Pollinators in peri-urban and rural orchards and gardens

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Abstract

Pollination is an important ecosystem service contributing to global food security and biodiversity. A large part of this pollination service is undertaken by pollinating insects which have seen a decline in the last decades. This decline is often linked to decreasing availability of suitable feeding and nesting resources. Urbanisation is thought to be one of the drivers behind this negative trend. The understanding of underlying mechanisms influencing pollinator abundance and diversity is of great importance in order to promote and protect them. The aim of this study was to identify drivers of pollinator abundance at the local as well as the landscape scale. Here, the focus was set on orchards and gardens as green infrastructure elements that are found along the urbanisation gradient. Pollinator abundance was measured in four peri-urban locations in Freising (Germany) and four rural locations in the Lower Engadine (Switzerland), using a non-intrusive observational method in 1 m^2 plots. In both regions two orchards and two gardens were taken into account. Diversity of flowering plants and bare ground were registered as feeding and nesting resources on the plot scale, while the landscape scale was characterised by the area of land use types within three buffer sizes around the study locations (300 m, 500 m, 1 km). The results suggest negative influence on pollinator abundance from built-up area. The negative correlation is clear in particular for non-bee pollinators which are more abundant in the rural than in the peri-urban region. However, the high abundance of wild bees in peri-urban gardens indicates that local abundance of feeding and nesting resources might overcome negative landscape scale effects. Non-bee pollinators, however, showed a higher dependency on landscape scale factors, though they seem to profit from local feeding resources in general. Honey bee abundance is found to be independent from both landscape and local scale conditions. However, the size of the dataset limits the validity of these results and several effects of land use types other than built-up area remain unclear, suggesting that more research is needed on the effects on pollinator abundance and diversity. The implementation of a citizen science project in the future, covering a larger temporal and spatial scale and using the method of this study could be an important contribution to current research.

Zusammenfassung

Bestäubung ist eine wichtige Ökosystemleistung, die zur globalen Ernährungssicherheit und Artenvielfalt beiträgt. Ein Großteil dieser Leistung wird durch bestäubende Insekten vollbracht, die in den letzten Jahrzehnten einen starken Rückgang gezeigt haben. Dieser Rückgang wird häufig auf die abnehmende Verfügbarkeit von geeigneten Nahrungs- und Nistressourcen zurückgeführt. Die Ausweitung von Siedlungsgebieten wird als eine der Ursachen für diesen negativen Trend angesehen. Um Bestäuber zu fördern und schützen, ist das Verständnis der Mechanismen, die Bestäubervorkommen und -vielfalt beeinflussen, von großer Bedeutung. Ziel dieser Arbeit war es, Faktoren auf lokaler und Landschafts-Ebene zu ermitteln, die das Bestäubervorkommen beeinflussen. Der Schwerpunkt wurde dabei auf Streuobstwiesen und Gärten als Elemente grüner Infrastruktur gelegt, die entlang des Urbanisierungsgradienten zu finden sind. Der Bestand an Bestäubern wurde an vier peri-urbanen Standorten in Freising (Deutschland) und an vier ländlichen Standorten im Unterengadin (Schweiz) mit einer nicht-intrusiven Beobachtungsmethode in 1 m^2 Plots gemessen. In beiden Regionen wurden dazu je zwei Streuobstwiesen und zwei Gärten untersucht. Die Vielfalt blühender Pflanzen und der offene Boden wurden als Nahrungs- und Nistressourcen in den Plots erfasst, während die Landschaft durch Landnutzungstypen innerhalb von drei Puffergrößen um die Untersuchungsstandorte (300 m, 500 m, 1 km) charakterisiert wurde. Die Ergebnisse deuten auf einen negativen Einfluss von bebauten Flächen auf das Bestäubervorkommen hin. Bei Nicht-Bienen-Bestäubern, die in der ländlichen Region häufiger vorkommen als in der peri-urbanen, ist dieser negative Zusammenhang besonders deutlich. Die große Anzahl von Wildbienen in peri-urbanen Gärten deutet darauf hin, dass die negative Auswirkung der Landschaftsebene durch das lokale Angebot an Nahrungs- und Nistressourcen ausgeglichen werden könnte. Die Ergebnisse der Nicht-Bienen-Bestäuber deuten hingegen auf eine stärkere Abhängigkeit von Landschaftsfaktoren hin, obwohl die Bestäuber-Gruppe im Allgemeinen von lokalen Nahrungsressourcen zu profitieren scheint. Die Abundanz von Honigbienen scheint unabhängig von den Bedingungen auf Landschafts- und lokaler Ebene zu sein. Der geringe Umfang des Datensatzes schränkt die Aussagekraft der Ergebnisse ein. Mehrere Auswirkungen anderer Landnutzungsarten als bebaute Fläche bleiben unklar. Dies deutet darauf hin, dass weitere Untersuchungen zu den Auswirkungen auf das Vorkommen und die Diversität der Bestäuber erforderlich sind. Die Durchführung eines bürgerwissenschaftlichen Projekts in einem größeren zeitlichen und räumlichen Maßstab, mit der hier verwendeten, beobachtenden Methode, könnte einen wichtigen Beitrag zur aktuellen Forschung leisten.

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List of abbreviations

ABSP: Arten- und Biotopschutzprogramm
(Programme for protection of species and biotopes)

ALG: Amt für Landwirtschaft und Geoinformation
(Agency for Agriculture and Geoinformation)

ALKIS: Amtliches Liegenschaftskatasterinformationssystem
(Official information system of the real estate cadaster)

ANOVA: Analysis of variance

BAFU: Bundesamt für Umwelt
(Federal Office for the Environment)

IPBES: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Service

LDBV: Landesamt für Digitalisierung, Breitband und Vermessung
(Agency for Digitisation, High-Speed Internet and Surveying of Bavaria)

LfL: Bayerische Landesanstalt für Landwirtschaft
(Bavarian State Research Institute for Agriculture)

LfU: Bayerisches Landesamt für Umwelt (Bavarian Environment Agency)

LPV Freising: Landschaftspflegeverband Freising
(Association for landscape maintenance of Freising)

LUIGI: Interreg Alpine Space project “Linking Urban and Inner Alpine Green Infrastructures”

PCA: Principal Component Analysis

1. Introduction

1.1 Project aim and research questions

The aim of this thesis was to contribute to the Interreg Alpine Space project "LUIGI" (see Section 1.2) with research on pollinators within green infrastructures in peri-urban and rural settings. The measuring of abundance and composition of pollinator communities in orchard meadows and gardens, their surrounding landscape as well as available feeding and nesting resources were the basis of this thesis. With this data the aim was to find important variables that influence pollinators in order to improve their protection and promotion. A second aim was to use a method that can be applied easily in other project regions. This could help improve awareness and interest among owners of orchards and gardens and improve the inclusion of the pollinator topic in relevant fields, such as planning and management (Peter et al., 2019). In general, this thesis should emphasise the need for pollinator protection and promotion in the private and the public and help to understand what is needed to do so.

