clay, sand
<i>Hesperis matronalis</i>	<i>Osmia brevicornis</i>	preexisting cavities in dead wood or nesting aids (boreholes in wood, bamboo canes, reed with inner diameter of c. 5 mm)	plant tissue
<i>Lysimachia punctata</i>	<i>Macropis europaea</i> , <i>M. fulvipes</i>	self-dug cavities in different soil types	flower oils from <i>Lysimachia</i> ssp.
<i>Reseda lutea</i>	<i>Hylaeus signatus</i>	various preexisting holes (e.g., in the soil, walls, beetle burrows in wood, dry <i>Rubus</i> - and <i>Rosa</i> -stems, abandoned Hymenoptera nests)	n.a.
<i>Lathyrus latifolius</i>	<i>Megachile ericetorum</i>	preexisting cavities in steep faces, breakoff edges or masonries, abandoned <i>Anthophora</i> -nests	clay, sand, resin
<i>Stachys byzantina</i>	<i>Anthidium manicatum</i>	various preexisting cavities (e.g., holes in the soil, rock crevices, loose masonry, crevices in wood beams, holes in clay walls, abandoned <i>Anthophora</i> -nests)	plant hair
<i>Echium vulgare</i>	<i>Osmia (Hoplitis) adunca</i>	preexisting cavities in dead wood or in rock faces, hollow plant stems, abandoned nests of other Hymenoptera, nesting aids (boreholes in wood, bamboo canes or reed; inner diameter 5–7 mm)	sandy loam, loamy sand, little stones
<i>Lythrum salicaria</i>	<i>Melitta nigricans</i>	self-dug cavities in sandy soil or loessy-loam	n.a.
<i>Knautia arvensis</i>	<i>Andrena hattorfiana</i>	self-dug cavities in different soil types	n.a.
<i>Cichorium intybus</i>	<i>Dasypoda hirtipes</i>	self-dug cavities in fine and medium sands, sometimes sandy loessy-loam	sand

3. MATERIAL AND METHODS

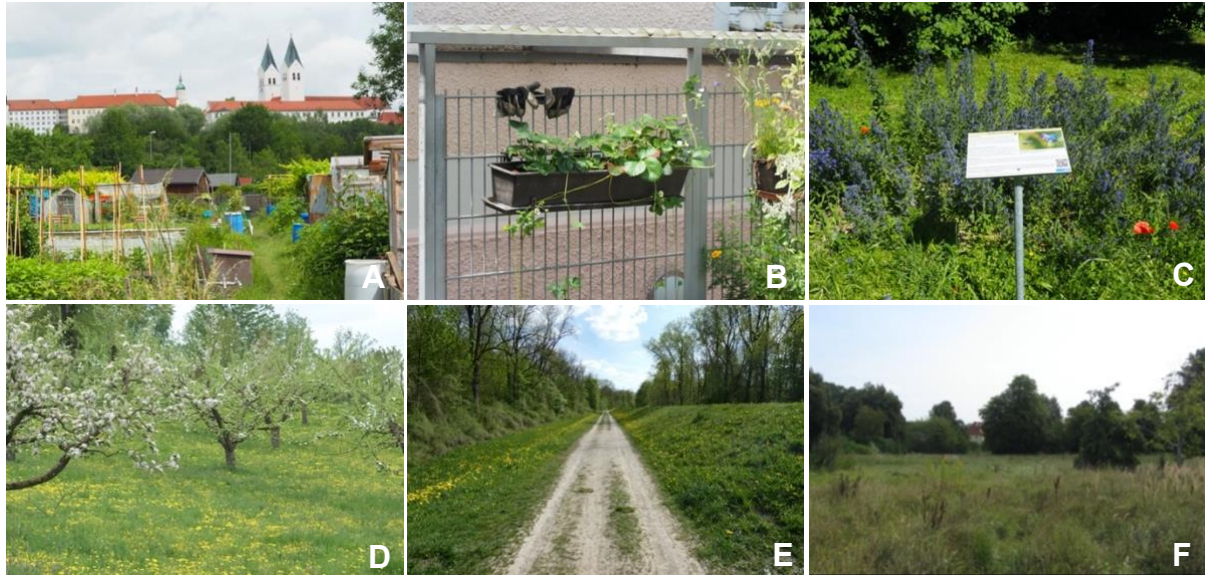


Figure 2. Examples of study sites: allotment garden (A), strawberry patch (B), flower patch with *Echium vulgare* (C), meadow orchard (D), river dike (E), wasteland (F) [pictures by Julie Weissmann (A-C), Iris Walldorf (D), Rasmus Ritz (E) and Sandra Rader (F)].

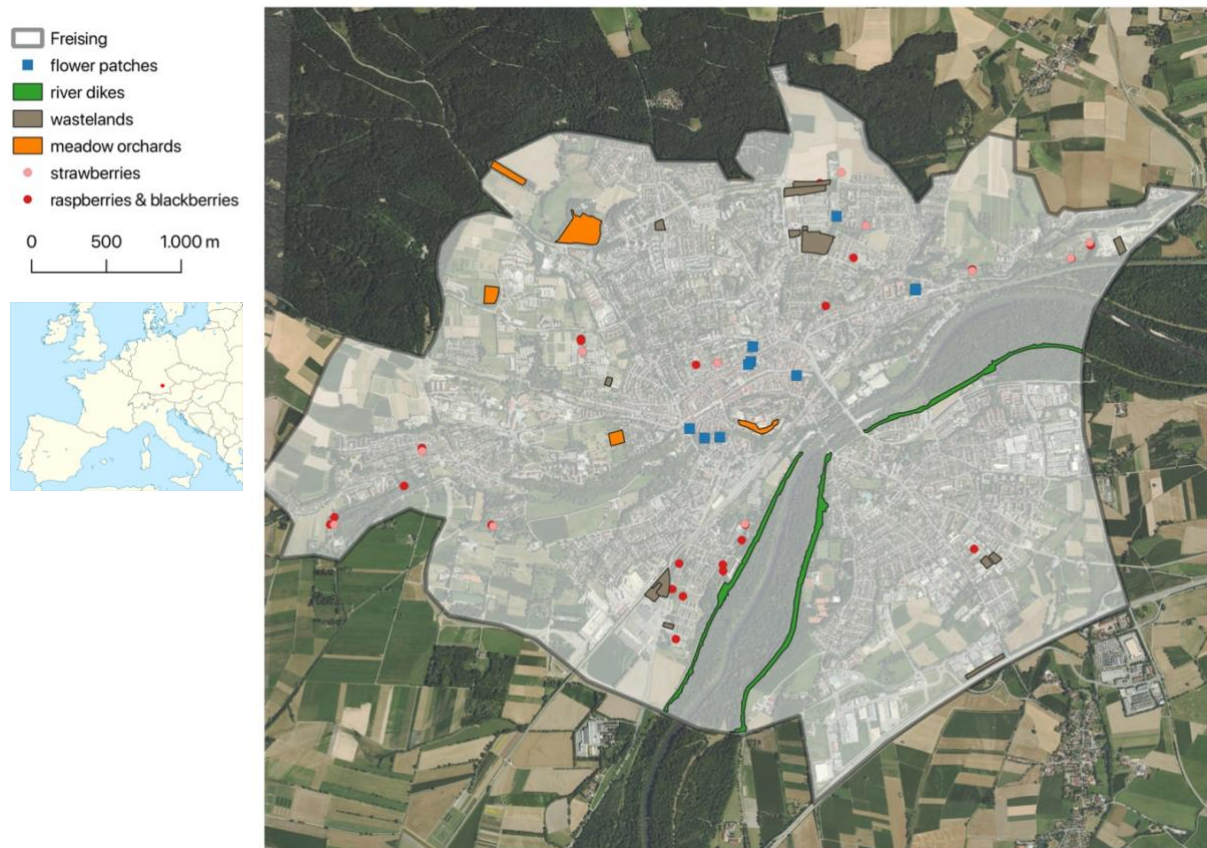


Figure 3. Location of Freising in Europe (inset) and distribution of bee-rich habitats, stepping-stone flower patches and sites for pollinator observations on straw-, rasp-, and blackberries [basemaps: Figure 4 (main map) & Wikimedia (inset)].

3. MATERIAL AND METHODS

3.3. Study species

For the pollinator survey, we selected nine plant species from the rose family which are common and widespread in urban environments: plum (*Prunus domestica* L.), cherry plum (*Prunus cerasifera* Ehrh.), sweet cherry (*Prunus avium* L.), sour cherry (*Prunus cerasus* L.), pear (*Pyrus communis* L.), apple (*Malus domestica* Borkh.), strawberry (*Fragaria x ananassa* Duchesne), raspberry (*Rubus idaeus* L.) and blackberry (*Rubus* sect. *Rubus*, mostly *Rubus armeniacus* Focke) (Figure 4). These fruit crops span the entire flowering season from early spring (cherry and plum) to late summer (blackberry), and their open flower morphology makes pollen and nectar available to a broad range of insects. (summarized in Publication 1)



Figure 4. Some of the study species for pollinator observations: *Prunus domestica* (A), *Malus domestica* (B), *Fragaria* spec. (C), and *Rubus* spec. (D) (pictures by Julie Weissmann).

3.4. Data sampling

3.4.1. Pollinator surveys

Pollinator surveys were performed between April and August 2018. Flower visitors were photographically recorded within a standardized area and observation period with the aim to at least differentiate between the four categories honeybee, bumblebee, large solitary bee (body size > 9 mm), and small solitary bee (body size up to 9 mm) (Figure 5) and enable identification to genus or species level whenever possible. For a detailed description of the protocol, see Publication 1.

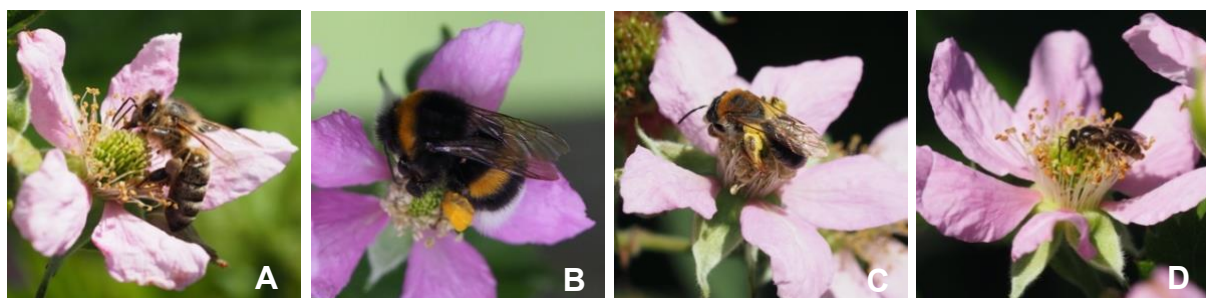


Figure 5. Bee categories used for pollinator surveys: honeybee (A), bumblebee (B), large solitary bee (C) and small solitary bee (D) (pictures by Julie Weissmann).

3.4.2. Standardized bee surveys

Bee surveys were performed between 2017 and 2021 in dry, sunny weather, with most observations between April and August 2018, and additional observation time in September dedicated to the late flowering plant species *Hedera helix* to obtain occurrence data of the ivy bee, *Colletes hederae*. Pollen- and nectar-offering plants in the herb and shrub layer were

3. MATERIAL AND METHODS

systematically observed for periods of 10–15 min to assess the visiting bees, and potential nesting sites were identified to assess the presence of nesting bees. Occurrence data for our ten target oligolectic bee species was gathered on existing and newly established flower patches throughout the city in 2019 and 2021. Wild bees were photographed directly in the field (*Figure 6*) or caught and cooled down on a cold pack to take high-resolution photographs for later identification (a specific permit to catch bees had been granted by the local conservation authorities at the Regierung von Oberbayern). (summarized in Publication 2)



Figure 6. Standardized bee surveys in meadow orchards (A), on the river dike (B), in wastelands (C), and on flower patches (D) (pictures by Julie Weissmann).

3.4.3. Citizen scientist bee surveys and pollinator observations

For the citizen science project, we set up a project webpage (www.wbf.wzw.tum.de) and directly contacted conservation NGOs, community and allotment garden groups, beekeeper associations, schools, and kindergartens. To give an introduction to the most common bee genera and species, their morphology, behavior, nesting sites, host plants, and identification methods, we offered public talks, guided walks, and personal visits to people's gardens advertised on the project website and through local media. In 2018 and 2019, we offered seven talks and information events, eleven guided walks, as well as visits to six classes (sixth and eighth grade) in three schools and two elementary school children's groups (*Figure 7*), and published eleven articles in local media about the project. Citizen scientists contributed observations via forms on the website, mail, and the iNaturalist project page (see *Appendix A1.2.* for outreach-related activities). (summarized in Publication 2)



Figure 7. Excursions for citizen science projects (A) and events with elementary school children's groups in an allotment (B) [pictures by Theresia Endriß (A) and Pi Besgen (B)].

3. MATERIAL AND METHODS

3.4.4. Bee identification

To facilitate photo-based bee identification, we developed a field identification guide (Publication 3). Species that are not distinguishable in the field or on photographs (e.g., *Colletes daviesanus*, *Colletes similis*, and *Colletes fodiens*) are treated as species groups. We uploaded at least one photograph for each recorded bee taxon and habitat type on the iNaturalist platform, where we set up a specific project for wild bee observations in Freising². This way, the photographs are accessible by everybody, and identifications can be checked and confirmed or updated. (summarized in Publication 2)

3.4.5. Species traits

For each species, information on threat level, life form, nesting type, nesting resources, lecty, body size, preferred host plants (oligolectic bees), and host species (parasitic bees) was compiled from Bayerisches Landesamt für Umwelt (2021), Scheuchl et al. (2023), Amiet et al. (2001, 2004, 2007, 2010, 2014), Dathe et al. (2016), H.-J. Martin (n.d.), Westrich (2018, 2019), Westrich et al. (2011), and Publication 3. For species that are not distinguishable on photographs, we chose a conservative approach and used the trait values of the most common, widespread, and least threatened species in the species group based on Publication 3 (e.g., *Colletes daviesanus* as representative of the species group *C. daviesanus*, *C. similis*, *C. fodiens*). (summarized in Publication 2)

3.4.6. Floral resources

In each studied site, we mapped all insect-pollinated flowering plant species in the herb-, shrub, and tree layer over the entire season until the sites had been mown. (summarized in Publication 2)

3.4.7. Landscape and meteorological metrics for pollinator surveys on meadow orchards

The proportion of urban habitat, agricultural habitat, lawns, flower-rich green spaces, and woody habitat in 100 m, 300 m, and 600 m zones surrounding the orchards was quantified based on aerial photographs (QGIS Development Team, 2016). The number of honeybee hives on the study sites and in zones of 300 m and 1,000 m diameter around each orchard and meteorological data (temperature at 2 m elevation in °C, relative humidity in %, wind speed in m/s, and global radiation in Wh/m²) were obtained from the local veterinary office and the agrometeorological weather station of the Bavarian State Research Center for Agriculture (LfL) in Freising, respectively. (summarized in Publication 1)

² iNaturalist project “Wildbienen in Freising – urban pollinators: bees in Freising” by “hanno_schaefer” (retrieved January 24, 2025, from <https://www.inaturalist.org/projects/wildbienen-in-freising-urban-pollinators-bees-in-freising>).

3. MATERIAL AND METHODS

3.5. Analytical tools

The statistical analyses were performed using R version 4.0.3 (R Code Team, 2020) with the packages ggplot2 (Wickham, Chang, et al., 2019), dunn.test (Dinno, 2017), MASS (Ripley et al., 2016), lme4 (Bates et al., 2020), car (Fox et al., 2020) and rich (Rossi, 2016) (Publication 1), and R version 4.2.3 (R Code Team, 2023) with the packages vegan (Oksanen et al., 2022), VennDiagram (Chen, 2022), tidyverse (Wickham, Averick, et al., 2019), reshape 2 (Wickham, 2007), and patchwork (Pedersen, 2022) (Publication 2).

The following overview summarizes the variables we studied in Publication 1 and Publication 2 and systematically lists the analytical tools applied for each research question.

Publication 1

1. Variables

1.1. Response variables:

- Wild bee taxa richness
 - Cumulative wild bee taxa richness per crop including species recorded during the 10 minutes-long systematic observation periods and species recorded during the additional observation periods dedicated to catch flower visitors
- Flower visitor abundance
 - Flower visitor categories: small solitary bees, large solitary bees, bumblebees, all wild bees, honeybees, other insects
 - For comparisons between fruit trees: sum of the maximum values of individuals per species observed per 10 min observation period within a standardized 4 m² frame
 - For comparisons between fruit trees and garden crops: each individual of the same insect species and sex was counted only once per 10 min observation period

1.2. Explanatory variables:

- Crop species:
 - All crops: cherry, plum, pear, apple, strawberry, rasp-/blackberry
 - Fruit trees: cherry, plum, pear, apple
 - Garden crops: strawberry, rasp-/blackberry
- Weather conditions: temperature at 2 m elevation, relative humidity, wind, global radiation
- On site flowering plant species diversity
- Proportion of urban habitat at a 100 m, 300 m, and 1,000 m scale around each site
- Number of honeybee hives on site, at a 300 m radius, at a 1,000 m radius

3. MATERIAL AND METHODS

2. Research questions and analytical tools

2.1. Analysis of crop flower visitor community composition and taxa richness

2.1.1. Assess similarities in wild bee community composition and taxa richness between all crops:

- Sørensen index (based on cumulative wild bee species richness per crop)
- Species-time relationship (mean number of wild bee taxa per 10 min observation period within a standardized 4 m² frame) per crop
- Mean rarefied species richness for 35 observation periods based on rarefaction curves (function `rarc`) per crop
- Pearson's Chi-squared test (function `chisq.test`) and Fisher's Exact Test for Count Data (function `fisher.test`) to test whether the number of bee species per category (small solitary bees, large solitary bees, bumblebees) is similarly distributed across crop species

2.1.2. Test for a correlation of wild bee taxa richness on apple flowers (cumulative wild bee taxa richness on apple flowers per orchard) to on site flowering plant species richness:

- Correlation test (function `cor.test`)

2.2. Analysis of the relative abundances of crop flower visitor categories

2.2.1. Test whether honeybee and wild bee abundance on fruit trees are significantly different:

- Unpaired two-samples Wilcoxon test (function `wilcox.test`)
- Unpaired two-sampled t-test (function `t.test`)
- Poisson regression model (function `glm`)

2.2.2. Test significant differences in abundance of different insect groups (honeybees, bumblebees, large solitary bees, small solitary bees, other insects) among fruit trees:

- Kruskal-Wallis rank sum test (function `Kruskal.test`)
- Post-hoc tests for pairwise multiple comparisons (function `dunn.test`)

2.2.3. Study landscape effects (explanatory variables: on site flowering plant species diversity; proportion of urban habitat at a 100 m, 300 m, and 1,000 m scale around each site; number of honeybee hives on site, at a 300 m radius, and at a 1,000 m radius) on bee abundance per category (small solitary bees, large solitary bees, bumblebees, all wild bees, honeybees) on apple flowers:

- Poisson regression models (function `glm`)

2.2.4. Study weather effects (explanatory variables: temperature at 2 m elevation, relative humidity, wind, and global radiation) on bee abundance per category (small solitary bees, large solitary bees, bumblebees, honeybees) on fruit tree flowers:

3. MATERIAL AND METHODS

- Poisson regression models (function glm)
 - Simplification of full models through stepwise automated model selection program (Package MASS, function stepAIC, selection in both directions)
- 2.2.5. Joint models to explain the abundance of different bee categories (small solitary bees, large solitary bees, bumblebees, all wild bees, honeybees) on apple flowers, taking into account the following explanatory variables: number of honeybee hives at different landscape scales, floral diversity on site, proportion of urban habitat at different landscape scales, global radiation
- Variance inflation factors (function vif) to test whether the predictor variables are correlated
 - Poisson regression models (function glm)

3. MATERIAL AND METHODS

Publication 2

1. Variables

1.1. Response variables:

- Wild bee taxa richness

1.2. Explanatory variables:

- Site characteristics
 - Number of flowering plant species on site
 - Habitat type: meadow orchard, river dike, wasteland
 - Habitat and management type/succession stage: river dike mown in September, river dike mown in August/September, river dike mown in July; meadow orchard fallow, meadow orchard mixed, meadow orchard grazed, meadow orchard mowed, meadow orchard mulched; wastelands of early succession stage, wastelands of medium succession stage, wastelands of late succession stage
 - Distance from the river dikes

2. Research questions and analytical tools

2.1. Study the effects of site characteristics (explanatory variables: number of flowering plant species on site, habitat type, distance from the river dikes) on wild bee taxon-richness:

- Poisson regression model (function glm)

2.2. Assess similarities in wild bee community composition between habitat types:

- Analysis of similarities (ANOSIM)
- Sørensen index

2.3. Assess similarities in wild bee community composition between habitat and management type/succession stage:

- Non-metric Multi-dimensional Scaling (NMDS)

2.4. Test whether the number of bee taxa per trait (sociality, nesting, lecty, size) is similarly distributed across habitat types:

- Pearson's Chi-squared test (function chisq.test)
- Fisher's Exact Test for Count Data (function fisher.test)
- Kruskal-Wallis rank sum test (function Kruskal.test)

4. SUMMARY OF PUBLICATIONS

Publication 1: The importance of wild bee communities as urban pollinators and the influence of honeybee hive density on wild bee crop visitation rates

Weissmann, J. A., Walldorf, I. R. M., & Schaefer, H. (2021). The importance of wild bee communities as urban pollinators and the influence of honeybee hive density on wild bee crop visitation rates. *Journal of Pollination Ecology*, 29(16), 204–230.