To reach these aims the following research questions were asked:

A) What is the abundance of different pollinator groups in peri-urban and rural orchards and gardens?

B) What are the available feeding and nesting resources for pollinators in orchards and gardens and how do these resources influence pollinator abundance?

C) How do different landscape contexts influence pollinator abundance in orchards and gardens?

1.2 Project background

Green infrastructures provide us with a variety of ecosystem services. The ongoing Interreg Alpine Space project Linking Urban and Inner-Alpine Green Infrastructures (LUIGI) focuses on these benefits and aims to strengthen them in rural and urban areas in the Alps (Schrapp et al., 2020). Within the project the definition of green infrastructure from the EU is followed (Giombini et al., 2020). This definition states that green infrastructure is "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Commission, 2013, p. 3). Starting in autumn 2019, the projectpartners aim to find ways to promote ecosystem services and networks of green infrastructure and the benefits that come with them (Interreg Alpine Space LUIGI, 2021). Additionally, the 14 partners from six Alpine countries focus on the network connecting Inner-Alpine regions with urban centres and the services that are exchanged here. In this thesis, two of the partners were involved, namely the University of Applied Sciences Weihenstephan-Triesdorf (HSWT) in Freising and the Fundaziun Pro Terra Engiadina (PTE) in the Swiss Alps. Orchard meadows and gardens are the two green infrastructure elements that are focused on in this thesis.

2. Theoretical background

2.1 Importance of pollinators and pollination service

Pollinators are key to the functioning of terrestrial ecosystems. Almost 90 % of the wild plant species rely on pollination by animals for their reproduction (IPBES, 2016). These plants form the basis of functioning ecosystems, providing food and habitat as well as other regulating and provisional functions to other species and to mankind (IPBES, 2016; Ollerton et al., 2011). Furthermore, the pollination service is important for the production of food, where 35 % of the total volume produced is dependent on animal pollination (Klein et al., 2007). Pollinators are thereby essential for the richness in ecosystems, plants and food on this planet. Additionally, the diversity of pollinators is likely to be relevant in the future, as peaks of blooming might shift with climate change (Bartomeus et al., 2013). Thus, a desynchronisation between pollinators and plants could be prevented through diversity of species, as the flowers would still be pollinated, although by different species. This would ensure the continued existence of the vegetation, as one building stone of ecosystems.

On the one hand, pollinators sustain the diversity of plants and ecosystems, while on the other hand they rely on these functioning, diverse ecosystems for their own survival. Wild bees, in particular, are dependent on feeding and nesting resources for successful reproduction (Zurbuchen & Müller, 2012). Studies showed that wild bees are sensible to changes in the environment, which lead to longer foraging distances and reduce small-scale structures and flower-supply needed for nesting and feeding (Bartholomée et al., 2020; Garibaldi et al., 2011; Peterson & Roitberg, 2006; Zurbuchen et al., 2010b; Zurbuchen & Müller, 2012). This sensibility is visible in the current decline of wild bee abundance and diversity resulting in increasing numbers of species listed as endangered (Brown & Paxton, 2009; IPBES, 2016). Environmental changes in the landscapes of Central Europe happened mainly due to the settlement development and the agricultural intensification and mechanisation, leading to a diminished structural and flowering diversity (Lachat et al., 2010; Zurbuchen & Müller, 2012). Furthermore, the abandonment of grasslands leads to succession, resulting in diminished diversity and feeding resources (Bartsch et al., 2009; Lachat et al., 2010; Pedersen et al., 2020). Regarding settlement development, studies found declining numbers of pollinators the more built-up an area is (Burdine & McCluney, 2019; Lagucki et al., 2017; Levé et al., 2019; Wenzel et al., 2020). However, these effects might be reduced by appropriate habitats within the urban matrix and different pollinator groups respond differently to the degree of urbanisation (Ahrné et al., 2009; Baldock et al., 2015; Baldock et al., 2019; Daniels et al., 2020; Geslin et al., 2013). Additional threats to pollinators are the use of pesticides and the exposure to parasites which are interacting with other stressors like the scarcity of feeding opportunities and are likely to increase with climate change (Goulson et al., 2015). Yet, Rader et al. (2016) show in their review, that non-bee pollinators are less negatively affected by land use changes than bees are. A similar finding was stated by Jauker et al. (2009) looking at impacts of landscape structure on hoverflies and wild bees. Nevertheless, changes in the presence of hoverfly species connected to changes in the landscape have also been observed (Bartsch et al., 2009).