[https://doi.org/10.26786/1920-7603\(2021\)641](https://doi.org/10.26786/1920-7603(2021)641)

Author contributions: JW and HS designed the study. JW trained IW and citizen scientists for data collection. JW, IW, and citizen scientists collected data. JW organized, analyzed, and interpreted the data (identification of species or revision of identifications by co-authors, upload of photo vouchers on iNaturalist, statistical analysis, literature research). JW wrote the first draft of the manuscript as exclusive leading author. JW and HS contributed to manuscript revision.

Summary

While urban beekeeping is a popular trend, studies on the role of wild bee communities as crop pollinators in cities are still scarce. We analyzed wild bee visitation rates on common and widespread fruit crops from the rose family spanning the entire flowering season from early spring to late summer (cherry, plum, pear, apple, straw-, rasp- and blackberry) in a Bavarian city with a very high honeybee density of c. 19 hives/km². During more than 135 hours of observation time, we observed 52 wild bee species on the studied crop plants, with 32 taxa of seven genera in the fruit trees and 37 taxa of 14 genera in the berry crops. During more than 50 h of observation time on fruit trees in flower, we found that honeybees provided 59% and wild bees 41% of total bee visits. Among the wild bee categories, large solitary bees were predominant on fruit trees in meadow orchards, small wild bees were more abundant on berry crops in gardens, and bumblebees were abundant on rasp- and blackberries and on the orchard trees. C. 75% of all bee visits on our crops were performed by ground-nesting bees. Bee abundance on fruit tree flowers was negatively affected by honeybee density. Lower humidity and higher temperature and radiation levels had negative effects on honeybee, large and small solitary bee abundance, and positive effects on bumblebee abundance. Rising proportions of urban habitat had negative effects on honeybee and bumblebee abundance and positive effects on small and large solitary bee abundance. Flower diversity in the surroundings of the trees did not significantly impact wild bee species richness on apple flowers.

Together, our results suggest that species-rich wild bee communities in cities are important for pollination success in common fruit crops and favor resilience against climate-induced disruptions. In order to reduce competition with endangered wild bees, hive density should be adapted to floral resource availability. Bee-friendly management of urban spaces should be prioritized to support wild bee communities as well as urban honeybees.

4. SUMMARY OF PUBLICATIONS

Publication 2: Holistic wild bee management in urban spaces

Weissmann, J. A., Rader, S., Ritz, R., Walldorf, I. R. M., Probst, J., Szydlík, K. R., & Schaefer, H. (2023). Holistic wild bee management in urban spaces. *Frontiers in Sustainable Cities*, 5, 1155714. <https://doi.org/10.3389/frsc.2023.1155714>

Author contributions: JW and HS designed the study. JW trained SR, RR, IW, JP, KS and citizen scientists for data collection. JW, SR, RR, IW, JP, KS and citizen scientists collected data. JW organized, analyzed, and interpreted the data (identification of species or revision of identifications by co-authors, upload of photo vouchers on iNaturalist, statistical analysis, literature research). JW wrote the first draft of the manuscript as exclusive leading author. JW and HS contributed to manuscript revision.

Summary

Bee projects are in fashion and in many European cities, different stakeholders independently work towards improving urban habitats for this important pollinator group. There is, however, a striking lack of comprehensive programs with forces combined into a holistic approach throughout a city. We developed and tested such a comprehensive approach combining systematic specialist surveys with photograph-based citizen science data collection to gather species lists and distribution data for a city's bees. Based on this data, we identified centers of bee diversity, analyzed connectivity between hotspots and implemented stepping-stone flower patches to evaluate their impact for oligolectic bees.

Participation by urban citizens in bee identification trainings was high (more than 600 persons), but their contribution through observation reports was relatively low (1,165 records by 140 observers). However, combining systematic and citizen science survey data, we identified a total of 139 bee taxa across the city, seven of them only discovered by citizen scientists. Extensively managed orchards, semi-natural river dike habitats mown in late summer, and early succession wasteland areas were bee hotspots within the city. On ten newly established stepping-stone flower patches, half of the target oligolectic bee species could be confirmed in the year of planting, and all but two species could be confirmed after three years.

We suggest a five-step concept for bee management in cities: (1) standardized surveys in bee hotspots; (2) training of citizen scientists at two different levels for comprehensive surveys in all parts of the city: (a) public talks and guided walks to create more general awareness on wild bee diversity, ecology and conservation and (b) workshops for in-depth training of a small number of dedicated citizen scientists; (3) special conservation programs for very rare species and extensive management of existing habitats; (4) creation of high-value habitats taking into account the varied floral and nesting resource needs of bees within flight ranges of only a few hundred meters; (5) creation of stepping stone habitats integrating educative aspects.

4. SUMMARY OF PUBLICATIONS

Publication 3: Field Guide to the wild bees of Bavaria

Weissmann, J. A., & Schaefer, H. (2022). Feld-Bestimmungshilfe für die Wildbienen Bayerns. *Nachrichtenblatt der Bayerischen Entomologen*, 69(2), 1–64, 2nd ed.

First Edition (2020) available online at:

https://www.zobodat.at/pdf/NachBlBayEnt_069_SB_0001-0064.pdf

Author contributions: JW and HS designed the study. JW performed literature research and organized the database. JW wrote the first draft of the manuscript as exclusive leading author. JW and HS contributed to manuscript revision.

Summary of Publication 3

Bee citizen science projects require tools for bee identification in the field or by photographs, since lethal methods require collecting permits. However, most bee identification keys are based on micromorphological features only visible on collected insects. Furthermore, since photo-based identification of bees is easier in some genera than in others, comparing diversity per genus or comparing diversity values between different studies gets more complicated.

The aim of this field guide is to enable and systematize identification based on traits visible in the field or on photographs for the wild bee species of Bavaria. It provides descriptions to identify the females of 353 nesting species and 119 cuckoo bee species currently known for this region and mentions additional 48 species with historical records from Bavaria. Features like phenology, specialization on plant species or families, flower visitation behavior, nesting type, and flight behavior are highlighted to support morphology-based identification in the field. Species that are not distinguishable in the field or on photographs (e.g., *Colletes daviesanus*, *Colletes similis*, and *Colletes fodiens*) are systematized into species groups. Focusing on the species documented in a defined region (Bavaria) enables to narrow down the number of possible species in those groups. Grouping species that cannot reliably be distinguished on photographs into consistent taxon groups enables comparisons of diversity between projects following the same system.

5. GENERAL DISCUSSION

5.1. Wild bees as pollinators in urban environments

Urban ecology researchers and conservationists raise awareness about the necessity to study and target not only species(groups) but also species interactions, especially in light of climate- or management-change-induced shifts in species composition (Heinen et al., 2020; Theodorou, 2022). Although it is important to keep in mind that studying pollination of fruit crops in cities will neither comprehensively address issues of global food security nor suffice as an argument for bee conservation (Kleijn et al., 2015), looking at the effects, e.g., of temperature or honeybee density on plant-pollinator interactions can help understand important ecological interactions in cities, which are particularly impacted by, e.g., climate change and massively introduced managed species (Geslin et al., 2017, 2023).

5.1.1. Diverse pollinator communities on trees and berries from the rose family

During more than 50 hours of observation time on apple, pear, plum and cherry in flower, we found that more than half (59%) of the flower visits were performed by honeybees. This can be explained by the high density of honeybee hives within the city, with at least 90 honeybee hives in a 1 km radius around each of the studied meadow orchards (containing in late spring up to 4.5 Mio worker bees), and by the large flight range of honeybees as they routinely forage in distances of 1.5 km, and can travel more than 10 km in search of floral rewards (Zurbuchen, Landert, et al., 2010). (discussed in Publication 1)

At the same time, our study shows that wild bees provide an important share (41%) of total bee flower visits on fruit trees (33% of total bee visits on cherry, 39% on apple, 46% on plum, and 52% on pear). This is comparable or higher than rates recorded in orchards outside urban areas: 16% of bee visits on apple, 38% on *Prunus* spp. and 40% on pear in orchards in Baden-Württemberg were performed by wild bees (Schwenninger & Wolf-Schwenninger, 2012), and about one-third of the bee visits on sweet cherry in orchards in northern Hesse were from wild bees (Holzschuh et al., 2012). (discussed in Publication 1)

Overall, the observed wild bee community in Freising on apple, plum, cherry, pear, blackberry, raspberry and strawberry flowers comprised a large number of species and genera characterized by a variety of functional traits. During more than 135 hours of observation time, we observed 52 wild bee taxa on the studied crop plants (32 taxa of seven genera in the fruit trees and 37 taxa of 14 genera in the berry crops). Among the wild bee categories, large solitary bees (mainly *Andrena* spp. and *Osmia* spp.) were predominant on fruit trees in meadow orchards, small wild bees were more abundant on straw-, rasp- and blackberries in gardens, and bumblebees were abundant on rasp- and blackberries and the orchard trees (especially apple and cherry). This might partly be explained by different flight periods of wild bee taxa, as many larger-bodied species (e.g., *Andrena* spp., *Osmia* spp., *Anthophora* spp.)

5. GENERAL DISCUSSION

are active early in the season when fruit trees flower, many small bees (e.g., *Hylaeus* spp., *Hoplitis* spp.) are active later in the season when many of the berry crops still flower, and bumblebees are active from spring to late summer (Westrich, 2019). The abundance of honeybees, large and small solitary bees increased with lower humidity and higher temperature and radiation levels, while bumblebee abundance decreased under the same weather conditions. This corresponds to findings that bee species differ in sensitivity to climatic conditions (Burdine & McCluney, 2019). Bumblebees in particular are more tolerant to cold and wet weather (Nielsen et al., 2017; Tuell & Isaacs, 2010). This suggests that they are especially valuable pollinators in early spring and during poor weather periods. Unfortunately, this makes them also more vulnerable to climate change-induced rises in temperature (Kerr et al., 2015; Martinet et al., 2021; Soroye et al., 2020). As the urban heat effect often exacerbates these effects, bumblebees might suffer even faster declines (Hamblin et al., 2017) unless sufficient cooler green space is provided as a refugium. (discussed in Publication 1)

Together, our results suggest that diverse wild bee communities are important for the pollination of common fruit crops in the urban environment. Bee diversity assures continuous pollination throughout the seasons, in variable weather conditions (Rogers et al., 2014), and under phenological shifts (Bartomeus et al., 2013) intensified by climate change. A diversity of wild bee species differing in size, flight range, flower visitation behavior, nesting behavior, seasonality, and tolerance to weather conditions can guarantee efficient pollination at levels honeybees alone are unlikely to reach. (discussed in Publication 1)

5.1.2. Impact of honeybee hive density on wild bee flower visitation rate on orchard crops

Honeybee density is very high in Freising with c. 19 hives/km², ten times the mean German density as assessed in 2010 (Chauzat et al., 2013) and 2–3 times as high as in Berlin, Hamburg (Beckedorf, 2015), and Paris (Ropars et al., 2019). We found honeybee hive density (ranging from 90 to 147 hives in a 1 km radius around each of our study sites) to have a negative effect on wild bee abundance on orchard crops, which is in line with previous studies in natural habitats, agroecosystems, and urban environments (Renner et al., 2021; Ropars et al., 2019; Torné-Noguera et al., 2016; Weekers et al., 2022). (discussed in Publication 1)

In light of shared interests of beekeeping and wild bee conservation regarding, e.g., advocacy for landscapes with abundant floral resources and protected from pesticides, inclusive solutions to preserve both biodiversity and beekeeping activities are required (Egerer & Kowarik, 2020; Kleijn et al., 2018; Schwenninger et al., 2025). In order to reduce competition with endangered wild bees, it is advisable to sensitize urban planning and green space management about potential competition effects at high honeybee hive densities without condemning beekeeping across the board. Schwenninger et al. (2025) suggest assessing hive densities and adapting them to the occurrence of floral resources, establishing 0.5 ha of high-

5. GENERAL DISCUSSION

quality floral resources for wild bees per honeybee hive, and abstaining from putting bee hives within, and in a 2.5km radius around, nature conservation areas. As honey bees are generalists who prefer exploiting mass foraging resources, planting an abundance of trees flowering across the season has been suggested to mitigate competition on flowering plants essential to specialized wild bee species (Koelzer et al., 2024; Stevenson et al., 2020). For case-to-case assessments, sound ecological knowledge of local conditions regarding honeybee hive densities, floral supply [taking into account floral abundance, species composition, and phenology (Sponsler et al., 2023)], and occurrence and ecology of rare bee species in the surroundings is essential. Overall, bee-friendly management of urban spaces should be prioritized to support wild bee communities as well as the increasing number of honeybees in cities (Casanelles-Abella et al., 2023). (discussed in Publication 1)

5. GENERAL DISCUSSION

5.2. Opportunities and limitations of wild bee conservation in urban environments

5.2.1. Contextualized results

Our study exemplifies that cities can harbor a variety of wild bee species, including some specialized and rare ones. Nevertheless, concentrating conservation efforts on cities is far from being a sufficient overall strategy for wild bee conservation. What characterizes the species that do find refuge in the city – and those that don't? Our results regarding wild bee species richness and community composition can be contextualized in light of a much more comprehensive dataset covering a timespan of over 200 years from the closeby and much larger and urbanized city of Munich (Schuberth & Bräu, 2024), specialist surveys from 2015 in new river- and gravel-bank habitats and one area of a relocated dam in three small restored sections of the Isar river in a protected area nearby Freising (Mandery, 2016), and published urban bee studies.

5.2.1.1. Bee species richness

Overall, we recorded 144 wild bee taxa between 2017 and 2024 in Freising (c. 17 km²), representing 27% of the 531 bee species currently known in Bavaria. Five additional taxa were only recorded in the “Große Kreisstadt Freising” (c. 89 km²) and one additional taxon only in the administrative district of Freising (c. 800 km²) (see *Appendix A1.3.*). Since our species identification approach based on high-resolution photographs instead of collected bees leads to an underestimation of total species numbers in difficult genera like *Lasioglossum* and *Sphecodes*, the real diversity can be expected to be even higher. Our results are comparable to results from other central European cities: 344 species (65% of the species currently known in Bavaria) have been recorded in Munich (c. 310 km²) since 1795 and 265 species (50% of the bee species currently known in Bavaria) have been re-observed or newly observed since 2000 (Schuberth & Bräu, 2024) (see *Table 5*); 104 species have been recorded in Poznan (Poland, c. 260 km², 2006–2008) (Banaszak-Cibicka & Żmihorski, 2012); 145 species in Paris (France, c. 100 km², 2011–2022) (Zaninotto & Dajoz, 2022), 291 in the Lyon Metropolis (France, c. 530 km², 2012–2014) (Fortel et al., 2015); 210 in the Brussels-Capital Region (Belgium, c. 160 km², 1999–2020) (Vereecken et al., 2021); 170 in Zurich (Switzerland, c. 92 km², 2008–2018) (Casanelles-Abella et al., 2021). In new river- and gravel-bank habitats and one area of a relocated dam in three small restored sections of the Isar river nearby Freising, a total of 118 wild bee species (22% of the bees species currently known in Bavaria) was recorded during specialist surveys in 2015 (Mandery, 2016; Scheuchl et al., 2023) (see *Table 5*). (discussed in Publication 2)

5.2.1.2. Conservations status

Twenty-two percent (n = 32) of the 144 taxa we recorded in Freising since 2017 are threatened according to the Bavarian Red List [categories RL 0 (extinct or lost), RL 1 (threatened with extinction), RL 2 (highly threatened), RL 3 (threatened), RL G (threat of unknown extent), RL R

5. GENERAL DISCUSSION

(extremely rare), RL V (near threatened)]. In comparison, 33% (n = 87) of the 265 species recorded in Munich since 2000 and 47% (n = 160) of the 344 species recorded since 1795 are threatened (Schuberth & Bräu, 2024). In new river- and gravel-bank habitats and one area of a relocated dam in three small restored sections of the Isar river in a protected area near Freising, 14% (n = 16) of the 118 species recorded in 2015 are threatened, representing 5% of the Bavarian Red List species (Mandery, 2016). Overall, 57% (n = 303) of the 531 species assessed for Bavaria are threatened (Scheuchl et al., 2023). Although we found wild bees with concerning conservation status in Freising, including highly threatened species like *Bombus subterraeneus*, the city harbors only one-tenth of the Bavarian Red List species (11% of the 303 species categorized as threatened in the Bavarian Red List). In Munich, even in the most comprehensive scenario including all records since 1795, the city harbors only half (53%) of the Bavarian Red List species. Considering only the records since 2000, this share drops to one-third (29%) (see Table 5). Seventy-nine bee species recorded between 1795 and 2000 in Munich have not been re-recorded since 2000, and 73 of them are threatened. In contrast, 41 species were new records since 2000, and thirteen of them are threatened (Scheuchl et al., 2023; Schuberth & Bräu, 2024). This corresponds to a period during which Munich was developed from a relatively rural city with less than 150,000 inhabitants in 1840 (Bayerisches Landesamt für Statistik, 2024b) and well connected to natural areas (e.g., large heath areas) to the densest city in Germany (Statistisches Bundesamt (Destatis), 2023) with more than 1,500,000 inhabitants in 2023 (Statistisches Amt der Landeshauptstadt München, 2024).

Although rare species may be underrepresented due to our identification approach, our results are in line with other studies finding lower shares of Red List species in urban environments and identifying an “urban gap in terms of conservation status” (Fauvieu et al., 2024; Moens et al., 2023). A significant share of wild bee species, particularly those with concerning conservation status, cannot be conserved in cities, especially as those densify. It is all the more important to identify and protect those rare species that occur in specific cities (e.g., *Bombus subterraneus* and *Andrena curvungula* within Freising or *Anthophora aestivalis* and *Melecta luctuosa* in Munich), especially as findings from Fauvieu et al. (2024) suggest that the rarest species, in particular, differ among cities.

5.2.1.3. Floral specialization (lecty)

The share of oligolectic taxa in Freising (26%, n = 37) is comparable to that of Bavaria (23%) and of Munich (23% of all records since 1795 and since 2000). This contrasts with other studies showing that generalist species are more prevalent in urban areas (Buchholz & Egerer, 2020; discussed in Publication 2). Although generalist diversity may be underrepresented due to our identification approach, the fact that Freising harbors 31% and Munich harbors 65% (since 1795) and 52% (since 2000) of Bavarias oligolectic species indicates that an important share

5. GENERAL DISCUSSION

of specialized bees do find their required food sources in cities – but at least half of them don't (see Table 5). How can the winning and losing bees among the specialists be characterized?

Half of the stepping stone flower patches were occupied by the target oligolectic bee species in the year of planting, and after three years, all but two species could be confirmed (discussed in Publication 2). However, the flower patches were mainly used by those oligolectic bee species that are relatively common and widespread in Bavaria and whose nesting requirements are commonly met in urban environments (e.g., cavity nesters or ground nesters without special requirements on the substrate). For example, among the bee species specialized on *Echium vulgare*, we detected the cavity-nesting *Osmia (Hoplitis) adunca* but not *Osmia (Hoplitis) anthocopoides* or *Osmia (Hoplitis) lepeletieri*, which both build free-standing nests out of a mortar made from sand or clay and little stones in depressions in stones and rocks (Westrich, 2019). Among the bee species specialized on *Campanula* spp., we detected the common *Chelostoma rapunculi*, *Chelostoma campanularum*/*C. distinctum*, and *Melitta haemorrhoidalis*, but not the Bavarian Red List species *Lasioglossum costulatum*, *Dufourea dentiventris*, *D. inermis*, *Osmia (Hoplitis) mitis*, *Andrena curvungula* and *A. rufizona* (Scheuchl et al., 2023). Both species that were not detected on the flower patches are the only Red List species among our target species: *Dasypoda hirtipes* requires sandy soil or sandy loessic loam to nest and was only detected on two fallow land areas in the south-western part of the city (the flower patch was situated in a park in the north), and *Osmia brevicornis* requires dead wood (its existence in Freising is currently doubtful as the only photograph is not detailed enough) (see Table 4).

Table 4. Plant species selected for stepping-stone flower patches and which of the bee specialized on those plant species we did and which we did not detect [information on oligolectic bee species compiled from Westrich (2018), information on Red List status for Bavaria (in brackets) compiled from Scheuchl et al. (2023)].

plant species	detected oligolectic bee species	oligolectic bee species we could not detect
<i>Campanula persicifolia</i> , <i>C. rotundifolia</i> , <i>C. rapunculoides</i> , <i>C. trachelium</i> , <i>C. latifolia</i> var. <i>macrantha</i> , and <i>C. poscharskyana</i>	<i>Chelostoma rapunculi</i> (*), <i>C. campanularum</i> (*)/ <i>C. distinctum</i> (*), <i>Melitta haemorrhoidalis</i> (*)	<i>Andrena curvungula</i> (2), <i>A. rufizona</i> (0), <i>Dufourea dentiventris</i> (3), <i>D. inermis</i> (2), <i>Lasioglossum costulatum</i> (3), <i>Osmia (Hoplitis) mitis</i> (2)
<i>Hesperis matronalis</i>		<i>Osmia brevicornis</i> (3)
<i>Lysimachia punctata</i>	<i>Macropis europaea</i> (*), <i>M. fulvipes</i> (*)	
<i>Reseda lutea</i>	<i>Hylaeus signatus</i> (*)	
<i>Lathyrus latifolius</i>	<i>Megachile ericetorum</i> (*)	
<i>Stachys byzantina</i>	<i>Anthidium manicatum</i> (*)	<i>Anthophora furcata</i> (V)
<i>Echium vulgare</i>	<i>Osmia (Hoplitis) adunca</i> (*)	<i>Osmia (Hoplitis) anthocopoides</i> (3), <i>Osmia (Hoplitis) lepeletieri</i> (0)
<i>Lythrum salicaria</i>	<i>Melitta nigricans</i> (V)	<i>Eucera salicariae</i> (0)
<i>Knautia arvensis</i>	<i>Andrena hattorfiana</i> (3)	<i>Andrena marginata</i> (1), <i>Dasypoda suripes</i> (n.a.)
<i>Cichorium intybus</i>		<i>Dasypoda hirtipes</i> (3), <i>Andrena denticulata</i> (V), <i>A. polita</i> (2), <i>Heriades truncorum</i> (*), <i>Osmia leaiana</i> (3), <i>O. spinulosa</i> (V), <i>O. villosa</i> (3), <i>Panurgus banksianus</i> (3), <i>P. calcaratus</i> (V), <i>P. dentipes</i> (n.a.)

5. GENERAL DISCUSSION

In Munich, many of the oligolectic Red List species that have been recorded since 2000 occur on plant species which are relatively widespread in urban areas, e.g., in gardens, on flower strips or on bare land areas: *Allium* spp. (*Hylaeus punctulatissimus*, RL 3); common Brassicaceae like *Sinapis arvensis* (*Andrena agilissima*, RL 3) or *Erysimum* spec. (*Osmia brevicornis*, RL 3); common Apiaceae like *Daucus carota* (*Andrena rosae*, RL 1); common Asteraceae like *Leontodon hispidus* (*Andrena fulvago* and *Hoplitis villosa*, both RL 3), *Tanacetum vulgare* (*Colletes fodiens*, RL 3), *Cirsium vulgare* (*Osmia leaiana* and *Pseudoanthidium nanum*, both RL 3), or *Knautia arvensis* (*Andrena hattorfiana*, RL 3); common Fabaceae like *Trifolium pratense* (*Andrena gelrae*, RL 1 and *Andrena labialis*, RL 3) or *Lotus corniculatus* [*Osmia parietina* and *Trachusa byssina* (both RL 3), *Andrena similis* and *Hoplitis ravouxi* (both RL 2)]; *Campanula* spp. [*Andrena pandellei* (RL 3), *Andrena curvungula* and *Hoplitis mitis* (both RL 2)]; *Potentilla* spec. (*Andrena potentillae*, RL 2); *Echium vulgare* (*Hoplitis anthocopoides*, RL 3) and *Salix* spp. (*Andrena ruficrus*, RL 3). In contrast, many of the oligolectic bee species which have *not* been recorded in Munich at all since 1795 are specialized on rare plants [e.g., *Ornithogalum umbellatum* (RL V) for *Andrena saxonica* (RL 3), *Anchusa officinalis* (RL 3) for *Andrena nasuta* (RL 1)], or on plants specific to non-urban environments, e.g. acidic woodlands, highmoors and mountain heath for the *Vaccinium*-specialist *Andrena lapponica* (not threatened), dry sand heaths for the *Calluna*-specialists *Andrena fuscipes* (RL V) and *Colletes succinctus* (RL 3), areas of extensive agriculture on calcareous clay soil for honeywort (*Cerinth minor*, RL 2) and its specialist bee *Osmia cerinthidis* (RL 1), or mountain and subalpine tall forbs for monkshood [*Aconitum* spec.] and its specialist bee *Bombus gerstaeckeri* (RL 3) and the *Jasione montana* (RL 3) specialist *Dufourea halictula* (RL 1) (Bayerisches Landesamt für Umwelt, 2024; Scheuchl et al., 2023; Schuberth & Bräu, 2024).

5.2.1.4. Nesting type

The share of hypogeic species (excluding parasitic species) was higher in Freising (34%, n = 49) than in Bavaria (22%, n = 118). Freising harbors 42% (Munich since 2000: 64%) of Bavarias hypogeic and only 26% (Munich since 2000: 46%) of Bavarias endogeic taxa, a pattern that has been related to urbanization (C. J. Wilson & Jamieson, 2019) (see *Table 5*). (discussed in Publication 2)

The share of brood parasitic taxa in Freising (22%, n = 32) is comparable to that in Bavaria (24%, n = 129), which is remarkable because in these genera, species-level identification based on photographs is often impossible. Freising harbors 25% of Bavarias parasitic taxa (Munich since 2000: 52%), a particularly vulnerable group as they are dependent on the occurrence of specific host species (see *Table 5*). (discussed in Publication 2)

5. GENERAL DISCUSSION

Regarding nesting resources, the high share of hypogeic species found in our and other urban bee studies suggests there is still untapped potential in improving the availability of resources for ground-nesting bees in cities. Three-quarters of nest-building species in Germany, including many rare species, nest in the ground (see *Table 1*). As hypogeic bees are already over-represented in cities, it is advisable to shift the focus from the very popular provision of nesting aids for cavity-nesting bees, which are usually colonized only by very common species (Geslin et al., 2022; Grobbauer et al., 2024), toward the needs of ground-nesters. Fruitful collaborations can emerge in unexpected sites, e.g., dirtbike trails, playgrounds, or construction sites. In the city of Munich for example, collaborations between residents, a local environmental NGO, and the municipal garden and nature conservation departments enabled to preserve and maintain a loamy edge created during construction in an urban development area, which provides a nesting site for many bee genera (e.g., *Colletes*, *Andrena*, *Megachile*, *Halictus*, *Lasioglossum*, *Sphecodes*, *Nomada*), including Red List species (*Anthophora aestivalis*, *Melecta luctuosa*, *Melecta albifrons*, *Trachusa byssina*)³.

5.2.1.5. Nesting requisites

Eleven percent of the taxa we recorded for Freising (n = 16) have special requirements regarding requisites to build their nests [vs. 13%, n = 70 of the species recorded for Bavaria and 12% (n = 33) of the species recorded in Munich since 2000], e.g., Sand (*Andrena praecox*, *Colletes cunicularius*, *Dasypoda hirtipes*), vertical soil profiles (*Anthophora plumipes*, *Anthophora quadrimaculata*, *Colletes daviesanus*, *Hylaeus nigritus*, *Lasioglossum nitidulum*), rotting/dead wood (*Anthophora furcata*, *Megachile nigriventris*, *Xylocopa violacea*), pithy plant stems (*Ceratina cyanea*, *Hoplitis tridentata*), or empty snail shells (*Osmia aurulenta*, *O. bicolor*, *O. spinulosa*) (see *Table 5*).

Seventeen percent of the taxa we recorded for Freising (n = 25) have special requirements regarding requisites to build their brood cells (vs. 13%, n = 67 of the species recorded for Bavaria and 14%, n = 38 of the species recorded in Munich since 2000), e.g., plant hair (*Anthidium manicatum*, *A. oblongatum*, *A. punctatum*, *Pseudoanthidium nanum*), leaf pieces (*Megachile centuncularis*, *M. lapponica*, *M. nigriventris*, *M. argentata/pilidens*, *M. rotundata*, *M. versicolor*, *M. willughbiella*, *Trachusa byssina*), resin (*Anthidiellum strigatum*, *Megachile ericetorum*, *Trachusa byssina*), wood pieces (*Xylocopa violacea*, *Hoplitis adunca*), mineral mortar (*Hoplitis leucomelana*, *H. tridentata*, *Osmia aurulenta*, *O. bicolor*, *O. caerulescens*, *O. niveata*, *O. spinulosa*, *Megachile ericetorum*, *Hoplitis adunca*), or loam/loamy sand (*Osmia bicornis*, *O. cornuta*). (see *Table 5*)

³ See iNaturalist project “BN Patenschaftsfläche Lehmabbruchkante für bodennistende Wildbienen im Prinz-Eugen-Park” by „bund_naturschutz_kreisgruppe_muenchen“ (retrieved January 24, 2025, from <https://www.inaturalist.org/projects/bn-patenschaftsflaeche-lehmabbruchkante-fuer-bodennistende-wildbienen-im-prinz-eugen-park>).

5. GENERAL DISCUSSION

Table 5. Number of taxa, share of taxa with specific traits, and share of Bavarias taxa with the same trait for: Bavaria (Scheuchl et al., 2023), Munich since 1795 (Schuberth & Bräu, 2024), Munich since 2000 (Schuberth & Bräu, 2024), new river- and gravel-bank habitats and one area of a relocated dam in three small restored sections of the Isar river in a protected area nearby Freising [surveyed in 2015, see Mandery (2016)], and Freising city (iNaturalist Project “Wildbienen in Freising”⁴). Red List categories are based on Scheuchl et al. (2023); traits are based on Westrich (2019).

	Bavaria	Munich since 1795	Munich since 2000	protected areas nearby Freising	Freising city
number of taxa					
total	531	344	265	118	144
RL (categories 0, 1, 2, 3, G, R, V)	303	160	87	16	32
RL category 0	45	9	0	0	0
RL category 1	64	25	5	1	0
RL category 2	55	34	15	2	2
RL category 3	68	50	36	4	14
RL category G	7	6	2	0	0
RL category R	24	2	1	0	0
RL category V	40	34	28	9	16
communal	7	5	3	1	3
social	46	33	24	19	17
solitary	304	202	160	65	90
oligolectic	120	78	62	17	37
hypogeic	118	89	75	32	49
endogeic	280	175	130	64	72
parasitic	129	91	67	25	32
specific requirements for nests	70	39	33	13	16
specific requirements for brood cells	67	47	38	10	25
share of taxa with specific traits (reference = total number of taxa of the reference area) (in %)					
RL (categories 0, 1, 2, 3, G, R, V)	57	47	33	14	22
RL category 0	8	3	0	0	0
RL category 1	12	7	2	1	0
RL category 2	10	10	6	2	1
RL category 3	13	15	14	3	10
RL category G	1	2	1	0	0
RL category R	5	1	0	0	0
RL category V	8	10	11	8	11
communal	1	1	1	1	2
social	9	10	9	16	12
solitary	57	59	60	55	63
oligolectic	23	23	23	14	26
hypogeic	22	26	28	27	34
endogeic	53	51	49	54	50
parasitic	24	26	25	21	22
specific requirements for nests	13	11	12	11	11
specific requirements for brood cells	13	14	14	8	17
share of Bavarias taxa with the same trait (in %)					
share of the taxa recorded in Bavaria	N.A.	65	50	22	27
RL (categories 0, 1, 2, 3, G, R, V)	N.A.	53	29	5	11
RL category 0	N.A.	20	0	0	0
RL category 1	N.A.	39	8	2	0
RL category 2	N.A.	62	27	4	4
RL category 3	N.A.	74	53	6	21
RL category G	N.A.	86	29	0	0
RL category R	N.A.	8	4	0	0
RL category V	N.A.	85	70	23	40
communal	N.A.	71	43	14	43
social	N.A.	72	52	41	37
solitary	N.A.	66	53	21	30
oligolectic	N.A.	65	52	14	31
hypogeic	N.A.	75	64	27	42
endogeic	N.A.	63	46	23	26
parasitic	N.A.	71	52	19	25
specific requirements for nests	N.A.	56	47	19	23
specific requirements for brood cells	N.A.	70	57	15	37

⁴ iNaturalist project “Wildbienen in Freising – urban pollinators: bees in Freising” by “hanno_schaefer” (retrieved August 15, 2024, from <https://www.inaturalist.org/projects/wildbienen-in-freising-urban-pollinators-bees-in-freising>).

5. GENERAL DISCUSSION

5.2.1.6. *Habitat types and their management*

Our study mainly focused on the habitat types meadow orchards, wastelands, and semi-natural river dikes. Although the bee communities were similar across all sites, each habitat type had specific contributions to a diverse wild bee community. (discussed in Publication 2)

The meadow orchards harbored the highest total number of bee taxa (98 taxa), of Red List species (thirteen taxa), and the highest share of oligolectic species. Regarding particular nesting requisite requirements, two specialists of rotten wood (*Anthophora furcata* and *Xylocopa violacea*) and the resin specialist *Anthidiellum strigatum* were only found here. Although studies on urban orchard meadows are scarce [but see Rada et al. (2023)], meadow orchards in general (usually located in the surroundings of small villages) have been found to be important wild bee habitats (Horak et al., 2013; Saure, 2016; Schwenninger & Wolf-Schwenninger, 2012; Steffan-Dewenter, 2003; Steffan-Dewenter & Leschke, 2003). (discussed in Publication 2)

The river dike hosts a large part of the wild bee communities of the city (77 taxa) with ten Red List species, including the species with the highest threat level in the city (*Bombus subterraneus*). This is comparable to studies on river dikes along the Rhine (Westrich, 1985) and Loire (Villalta et al., 2021), which found river dikes to be important bee habitats. The high share of bumblebees and *Sphecodes* bees (a parasitic genus specialized mainly on *Andrena* and halictid bee hosts) indicates the availability of abandoned rodent holes [see also McFrederick & LeBuhn (2006)] and nesting sites for ground-nesting bees. (discussed in Publication 2)

Finally, the wastelands were also hotspots within the city with 80 taxa and seven Red List species. The willow specialist *Andrena praecox*, the willowherb specialist *Megachile* cf. *lapponica*, the snail-shell nesting *Osmia aurulenta*, and the parasitic genus *Epeolus* were only found on wastelands. Together with studies in other European cities revealing even higher species numbers in wastelands [112, 127, and 201 species in Freiburg/Germany, Brussels/Belgium, and Bydgoszcz/Poland, respectively (Klatt, 1989; Twerd & Banaszak-Cibicka, 2019; Vereecken et al., 2021)], this suggests those ephemeral habitats should not be overlooked. Large proportions of bare ground, diversity in early successional plant species, and favorable microclimatic conditions provide favorable nesting and foraging conditions until succession or development projects put an end to the bee community in this site and refugial habitats nearby are needed. (discussed in Publication 2)

Within each habitat type, bee taxon richness differed depending on the management type or succession stage. The sites with the highest bee diversity and the highest flowering plant species diversity were the meadow orchards with extensive management, the river dike area with the latest mowing date (September), and the wastelands in early succession stages.

5. GENERAL DISCUSSION

These findings support extensive management of green spaces with grazing animals or late summer/autumn mowing (1–2 times per year), always leaving some stripes or patches unmown [see also Wastian et al. (2016)]. Also, the importance of early succession stage wasteland areas should not be overlooked. (discussed in Publication 2)

5.2.1.7. *Connectivity and connection to source habitats*

In our study, bee species richness on a site was not related to the distance from the river dikes, the city center did not seem to be a barrier, and the bee community composition in hotspots was relatively similar. Our findings also suggest that although flower patches for oligolectic bee species might be important additional stepping stones for relatively widespread oligolectic species, their conservation potential for rare species – provided the existence of source habitats in the wider biotope network – might be limited unless they consider specific nesting requirements of target species. Overall, our results suggest that, for cities to conserve and foster diverse bee communities, including rare species, it might be more important to provide small-scale connectivity between foraging and nesting resources than continuous connectivity between floral resources. This is in line with other studies which found that small-scale habitat conditions can outweigh negative effects of urbanization at the landscape level for several pollinator groups (Berthon et al., 2021; Daniels et al., 2020; Wenzel et al., 2020). Rather than large homogeneous biotopes at the landscape level, wild bees are opportunistic in their requirement of a network of sub-habitats that meet their species-specific requirements regarding nesting and feeding resources (Falk & Lewington, 2015; Westrich, 2018) and belong to mobile species groups capable of using small habitat patches and with open population structures which can do relatively well in urban environments. While foraging ranges are estimated to reach only a few hundred meters especially for the smaller bee species (Hofmann et al., 2020; Zurbuchen, Landert, et al., 2010), flight ranges for colonization of new habitats are probably larger, and bees might occasionally be able to cross local physical barriers (Zurbuchen, Bachofen, et al., 2010). If the goal is to provide hotspots and refugial areas for rare and threatened species, we argue the better approach is to create structurally diverse habitats taking into account the nesting and feeding requirements of wild bees within a few hundred meters radius (Hofmann et al., 2020; Zurbuchen, Müller, et al., 2010). (discussed in Publication 2)

5.2.1.8. *Climate and overall habitat conditions*

Although elements characteristic for habitat types like wetland areas, parcels of woodland, high- and low-nutrient meadows, arable and grazing land, meadow orchards, hedgerows, river dams or wastelands can partially occur in urban environments, some habitat characteristics like altitude or climate cannot be reproduced in cities and species adapted to, e.g., moors (e.g., *Osmia laticeps*), inland dunes (e.g., *Nomioides minutissimus*), coastal dunes (e.g., *Colletes*

5. GENERAL DISCUSSION

halophilus) or alpine environments (e.g., *Bombus monticola*, *B. pyrenaeus*, *Panurginus montanus*) cannot be targeted by urban conservation efforts.

Furthermore, although some of the resources characteristic for specific habitat types, like wet habitats, can occur in cities, they are often isolated and occur on a small scale, which makes it less likely for them to be suitable and accessible for rare species. For example, the frit fly *Lipara lucens* requires specific conditions (i.e., relatively thin and sparsely growing reeds which mainly occur in swampy or gravelly-loamy substrate undisturbed for at least three years) to create suitable reed galls for reed-gall nesting bee species like *Hylaeus pectoralis* (RL 3, last record for Munich from 1911) or *H. pfankuchi* (RL 2, no records for Munich) (Bogusch et al., 2024; Schuberth & Bräu, 2024; Westrich, 2018).