In addition to the threats seen on pollinators in general, beekeepers around the world report decreasing numbers of honeybees. Reasons that are often reported are Varroa mites and the Colony Collapse Disorder (Le Conte et al., 2010; van Engelsdorp et al., 2008). In the last decades the so-called *Pollination crisis* has caused an increase in research and conservation efforts for pollinators (Potts et al., 2010; Zurbuchen & Müller, 2012). Examples that prove this are *The Assessment Report on Pollinators, Pollination and Food Production* by the IPBES (IPBES, 2016) and several programmes and strategies on different scales (regional to international), e.g. *Nasjonal pollinatorstrategi: Ein strategi for levedyktige bestandar av villbier og andre pollinerande insekt* (Landbruks- og matdepartementet et al., 2018) in Norway or *Pollinator Strategy for Scotland: 2017-2027* (NatureScot, 2017). In order to be able to transport the information from research to policy and management, the mapping and assessment of the pollination ecosystem service is very important (Bartholomée & Lavorel, 2019). Ecosystem services are generally referred to as the benefits that humans get from ecosystems and the interaction of organisms within them (Grunewald & Bastian, 2015). However, the pollination service is not very well defined and still needs standardisation of definition and method to establish clear communication about it (Bartholomée & Lavorel, 2019). In their review, Bartholomée and Lavorel (2019) found four definitions of the service, split into two categories: The first category describes the *supply capacity* of an ecosystem, trying to define how much service would be possible. Here, definitions are *pollinator presence* or *pollen transfer*, which can be measured by captures and observations. The second category targets the *flow* of the service, relying on *pollination success* or *harvest for human consumption*. This can be measured in the produced fruit after pollination, either by number, size, or quality (e.g. sugar content in apples). The authors point out that the supply capacity and the flow of pollination do not always correlate. They further suggest that non-expert suitable methods are very relevant for the mapping of this service. In this study, such a method was implemented, relying on an ongoing citizen science project. The abundance of pollinators can be seen as a measurement for pollinator presence indicating the supply capacity of the ecosystems studied.

2.2 Pollinator ecology

For pollination, bees are regarded as one of the most important groups (Cardinal & Danforth, 2013; Potts et al., 2010). This is due to the fact that bees are one of the only groups that need nectar and pollen for their own nutrition as well as for their reproduction, which leads to a higher total flower-visitation rate compared to other pollinator groups (Zurbuchen & Müller, 2012). Also, it is known that the evolution of bees and angiosperms are closely intertwined (Cardinal & Danforth, 2013; Peters et al., 2017). This means that plants and bees have a relationship that is very well adapted. Nevertheless, there are other flower visitors that perform an important part of the total pollination service and are often overlooked in pollination studies (Rader et al., 2016; Senapathi et al., 2017). In addition to the non-insect pollinators like bats and birds, the insect groups mostly regarded as pollinators are bees, flies, wasps, beetles, butterflies and moths, as well as minor groups such as ants (Kevan & Baker, 1983; Rader et al., 2016). Regarding the efficiency of different pollinator groups, there is still the need for more research (Bartholomée & Lavorel, 2019). Different studies point out that the honeybee is not the most efficient pollinator and that a broad diversity of pollinators is key for sustaining the pollination service (Bartomeus et al., 2013; Breeze et al., 2011; Brittain et al., 2013; Rader et al., 2016). In their review, Rader et al. (2016) found that non-bee taxa pollinators show higher visitation rates than bees, and thus make up for their less efficient pollination. The pollinator groups are thought to complement each other's service (Rader et al., 2016).

In this report "solitary bees" is used for all the bees that do not belong to the *Bombus* or *Apis* genus (e.g. Figure 1 a), although not all of them live solitarily (some even being "cuckoo bees" which means that they are parasitising other bees (Westrich, 2018)). Furthermore, "wild bees" is used when referring to all the bee species that are not domesticated (e.g. Figure 1 a & b) and "bees" is used for wild bees and honeybees altogether (all the examples on Figure 1).

Figure 1 Bees on flowers. **a)** solitary bee, **b)** bumblebee, **c)** honeybee

2.3 Orchards and gardens for pollinators

Orchard meadows and gardens can be found on the entire urbanisation gradient. In addition to the historical and recreational value of orchards, these semi-natural spaces are of great value for the production of fruit, especially regarding the diversity of old fruit varieties they hold (Forejt & Syrbe, 2019). Orchard meadows have a high potential to cover needs of pollinators (nesting and feeding resources) even after the flowering of the fruit trees is over, as the meadow under the fruit trees is often rich in flowers and managed extensively and different nesting habitats are offered (Kay et al., 2020; Potts et al., 2003). In this report "orchard" refers to orchard meadows used as pasture or that are mown. The fruit might be used or even sold, but in general the aim of the area is not for commercial production anymore, as it is not profitable and is connected to hard, manual work (Amt für Landschaftspflege und Naturschutz, 1999). Abandonment and settlement expansion are among the most important factors, threatening these traditional agroforestry systems, that characterise the landscape in the Alps as well as in lower regions. In Germany, only around 20 % of the original orchard meadows are left (Schrapp et al., 2020). Similarly, in the canton of Grisons in Switzerland 300,000 fruit trees were counted in 1951, while the number was less than 50,000 only fifty years later (Amt für Landschaftspflege und Naturschutz, 1999). An increase in public awareness and appreciation would be important to maintain orchards and the ecosystem services they provide (Schrapp et al., 2020).

Gardens can also play an important role in providing habitats for wildlife, improving the local climate and mitigating floods, in addition to the production of food and the space for social and recreational activities (Breuste, 2010; Cameron et al., 2012). Regarding pollination they can serve as important reservoirs, especially within urban areas (Ayers & Rehan, 2021; Baldock et al., 2019; Daniels et al., 2020; Levé et al., 2019). By specific management for high richness in plant and structure diversity, wild bees can be promoted in gardens, although it is beneficial for the pollinators to have networks, rather than being situated in isolated areas (Zurbuchen & Müller, 2012). “Gardens” in this study are mainly vegetable gardens, either privately owned or in the ownership of an association. House gardens, including lawn, playground etc. are not regarded here. Nevertheless, the included gardens might not be used for food production only, but also as recreational areas. Also, flowers and vegetation other than edible products might be planted in these gardens.

3. Materials and methods

3.1 Fieldwork methods

Count of pollinators on plot level

The goal of this study was to use a non-intrusive method due to the low impact on pollinators and the accessibility for the broad public, as no equipment, no permit and only very little specific knowledge is needed. These aspects make the method approachable for garden and orchard owners who want to learn more about the pollinators living in their area. Pollinator abundance and richness were estimated by observation of insects on 1x1 m plots. The method is based on the ongoing citizen science project on pollinators “Schwalbenschwanz & Seidenbiene” (Gloor et al., 2021). A similar non-intrusive approach was also suggested and used by Geslin et al. (2013) and Bartholomée et al. (2020) in their research.