With climate change, species most sensitive to warm temperatures, like bumblebees (Hamblin et al., 2017; Soroye et al., 2020), might not tolerate urban heat island effects. In our study, bumblebee abundance on apple flowers decreased with higher temperatures (see Publication 1) and records of the thermophilic *Xylocopa violacea* increased from a single to regular observations between 2018 and 2024⁵, which is in line with other studies observing a recent range expansion of the species (Bauer et al., 2022). Hofmann et al. (2018) found that changes in the bee fauna of the Munich botanical garden between 1997 and 2017 are driven by climate warming. Amongst the species lost in Munich since 2000 are nine bumblebee species [*Bombus confusus* (RL 1), *B. distinguendus* (RL 1), *B. jonellus* (RL V), *B. mesomelas* (RL 0), *B. muscorum* (RL 1), *B. pomorum* (RL 0), *B. quadricolor* (RL 2), *B. ruderatus* (RL G), *B. wurflenii* (RL V)] and amongst the species recorded since 2000 and not before are thermophilic species like *Halictus scabiosae*, *Lasioglossum politum*, *Ceratina cucurbitina*, *Megachile pilidens* (all not threatened according to the Bavarian Red List) (Scheuchl et al., 2023; Schuberth & Bräu, 2024; Westrich, 2019). This is in line with studies in Rome (Italy), Toledo (Ohio, USA), and Raleigh (North Carolina, USA) identifying differential sensitivities to thermal and desiccation tolerance amongst bee species and changes in abundance and community composition driven by urban warming (Burdine & McCluney, 2019; Geppert et al., 2023; Hamblin et al., 2018). Whilst thermophilic, Mediterranean species already favored by rising temperatures might find favorable conditions in cities, those species most sensitive to climate change and, therefore, with increasing conservation relevance, most likely will not.

⁵ See iNaturalist project “Wildbienen in Freising – urban pollinators: bees in Freising” by “hanno_schaefer” with species search for “*Xylocopa*” (retrieved January 24, 2025, from https://www.inaturalist.org/observations?project_id=107958&taxon_id=51111).

5. GENERAL DISCUSSION

5.2.2. Management recommendations

The referendum „Artenvielfalt und Naturschönheit in Bayern – Rettet die Bienen“ (the most successful referendum ever in Bavaria with 1.7 million votes) from 2019 had the positive effect of raising general awareness and interest in wild bees and generating campaigns developing and disseminating generalizable and reproducible recommendations for bee-friendly management of common urban habitat types like grasslands, gardens, cemeteries, and even playgrounds. Our study suggests that, in order to have an impact on species with concerning conservation status and with specific resource requirements, there is, besides general recommendations, a need for bee conservation concepts based on monitoring and species-specific biological and ecological knowledge in order to implement targeted measures.

To increase the conservation potential of cities for wild bees including rarer and threatened species, the following three dimensions should be considered:

- (1) Providing targeted resources within a few hundred meters (for a list of resources suitable for bees and which taxa can be targeted by providing them, see *Table 1*):
 - Provide pollen, nectar and oil sources, ideally different plant families flowering throughout the season (Hofmann et al., 2019) and with a special focus on the host plants of oligolectic bees. As it is recommended but often challenging in urban management and restoration practice to preserve and use native plants with seeds of regional origin, local collaborations between research projects, conservation agencies, environmental NGOs, and seed producers and nurseries are essential on that matter (Bucharova et al., 2021; Crispi & Hoiß, 2021; Sommer & Zehm, 2020).
 - Provide nesting materials: e.g., moist clay for mason bees, resin for resin-leafcutter and rotund resin bees, hairy plant species for wool carder bees or leaves of plant species suitable for leafcutter-bees (Requier & Leonhardt, 2020; Sinu et al., 2022).
 - Provide nesting sites for a variety of nesting types, especially ground-nesting species. Wildflower plantings (Williams et al., 2024), grassland extensification (Albrecht et al., 2023), artificial bare ground patches in calcareous grasslands (Gardein et al., 2022), and even pavement design (Noël et al., 2024; Weber et al., 2024) have been shown to enhance the conditions for ground-nesting species. As the requirements on substrates are species-specific and often yet unknown, protecting and maintaining structures that have already been colonized is preferable. Tutorials to create habitats for ground-nesters are being developed and disseminated (A. Martin et al., 2017; Neumüller et al., 2022; Verein Deutscher Ingenieure e.V., 2024a; wildBee.ch, 2017), but there is a need for more research, e.g., on appropriate substrates (Antoine & Forrest, 2021; Harmon-Threatt, 2020; Kueneman et al., 2024; Maher et al., 2019). Also, bees nesting in dead wood (Eckert et al., 2021; Felderhoff et al., 2022) and pithy plant stems require more “wild” places in parks

5. GENERAL DISCUSSION

and private gardens [e.g., unmown grass patches during winter (Unterweger et al., 2018) and dry *Verbascum* or *Rubus* stems left for at least two winters].

- Ensure small-scale connectivity between foraging and nesting resources by creating structurally diverse habitats considering the varied resource needs of wild bees within a few hundred meters. (see also Publication 2)

(2) Identifying, maintaining, and enhancing the specific potentials of habitat types that are common across cities like parks, community and private gardens, balconies or wastefields:

- Fostering flower- and structure-rich parks and gardens, also considering the importance of wastelands in early succession stages which tend to be short-lived in cities but will reappear whenever new demolition or construction sites appear.
- Educating about specific measures enhancing specific urban habitat types, e.g., considering nesting resource availability in community gardens (Felderhoff et al., 2022) or providing *Lythrum salicaria* or *Lysimachia vulgaris* for oligolectic bees in wet habitats (Moroń et al., 2008).
- Regarding green space management, our findings support extensive management with grazing animals or late summer/autumn mowing (1–2 times per year), always leaving some stripes or patches unmown. (see also Publication 2)

(3) Identifying, maintaining, and enhancing city-specific particularities and potentials, for example:

- habitats for ground-nesting species with region-specific soil substrates (e.g., calcareous fluviatile gley and loessic loam in Freising);
- enhancing the conditions in habitat types specific in a particular city [in Freising, e.g., extensive management of meadow orchards and of dry grasslands on the river dikes, and preservation of remnants of alluvial forest (particularly valuable for rotten wood or resin specialists, ground-nesting species, and willow specialists, respectively)];
- rare species identified by citizen scientists or during specialist surveys (in Freising, e.g., protecting the nests and providing additional feeding and nesting resources for *Rophites hartmanni/quinquespinosus*).

Such a targeted approach requires regular species inventories and monitoring in order to identify species and habitats of specific conservation relevance and to react to negative trends. As regular and large-scale monitoring is very time- and cost-intensive, novel approaches integrating efforts by specialists and citizen scientists can be fruitful.

5. GENERAL DISCUSSION

5.3. Methodological explorations: challenges and opportunities of community-based survey approaches and photo-based inventories in wild bee research

5.3.1. Participation

Participation by urban citizens in public talks, guided walks, and bee identification trainings was high (c. 630 persons), but their subsequent contribution through observation reports was much lower (c. 1,165 records by 2023). A total of 140 persons (excluding the authors) contributed observations to our iNaturalist project, but only six of them contributed more than thirty observations by 2023) (discussed in Publication 2). Participation increased strongly over time: by August 15 2024, 4,148 observations had been contributed by 295 observers, eleven of them (excluding the authors) with more than thirty observations.

Species that were discovered by citizen scientists and not us (= 15 taxa within the city Freising) were by three highly involved persons who contributed 317, 417, and 653 observations, respectively, by August 15 2024 (see *Appendix A1.3.*). This corresponds to a pattern characteristic on iNaturalist of few observers contributing the vast majority of observations, including the majority of high-quality observations, whereas most observers contribute only a few observations (Di Cecco et al., 2021; Pereira et al., 2024). To maximize the advantages of deep and shallow participation for engagement and data quality (Loiselle et al., 2016), it is advisable to train citizen scientists at two levels: a) general introductions to wild bee diversity, ecology, and conservation for a larger public in order to create more awareness, and (b) workshops for in-depth training of a small number of dedicated citizen scientists. (discussed in Publication 2)

Noticeably, some of the most interesting observations from a conservation perspective [*Andrena curvungula* (RL 2), *Pseudoanthidium nanum* (RL 3), *Trachusa byssina* (RL 3), *Melitta leporina* (RL V), *Osmia spinulosa* (RL V) and *Andrena cf. trimmerana* (RL D) within the city of Freising and *Andrena denticulata* (RLV), *Colletes cf. succinctus* (RL 3), *Melitta tricincta* (RL 3), *Nomada cf. rufipes* (RL 3) and *Rophites cf. hartmanni* [not assessed, newly recorded for Bavaria/Germany (Zimmermann et al., 2023)] nearby Freising] were by citizen scientists (see *Appendix A1.3.*). Combined with systematized surveys, they can increase inventories' temporal and spatial resolution. In Belgium, community-based surveys streamlining survey efforts by academics, (para-)taxonomists, and citizen scientists allowed to add 24 new records and the rediscovery of eleven species previously thought to be regionally extinct according to the most recent Red List of Belgian bees (Drossart et al., 2019). This exemplifies that such efforts can be upscaled to the national level when building on strong collaborations between universities and naturalist networks (Vertommen et al., 2024).

From an institutional perspective, when initiating projects based on participative inventory methods within research projects funded for time-limited periods, it is important to bear in mind that these gain in potential over more extended time periods, and it is worth anchoring their

5. GENERAL DISCUSSION

coordination and supervision within institutionalized structures (e.g., universities, environmental NGOs, nature conservation agencies). Those can evaluate the data, assign local protection priorities, and develop species protection programs. Community-based surveys depend on dedicated specialists who give feedback on species identification – often in their free time – particularly for species that are difficult to identify. They, therefore, rely on training and positions for taxonomy and special species experts (Hochkirch et al., 2022; Páll-Gergely et al., 2024; Schulte et al., n.d.; Verein Deutscher Ingenieure e.V., 2024b). Also, publications based on citizen science projects might require novel frameworks for author recognition (Klaus et al., 2024; Ollerton et al., 2022; Vertommen et al., 2024). Furthermore, the local structural context has to be considered. Freising has particularly favorable conditions as a relatively small university city with two life science Campuses and active environmental NGOs, which favors a relatively high density of citizen scientists with prior knowledge and affinity for species identification of challenging species groups. This also allows the integration of species identification training and surveys (e.g., Bioblitz) in university courses. As different naturalist platforms exist (Kaufmann & Lindner, 2021), evaluating and synthesizing the data and making it available and relevant to practice is important. For example, the geodata application “bee finder” suggests plants suitable for rare bee species occurring in a 1000 m radius around any address in Switzerland to encourage targeted conservation measures (IG Wilde Biene, n.d.). Local contact institutions (within environmental NGOs, nature conservation agencies, or research projects) where citizens can report observations (e.g., of ground-nesting bees on playgrounds) and receive scientific advice can be helpful starting points for residents. Those can provide the regular care required in dynamic and disturbance-prone urban environments to conserve and create high-quality habitats in their neighborhood. Overall, citizen science projects can motivate participants for conservation practice (Lewandowski & Oberhauser, 2017; McKinley et al., 2017) and increase scientific knowledge, e.g., on nesting behavior or incidental and often ephemeral structures like bee nest sites (Grobbauser et al., 2024; Kueneman et al., 2024; Maher et al., 2019). In light of the global biodiversity crisis, joint specialists and citizen scientists survey and conservation efforts are all the more important.

5.3.2. Opportunities of photo-based approaches in combination with citizen science platforms

Using photography, the Field Guide and the iNaturalist App as common tools both for the systematic surveys by trained scientists and for records by citizen scientists has a range of advantages:

- *Promotes accuracy of identification:* Having a large reference base of pictures facilitates photo-based identification. Adding correctly identified photographs of a particular species for a particular geographic region enhances the artificial intelligence species identification algorithms (Klaus et al., 2024; Spiesman et al., 2021).

5. GENERAL DISCUSSION

- *Minimizes specimen collection*⁶: Because of required permits, citizen scientists are unlikely to use invasive methods (BArtSchV Anlage 1, Spalte 2, n.d.; BNatSchG § 44 Abs. 1 Nr. 1 & BNatSchG § 45 Abs. 7 Nr. 3, n.d.; Verein Deutscher Ingenieure e.V., 2023b).
- *Accelerates feedback loops*: Making observations readily available accelerates the species identification process and enables to re-visit sites of observations to try to make additional pictures with missing features, collect samples for DNA analysis if required, or quickly intervene if, e.g., vulnerable nesting sites of rare species have been identified. Furthermore, it supports participants in developing observation, image capture, and species identification expertise as community members share knowledge on the morphological traits that are relevant for species identification and must be focused in image capture (Callaghan et al., 2022). Identifications can be revisited, e.g., if newly occurring taxa occur in an area (see *Rophites quinquespinosus/hartmanni* in Freising⁷).
- *Strengthens connections between participants involved in observing, identifying, and conserving insects*: Knowledge exchange is encouraged both at the local and wider scale between citizen and institutionalized science and between stakeholders involved in monitoring, taxonomy, and conservation (S. A. Marshall, 2008; Theobald et al., 2015). Citizen science platforms can help streamline survey and identification efforts by different stakeholders (individuals, schools, universities, environmental NGOs, and conservation agencies) and maximize the value of opportunistic observations for science and nature conservation (Callaghan et al., 2022; J. S. Wilson et al., 2020).
- *Promotes insect conservation through aesthetic means*: The process of image capture makes small and volatile animals otherwise outside of the field of perception tangible and meaningful (Simaika & Samways, 2018). High-quality pictures of insects identified to species level, in turn, can support outreach for conservation projects and education in insect identification (L. Marshall et al., 2024; S. A. Marshall, 2008; McCullough et al., 2013).

5.3.3. Opportunities and limitations of photo-based bee identification

Of 150 recorded wild bee taxa (for the administrative district of Freising), we identified 117 at species level; 33 are taxon groups. Taxa that could not be identified to species level could still be narrowed down to taxon groups. Eighteen taxa were treated as systematic taxon group with reference to the most common of a cluster of species usually very difficult to differentiate on pictures (e.g., *Colletes cf. daviesanus* for *Colletes daviesanus*/*C. similis*/*C. fodiens*), based on Publication 3. Taxa for which identification at species level was somehow uncertain because the pictures were not ideal for detecting relevant features (15 taxon groups, e.g., *Rophites*

⁶ Regarding lethal methods, see also Drinkwater et al. (2019), Fischer & Larson (2019), Gezon et al. (2015), Klaus et al. (2024), and Verein Deutscher Ingenieure e.V. (2023b, 2023a).

⁷ Species account on iNaturalist by “birdingjulia” retrieved January 24, 2025, from <https://www.inaturalist.org/observations/126986141>.

5. GENERAL DISCUSSION

hartmanni/quinquespinosus, *Megachile lapponica*) or because of nomenclatural issues (2 taxa, eg., *Andrena trimmerana*/*A. scotica*/*A. carantonica*) were annotated with “cf.” with reference to the species that it was believed to be (sometimes taking into consideration ecological data like flower visitation). Here, additional pictures or resolution of nomenclatural issues could dispel uncertainties in the future (see *Table 5* and *Appendix A1.3*).

The Project BienABest (Verein Deutscher Ingenieure e.V., n.d.) developed one of the first systematic guidelines for population-friendly recording of wild bees (Verein Deutscher Ingenieure e.V., 2023a). Specialists drafted a working list categorizing over 500 bee species according to whether they can be identified in the field as follows: of the 527 female and 485 male bees assessed, 58 females and 34 males, respectively, can be determined in the field without further aids, 246 females and 139 males can be identified in the field when temporarily fixated and with the help of a magnifying glass, 223 females and 312 males cannot be determined with certainty in the field. According to the board of experts, “only about 50 % of the species in the female sex and just under 30 % in the male sex can be identified in the field [...] However, experienced recorders can achieve significantly higher field identification rates, especially when considering regionally occurring species” (Verein Deutscher Ingenieure e.V., 2023a). High-resolution photographs informed by knowledge about the relevant features that have to be focused on can maximize species identification resolution. Helpful resources are increasingly being developed and made available to the public (for Europe, e.g., Arbeitskreis Entomologie im NABU Landesverband Sachsen e. V. et al., n.d.; BienABest, n.d.; Falk, n.d.; Falk & Lewington, 2015; Fritzsche & Fritzsche, n.d.; Gokcezade et al., 2010; info fauna, n.d.; Natuurpunt, n.d.; Scheuchl & Willner, 2024; WildBnB & ULB Agroécologie, n.d.), but there is still a need for more field guides for different regions, both for female and male bees. Furthermore, there is a lack of detailed descriptions of the features one should focalize in order to be able to differentiate similar species (Stafford et al., 2010). Marshall et al. (2024) coin this shortfall the “Keartonian Impediment” (after the wildlife photographers Richard and Cherry Kearton), “which addresses an absence of high-quality in situ photos and illustrations with diagnostic characteristics” (L. Marshall et al., 2024) necessary for monitoring, identification and outreach, particularly but not only for citizen science projects. In their analysis, this impediment constitutes one of seven major shortfalls impairing knowledge and conservation of wild bees in Europe (L. Marshall et al., 2024).

For systematic approaches, it is important to group those species that cannot reliably be distinguished with photographs into consistent taxon groups to enable comparisons of diversity between projects following the same system (Publication 3). One challenge lies in immobilizing the bees to make high-resolution pictures of important features from different angles before the bee flies away. Over time and having used both lethal and different nonlethal methods, I found catching the bees with an insect net, exhaustor, or insect viewer cup and immobilizing

5. GENERAL DISCUSSION

them by gently taking three legs in-between two fingers, using a thick garden glove or “observation boxes” [perky boxes used for mineral specimens with foam for fixation (Thünen-Institut für Biodiversität, 2023)] for larger species with thicker stingers (mainly *Bombus* and *Xylocopa*) most practical⁸. This minimizes equipment (e.g., chilling box and cooling packages) for fieldwork, accelerates the process as one can skip intermediate steps like chilling down the insects, and facilitates positioning the bee so one can light and focus on relevant features. Although this immobilization method is still stress-inducing for the insects, this is limited in duration compared to, e.g., cold or CO₂ anesthesia, for which knowledge about potential sublethal effects on bees is still limited (Toulzac et al., 2022). One picture at least should be made with millimeter paper for size reference. Permits are required to capture the bees (Verein Deutscher Ingenieure e.V., 2023b). It is helpful (but not imperative) to be in a team of two persons (one holding the bee, one making the picture). Taking photo-vouchers in situ prolongates the time needed in the field but enables the identification of some individuals immediately with some experience. This approach also enables one to take pictures of the bees on flowers before or after catching them. This is useful for including additional ecological and behavioral information on flower visitation (Weissmann & Schaefer, 2017), collection of non-floral resources (Weissmann & Schaefer, 2015), nesting (Kueneman et al., 2024), or mating (Schindler et al., 2018) and is ideal for science and conservation communication (S. A. Marshall, 2008; McCullough et al., 2013). After fieldwork, pictures have to be sorted, identified and uploaded on iNaturalist or other citizen science platforms. Also, species lists, including hyperlinks directing to the respective photo vouchers on the chosen platform (see *Appendix A1.3.*), should be kept up to date according to feedback on their identification on the platform. Some advantages of photographic vouchers are that pictures do not fade, features like eye and hair coloration are recognizable, and specialists worldwide can check the identification without having to visit physical specimens in museums and zoological collections (Hofmann & Fleischmann, 2020). One of the limitations is that identification to species level can be difficult

⁸ For pictures made with this method, see for example: iNaturalist account from “bund_naturschutz_kreisgruppe_muenchen” with Life list search for “Order Hymenoptera” (retrieved January 24, 2025, from https://www.inaturalist.org/lifelists/bund_naturschutz_kreisgruppe_muenchen?view=tree&details_view=observations&taxon_id=47201); iNaturalist account from “v_stefan” with Life list search for “Order Hymenoptera” (retrieved January 24, 2025, from https://www.inaturalist.org/lifelists/v_stefan?view=tree&details_view=observations&taxon_id=47201); iNaturalist account from “karimstrohriegl” with Life list search for “Order Hymenoptera” (retrieved January 24, 2025, from https://www.inaturalist.org/lifelists/karimstrohriegl?view=tree&details_view=observations&taxon_id=47201); iNaturalist account from “aureleb” with Life list search for “Order Hymenoptera” (retrieved January 24, 2025, from https://www.inaturalist.org/lifelists/aureleb?view=tree&details_view=observations&taxon_id=47201); iNaturalist account from “robertzimmermann” with Life list search for “Order Hymenoptera” (retrieved January 24, 2025, from https://www.inaturalist.org/lifelists/robertzimmermann?view=tree&details_view=observations&taxon_id=47201).

5. GENERAL DISCUSSION

when females have pollen on their scopae. Also, posterior morphological and molecular analysis is impossible (Herrera-Mesías et al., 2022). Photos cannot replace voucher collection, and it is important to make all participants in community-based surveys aware of the limitations of bee identification based on field traits, especially in difficult groups like some halictid, *Sphecodes*, and bumblebee species, where micromorphology or even DNA analysis are necessary for reliable identification (Weissmann et al., 2017). Molecular taxonomy through DNA barcoding is increasingly applied to meet the taxonomic challenges of bee species identification (Gill et al., 2016; Klaus et al., 2024; Magnacca & Brown, 2012; Schmidt et al., 2015). Here too, efforts are being deployed to develop non-lethal methods of DNA sampling through low-invasive tissue sampling [e.g., partial antennae removal, tarsus- or wing-tips clipping (Châline et al., 2004; Gould et al., 2011; Holehouse et al., 2003; Oi et al., 2013)], or environmental DNA metabarcoding [e.g., on flowers (Montero-Castaño et al., 2022; Thomsen & Sigsgaard, 2019) or nests (Sickel et al., 2023)].

For the administrative district of Freising, 109 taxa have been recorded (34 of them with last records since 2000) and not in our studies; 121 taxa were recorded for the administrative district (59 of them with last records since 2000) and in our studies (including our taxon groups with reference to the most common taxon). Twenty-eight taxa were recorded in our studies and not for the administrative district of Freising so far (for nine of them, species identification remained somehow doubtful: *Andrena* cf. *trimmerana*, *Coelioxys* cf. *inermis*, *Coelioxys* cf. *rufescens*, *Colletes* cf. *succinctus*, *Megachile* cf. *lapponica*, *Nomada* cf. *rufipes*, *Nomada* cf. *sheppardana*, *Rhophites* *hartmanni/quinquespinosus*, *Stelis* cf. *minima*) (Bayerisches Landesamt für Umwelt, 2023). Considering that more than twice as many bee taxa have been recorded in Munich in more than 200 years of surveys compared to our findings in Freising (Schuberth & Bräu, 2024) and that additional rare species have been discovered in the Freising area by citizen scientists every year, it is evident that bee surveys should ideally be performed over long time scales. Although some of the species recorded in the region are difficult to detect with our method, they also include numerous taxa that can be identified to species level from photographs. This suggests that there is potential for additional species, including rare ones, to be found in Freising in the coming years. (discussed in Publication 2)

6. CONCLUSION AND IMPLICATIONS FOR CONSERVATION

6.1. Concept for bee-friendly management of urban spaces

We suggest the following concept for bee-friendly management of urban spaces:

I- Monitoring

1. Taking inventory of existing wild bee surveys in exchange with local and regional nature conservation authorities, NGOs, and research institutions to identify bee hotspots.
2. Performing regular standardized surveys in bee hotspots.
3. Training citizen scientists at two levels for comprehensive surveys in all parts of the city: (a) public talks and guided walks to create more general awareness of wild bee diversity, ecology, and conservation, (b) regular in-depth bee survey and identification trainings for a small number of dedicated citizen scientists. (see also Publication 2)

II- Management

1. Identifying, maintaining, and enhancing city-specific particularities and potentials. Implementation of special conservation programs for rare species identified through monitoring.
2. Identifying, maintaining, and enhancing the specific potentials of habitat types common across cities like parks, cemeteries, balconies, and community and private gardens. Our findings support extensive management of green spaces with grazing animals or late summer/autumn mowing (1–2 times per year), always leaving some areas unmown. Besides protecting natural areas and fostering flower- and structure-rich parks and gardens, the importance of early succession stage wasteland areas should not be overlooked.
3. Providing targeted resources considering connectivity at small scales: provide hotspots and refugial areas for rare and threatened species by creating high-value habitats which take into account the varied feeding and nesting needs of bees within flight ranges of only a few hundred meters.
4. Creating feeding and nesting stepping stone habitats, integrating educative aspects. (see also Publication 2)

6.2. Outview

Wild bees are an increasingly popular insect group attractive for conservation measures in cities. Nevertheless, practices are often one-sided or misplaced – e.g., providing “bee hotels” for already very common species like *Osmia bicornis* and *Osmia cornuta* in otherwise bee-unfriendly environments like lawns. It is key – and often challenging – to channel this motivation towards truly effective conservation measures for rare species within cities. High population densities in cities imply that, e.g., voting and consumer behavior of city dwellers have an impact

6. CONCLUSION AND IMPLICATIONS FOR CONSERVATION

beyond city boundaries. Harboring diverse wild bee communities in urban environments – if combined with effective environmental education measures which a) raise awareness about the varied and species-specific habitat needs of wild bees and simultaneously b) educate both on opportunities and limitations of urban conservation measures in order to foster the protection of natural habitats in the wider biotope network essential as source habitats or for wild bee species that cannot dwell in urban environments – can therefore have behavioral and political effects positive for wild bee conservation within and beyond cities.

When integrated into the general green space management of a city and with the support of municipal nature conservation departments, local NGOs, schools, and universities, the holistic approach developed and tested in this thesis can be very effective in streamlining survey and species identification efforts, identifying bee hotspots and occurrences of rare species, and encouraging exchange between the different stakeholders engaged in bee research and conservation. Those are essential prerequisites for targeted and species-specific measures most efficient especially for species with concerning conservation status. The approach is scalable to cities of different sizes, easy to implement, and cheap. The collected bee photographs are stored and verifiable on an online citizen science platform, which assures independence from funding periods for local projects and allows to combine data from many different projects. Even though our photographic approach is limited when it comes to species-level identification of more difficult taxa, this is unlikely to significantly impact overall bee diversity patterns. Our strategy can be adopted in urban areas worldwide and help to combine the diverse local efforts, resulting in more efficient conservation of wild bees. It will also give rise to many new bee enthusiasts and even some future bee specialists, whose joint forces are desperately needed for effective and long-term conservation work dedicated to this fascinating group of insects. (discussed in Publication 2)

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The AI tool “Grammarly” was used to detect spelling, grammatical, and stylistic mistakes (last date of access: February 2, 2025).

APPENDIX

APPENDIX

A1 Supplementary data

A1.1. Systematization of bee- and pollination-related citizen science projects

Some examples of bee- and pollination-related citizen science-projects according to the systematization mentioned in §1.5.2. The list is non-exhaustive, and biased towards English-, French- and German-speaking projects in Europe, North America and Australia.

project name	institutions	country/region	focus				resolution of identification		methods			approach		target species / parataxonomic groups	platform / data management	website	publications
			species diversity & distribution	(nesting) behaviour	bee-plant interactions / pollination	pollination services	species level	parataxonomic group	observation / photo	capture / lethal	manipulative / experimental	opportunistic	systematic				
n.a.	Australian Museum	Australia	x				x		x			x		<i>Halictus smaragdulus</i>	form / protocol: https://www.youtube.com/watch?v=sDwXAIQyYK8		(Ashcroft et al., 2012) https://doi.org/10.1007/s10073-011-0092-x
Hummeln Österreichs	Naturschutzbund Österreich	Austria	x				x		x			x		<i>Bombus</i> spp.	platform / app: https://www.naturbeobachtung.at/platform/mo/nabearbeit/bombus/home.do?doHome		
Atlas Hymenoptera: Cartographie des abeilles sauvages de Bruxelles	Université Libre de Bruxelles, Université de Mons, Natagora Bruxelles, Apis Bruoc-sella	Belgium: Brussels	x				x		x			x		<i>Andrena fulva</i> , <i>Anthophora plumipes</i> , <i>Osmia cornuta</i> , <i>Dasypoda hirtipes</i> , <i>Melitta nigricans</i> , <i>Colletes hederæ</i> , <i>Bombus pascuorum</i>	E-mail: http://www.atlashymenoptera.net/page.aspx?id=161		
Wild BnB	Université Libre de Bruxelles, Natuurpunt, Natagora, Royal Belgian Institute of Natural Sciences	Belgium: Brussels	x				x		x	x		x			platform: https://waarnemingen.be	https://www.wildbnb.brussels/participez?lang=en	(Vereecken et al., 2021) https://doi.org/10.1111/icaad.12514
Apiformes	INRAE, La Bergerie Nationale, Pollinis	France	x				x	x		x			x	Apidae	form: https://www.pollinis.org/nos-projets/conserver-les-pollinisateurs/apiformes-dresser-l-etat-des-lieux-des-abeilles-sauvages-chainons-clefs-de-la-pollinisation/		(Le Féon et al., 2016) https://doi.org/10.1007/s10841-016-9927-1
Hummeln erfassen	Thünen Institut, Observation.org	Germany	x				x		x			x		<i>Bombus</i> spp.	platform: https://observation.org/	https://wildbienen.thuenen.de/mitmachen/hummeln-erfassen/app	
Hummel-Monitoring	Thünen Institut	Germany	x				x		x				x	<i>Bombus</i> spp.	form: https://wildbienen.thuenen.de/mitmachen/hummeln-erfassen/hummel-monitoring#c16997	https://wildbienen.thuenen.de/mitmachen/hummeln-erfassen/hummel-monitoring#c16997	
Wildbienenkataster	Wildbienen-Kataster	Germany	x				x		x			x		<i>Megachile willughbiella</i> , <i>Xylocopa violacea</i> , <i>Colletes cunicularius</i> , <i>Hyleus nigrus</i> , <i>Eucera nigrescens</i> , <i>Macropis fulvipes</i> , <i>Andrena aglissima</i> , <i>Halictus scabiosae</i> , <i>Andrena hattorfiana</i> , <i>Bombus sylvarum</i> , <i>Andrena ferea</i> , <i>Anthidium manicatum</i> , <i>Osmia bicolor</i> , <i>Megachile parietina</i>	e-mail: https://www.wildbienen-kataster.de/		(Burger, 2013) https://sammlungen.ub.uni-frankfurt.de/biodiv/periodical/pageview/9670756
Insektenommer	NABU	Germany	x				x		x				x	insects	platform: https://naturgucker.de/app/natur_n_m.dli/Form1	https://www.nabu.de/tiere-und-pflanzen/aktionen-und-projekte/insektenommer/index.html	
Hummelhotline	Institut für Biodiversitätsinformation e.V., BUND Naturschutz in Bayern e.V.	Germany: Bavaria	x				x		x			x		<i>Bombus</i> spp.	whatsapp: https://www.ifbi.net/hummelhotline		
Hummel-Challenge	Thünen Institut, BUND Naturschutz in Bayern e.V., Observation.org	Germany	x				x		x			x		<i>Bombus</i> spp.	platform: https://observation.org/	https://www.bund-naturschutz.de/aktionen/hummel-challenge	
Hummeln helfen! Rhein-Main	Johannes Gutenberg-Universität Mainz	Germany: Rhein-Main	x				x	x	x				x	<i>Bombus</i> spp.	form: https://hummeln-helfen.de/		(Christ et al., 2022) https://doi.org/10.3390/su142114524
Insekten Sachsen	Arbeitskreis Entomologie im NABU Landesverband Sachsen e.V., Sächsische Landesstiftung Natur und Umwelt, Senckenberg Gesellschaft für Naturforschung	Germany: Saxony	x				x		x			x		insects	platform / app: https://www.insekten-sachsen.de/Pages/RegistrationWizard.aspx	https://www.insekten-sachsen.de/	
All-Ireland Bumblebee Monitoring Scheme	National Biodiversity Data Centre	Ireland	x				x		x			x		<i>Bombus</i> spp.	form/platform: https://monitoring.biodiversityireland.ie/	https://biodiversityireland.ie/surveys/bumblebee-monitoring-scheme/	
UK Pollinator Monitoring Scheme (One km square survey)	UK Centre for Ecology & Hydrology, Joint Nature Conservation Committee	UK	x				x		x	x		x		insects	platform/app: https://ukpoms.org.uk/one-km-square-survey	https://record.org.uk/	(Powney et al., 2019) https://doi.org/10.1038/s41467-019-08974-9
BWARS	BWARS (Bee Wasps & Ants Recording Society)	UK	x				x		x			x		<i>Andrena cineraria</i> , <i>Andrena fulva</i> , <i>Anthophora plumipes</i> , <i>Osmia bicornis</i> , <i>Andrena vaga</i> , <i>Anthidium manicatum</i> , <i>Colletes hederæ</i>	form: https://bwars.com/index.php/content/submitting-your-records	https://bwars.com/	
BeeWalk	Bumblebee Conservation Trust	UK	x				x		x			x		<i>Bombus</i> spp.	form: https://beewalk.org.uk/resources	https://beewalk.org.uk/	

project name	institutions	country/region	focus				resolution of identification		methods			approach		target species / parataxonomic groups	platform / data management		website	publications
			species diversity & distribution	(nesting) behaviour	bee-plant interactions / pollination	pollination services	species level	parataxonomic group	observation / photo	capture / lethal	manipulative / experimental	opportunistic	systematic					
BeeWatch	University of Aberdeen, Bumblebee Conservation Trust	UK	x				x		x			x		<i>Bombus</i> spp.	platform	n.a.		(van der Wal et al., 2015) https://doi.org/10.1007/s13280-015-0709-x ; (van der Wal et al., 2016) https://doi.org/10.1111/cobi.12705 ; (Falk et al., 2019) https://doi.org/10.1371/journal.pone.0218614
n.a.	Coventry University	UK	x		x		x		x			x		<i>Bombus terrestris</i> / <i>lucorum</i> , <i>B. hortorum</i> , <i>B. pratorum</i> , <i>B. pascuorum</i> , <i>B. lapidarius</i> , <i>B. hypnorum</i> insects	form			(Foster et al., 2017) https://doi.org/10.1007/s11252-016-0604-7
Sow Wild!	University of Sussex	UK	x				x	x	x	x	x	x			form	https://www.thebuzzclub.uk/		(Griffiths-Lee et al., 2022) https://doi.org/10.1007/s10841-022-00387-2 ; (Griffiths-Lee et al., 2023) https://doi.org/10.5334/cstp.550
Bumble Bee Watch	Wildlife Preservation Canada, The Xerces Society for Invertebrate Conservation, York University	US, Canada	x				x		x			x		<i>Bombus</i> spp.	platform: https://www.bumblebeewatch.org/	https://www.bumblebeeatlas.org/		
Beespotter	University of Illinois	US: Illinois, Indiana, Missouri, Ohio	x				x		x			x		<i>Apis mellifera</i> , <i>Bombus</i> spp.	platform: https://beespotter.org/beeata/enter	https://beespotter.org/		
Minnesota Bee Atlas	University of Minnesota	US: Minnesota	x				x		x			x		Apidae	platform/app: https://www.inaturalist.org/projects/minnesota-bee-atlas	https://extension.umn.edu/natural-resources-volunteers/minnesota-bee-atlas		
Oregon Bee Atlas	Oregon Department of Agriculture, Oregon Department of Forestry, Oregon State University	US: Oregon	x				x		x	x		x		Apidae	platform/app: https://www.inaturalist.org/projects/oregon-bee-atlas-bee-pictures	https://extension.oregonstate.edu/bee-atlas		
Pacific Northwest Bumble Bee Atlas	Washington Department of Fish and Wildlife, Idaho Department of Fish and Game, Oregon Department of Fish and Wildlife, Xerces Society for Invertebrate Conservation	US: Oregon, Washington, Idaho	x				x		x			x		<i>Bombus</i> spp.	platform: https://www.bumblebeewatch.org/	https://www.pnwbumblebeeatlas.org/		
Vermont Bumble Bee Atlas	Vermont Center for Ecostudies	US: Vermont	x				x		x	x		x	x	<i>Bombus</i> spp., <i>Xylocopa virginica</i>	form	https://val.vtcecostudies.org/projects/bumble-bee-atlas/about/		
Vermont Wild Bee Survey	Vermont Center for Ecostudies	US: Vermont	x				x		x			x		Apidae	https://www.inaturalist.org/projects/vermont-wild-bee-survey	https://val.vtcecostudies.org/projects/vtbees/		
Nisthilfe-Patenschaft	Thünen Institut	Germany		x			x		x		x	x			protocol: https://wildbienen.thuenen.de/mitmachen/nisthilfe-patenschaft/anleitung	https://wildbienen.thuenen.de/mitmachen/nisthilfe-patenschaft/		
Schulinsektenhaus	Albert-Ludwigs-Universität Freiburg, UWX Robert Bosch College	Germany		x			x				x	x		Apidae	protocol: https://schulinsektenhaus.de/mitmachen/	https://schulinsektenhaus.de/		
n.a.	Helmholtz Centre for Environmental Research	Germany: Leipzig		x			x				x	x		<i>Osmia bicornis</i>	form / protocol			(Everaars et al., 2011) https://doi.org/10.1016/j.landurbplan.2011.05.008
Mitmach-Aktion "Flugdistanzen bei Wildbienen"	Munich Botanical Garden	Germany: Munich		x			x		x		x	x		<i>Chelostoma florissomme</i> , <i>Chelostoma rapunculii</i> , <i>Heriades truncorum</i> , <i>Hoplitis adunca</i> , <i>Osmia bicornis</i> , <i>Osmia cornuta</i>	form / e-mail	https://botmuc.snsb.de/flugdistanzen-bei-wildbienen/		(Hofmann et al., 2020) https://doi.org/10.3897/jbr.77.51182
National Bumblebee Nest Survey	Rothamsted Research, BBC Wildlife Magazine	UK		x				x	x			x		<i>Bombus</i> spp. (color groups)	form: https://besjournals.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fj.1365-2664.2007.01359.x&file=JPE_1359_sm_AppendixS1.pdf	n.a.		(Osborne et al., 2007) https://doi.org/10.1111/j.1365-2664.2007.01359.x
Air Bee 'n' Bee	University of Sussex	UK		x					x		x	x		Apidae	form: https://www.thebuzzclub.uk/files/ugd/7cd092_359098d4f0ae4e13b42a04af693510e5.pdf	https://www.thebuzzclub.uk/air-bee-n-bee		
The Big Bee Hotel Experiment	University of Sussex	UK		x					x		x	x		Apidae	form	https://www.thebuzzclub.uk/thebigbeehotalexperiment/		
Bees & Heatwaves	University of Sussex	UK			x			x	x			x		Apidae	form: https://www.thebuzzclub.uk/files/ugd/7cd092_27ed65b187274e63afbf985102cef759.pdf	https://www.thebuzzclub.uk/bees-heatwaves		