The fieldwork took place during the first three weeks of June, on sunny days with temperatures above 10 °C and low wind levels. In each study location 5 plots were placed. The chosen method was to split the area into 5 sub-areas and to place one plot in each of these areas, making sure that there were flowering plants in the plot. It was not possible to use a completely randomised design, as the presence of flowering plants is necessary for the method used. The plots were observed for 10 minutes between 10:00 and 17:00. The observations were repeated once, so that each location had counts in the morning and in the afternoon. This led to an observation time of 1 h 40 min per garden/orchard and a total observation time of 13 h 20 min. Observed insects were classified into 10 classes, being assigned to the group of honeybees, wild bees and non-bees (see Table 1).

Table 1 Flower visiting insects in 3 groups and 10 classes. Taxonomic groups were assigned to classes that are distinguishable in the field. For the statistical analyses these classes were aggregated into three pollinator groups.

Group	Class	Explanation
Honeybee	Honeybee	*Apis mellifera*
Wild bee	Bumblebee	*Bombus sp.*
	Solitary bee	Apiformes clade excluding the *Apis* and *Bombus* genus
Non-bee	Hoverfly	Syrphidae family in the Diptera order
	Other fly	Diptera order excluding the Syrphidae family
	Wasp	Apocrita suborder excluding Ants (Formicidae), Bees (Apiformes) and Spheciformes
	Sphecoid wasp	Spheciformes
	Butterfly	Lepidoptera
	Beetle	Coleoptera
	Bug	Hemiptera

This classification was inspired by Bartholomée et al. (2020), Geslin et al. (2013) and Gloor et al. (2021). Ants were not included in the counts due to their fast movement in high numbers, although they might have a little pollination effect by transporting pollen accidentally (Bartholomée et al., 2020). Insects were counted when they a) landed on a flower, b) landed on the ground or on parts of the vegetation other than the flower or c) passed through the plot, but did not land. Category c) was only used, when the reason for flying over the plot due to a gust of wind could be excluded. Double counting was excluded by the following rule: If several insects from the same class visit the plot they are only counted if they are present at the same time (e.g. two honeybees on two flowers within the plot) or if they are from a different species (e.g. tiny solitary bee and honeybee-sized solitary bee). If possible, a more specific identification than the pollinator class (see Table 1) of the insects was registered, although this could not be considered in the data analysis due to the limited amount of total data. For the same reason, the different classes of pollinators were not considered in all the analyses. Instead, a grouping into honeybees, wild bees and non-bee pollinators was used, inspired by the review by Rader et al. (2016) who gathered their findings into these groups.

Estimation of feeding and nesting resources

Plot level

On the plot level, bare ground was estimated as a proxy for the nesting resources using the pollinators counting plots. This proxy was inspired by different studies (Bartholomée et al., 2020; Kay et al., 2020) and was regarded as important, as about ¾ of the wild bees are nesting in the ground (Antoine & Forrest, 2021). For the feeding resources the flower cover was estimated. The estimations were taken in steps of minimum 5 %. Plots with less than 5 % coverage were noted as 0 % coverage, although

Figure 2 Overview of the types of nesting resources regarded on the location level. **a)** compost heap, **b)** dry-stone wall, **c)** cairn, **d)** bare ground, **e)** break-off edge, **f)** pile of branches, **g)** old plant stems, **h)** lying deadwood , **i)** standing deadwood, **j)** young trees, **k)** middle-aged trees, **l)** old trees (partially dead), **m)** nesting aid, **n)** water, **o)** beehive

there were flowers in the plot. In addition, the flowering plants were identified, at least to genus level, and counted. Depending on the type of inflorescence, single flowers or flower packages were counted. Later on, a flowering diversity index was calculated from this data and was used as a proxy for feeding resources available on the plot. The importance of flower diversity for pollinators was stated in several studies (Fründ et al., 2010; Goulson et al., 2015; Hülsmann et al., 2015; Majewska & Altizer, 2020). Mean vegetation height was also measured and noted as a variable that could explain differences in pollinator groups and abundances (Sjödin et al., 2008).

Location level

On the location level, nesting resources were registered using a presence/absence system. The structures taken into account to measure nesting resources were: compost heap, dry-stone wall, cairn, bare ground, break-off edge, pile of branches, old plant stems, lying deadwood , standing deadwood, young trees, middle-aged trees, old trees (partially dead), nesting aid and water (Figure 2). Woodplanks, old, wooden furniture and logs were regarded as lying deadwood. Additionally, the presence or absence of beehives was noted. The nesting categories for wild bees were mainly inspired by Wiesbauer (2020) and Zurbuchen and Müller (2012). Additional structures, such as compost heap and water, were included as possible nesting resource for non-bee insects and their larvae (Bartsch et al., 2009). The information on beehives was included as a possible explanation for high honeybee abundance.

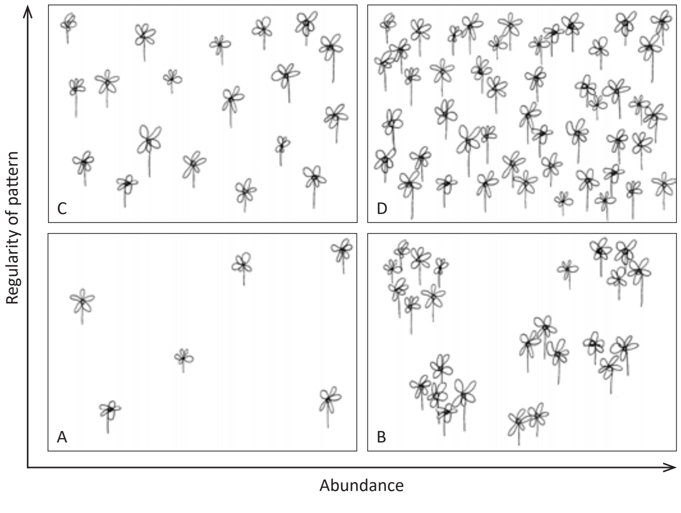


Figure 3 Categories of abundance and pattern of the flowering species on the location level. Categories: A - sporadic, B - patchy, C - distributed, but rare, D - commonly distributed.

The feeding resources were registered using a classification of four categories (Figure 3). Flowering plants on the entire location were identified (at least to genus level) and the abundance and regularity of the pattern of distribution was characterised with these categories.

The vegetation was identified using three sources: Jäger (2017); Lauber et al. (2018); Roloff and Bärtels (2018).

Characterisation of study locations

The studied locations were characterised descriptively. Here, a combination of the local feeding and nesting resources, the on-site impressions and notes, information by the owners or managers or their respective website and some information from the GIS analysis was used. Generally, the size, exposition and location context were described. The close surroundings were characterised by their structures and the most important plant species. Finally, a short insight into the type of use, the ownership and the management was given.

The data collection forms used for the fieldwork can be found in the Appendix A.

3.2 GIS analysis

The analysis of the landscape context was conducted using ArcGIS Pro (Esri, Version 2.8.1). The input data were vector data layers containing information about the land use. In Freising this was the Layer "Tatsächliche Nutzung" (factual use) from the ALKIS (Amtliches Liegenschaftskatasterinformationssystem) provided by the Agency for Digitisation, High-Speed Internet and Surveying (LDBV) of Bavaria (LDBV, 2020b). Furthermore, OpenStreetMap data was used for the localisation of buildings as part of the built-up area of the region (Geofabrik GmbH., 2021). For the Lower Engadine, data was retrieved from GeoGR, which is the central contact for geoinformation in the canton of Grisons. Similar to the data downloaded for Bavaria, the Layer "Bodennutzung" (Use of the ground) from the official surveying was used for the analysis (ALG, 2007). Additionally, a layer containing information about the agricultural usage from the same surveying data was used to determine cropland.

For the landscape analysis, the land use data was aggregated into 7 classes (see Table 2). These were mainly inspired by studies similar to the present project (Bartholomée et al., 2020; Földesi et al., 2016; Levé et al., 2019). Instead of the "orchard" or "domestic garden" class used in those studies, different garden-like structures were aggregated. Additionally, the water class was added inspired by findings related to aquatic habitats (Pfister et al., 2018; Stewart et al., 2017). Finally, the gravel class was added as this could include nesting sites for wild bees and wasps (Bellmann & Helb, 2017; Westrich, 2018). The division consisted of one class with impervious surfaces (built-up) and six classes of different pervious surfaces (see Table 2).

All the visited gardens and orchards were buffered with distances of 300 m, 500 m and 1 km and intersected with the created land use data. For the analysis percentages of each class were calculated.

Table 2 Overview of the content of the seven land use classes used for the landscape analysis.

Perviousness	Class	Explanation
Impervious	Built-up	houses, driveways, parking lots, roads, other transportation infrastructures, smaller paved surfaces, bare rocks
Pervious	Forest	forest, smaller forested patches, other tree and shrub structures (e.g. hedgerows)
	Cropland	fields (e.g. corn, grain)
	Grassland	managed grasslands; mowed meadows, pastures
	Garden	house gardens, parks, sports facilities, graveyards, wastelands
	Gravel	pits, banks in the river, gravel roads, tracks
	Water	standing and flowing waterbodies above ground

3.3 Statistical analyses

All statistical analyses were run with the program R (Version 4.0.5) (R Core Team, 2021) using the free software RStudio (Version 1.4.1106). The assumptions of statistical tests were assessed using Shapiro Wilk's normality test (stats package (R Core Team, 2021)) and Levene's test for homoscedasticity (car package (Fox & Weisberg, 2019)). If assumptions were not met, the data was transformed accordingly. Additionally, the data was standardised using the z-score before calculating correlations (Denis, 2020). Data manipulations and visualisations of the results were carried out using functions from diverse packages (dplyr, tidyr, plyr, data.table, ggplot2, ggpubr, RColorBrewer and openxlsx (Dowle & Srinivasan, 2021; Kassambara, 2020; Neuwirth, 2014; Schauberger & Walker, 2020; Wickham, 2011, 2016, 2021; Wickham et al., 2021)). For the analyses, only the pollinators counted on flowers were taken into account either as total pollinator abundance or split into pollinator group abundance (honeybee, wild bee and non-bee). Mostly, the data was grouped into four different area types regarded in this study: peri-urban orchards, peri-urban gardens, rural orchards and rural gardens.

Additional influences on pollinator abundance

Before analysing the research questions, a general investigation of possible influences on the pollinator abundance was conducted. Here, effects of weather, namely temperature, wind speed and cloud coverage were checked for association with the pollinator data using simple linear regression models. In addition to the association of each variable, an analysis of variance (ANOVA) was run, to find possible interactions between the variables that affect the pollinator abundance (Westfall & Arias, 2020). Furthermore, a paired t-test was conducted to check whether the afternoon data collection was different from the morning. Similarly, the association between vegetation height and pollinator abundance was checked. In addition, the numbers of counted honeybees were compared between locations with beehives within or close by the location, or locations without beehives. For this comparison a t-test was used. If the results were significant, the explanatory variable was tested on difference between the two regions using a t-test in order to better understand the results. For these tests, functions from the package "stats" (R Core Team, 2021) were used.

Abundance of pollinator groups in peri-urban and rural orchards and gardens

For the first research question the pollinator counts were used as the response variables and the categories of rurality and ecosystem type as the explanatory variables. After the viewing of the pollinators counted per category of area type and a deeper look into the abundance of different pollinator classes, the data was entered in a two-way ANOVA (Westfall & Arias, 2020). As the test assumptions were not met, the pollinator data was transformed with the Yeo-Johnson transformation (car package (Fox & Weisberg, 2019)) in order to gain normality of residuals (Yeo & Johnson, 2000). The main effects were compared in a pairwise comparison to find the influence of the single variables. For both the ANOVA and the pairwise comparison the rstatix package (Kassambara, 2021) was used.

Feeding and nesting resources and their influence on pollinator abundance

The sub-question regarding availability of nesting and feeding structures was evaluated in a descriptive way. The resources registered were grouped into peri-urban orchards, peri-urban gardens, rural orchards and rural gardens and compared. The proxies for feeding resources on the plot scale were the estimated flower coverage and the diversity of flowers (see Section 3.1). For the latter, a Shannon Diversity index was calculated from the number of flowers per species recorded in the field using the package "vegan" (Oksanen et al., 2020). To compare the results between the area types, means were calculated. Similarly, the bare ground coverage was used as a proxy for nesting resources. The availability of feeding and nesting resources on the location scale was compared using heatmaps. This data was not included in any further analyses.