project name	institutions	country/region	focus				resolution of identification		methods			approach		target species / parataxonomic groups	platform / data management	website	publications
			species diversity & distribution	(nesting) behaviour	bee-plant interactions / pollination	pollination services	species level	parataxonomic group	observation / photo	capture / lethal	manipulative / experimental	opportunistic	systematic				
MN Bee Atlas Bee Blocks project	University of Minnesota	US: Minnesota		x			x				x		x	tunnel-nesting Apidae	platform: https://www.inaturalist.org/projects/minnesota-bee-atlas	https://extension.umn.edu/natural-resources-volunteers/minnesota-bee-atlas	
<i>Megachile</i> Bee Leaf Cuts project	University of Minnesota	US: Minnesota		x					x				x	<i>Megachile</i> spp.	platform: https://www.inaturalist.org/projects/megachile-bee-leaf-cuts	https://extension.umn.edu/natural-resources-volunteers/minnesota-bee-atlas	
Wild Pollinator Count	Wild Pollinators Oceania	Australia			x			x	x				x	European honey bees, blue-banded bees, other bees, ladybird beetles, other beetles, butterflies or moths, hoverflies, other flies, european wasps, other wasps, other	online form: https://wildpollinatorcount.com/submit-observations/ ; platform: https://www.inaturalist.org/projects/wild-pollinator-count	https://wildpollinatorcount.com	
Spipoll	Muséum National d'Histoire Naturelle, Office pour les Insectes et leur Environnement	France			x			x	x				x	insects	platform: https://www.spipoll.org/	https://www.spipoll.org/	(Deguines et al., 2012) https://doi.org/10.1371/journal.pone.0045822 ; (Deguines et al., 2018) https://doi.org/10.1002/fee.1795 ; (Deguines et al., 2016) https://doi.org/10.1002/eece3.2009 ; (Desaegher et al., 2018) https://doi.org/10.1007/s11252-018-0759-5
UK Pollinator Monitoring Scheme (FIT Counts)	UK Centre for Ecology & Hydrology, Joint Nature Conservation Committee	UK			x			x	x				x	Bumblebees, Honeybees, Solitary bees, Wasps, Hoverflies, Other flies, Butterflies and moths, Beetles (larger than 3mm), small insects (such as pollen beetles) less than 3mm long, other insects	online form or app: https://ukpoms.org.uk/fit-counts	https://ukpoms.org.uk/fit-count-app	
Blooms for Bees	Coventry University's Centre for Agroecology, Water and Resilience (CAWR), Royal Horticultural Society (RHS), Bumblebee Conservation Trust (BBCT), Garden Organic	UK			x			x	x				x	<i>Bombus</i> spp.	app	https://www.bloomsforbees.co.uk/	(Falk et al., 2019) https://doi.org/10.1371/journal.pone.0218614
Bee Hunt!	Discover Life	US			x			x	x				x	insects	platform: https://www.discoverlife.org/bee/how.html	https://www.discoverlife.org/bee/	https://doi.org/10.1080/00368121003631637
The Goldenrod Challenge	Discover Life	US			x			x	x				x	insects	platform: https://www.discoverlife.org/goldenrod/#rules	https://www.discoverlife.org/goldenrod/	
Spring Beauty and the Bees	University of Toronto	US, Canada			x			x	x				x	parataxonomic groups: Female <i>Andrena erigeniae</i> , Male <i>Andrena erigeniae</i> , Bombyliid flies, Small dark bees (<i>Lasioglossum</i> , <i>Ceratina</i> , <i>Hylaeus</i>), Cuckoo bees (<i>Nomada</i> , <i>Sphecodes</i>), Other bee (green bee, bumblebee, larger <i>Andrena</i> species), other fly (Syrphid, Tachinid); focal plants: <i>Claytonia virginica</i> , <i>Claytonia caroliniana</i>	form: https://springbeauties.wordpress.com/	https://springbeauties.wordpress.com/	(Parker & Thompson, 2018) https://doi.org/10.26786/1920-7603(2018)10
The Great Southeast Pollinator Census	UGA Extensions, The Center for Urban Agriculture	US: Georgia, South Carolina, North Carolina, Florida, Alabama			x			x	x				x	Carpenter Bee, Bumble Bee, Honey Bee, Small Bees, Wasps, Flies, Butterflies & Moths, Other insects	form	https://gsepc.org/resources/	(Griffin et al., 2022) https://doi.org/10.18474/JES21-05 ; (Griffin & Brame, 2021) https://doi.org/10.18474/JES20-38 ; (Griffin et al., 2021) https://doi.org/10.5334/cstp.334
Squash bee citizen science survey	Michigan State University	US: Michigan			x			x	x	x			x	parataxonomic groups: squash bee, honey bee, bumblebee, other bee; focal plants: <i>Cucurbita</i> spp.	app ; form	https://vegetable.ent.msu.edu/	(Appenfeller et al., 2020) https://doi.org/10.1371/journal.pone.0230007
Great Pollinator Project, Bee Watcher	Center for Biodiversity and Conservation, Greenbelt Native Plant Center, Great Sunflower Project	US: New York City			x			x	x				x	parataxonomic groups: honey bee, bumble bee, large carpenter bee, shiny green bee, "other" type of bee ; focal plants: <i>Echinacea purpurea</i> , <i>Pycnanthemum</i> , <i>Asclepias syriaca</i> , <i>Solidago patula</i> , <i>Symphoricarpon laeve</i> , <i>Monarda</i> , <i>Helianthus divaricatus</i> , <i>Helianthus annuus</i>	online form	https://miamioh.edu/cas/graduate-studies/project-dragonfly/professional-development-courses/bee-quest/volunteer.html	(Toomey & Domroese, 2013) https://www.jstor.org/stable/24707571
The Great Sunflower Project	San Francisco State University	US: San Francisco, California			x			x	x				x	parataxonomic groups: unknown bee, bumble bee, honey bee, carpenter bee, other type of bee, bird, butterfly ; focal plants: <i>Helianthus annuus</i>	online form: https://www.greatsunflower.org/guide	https://www.greatsunflower.org/	

project name	institutions	country/region	focus				resolution of identification		methods			approach		target species / parataxonomic groups	platform / data management	website	publications
			species diversity & distribution	(nesting) beha- viour	bee-plant interactions / pollination	polli- nation services	species level	parataxo- nomic group	obser- vation / photo	cap- ture / lethal	manipu- lative / experi- mental	oppor- tu- nistic	system- atic				
Global Pollinator Watch	EarthWatch	world			x		x		x			x		platform: https://www.inaturalist.org/projects/global-pollinator-watch?tab=about	https://earthwatch.org/global-pollinator-watch		
Forschen für Wildbienen	Museum für Naturkunde Berlin, Technische Universität München	Germany: Berlin, Munich				x					x	x	focal plants: tomato, pepper, strawberry, cucumber, pumpkin, zucchini	form	https://www.wildbienenforschung.de/unsere-forschung/buergerforschung/	(Karleowski et al., 2023) https://doi.org/10.22323/1.442.009	
Pollination Investigators	Ohio State University	US: Ohio				x					x	x	focal plants: <i>Cucumis sativus</i> , <i>Solanum lycopersicum</i> , <i>Capsicum annuum</i> , <i>Helianthus annuus</i>	form	https://u.osu.edu/pollinationinvestigators/experiment/	(Kleinke et al., 2018) https://doi.org/10.5334/cstp.99	
Bees 'n Beans	University of Sussex	US: Sussex				x					x	x	focal plant: <i>Vicia faba</i>	online form	https://www.ljbees.org.uk/	(Birkin & Goulson, 2015) https://doi.org/10.1111/een.12222	

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APPENDIX

A1.2. Outreach

A1.2.1. Project website and iNaturalist project site

A1.2.2. Flyer

A1.2.3. Online forms on the project website

A1.2.4. Announcements of guided talks and walks

A1.2.5. Information boards accompanying stepping-stone flower patches

A1.2.6. Publications in local media

A1.2.1. Project website and iNaturalist project site

Project website: <https://www.lss.lss.tum.de/biodiv/projekte/urban-pollinators-wildbienen-in-freising-1/>

Professur für Biodiversität der Pflanzen
TUM School of Life Sciences
Technische Universität München

Startseite

Team

Forschung

Projekte

Urban Pollinators - Wildbienen in Freising

Mitmach-Aktion

Blühflächen

Hintergrundinformationen

Aktuelles und Veranstaltungen

Ressourcen

Kontakt

Lehre

Publikationen

Herbarium

Jobs

Startseite

Projekte

Urban Pollinators - Wildbienen in Freising

Urban Pollinators - Wildbienen in Freising

Holzbiene an Bohnenblüte
(J. Weissmann)

Maskenbiene an Färber-Kamille
(J. Weissmann, Freising)

Sandbiene an Brombeerblüte
(J. Weissmann, Freising)

Neben der Honigbiene besucht eine Vielfalt an Wildbienen die Blüten unserer Gartenpflanzen. Hier findet man eine große Diversität an Formen und Lebensweisen: von ameisenartigen Maskenbienen bis hin zu 3 cm großen Holzbienen; von roten, gelben, schwarzen, bis hin zu grün oder golden gefärbten Arten; von tief brummenden Hummeln bis zum auffällig hohen Flugton hektisch fliegender Pelzbienen. Bei den meisten Wildbienen zieht das Weibchen die Brut alleine in selbstgegrabenen Erdnestern, in Pflanzenstängeln, Schneckenhäusern oder Mauerritzen auf. Manche Arten sind auf den Pollen und Nektar einer ganz spezifischen Pflanze angewiesen, andere wiederum können Blüten diverser Pflanzenarten besuchen.

Der Erhalt dieser Vielfalt ist für unsere Pflanzenwelt von großer Bedeutung: Hummeln und Pelzbienen gelangen mit ihrem besonders langen Rüssel an den Blütengrund des Salbeis, kurzrüsselige Seidenbienen wiederum an Pollen und Nektar der Kamille. Blattschneiderbienen sind kräftig genug um Erbsenblüten zu öffnen, Hummeln wiederum können den Pollen aus Tomatenblüten heraus-schütteln. Mauerbienen können auch während Schlechtwetterperioden fliegen, Holzbienen wiederum während Hitzeperioden fliegen. Die Bestäubung vieler Pflanzen gewährleisten. Einige Sandbienen fliegen schon ab März zur Kornelkirschblüte, während die Efeu-Seidenbiene für die Efeublüte bis in den Oktober hinein bedeutsam ist.

Diese Vielfalt ist stark bedroht: von den 585 in Deutschland heimischen Wildbienenarten ist laut Roter Liste 3/5 mehr als die Hälfte gefährdet. Sie sind angewiesen auf das Vorhandensein von Nistplätzen, Nistmaterialien und Nahrungsquellen in Form von Pollen und Nektar innerhalb ihres Flugradius von nur wenigen 100 Metern. Dementsprechend wirken sich die Monotonie und zeitlich begrenzte Verfügbarkeit des Blütenangebots, der Mangel an Nistmöglichkeiten und der Einsatz von Pestiziden in vielen von großen Monokulturen geprägten Agrarlandschaften besonders negativ aus.

Städte wie Freising bieten gute Ausgangsbedingungen für die Förderung von Wildbienen: Hier herrscht ein relativ warmes Mikroklima, oftmals besteht auf kleinem Raum eine Vielfalt an Strukturen, sowie ein durchgehendes und vielfältiges Blütenangebot.

Das Projekt "Städtische Bestäuber - Wildbienen in Freising" widmet sich ab März 2018 der Untersuchung von Bestäubungsvorgängen in Freisinger Gärten unter Einbeziehung der Bevölkerung. Freising ist besonders geeignet für die Wildbienenforschung, weil hier auf engem Raum städtische Elemente, naturnahe Bereiche wie die Isarauen, und von landwirtschaftlicher Nutzung geprägte Flächen wie innerstädtische Streuobstwiesen und eine Vielfalt an Gemeinschafts-, Klein- und Privatgärten zusammentreffen. Die Größe der Stadt ermöglicht es dabei, eine vergleichende Sicht auf diese Habitate mit einer ganzheitlichen Perspektive auf das Stadtgefüge zu verbinden. Die hohe Dichte an gärtnerisch genutzten Flächen fördert ein integriertes Erforschen von Wildbienenenddiversität und Bestäubungssicherheit im städtischen Raum.

Professur für Biodiversität der Pflanzen

Prof. Dr. Hanno Schäfer
Emil-Ramann-Strasse 2
85354 Freising
Tel: +49 8161 71 5884
E-Mail

Meldungen

Beobachtungen von Wildbienen in Freising, die mit Foto dokumentiert sind, können Sie auf der iNaturalist Web-seite hochladen. Dort gibt es ein spezielles Projekt für die Freisinger Bienen

Publikation: Feld-Bestimmungshilfe für die Wildbienen Bayerns

Die Bestimmungshilfe konzentriert sich auf die meist besser zu beobachtenden Weibchen und soll den Einstieg in die Artenkenntnis über die Wildbienen erleichtern.

Das Heft enthält einen Bestimmungsschlüssel für alle in Bayern vorkommenden Gattungen und kurze Beschreibungen der wichtigsten Merkmale für die einzelnen, nach Gruppen geordneten Arten. Die Mehrzahl der 93 Farbfotografen wurde in Freising

Project Site on iNaturalist: <https://www.inaturalist.org/projects/wildbienen-in-freising-urban-pollinators-bees-in-freising>

iNaturalist

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Wildbienen in Freising - urban pollinators: bees in Freis...

Project Journal

Overview

4,533 OBSERVATIONS

147 SPECIES

207 IDENTIFIERS

294 OBSERVERS

Stats

Recent Observations

View All

Common Carder

Furrow Bees

Yellow-legged Mining

European Orchard Bee

Most Observations

Most Species

Most Observed Species

Appendix A1.2. Page 1

A1.2.3. Online forms on the project website

30/03/2024, 18:41

Urban Pollinators - Wildbienen in Freising: Meldungen

Wildbienenmonitoring - Meldungen

Alternativ zu dem Formular können Sie uns auch gerne einfach formlos eine Email senden oder uns telefonisch [kontaktieren](#).

Formular zur Meldung von Wildbienen-sichtungen (ab 20.05.2019)

Wildbienenmonitoring - Meldungen (ab 20.05.2019)

Bienenart
Bitte wählen Sie aus ... ▾

Fundort (Adresse, GPS-Koordinaten oder Google-maps Link)

Datum
dd . mm . yyyy

Uhrzeit

Verhalten
Bitte wählen Sie aus ... ▾

Anmerkungen (ggf. können Sie hier optional die Pflanzengattung o. -art (Bildupload auch möglich), bzw. den Nistplatztyp (z.B.: Totholz, Vogelnistkasten, Gemäuer, Fensterrahmen, offener Boden an Straßenböschung, Pflanzenstängel, Nisthilfe, etc.) angeben)

Name, Vorname*

E-Mail Adresse*

Foto-Upload
 No file chosen

Spamschutz, bitte geben Sie das Ergebnis der folgenden Aufgabe ein.*



30/03/2024, 18:42

Urban Pollinators - Wildbienen in Freising: Meldungen

Bestäubungsbeobachtungen - Meldungen

Alternativ zu dem Formular können Sie uns auch gerne einfach formlos eine Email senden oder uns telefonisch [kontaktieren](#).

Formular zur Meldung von Bestäubungsbeobachtungen (ab 20.05.2019)

Bestäubungsbeobachtungen - Meldungen (ab 20.05.2019)

Pflanzenart
Bitte wählen Sie aus ... ▾

Fundort (Adresse, GPS-Koordinaten oder Google-maps Link)

Datum
dd . mm . yyyy

Uhrzeit (Beginn des 10-minütigen Beobachtungszeitraums)

Ich habe während des Beobachtungszeitraums an den Blüten der ausgewählten Pflanze folgende Bienengruppen beobachtet:

☐ Honigbiene(n)
☐ Hummel(n)
☐ Mittelgroße bis große Wildbiene(n)
☐ Kleine Wildbiene(n)
☐ Weitere (Fliege, Wespe, Käfer)

Anmerkungen (falls Sie innerhalb der 4 Bienengruppen unterschiedliche Arten beobachtet haben, können Sie dies hier ergänzen, z.B. "mittelgroße bis große Wildbienen: 4 verschiedene Arten, darunter 1 Holzbiene und 1 Mauerbiene)

Temperatur (optional)
Bitte wählen Sie aus ... ▾

Name, Vorname*

E-Mail Adresse*

Foto-Upload
 No file chosen

Spamschutz, bitte geben Sie das Ergebnis der folgenden Aufgabe ein.*



Announcements on the project website

[illegible]



Freising

Die Feilsche
Vogel des Jahres 2019

STAMMTISCH MIT VORTRAG

Wir treffen uns in der Regel jeden ersten oder zweiten Mittwoch im Monat um 19.30 Uhr zum Stammtisch im Hotel zur Grotz in Freising. Dort werden Neugkeiten ausseren gegenseitig, es gibt Fingerhelfer und um den Naturschutz und M6glichkeit zum Austausch unter Gleichgesinnten. Die Veranstaltung ist frei und f6rderung, wir freuen uns jedoch 6ber Spenden.

09.01.19 **Mitbestimmung Scherenschneiderei**
Prof. Dr. Volker Zahner, HSBT Freising

04.02.19 **Wildbienen im Freising**
Aktuelles von der Wildbienen-Aktion
Julie Weissmann, TUM M6nchengladbach

04.03.19 **gelbeschnabelschwarzst6rche**
Die Feilsche - Vogel des Jahres 2019
Marcel Sch6nke, LBV Freising

04.04.19 **Die Adler der Welt - Vorf6h, 6berz6ge, Schutz**
Marcel Sch6nke, LBV Garmisch

05.05.19 **Neues aus dem 6stlichen Landkreis**
der Freisinger See
Dr. Christian Leggert, LBV Freising

04.06.19 **Externe Medien**
Freisinger Medien
Dr. Martin D6rner, HSBT Freising



Knollen & Co
Gemeinschaftsg6rten und mehr...

Stammtisch 6ber uns G6rten Fotos Freunde und Interessierten Mitmachen Diagramm



Wildbienen in Freising - ein Vortrag von Julie Weissmann
Freitag, 10. Januar 2019, 19.30 Uhr
TUM M6nchengladbach | 10. Februar 2019, 19.30 Uhr

Leide Naturfreunde
In Freising gibt es zahlreiche Wildbienenarten: die gelbe Wildbiene, Blauschwarze Wildbiene, F6rtr6ge Wildbiene, G6rtner Wildbiene, F6rtr6ge G6rtnerbiene, K6nigsbiene und die Blauschwarze, die sch6nster durch unsere G6rten und nat6rlichen Natur erleben k6nnen. Wie werden sie best6tigt und wie k6nnen wir ihnen helfen? Wir besprechen aktuelle Zahlen zusammen mit der TUM M6nchen in Freising. Dabei werden wir um 19.30 Uhr eine Vorlesung 6ber Wildbienen-Themen halten. Da sich alle Mitglieder und Wildbienen-Freunde eingeladen um 19.30 Uhr zum Stammtisch (in Freising) werden wir kommen!

Einladung Dr6rler

Situation in Freising

Vortrag 6ber Wildbienen

9. januar 2018, 22:02 Uhr



Der Landesbund f6r Vogelschutz, Kreisgruppe Freising, l6dt an diesem Mittwoch, 10. Januar, um 19.30 Uhr zum n6chsten Treffen ins Hotel "Zur Grotz" (Bahnhofstrasse 8) ein. Im Mittelpunkt steht der Vortrag von Julie Weissmann, TUM M6nchen, 6ber "Wildbienen in Freising". Vor dem Vortrag werden Neugkeiten bekanntgegeben und besprochen. Die Veranstaltung ist 6ffentlich und kostenfrei. Nichtmitglieder sind willkommen.

Kratzdistel, BUND Naturschutz in Bayern e.V., Kreisgruppe Freising
Nr, 1/30, Frühjahr/Sommer/Herbst 2018

Nr. 1/31, Frühjahr/Sommer/Herbst

[illegible]

A1.2.5. Information boards accompanying stepping-stone flower patches

Map with sites on: <https://www.lss.ls.tum.de/biodiv/projekte/urban-pollinators-wildbienen-in-freising-1/bluehflaechen/>



Reseden-Maskenbiene (*Hylaeus signatus*)

Kennzeichen:
Die Maskenbienen haben helle Gesichtsflecken, wovon sich der deutsche Gattungsname ableitet. Die Reseden-Maskenbienen werden 7 – 9 mm groß, sind dunkel gefärbt und kaum behaart. Die Weibchen haben glasklare Flügel und zwei weiße Gesichtsflecken, die weiße Gesichtsmarkierung der Männchen bedeckt das ganze Gesicht.

Verbreitung und Lebensweise:
Die Biene ist weit verbreitet und sehr häufig. Sie lebt auf Ruderal- und Brachflächen, an Hochwasserlärmern, in Sand- und Lehmgruben und an Wegrändern. Sie nistet in vorhandenen Hohlräumen, wie Käferfahrgängen in Totholz, in Mauerfugen, in hohlen Pflanzenstängeln und in verlassenen Nestern anderer Bienen.

Blütenbesuch:
Die Reseden-Maskenbiene ist eine streng auf Reseda spezialisierte Art. Die Pflanzen dieser Gattung dienen nicht nur zum Sammeln von Pollen, sondern sind für beide Geschlechter auch eine bevorzugte Nektarquelle. Maskenbienen haben keine Sammelhaare, sondern speichern den Pollen im Kropf. Die Flugzeit der Biene ist von Mai bis September.

Als Pollenquelle dient hier die Wilde Resede (*Reseda lutea*), die Biene geht aber auch an die Färber-Resede (*Reseda luteola*). Beide gehören zur Familie der Resedaceae.

Ein Männchen der Reseden-Maskenbiene auf der wilden Resede

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Glockenblumen-Scherenbiene (*Chelostoma rapunculi*)

Kennzeichen:
Die Glockenblumen-Scherenbiene ist eine ca. 9 mm große, schwarze Biene mit langgestrecktem, spärlich behaartem Körper. Die Weibchen haben mächtige, scherenartige Oberkiefer, woher der Name dieser Gattung stammt. Sehr ähnlich ist die etwas kleinere Kurzfransige Scherenbiene, die jedoch im Gegensatz zur Glockenblumen-Scherenbiene keine deutlichen Binden am Hinterleib hat.

Verbreitung und Lebensweise:
Die Biene ist weit verbreitet und häufig. Sie lebt solitär in Magerwiesen, Waldsäumen, Gärten und Parks. Ihre Nistplätze richtet sie in vorhandenen Hohlräumen, besonders in totem Holz ein.