In order to answer the question about the influence of nesting and feeding resources on pollinator abundance, the variables were scaled and entered in Principal Component Analyses (PCA) (Tabachnick & Fidell, 2014). Nesting resources were presented by the bare ground coverage, while the Shannon Diversity index was used for the feeding resources. For the pollinators, both the total number of pollinators and the pollinator groups (Honeybee, wild bee and non-bee) were used in different analysis plots. The analysis was run for both the plot and the location level, using means for the latter. In addition to the PCA, correlations were calculated for both levels and for pollinator totals as well as groups. Pearson correlation was used, if the entire dataset was normally distributed. Meanwhile, Spearman correlation was used if any of the variables showed a non-normal distribution (Denis, 2020). The packages used for the PCA and the correlation matrix included FactoMineR (Le et al., 2008), facoextra (Kassambara & Mundt, 2020), corrplot (Wei & Simko, 2021), Hmisc (Harrell, 2021) and broom (Robinson et al., 2021).

Landscape context and its influence on pollinator abundance

The surrounding landscape of the sites was compared visually between the regions and ecosystem types, for all three buffers (300 m, 500 m, 1 km). First, the area of impervious surfaces was compared between the two regions, using the built-up category from the land use GIS analysis (see Section 3.2). After that, the pervious land use types were compared between the buffers as well as between the regions.

In a second step, the aim was to answer the question of how pollinator abundance correlates with certain land uses. To answer this, a PCA (Tabachnick & Fidell, 2014) was conducted using the land use types as well as the pollinator abundance data as variables. Additionally, correlations between these variables were calculated. For both tests, the dataset was scaled before calculating the test. The method chosen for the correlations was Spearman, as the data was not normally distributed (Denis, 2020). The correlations were calculated with the correlation function within the Hmisc package (Harrell, 2021). For the analysis, several PCAs and correlations matrices were calculated. On every buffer scale

(300 m, 500 m and 1 km) the analysis was run once with the total pollinator abundance, and once with the abundance of each pollinator group. A separate investigation of orchards and gardens could not be performed, due to the small sample size (Mundfrom et al., 2005). To run the PCA and the correlations several R packages were used (FactoMineR (Le et al., 2008), facoextra (Kassambara & Mundt, 2020), corrplot (Wei & Simko, 2021), Hmisc (Harrell, 2021) and broom (Robinson et al., 2021)).

4. Study regions

This study included the two LUIGI partner regions Lower Engadine (CH) and Freising (DE). The regions of the Lower Engadine and Freising were chosen due to their difference in terms of rurality, the Lower Engadine being a rural landscape in the Alps and Freising being an urban settlement within the metropolitan region of Munich (see Figure 4). Here, it has to be noted that the study locations chosen in Freising were at the borders of the town and showed a peri-urban character (see Section 6.2). Also, these two regions offered good accessibility in terms of travelling, language and established contacts to the owners of green infrastructure elements of interest for this study.

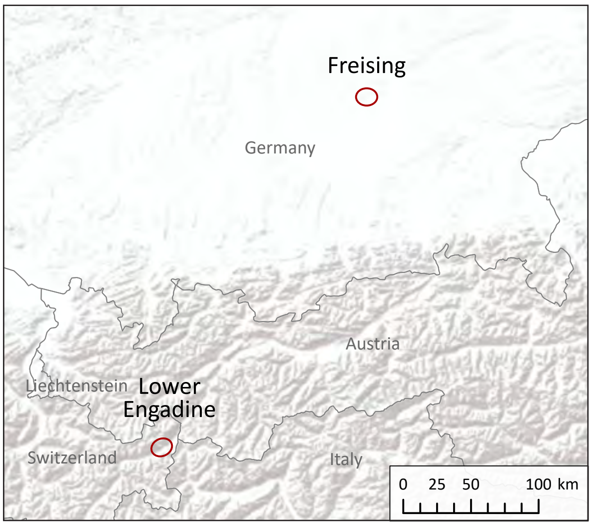


Figure 4 Overview map of the two studied regions in the Alpine context. Red circles indicate the region. The map is oriented towards the north. Data sources: Esri et al. (2017) & Garmin International (2019)

Four study locations were chosen in Freising and the Lower Engadine respectively. The aim was to have as little overlap in a 1 km radius around the location as possible. In the Lower Engadine two orchards and two gardens were chosen within the districts of Sot Tasna and Ramosch. The lower part of the region was chosen due to the further progressed season compared to places in higher altitudes such as Lavin and Zernez. The two sites in Ramosch have an overlap in their landscape buffer, as their core is just over 1 km apart. The same holds true for the orchards in Freising, namely the orchard at the Plantage and the orchard of the LfL (Bayerische Landesanstalt für Landwirtschaft).

4.1 Peri-urban - Freising

Freising is a town with approximately 49,000 inhabitants in the Bavarian district Upper Bavaria, close to the city of Munich (Landratsamt Freising, 2021). It is at the outer, northern border of the Alps (see Figure 4), at around 448 m above sea level (LDBV, 2021). The climate is temperate continental, with higher precipitation levels in the summer months, and is influenced by the proximity to the Alps (Schober & Schaller, 2007). In 2020 the total rainfall was 767 mm, the average temperature 9.6 °C and there were 96 frost days (LfL, 2021). The town is characterised by its hills, as it lies on the border of the Danube-Isar-hills in the north and the gravel plain of Munich in the south (Schober, 2001). It is also crossed by the Isar, with its bordering floodplain forest. In the northern part the settlement area reaches the forest edge of the protected forest of Freising (see Figure 5). Here, further development and expansion of the urban area is limited (Amt für Stadtplanung und Umwelt, 2015). A similar situation is found in the south where the Airport of Munich is located, and expansion is stopped mainly due to noise exposure (Amt für Stadtplanung und Umwelt, 2015). Nevertheless, expansion of settlement is an actual threat to existing fruit trees in the broader picture of the entire district, which is a common trend in Germany (see Section 2.3). Orchard meadows, fruit trees along roads and between fields have a long and interesting history in the region but are currently threatened (LPV Freising, 2021). In addition to removal, the neglect of proper care and the lack of replacement plantations are important factors for the decline (Schrapp et al., 2020). The "Landschaftspflegeverband Freising" (LPV Freising) has several ongoing projects addressing this topic including environmental education for children and youth (LPV Freising, 2021).