Blütenbesuch:
Diese Scherenbienen sammeln ihren Pollen ausschließlich auf Glockenblumen (*Campanula*). Die Weibchen transportieren den Pollen in ihren Bauchbürsten zum Nest, wo er dann als Proviant für die Larven dient. Die Männchen patrouillieren über den Glockenblumen und schlafen zum Teil in den Blüten. Die Flugzeit ist von Juni bis August.

Belebte Pollenquellen sind Glockenblumengewächse. Bei Glockenblumen wird der Pollen von den Staubblättern auf Fegehaare am Griffel abgegeben und dort sekundär präsentiert. Erst nachdem der eigene Pollen aus der Blüte hinausgetragen wurde, kann fremder Pollen aufgenommen werden. Dieser Mechanismus fördert Fremdbestäubung.

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Natternkopf-Mauerbiene (*Osmia adunca*)

Kennzeichen:
Diese Biene gehört zur Gattung der Mauerbienen (*Osmia*). Sie ist 11-13 mm lang, mit einem fast kahlen Körper. Die Weibchen haben eine weiße Bauchbürste und einen glänzenden Hinterleib mit schmalen, hellen Binden. Sie sind leicht zu verwechseln mit der Matten Natternkopfbiene. Die Männchen haben am Hinterleibsende einen zahnartigen Fortsatz.

Verbreitung und Lebensweise:
Die Natternkopf-Mauerbiene ist eine weit verbreitete und häufige Art. Sie lebt solitär auf Trockenstandorten und Brachen. Im Winter überdauert sie als Ruhelarve im Kokon. Die Biene nistet in vorhandenen Hohlräumen, wie z.B. in Fraßgängen in altem Holz, hohlen Pflanzenstängeln, Nisthilfen oder in verlassenen Nestern anderer Bienen.

Blütenbesuch:
Diese Art ist auf die Pflanzengattung der Natternköpfe spezialisiert. Die Männchen patrouillieren über dem Blütenvorkommen, um paarungswillige Weibchen zu finden. Die Weibchen transportieren den gesammelten Pollen in Bauchbürsten. Durch Zugabe von Nektar dient der Pollen als Larvenproviant. Die Flugzeit ist von Juni bis Juli.

Die häufigste Pollen- und Nektarquelle im mitteleuropäischen Verbreitungsgebiet ist der Gewöhnliche Natternkopf (*Echium vulgare*), der zur Familie der Raublattgewächse gehört. Die leicht geöffneten, noch rosafarbenen Blüten bieten am meisten Nektar. Später färben sich die Blüten lila. Die Blütezeit ist von Mai bis September.

Die Natternkopf-Mauerbiene im Anflug auf den Gewöhnlichen Natternkopf

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Schenkelbienen (*Macropis*)

Kennzeichen:
Die Schenkelbienen sind 9 - 10 mm groß, kaum behaart und haben einen schwarzen Hinterleib mit weißen Haarbinden. Die Weibchen haben an den Hinterbeinen Saugpolster, um das von der Futterpflanze abgesonderte Öl zu sammeln und zu transportieren. Beim Sammeln strecken sie ihre Hinterbeine auffällig nach hinten in die Höhe. Die Männchen haben einen gelben Kopfschild und vertikale Hinterschenkel, woher auch der deutsche Gattungsname kommt.

Verbreitung und Lebensweise:
Die Auen-Schenkelbiene (*Macropis europaea*) ist häufiger als die Wald-Schenkelbiene (*Macropis fulvipes*). Die Schenkelbienen nisten in selbstgegrabenen Hohlräumen in der Erde, die sie mit wasserabweisendem Blumenöl auskleiden.

Blütenbesuch:
Sie sind spezialisiert auf Ölblumen der Gattung *Lysimachia* (Gilbweiderich). Die Weibchen transportieren Pollen und Öl an ihren Hinterbeinen in die Nester. Die Männchen patrouillieren über den Blütenständen, um paarungswillige Weibchen zu finden. Der Gilbweiderich liefert den Bienen anstatt Nektar Öl, zur Eigenversorgung mit Nektar müssen die erwachsenen Bienen andere Blütenpflanzen aufsuchen.

Als Öl- und Pollenquelle dient der Punkt-Gilbweiderich (*Lysimachia punctata*) und einige weitere Arten der Gattung *Lysimachia*. Der Punkt-Gilbweiderich blüht von Juni bis August.

Ein Schenkelbienenweibchen beim Pollensammeln auf dem Punkt-Gilbweiderich

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Garten-Wollbiene (*Anthidium manicatum*)

Kennzeichen:
Die Weibchen der Garten-Wollbiene sind etwas kleiner als die Männchen, die 14 - 18 mm groß werden. Die Männchen haben drei Seitendornen am Hinterleib. Die Weibchen haben eine auffällige schwarz-gelbe Zeichnung und gelbe Bauchbürsten. Außerdem ist diese Art an einem hohen Flug und einem heftigen, schwebeliegenden Flug zu erkennen. Man kann sie gut beim Abschaben von Pflanzenhaaren an Blättern des Wolligen Ziest oder der Königskeuze beobachten.

Verbreitung und Lebensweise:
Die Garten-Wollbiene ist die häufigste Art der Gattung der Wollbienen und ist weit verbreitet. Sie lebt in Gärten, Parks und auf Trockenstandorten. Die Biene nistet in vorhandenen Hohlräumen verschiedenster Art. Die Brutzellen werden mit abgeschabten Pflanzenhaaren ausgekleidet und mit Drüsensekret von Pflanzen imprägniert, die die Weibchen an Haarflecken an den Vorderbeinen sammeln. Das Nest wird durch Erdrückern, Steinen, Pflanzenteile und einem Wollpfropf verschlossen.

Blütenbesuch:
Die Garten-Wollbiene sammelt den Pollen mit ihrer Bauchbürste auf Schmetterlingsblütlern (*Fabaceae*), Braunwurzgewächsen (*Scrophulariaceae*) und Lippenblütlern (*Lamiaceae*). Die Weibchen sammeln Pollen an verschiedenen Pflanzen der drei Familien. Die Männchen wählen ihr Territorium nach den Nektar- und Pollenquellen der Weibchen aus. Die Flugzeit dauert von Juni bis August.

Als Pollenquelle dienen hier Zieste aus der Familie der Lippenblütler, wie der Woll-Ziest (*Stachys byzantina*). Diese Pflanze blüht von Juni bis Juli. Ihre behaarten Blätter werden von der Wollbiene abgeschabt und die Pflanzenhaare zum Auskleiden der Nester verwendet.

Die Garten-Wollbiene schabt Pflanzenhaare von Blättern des Woll-Ziest ab

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Blutweiderich-Sägehornbiene (*Melitta nigricans*)

Kennzeichen:
Die Blutweiderich-Sägehornbiene wird 10 - 12 mm groß und hat schmale, weiße Hinterleibsbinden. Die Männchen haben auffällig lange, gesägte Fühler, die Weibchen sind am Rücken dunkel behaart.

Verbreitung und Lebensweise:
Die Biene ist in Deutschland weit verbreitet und kommt häufig vor. Sie lebt in unterschiedlichen Feuchtgebieten, an Fließgewässern und Auwiesen, wenn es dort einen ausreichend großen Bestand an Blutweiderich gibt. Als Nester dienen den Bienen selbstgegrabene Hohlräume in der Erde.

Blütenbesuch:
Wie der Name bereits vermuten lässt, ist die Blutweiderich-Sägehornbiene eine auf Blutweiderich spezialisierte Art. Die Weibchen sammeln den Pollen mit ihren Beinbürsten und befeuchten ihn mit Nektar. Die Männchen patrouillieren oftmals in großer Zahl an den Blüten, da der Blutweiderich beiden Geschlechtern als Nektarquelle dient. Die Bienen fliegen von Juli bis August.

Die Hauptpollenquelle in Mitteleuropa ist der Gewöhnliche Blutweiderich (*Lythrum salicaria*). Diese Art hat unterschiedliche Blütentypen ausgebildet, sodass es Blüten mit kurzem Griffel und langen Staubblättern, und Blüten mit langem Griffel und kurzen Staubblättern gibt. Dieses Phänomen nennt man Heterostylie und es dient dazu, Fremdbestäubung zu fördern. Jede Pflanze besitzt je einen Blütentyp. Der gewöhnliche Blutweiderich blüht von Juli bis September.

Die Blutweiderich-Sägehornbiene auf dem Gewöhnlichen Blutweiderich

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Plattierbier-Mörlbiene (*Megachile ericetorum*)

Kennzeichen:
Die Plattierbier-Mörlbiene gehört zur Gattung der Plattierbierbienen (Megachilidae). Sie wird 12 - 15 mm groß und hat glatte Flügel. Die Weibchen haben eine auffällige schwarz-gelbe Zeichnung und gelbe Bauchbürsten. Die Biene nistet in vorhandenen Hohlräumen in Totholz, Steinblöcken und in verlassenen Nestern anderer Bienen.

Verbreitung und Lebensweise:
Die Plattierbier-Mörlbiene ist eine weit verbreitete und häufige Art. Sie lebt solitär auf Trockenstandorten und Brachen. Im Winter überdauert sie als Ruhelarve im Kokon. Die Biene nistet in vorhandenen Hohlräumen, wie z.B. in Fraßgängen in altem Holz, hohlen Pflanzenstängeln, Nisthilfen oder in verlassenen Nestern anderer Bienen.

Blütenbesuch:
Diese Art ist auf Blüten der Gattung der Farnblütler (*Fabaceae*) spezialisiert. Die Weibchen transportieren den gesammelten Pollen in Bauchbürsten. Durch Zugabe von Nektar dient der Pollen als Larvenproviant. Die Flugzeit ist von Juni bis Juli.

Als Pollenquelle dienen hier die Farnblütler (*Fabaceae*), wie die Farnblütler (*Fabaceae*). Diese Pflanze blüht von Juni bis Juli. Ihre behaarten Blätter werden von der Wollbiene abgeschabt und die Pflanzenhaare zum Auskleiden der Nester verwendet.

Die Plattierbier-Mörlbiene auf der Farnblütler (*Fabaceae*)

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Krautwaben-Sandbiene (*Andrena hortorum*)

Kennzeichen:
Die Krautwaben-Sandbiene wird 14 - 15 mm groß. Die Weibchen haben eine auffällige schwarz-gelbe Zeichnung und gelbe Bauchbürsten. Die Biene nistet in vorhandenen Hohlräumen in Totholz, Steinblöcken und in verlassenen Nestern anderer Bienen.

Verbreitung und Lebensweise:
Die Krautwaben-Sandbiene ist eine weit verbreitete und häufige Art. Sie lebt solitär auf Trockenstandorten und Brachen. Im Winter überdauert sie als Ruhelarve im Kokon. Die Biene nistet in vorhandenen Hohlräumen, wie z.B. in Fraßgängen in altem Holz, hohlen Pflanzenstängeln, Nisthilfen oder in verlassenen Nestern anderer Bienen.

Blütenbesuch:
Diese Art ist auf Blüten der Gattung der Farnblütler (*Fabaceae*) spezialisiert. Die Weibchen transportieren den gesammelten Pollen in Bauchbürsten. Durch Zugabe von Nektar dient der Pollen als Larvenproviant. Die Flugzeit ist von Juni bis Juli.

Als Pollenquelle dienen hier die Farnblütler (*Fabaceae*), wie die Farnblütler (*Fabaceae*). Diese Pflanze blüht von Juni bis Juli. Ihre behaarten Blätter werden von der Wollbiene abgeschabt und die Pflanzenhaare zum Auskleiden der Nester verwendet.

Die Krautwaben-Sandbiene auf der Farnblütler (*Fabaceae*)

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Wegwarten-Hosenbiene (*Desmopoda hirtipes*)

Kennzeichen:
Die Wegwarten-Hosenbiene wird 12 - 15 mm groß. Die Weibchen haben eine auffällige schwarz-gelbe Zeichnung und gelbe Bauchbürsten. Die Biene nistet in vorhandenen Hohlräumen in Totholz, Steinblöcken und in verlassenen Nestern anderer Bienen.

Verbreitung und Lebensweise:
Die Wegwarten-Hosenbiene ist eine weit verbreitete und häufige Art. Sie lebt solitär auf Trockenstandorten und Brachen. Im Winter überdauert sie als Ruhelarve im Kokon. Die Biene nistet in vorhandenen Hohlräumen, wie z.B. in Fraßgängen in altem Holz, hohlen Pflanzenstängeln, Nisthilfen oder in verlassenen Nestern anderer Bienen.

Blütenbesuch:
Diese Art ist auf Blüten der Gattung der Farnblütler (*Fabaceae*) spezialisiert. Die Weibchen transportieren den gesammelten Pollen in Bauchbürsten. Durch Zugabe von Nektar dient der Pollen als Larvenproviant. Die Flugzeit ist von Juni bis Juli.

Als Pollenquelle dienen hier die Farnblütler (*Fabaceae*), wie die Farnblütler (*Fabaceae*). Diese Pflanze blüht von Juni bis Juli. Ihre behaarten Blätter werden von der Wollbiene abgeschabt und die Pflanzenhaare zum Auskleiden der Nester verwendet.

Die Wegwarten-Hosenbiene auf der Farnblütler (*Fabaceae*)

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Schötcher-Mauerbiene (*Osmia brevicornis*)

Kennzeichen:
Die Schötcher-Mauerbiene ist eine kleine Biene, die 8 - 10 mm groß ist. Sie hat einen kahlen Körper und eine auffällige schwarz-gelbe Zeichnung. Die Weibchen haben eine weiße Bauchbürste und einen glänzenden Hinterleib mit schmalen, hellen Binden. Sie sind leicht zu verwechseln mit der Matten Natternkopfbiene. Die Männchen haben am Hinterleibsende einen zahnartigen Fortsatz.

Verbreitung und Lebensweise:
Die Schötcher-Mauerbiene ist eine weit verbreitete und häufige Art. Sie lebt solitär auf Trockenstandorten und Brachen. Im Winter überdauert sie als Ruhelarve im Kokon. Die Biene nistet in vorhandenen Hohlräumen, wie z.B. in Fraßgängen in altem Holz, hohlen Pflanzenstängeln, Nisthilfen oder in verlassenen Nestern anderer Bienen.

Blütenbesuch:
Diese Art ist auf Blüten der Gattung der Farnblütler (*Fabaceae*) spezialisiert. Die Weibchen transportieren den gesammelten Pollen in Bauchbürsten. Durch Zugabe von Nektar dient der Pollen als Larvenproviant. Die Flugzeit ist von Juni bis Juli.

Als Pollenquelle dienen hier die Farnblütler (*Fabaceae*), wie die Farnblütler (*Fabaceae*). Diese Pflanze blüht von Juni bis Juli. Ihre behaarten Blätter werden von der Wollbiene abgeschabt und die Pflanzenhaare zum Auskleiden der Nester verwendet.

Die Schötcher-Mauerbiene auf der Farnblütler (*Fabaceae*)

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A1.2.6. Publications in local media

Praun, N. (2020, September 7). Die Artenkenner: Die Spätfliegerin. *Münchner Merkur*.

Regelein, G. (2020, September 1). Wildbienen sind gefährdet. *Süddeutsche Zeitung*, p. Freising Seite R5.

Blühende Landschaften. Stadt fördert Projekte zum Erhalt der Artenvielfalt. (2020, July). *fink Das Freisinger Stadtmagazin*, pp. 30-31.

Auf der Suche nach summenden Schätzen. (2020, May 25). *Freisinger Tagblatt*, Nr. 119, p. 3.

Baumeister, K. (2020, May 23). Städte können zum Artenschutz beitragen. *Moosburger Zeitung*.

Schnirch, P. (2018, March 15). Die Wildbiene retten. *Süddeutsche Zeitung*, p. Freising Seite R7.

APPENDIX

A1.3. Extended list of the wild bee taxa recorded in Freising with links to photo-vouchers on iNaturalist, information on Red List Status (Bavaria), notes on identification, and contributions by citizen scientists

taxon name, Red List Status and photo-voucher			occurrence			citizen science	notes on identification			
taxon name (Scheuchl et al., 2023)	Bavarian Red List category (Scheuchl et al., 2023)	species accounts on iNaturalist (Hyperlink)	Freising city	"Große Kreisstadt" Freising	administrative district of Freising (Landkreis)	discovered by citizen scientists only	ID to species level	ID to taxon group	ID not unequivocal ("cf.")	comments regarding species not identified unequivocally to species level
<i>Andrena aglissima</i> (SCOPOLI, 1770)	3	X	1				1			
<i>Andrena bicolor</i> FABRICIUS, 1775	*	X	1				1			
<i>Andrena carantonica</i> PÉREZ, 1902	*	X	1						1	cf. dark form of <i>Andrena trimmerana</i> ; nomenclatural issues (<i>Andrena trimmerana</i> / <i>A. scotica</i> / <i>A. carantonica</i>), see Scheuchl et al., 2023
<i>Andrena chrysosceles</i> (KIRBY, 1802)	*	X	1				1			
<i>Andrena cineraria</i> (LINNAEUS, 1758)	*	X	1				1			
<i>Andrena clarkella</i> (KIRBY, 1802)	*	X	1			1	1			
<i>Andrena curvungula</i> THOMSON, 1870	2	X	1			1	1			
<i>Andrena denticulata</i> (KIRBY, 1802)	V	X		1		1	1			
<i>Andrena dorsata</i> (KIRBY, 1802)	*	X	1					1		<i>Andrena dorsata</i> / <i>A. propinqua</i> / <i>A. congruens</i> / <i>A. confinis</i>
<i>Andrena flavipes</i> PANZER, 1799	*	X	1				1			
<i>Andrena fulva</i> (MÜLLER, 1766)	*	X	1				1			
<i>Andrena gravida</i> IMHOFF, 1832	*	X	1				1			
<i>Andrena haemorrhoa</i> (FABRICIUS, 1781)	*	X	1				1			
<i>Andrena hattorfiana</i> (FABRICIUS, 1775)	3	X	1				1			
<i>Andrena helvola</i> (LINNAEUS, 1758)	*	X	1				1			
<i>Andrena labiata</i> FABRICIUS, 1781	*	X	1				1			
<i>Andrena lagopus</i> LATREILLE, 1809	*	X		1		1	1			
<i>Andrena lathyri</i> ALFKEN, 1899	V	X	1				1			
<i>Andrena minutula</i> (KIRBY, 1802)	*	X	1					1		<i>Andrena minutula</i> / <i>A. minutuloides</i> / <i>A. falsifica</i> / <i>A. strohmella</i> / <i>A. subopaca</i> / <i>(A. alfkennella)</i> / <i>A. nana</i> / <i>A. semilaevis</i> / <i>A. floricola</i> / <i>A. niveata</i> / <i>A. pusilla</i> / <i>A. anthrisci</i> (Micrandrena)
<i>Andrena nigroaenea</i> (KIRBY, 1802)	*	X	1				1			
<i>Andrena nitida</i> (MÜLLER, 1776)	*	X	1				1			
<i>Andrena nitidiuscula</i> SCHENCK, 1853	3	X	1				1			photographs not sufficient for unequivocal identification
<i>Andrena ovatula</i> (KIRBY, 1802)	*	X	1					1		<i>Andrena ovatula</i> / <i>A. wilkella</i> / <i>A. similis</i> / <i>A. gelriae</i> (Taeniandrena excluding <i>Andrena lathyri</i>)
<i>Andrena praecox</i> (SCOPOLI, 1763)	*	X	1			1	1			
<i>Andrena proxima</i> (KIRBY, 1802)	*	X	1			1	1			
<i>Andrena tibialis</i> (KIRBY, 1802)	*	X	1						1	photographs not sufficient for unequivocal identification
<i>Andrena trimmerana</i> (KIRBY, 1802)	D	X	1			1			1	nomenclatural issues (<i>Andrena trimmerana</i> / <i>A. scotica</i> / <i>A. carantonica</i>), see Scheuchl et al., 2023
<i>Andrena vaga</i> PANZER, 1799	*	X	1				1			
<i>Andrena ventralis</i> IMHOFF, 1832	*	X	1			1	1			
<i>Andrena viridescens</i> VIERECK, 1916	V	X	1				1			
<i>Anthidium strigatum</i> (PANZER, 1805)	V	X	1				1			
<i>Anthidium manicatum</i> (LINNAEUS, 1758)	*	X	1				1			
<i>Anthidium oblongatum</i> (ILLIGER, 1806)	*	X	1				1			
<i>Anthidium punctatum</i> LATREILLE, 1809	*	X	1				1			
<i>Anthophora aestivalis</i> (PANZER, 1801)	3	X	1				1			
<i>Anthophora furcata</i> (PANZER, 1798)	V	X	1				1			
<i>Anthophora plumipes</i> (PALLAS, 1772)	*	X	1				1			
<i>Anthophora quadrimaculata</i> (PANZER, 1798)	3	X	1				1			
<i>Bombus barbutellus</i> (KIRBY, 1802)	*	X	1				1			
<i>Bombus bohemicus</i> SEIDL, 1838	*	X	1				1			
<i>Bombus campestris</i> (PANZER, 1801)	*	X	1				1			
<i>Bombus hortorum</i> (LINNAEUS, 1761)	*	X	1				1			
<i>Bombus humilis</i> ILLIGER, 1806	3	X	1				1			
<i>Bombus hypnorum</i> (LINNAEUS, 1758)	*	X	1				1			
<i>Bombus lapidarius</i> (LINNAEUS, 1758)	*	X	1				1			
<i>Bombus lucorum</i> (LINNAEUS, 1761)	*	X	1				1			
<i>Bombus pascuorum</i> (SCOPOLI, 1763)	*	X	1				1			
<i>Bombus pratorum</i> (LINNAEUS, 1761)	*	X	1				1			
<i>Bombus ruderarius</i> (MÜLLER, 1776)	3	X	1				1			
<i>Bombus rupestris</i> (FABRICIUS, 1793)	*	X	1				1			
<i>Bombus soroeensis</i> (FABRICIUS, 1776)	V	X	1				1			
<i>Bombus subterraneus</i> (LINNAEUS, 1758)	2	X	1				1			
<i>Bombus sylvarum</i> (LINNAEUS, 1761)	V	X	1				1			
<i>Bombus sylvestris</i> (LEPELETIER, 1832)	*	X	1					1		<i>Bombus sylvestris</i> / <i>B. norvegicus</i>
<i>Bombus terrestris</i> (LINNAEUS, 1758)	*	X	1				1			