The topic of pollinators has been present in the region over the last few years. On the one hand, the Bavarian referendum "Rettet die Bienen" (Save the bees) has helped to raise awareness among the broad public. On the other hand, Freising has a close relation to science due to it playing host to the university campus of the TUM (Technical University of Munich) and the HSWT (Hochschule Weihenstephan-Triesdorf). Here, several projects addressing pollinators are and have been underway, e.g. "Urban pollinators" (Weissmann, 2019) including a Master's thesis that addressed pollinators in orchard meadows (Krömmüller, 2019).

4.2 Rural - Lower Engadine

The Engadine is an Inner-Alpine dry-valley in the south east of the canton of Grisons, Switzerland. While the upper part of the valley is famous for its wide valley floor and its lakes, the lower part is narrower, steeper and wilder. This part, the Lower Engadine, forms the easternmost part of Switzerland and borders both Italy and Austria (see Figure 4). The part of the valley belonging to the Lower Engadine is about 50 km long and stretches from 1560 m above sea level at Punt Ota to 1035 m in Martina (swisstopo, 2021a). However, these values are representing the altitude above sea level of the valley bottom. The climate is mainly continental with the peak of precipitation in the summer months (Bader et al., 2012). Due to the special constellation and exposure of the mountains in the north and south the valley is famous for its sunny weather, as these mountain ranges shield the valley from the northern as well as the southern influences (Bader et al., 2012). In 2020 an average temperature of 6.5 °C and a total precipitation of 749 mm were registered (BAFU, 2021). On 165 days, the

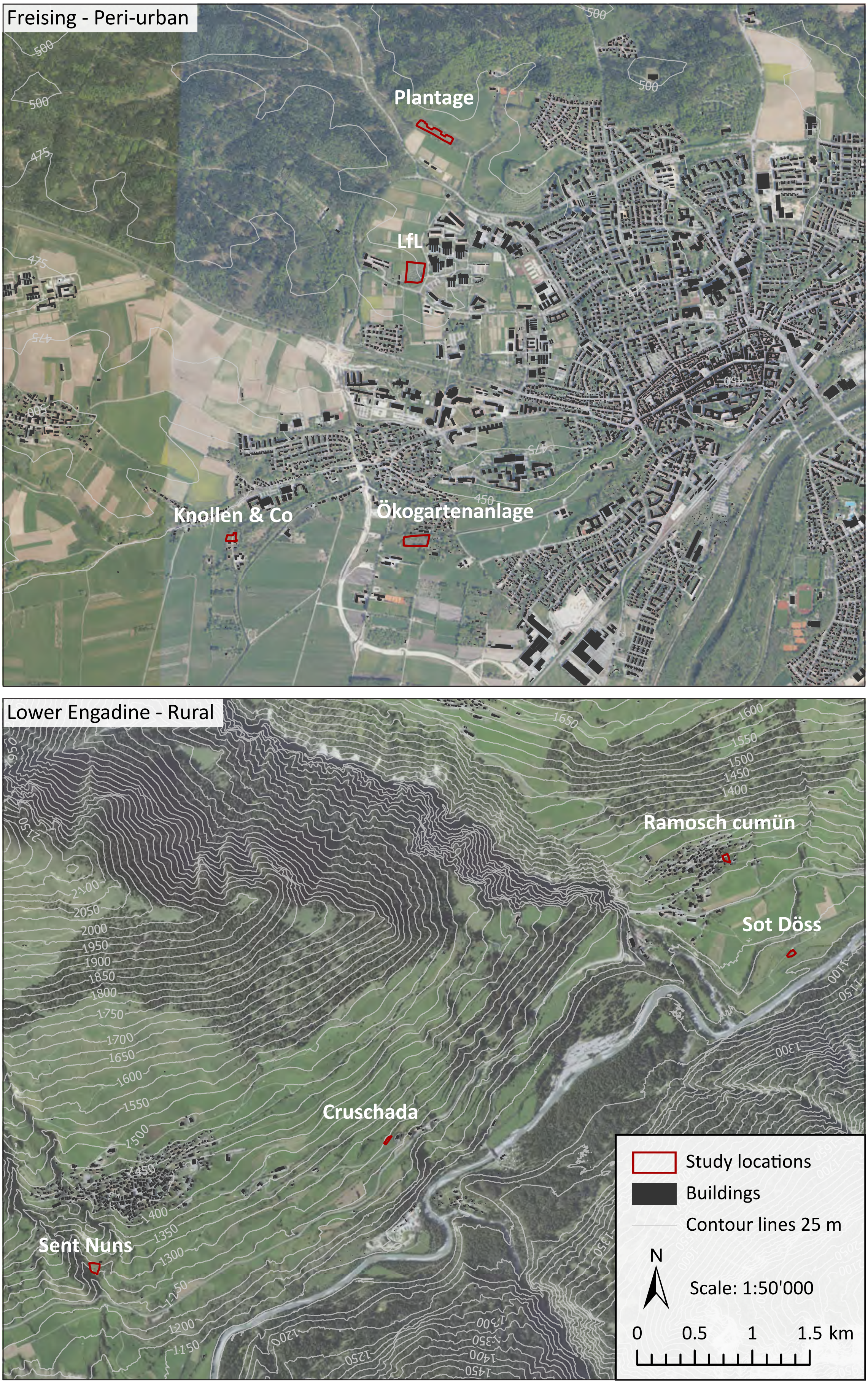


Figure 5 Overview map of the study locations within the two regions. Data sources: ALG (2007), Geofabrik GmbH. (2021), LDBV (2020a, 2020c) & swisstopo (2021b, 2020)

temperature reached below zero (BAFU, 2021). As the snow cover can last very long into the spring, especially on the valley bottom and the north oriented hillsides, the main part of the agriculturally used land is on south oriented hillsides (see Figure 5). Agriculture has a long history in this valley. The region around Ramosch has been cultivated since the bronze age (Zoller et al., 1996). The landscape is characterised by the field terraces this early cultivation has left behind. In the 1750s the inhabitants cultivated their own house gardens in addition to the cultivation of grain (Mathieu, 1987). What started as a measure for self-sufficiency turned into a status symbol for wealthy people later on. The first fruit trees within gardens could be found in the aristocratic gardens. Nevertheless, fruit and nuts were often brought into the valley from the adjacent valleys and exchanged for grain (Mathieu, 1987).