taxon name, Red List Status and photo-voucher			occurrence			citizen science	notes on identification			
taxon name (Scheuchl et al., 2023)	Bavarian Red List category (Scheuchl et al., 2023)	species accounts on iNaturalist (Hyperlink)	Freising city	"Große Kreisstadt" Freising	administrative district of Freising (Landkreis)	discovered by citizen scientists only	ID to species level	ID to taxon group	ID not unequivocal ("cf.")	comments regarding species not identified unequivocally to species level
<i>Bombus vestalis</i> (GEOFFROY, 1785)	*	x	1				1			
<i>Ceratina cyanea</i> (KIRBY, 1802)	*	x	1				1			
<i>Chelostoma campanularum</i> (KIRBY, 1802)	*	x	1					1		<i>Chelostoma campanularum</i> /C. <i>distinctum</i> (Foveosmia)
<i>Chelostoma distinctum</i> (STÖCKHERT, 1929)	*	x								
<i>Chelostoma florisomne</i> (LINNAEUS, 1758)	*	x	1				1			
<i>Chelostoma rapunculi</i> (LEPELETIER, 1841)	*	x	1				1			
<i>Coelioxys afer</i> LEPELETIER, 1841	*	x	1			1	1			
<i>Coelioxys aurolimbatus</i> FÖRSTER, 1853	3	x	1				1			
<i>Coelioxys inermis</i> (KIRBY, 1802)	3	x	1						1	cf. <i>Coelioxys mandibularis</i> /C. <i>elongata</i>
<i>Coelioxys rufescens</i> LEPELETIER & SERVILLE, 1825	3	x	1						1	photographs not sufficient for unequivocal identification
<i>Colletes cunicularius</i> (LINNAEUS, 1761)	*	x	1				1			
<i>Colletes daviesanus</i> SMITH, 1846	*	x	1					1		<i>Colletes daviesanus</i> /C. <i>similis</i> /C. <i>fodiens</i>
<i>Colletes hederæ</i> SCHMIDT & WESTRICH, 1993	*	x	1				1			
<i>Colletes succinctus</i> (LINNAEUS, 1758)	3	x		1		1			1	difficult to separate from <i>Colletes hederæ</i> (Zenz et al., 2021) but flower visitation on <i>Calluna</i> spec. supports C. <i>succinctus</i> (Westrich, 2019)
<i>Dasypoda hirtipes</i> (FABRICIUS, 1793)	3	x	1				1			cf. <i>Dasypoda morawitzi</i>
<i>Epeoloides coecutiens</i> (FABRICIUS, 1775)	*	x	1			1	1			
<i>Epeolus variegatus</i> (LINNAEUS, 1758)	*	x	1				1			
<i>Eucera longicornis</i> (LINNAEUS, 1758)	V	x	1				1			
<i>Eucera nigrescens</i> PÉREZ, 1879	V	x	1				1			
<i>Halictus eurygnathus</i> BLÜTHGEN, 1930	*	x	1					1		<i>Halictus eurygnathus</i> /H. <i>simplex</i> /H. <i>langobardicus</i> (Monilapis)
<i>Halictus rubicundus</i> (CHRIST, 1791)	*	x	1				1			
<i>Halictus scabiosae</i> (ROSSI, 1790)	*	x	1				1			
<i>Halictus sexcinctus</i> (FABRICIUS, 1775)	V	x	1				1			
<i>Halictus subauratus</i> (ROSSI, 1792)	*	x	1				1			
<i>Halictus tumulorum</i> (LINNAEUS, 1758)	*	x	1					1		<i>Halictus tumulorum</i> /H. <i>confusus</i> /H. <i>leucaheneus</i> (Seladonia excluding <i>Halictus subauratus</i>)
<i>Heriades truncorum</i> (LINNAEUS, 1758)	*	x	1				1			cf. <i>Heriades crenulatus</i>
<i>Hoplitis adunca</i> (PANZER, 1798)	*	x	1				1			
<i>Hoplitis leucomelana</i> (KIRBY, 1802)	*	x	1				1			
<i>Hoplitis tridentata</i> (DUFOR & PERRIS, 1840)	*	x	1						1	photographs not sufficient for unequivocal identification
<i>Hylaeus communis</i> NYLANDER, 1852	*	x	1				1			
<i>Hylaeus confusus</i> NYLANDER, 1852	*	x	1						1	photographs not sufficient for unequivocal identification
<i>Hylaeus cornutus</i> CURTIS, 1831	*	x	1			1	1			
<i>Hylaeus difformis</i> (EVERSMANN, 1852)	*	x	1				1			
<i>Hylaeus dilatatus</i> (KIRBY, 1802)	*	x	1				1			
<i>Hylaeus hyalinatus</i> SMITH, 1842	*	x	1				1			
<i>Hylaeus nigrinus</i> (FABRICIUS, 1798)	*	x	1				1			
<i>Hylaeus punctatus</i> (BRÜLLÉ, 1832)	*	x	1			1	1			
<i>Hylaeus rinki</i> (GORSKI, 1852)	*	x	1						1	photographs not sufficient for unequivocal identification
<i>Hylaeus signatus</i> (PANZER, 1798)	*	x	1				1			
<i>Hylaeus sinuatus</i> (SCHENCK, 1853)	*	x	1				1			
<i>Hylaeus styriacus</i> FÖRSTER, 1871	*	x	1				1			
<i>Lasioglossum albipes</i> (FABRICIUS, 1781)	*	x	1					1		<i>Lasioglossum albipes</i> /L. <i>calceatum</i> (Sphecodogastra)
										<i>Lasioglossum fulvicorne</i> /L. <i>malachurum</i> /L. <i>pauillum</i> /L. <i>laticeps</i> /L. <i>subhirtum</i> /L. <i>lineare</i> /L. <i>truncatum</i> /L. <i>nigripes</i> /L. <i>subfulvicorne</i> /L. <i>fratellum</i> /L. <i>puncticolle</i> /L. <i>minutulum</i> /L. <i>interruptum</i> /L. <i>punctatissimum</i> /L. <i>angusticeps</i> /L. <i>tarsatum</i> /L. <i>intermedium</i> /L. <i>limbellum</i> /L. <i>quadrinotatum</i> /L. <i>pallens</i> /L. <i>minutissimus</i> /L. <i>lucidulum</i> /L. <i>brevicorne</i> /L. <i>sexstrigatum</i> /L. <i>monstrificum</i> /L. <i>setulosum</i> /L. <i>griseolum</i> /L. <i>glabriusculum</i> /L. <i>clypeare</i> /L. <i>buccale</i> /L. <i>pygmaeum</i> /L. <i>rufitarse</i> /L. <i>semilucens</i> /L. <i>quadrisignatum</i> /L. <i>villosulum</i> /L. <i>pauperatum</i> /L. <i>parvulum</i> /L. <i>nitidiusculum</i> /L. <i>bluethgeni</i> [Evylaeus (Ebmer)]; cf. Weissmann et al. (2022): <i>Lasioglossum</i> group D excluding <i>Lasioglossum albipes/calceatum</i>)
<i>Lasioglossum fulvicorne</i> (KIRBY, 1802)	*	x	1					1		
<i>Lasioglossum leucozonium</i> (SCHRANK, 1781)	*	x	1				1			
<i>Lasioglossum morio</i> (FABRICIUS, 1793)	*	x	1					1		<i>Lasioglossum morio</i> /L. <i>leucopus</i>
<i>Lasioglossum nitidulum</i> (FABRICIUS, 1804)	*	x	1					1		<i>Lasioglossum nitidulum</i> /L. <i>smeathmanellum</i> /L. <i>aeratum</i> /L. <i>lissonotum</i>)

taxon name, Red List Status and photo-voucher			occurrence			citizen science	notes on identification			
taxon name (Scheuchl et al., 2023)	Bavarian Red List category (Scheuchl et al., 2023)	species accounts on iNaturalist (Hyperlink)	Freising city	"Große Kreisstadt" Freising	administrative district of Freising (Landkreis)	discovered by citizen scientists only	ID to species level	ID to taxon group	ID not unequivocal ("cf.")	comments regarding species not identified unequivocally to species level
<i>Lasioglossum politum</i> (SCHENCK, 1853)	*	X	1				1			
<i>Lasioglossum zonulum</i> (SMITH, 1848)	*	X	1				1			
<i>Macropis europaea</i> WARNCKE, 1973	*	X	1				1			
<i>Macropis fulvipes</i> (FABRICIUS, 1804)	*	X	1				1			
<i>Megachile argentata</i> (FABRICIUS, 1793)	*	X	1					1		<i>Megachile pilidens</i> /M. <i>leachella</i> (Eutricharaea) (M. <i>leachella</i> requires sandy soil)
<i>Megachile centuncularis</i> (LINNAEUS, 1758)	V	X	1				1			
<i>Megachile ericetorum</i> LEPELETIER, 1841	*	X	1				1			
<i>Megachile lapponica</i> THOMSON, 1872	*	X	1						1	photographs not sufficient for unequivocal identification, cf. <i>Megachile centuncularis</i>
<i>Megachile nigriventris</i> SCHENCK, 1868	*	X	1				1			
<i>Megachile rotundata</i> (FABRICIUS, 1787)	*	X	1				1			
<i>Megachile versicolor</i> SMITH, 1844	*	X	1				1			
<i>Megachile willughbiella</i> (KIRBY, 1802)	*	X	1				1			
<i>Melecta albifrons</i> (FORSTER, 1771)	V	X	1				1			
<i>Melitta haemorrhoidalis</i> (FABRICIUS, 1775)	*	X	1				1			
<i>Melitta leporina</i> (PANZER, 1799)	V	X	1			1	1			
<i>Melitta nigricans</i> ALFKEN, 1905	V	X	1				1			
<i>Melitta tricolor</i> KIRBY, 1802	3	X			1	1	1			
<i>Nomada bifasciata</i> OLIVIER, 1811	*	X	1				1			
<i>Nomada fabriciana</i> (LINNAEUS, 1767)	*	X	1				1			
<i>Nomada flava</i> PANZER, 1798	*	X	1					1		<i>Nomada flava</i> /N. <i>panzeri</i> /N. <i>ruficornis</i>
<i>Nomada flavoguttata</i> (KIRBY 1802)	*	X	1					1		<i>Nomada flavoguttata</i> /N. <i>castellana</i> /N. <i>conjungens</i>
<i>Nomada flavopicta</i> (KIRBY 1802)	*	X	1			1	1			
<i>Nomada fucata</i> PANZER, 1798	*	X	1				1			
<i>Nomada fulvicornis</i> FABRICIUS, 1793	*	X	?						?	photographs not sufficient for unequivocal identification
<i>Nomada goodeniana</i> (KIRBY 1802)	*	X	1				1			supported by host <i>Andrena cineraria</i>
<i>Nomada lathburiana</i> (KIRBY, 1802)	*	X	1				1			supported by host <i>Andrena vaga</i>
<i>Nomada marshalli</i> (KIRBY, 1802)	*	X	1				1			
<i>Nomada rufipes</i> FABRICIUS, 1793	3	X		1		1			1	atypical characters
<i>Nomada sexfasciata</i> PANZER, 1799	V	X	1				1			supported by host <i>Eucera longicornis</i>
<i>Nomada sheppardana</i> (KIRBY 1802)	*	X	1					1		<i>Nomada sheppardana</i> /N. <i>minuscule</i> /N. <i>atroscutellaris</i> /N. <i>argentata</i> /N. <i>similis</i> /N. <i>stigma</i> /N. <i>femorals</i> /N. <i>integra</i> /N. <i>kohli</i> /N. <i>pleurostincta</i> /N. <i>distinguenda</i> /N. <i>facilis</i>
<i>Nomada signata</i> JURINE, 1807	*	X	1				1			
<i>Nomada striata</i> FABRICIUS, 1793	*	X	1				1			
<i>Nomada succincta</i> PANZER, 1798	*	X	1						1	photographs not sufficient for unequivocal identification
<i>Osmia aurlenta</i> (PANZER, 1799)	*	X	1				1			
<i>Osmia bicolor</i> (SCHRANK, 1781)	*	X	1				1			
<i>Osmia bicornis</i> (LINNAEUS, 1758)	*	X	1				1			
<i>Osmia brevicornis</i> (FABRICIUS, 1798)	3	X	?						?	photographs not sufficient for unequivocal identification
<i>Osmia caerulea</i> (LINNAEUS, 1758)	*	X	1				1			
<i>Osmia cornuta</i> (LATREILLE, 1805)	*	X	1				1			
<i>Osmia niveata</i> (FABRICIUS, 1804)	3	X	1					1		<i>Osmia niveata</i> /O. <i>leaiana</i> /O. <i>labialis</i>
<i>Osmia spinulosa</i> (KIRBY, 1802)	V	X	1			1	1			
<i>Panurgus calcaratus</i> (SCOPOLI, 1763)	V	X	1				1			
<i>Pseudoanthidium nanum</i> (MOCSÁRY, 1881)	3	X	1			1	1			
<i>Rophites hartmanni</i> FRIESE, 1902	•	X		1		1			1	<i>Rophites hartmanni</i> /R. <i>quinquespinosus</i>
<i>Sphecodes albilabris</i> (FABRICIUS, 1793)	*	X	1				1			
<i>Sphecodes monilicornis</i> (KIRBY, 1802)	*	X	1						1	photographs not sufficient for unequivocal identification
<i>Sphecodes</i> spp.	N.A.	X	1					1		most <i>Sphecodes</i> spp. difficult to identify even on good pictures
<i>Stelis minima</i> SCHENCK, 1861	D	X	1						1	photographs not sufficient for unequivocal identification
<i>Stelis ornatula</i> (KLUG, 1807)	*	X	1				1			
<i>Stelis punctulatis</i> (KIRBY, 1802)	*	X	1				1			
<i>Trachusa byssina</i> (PANZER, 1798)	3	X	1			1	1			
<i>Xylocopa violacea</i> (LINNAEUS, 1758)	*	X	1				1			cf. <i>Xylocopa valga</i>
SUM			144	5	1	21	117	18	15	

Last update of hyperlinks: 15.08.2024

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Red List Categories:

- *: Least concern ("Ungefährdet")
- V: Near threatened ("Vorwarnliste")
- 3: Vulnerable ("Gefährdet")
- 2: Endangered ("Stark gefährdet")
- D: Data deficient ("Daten unzureichend")

Definition of Geographical limits:

Freising city: Taxon found in the city of Freising [according to the geographical limits defined by: https://www.freising.de/media/user_upload/61_Stadtplanung_Umwelt/6110_pdf-Files/STEP/stadtteilsteckbrief-weihenstephan.pdf (18.01.2025)]

"Große Kreisstadt Freising": Taxon found outside of the city of Freising as defined above, but within the "Große Kreisstadt Freising" [geographical limits: <https://v.bayern.de/5Nvk8> (18.01.2025)]

Administrative district of Freising ("Landkreis Freising"): Taxon found outside of the city of Freising and outside of the "Große Kreisstadt Freising", but within the administrative district of Freising [geographical limits: <https://v.bayern.de/G3PHK> (18.01.2025); this corresponds to the geographical limits of the iNaturalist Project: <https://www.inaturalist.org/projects/wildbienen-in-freising-urban-pollinators-bees-in-freising>]

APPENDIX

A2 Publication List

Peer-reviewed journal publications

- Weissmann, J. A.**, Rader, S., Ritz, R., Walldorf, I. R. M., Probst, J., Szydlík, K. R., & Schaefer, H. (2023). Holistic wild bee management in urban spaces. *Frontiers in Sustainable Cities*, 5, 1155714. <https://doi.org/10.3389/frsc.2023.1155714>
- Weissmann, J. A.**, Walldorf, I. R. M., & Schaefer, H. (2021). The importance of wild bee communities as urban pollinators and the influence of honeybee hive density on wild bee crop visitation rates. *Journal of Pollination Ecology*, 29(16), 204–230. [https://doi.org/10.26786/1920-7603\(2021\)641](https://doi.org/10.26786/1920-7603(2021)641)
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- Weissmann, J. A.**, & Schaefer, H. (2020). Feld-Bestimmungshilfe für die Wildbienen Bayerns. *Nachrichtenblatt der Bayerischen Entomologen*, 69(2), 1–64, 1st ed. Available online at: https://www.zobodat.at/pdf/NachBIBayEnt_069_SB_0001-0064.pdf
- Bretzel, J., Endriß, T., Halbinger, F., Hanusch, M., Hege, R., Krömmüller, I., Reith, S., Rupprecht, V., Sach, M., Schwaiger, S., Stiglmaier, V., Thum, N., **Weissmann, J. A.**, & Schaefer, H. (2018). Additions to the checklist of terrestrial biodiversity of Cabo Verde. *Zoologia Caboveridiana*, 7(2), 28–38. Available online at: http://www.scvz.org/zoolcv/vol7no2/ZoolCV2018_7_2_Bretzel_etal.pdf
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- Weissmann, J. A.**, Picanço, A., Borges, P. A. V., & Schaefer, H. (2017). Bees of the Azores: an annotated checklist (Apidae, Hymenoptera). *ZooKeys*, 642, 63–95. <https://doi.org/10.3897/zookeys.642.10773>.
- Weissmann, J. A.**, & Schaefer, H. (2015). Honeybees (*Apis mellifera*) collect latex of Azores bellflowers (*Azorina vidalii*, Campanulaceae). *Arquipelago. Life and Marine Sciences* 32. Available online at: <https://repositorio.uac.pt/handle/10400.3/3906>

Conference participations

- SCAPE Conference, Annual Meeting of the Scandinavian Association of Pollination Ecology, Höör/Sweden, October 24 to 27, 2019. Talk: *Urban Pollinators – Solitary bees in Freising*.
- EEF Congress, Ecology Across Borders: Embedding Ecology in Sustainable Development Goals, Lisbon/Portugal, July 29 to August 2, 2019. Talk: *Urban Pollinators – Solitary bees in Freising*.
- Workshop “Anthropocene and Citizen Science: Evidence gained through the ‘Opening-Up’ of Academic Knowledge Production?”, Munich/Germany, July 19 to 20, 2018. Talk (together with Felix Remter): *“Urban pollinators” and “beetrees”: two citizen science projects on bees*.
- Island Biology, International Conference on Island Evolution, Ecology and Conference, Angra do Heroísmo/Azores/Portugal, July 18 to 22, 2016. Talk: *Threat analysis and conservation plans for selected Azorean endemic plants on Corvo Island*.