In the last decade the topic of fruit trees gained attention in the area through the landscape quality project within the agricultural policy 14-17 (Richner Kalt, 2013). For this reason, first mappings of fruit trees within the agriculturally used area started. Within the Interreg Alpine Space Project LUIGI, the Fundaziun Pro Terra Engiadina mapped all the fruit trees in the Lower Engadine, including their condition and sort, independent of their location within or outside the agricultural perimeter (Fundaziun Pro Terra Engiadina, 2021). Additionally, this year the first mapping of wild bees took place, setting the baseline for further research.

4.3 Study locations

Peri-urban locations

Description orchards

Plantage

The orchard at the Plantage (see Figure 6) is located in the north-western part of Freising, bordering the forest on the western end (see Figure 5). To the north there is an open field currently used for corn production, which is separated from the orchard by a structure of trees and shrubs. This hedge-like structure is found around the entire orchard, although it is replaced by forest edges in the west and flows into a broader tree patch on the eastern side (see Figure 7). On the southern end there is a stream (Wippenhauser Graben) which is overgrown by trees and shrubs. A path leads through this structure along the stream. The tree and shrub layer surrounding the orchard mainly consists of native species such as *Cornus sanguinea* L., *Sambucus nigra* L., *Sorbus aucuparia* L., *Corylus avellana* L., *Betula pendula* Roth, *Acer pseudoplatanus* L. and *A. platanoides* L. as well as *Salix* sp. L. and *Populus* sp. L.. In the herb layer nitrogen indicators such as *Urtica dioica* L. and *Galium aparine* L. are dominant. On the opposite side of the stream a meadow and a hops plantation border the area. To the east a long-established beehive is located. Further away the extensively used hill where the Schafhof (formerly Schönleutnerhof) is situated (Michler et al., 2017) offers several break-off edges and bare ground. The orchard itself is exposed and inclined towards the south-southwest. At the upper end a small area of

430 m² is planted with grape vines. Further towards west but still on the upper end an area of 800 m² is excluded from the main orchard, where a Tipi and another 6 trees are located (see Figure 7). In this exclusion there is a second, but only small, beehive. These two areas were not included in the

Figure 6 Impression of the orchard at the Plantage.

Figure 7 Overview of the orchard at the Plantage including the position of the plots. Data source: LDBV (2020b)

study. Therefore, the following characteristics might not be representative for them. In total, the area regarded as the orchard is 0.7 ha large with 57 trees that were mainly planted in 4 rows. The trees are mainly apple trees of varied age, some of them only planted a few years ago, others already in their phase of full yield. Furthermore, pear, damson, walnut and service trees (*Sorbus domestica* L.), as well as a birch and an oak can be found. The flowering diversity consists of 9 different plant species of different abundance on the site (see Figure 8). *Stellaria graminea* L. and *Trifolium repens* L. are distributed on the entire area, while other species appear less abundantly. Within the orchard there are several nesting possibilities for wild pollinators. There are spots with bare ground on the entire orchard, while plant stems can be found mainly in the less sun-exposed parts towards the west. Along the fence that encloses the orchard branches are piled up. The fence itself is made out of wooden posts.

Galium mollugo agg.	C
Hypochoeris radicata L.	A
Ranunculus acris L.	A
Stellaria graminea L.	D
Symphytum sp. L.	A
Trifolium repens L.	D
Veronica chamaedrys agg.	A
Veronica officinalis L.	B
Vicia sp. L.	A

Figure 8 Plant species and category of abundance and pattern within the area of the orchard at the Plantage. Categories found: A - sporadic, B - patchy, C - distributed, but rare, D - commonly distributed.

The area is listed as an ecological compensation area in the Bavarian “Ökoflächenkataster” (Land register of ecologically important areas), where it was used as a compensation for the new construction of an antenna mast (LfU, 2021). Furthermore, the orchard is part of the focus area “Freisinger und Kranzberger Forst mit Umfeld” of the ABSP (Arten- und Biotopschutzprogramm) (Schober, 2001). The orchard is managed by the Landschaftspflegeverband Freising (LPV Freising). For over 25 years they have been working on extensifying the use of the orchard meadow at the Plantage as well as on the topic of orchard meadows as cultural and ecological worthy spaces in general (LPV Freising, 2021; Maino, 2021). This year, the orchard was grazed by horses for two weeks from the beginning of June (Maino, 2021).

Bayerische Landesanstalt für Landwirtschaft (LfL)

The second orchard in Freising is also located at the north-western border of the town (see Figure 5). It is part of the LfL (Bayerische Landesanstalt für Landwirtschaft) and is surrounded by the institute’s infrastructure including office buildings, parking lots, greenhouses and agricultural testing areas (see Figure 10). To the north, the orchard borders an apple-production testing area, as well as other testing areas. On the western end, up the hill, there is an extensively used meadow and behind that a community garden for students called “Knosporus”. The Garden includes a polytunnel and additional testing areas including a chestnut avenue. To the south, there is a broad band of trees with dense undergrowth, consisting of native as well as non-native species. This structure surrounds the orchard along half of the eastern side as well, fading off into a structure of single trees (oaks) and shrubs on an extensively managed meadow. The tree layer of the vegetation band is dominated by the non-native *Liriodendron* *tulipifera* L. but hosts native species like *Betula pendula* Roth, *Salix* sp. L. and *Populus* sp. L. as well. The shrub layer includes species like *Acer campestre* L., *Ligustrum vulgare* L., *Cornus sanguinea* L., *Crataegus* sp. L. and *Rosa* sp. L.. However, the herb layer within this structure could not be accessed, due to the density. On the eastern border species like *Lotus corniculatus* L., *Onobrychis viciifolia* Scop. and

Figure 9 Impression of the orchard of the LfL.

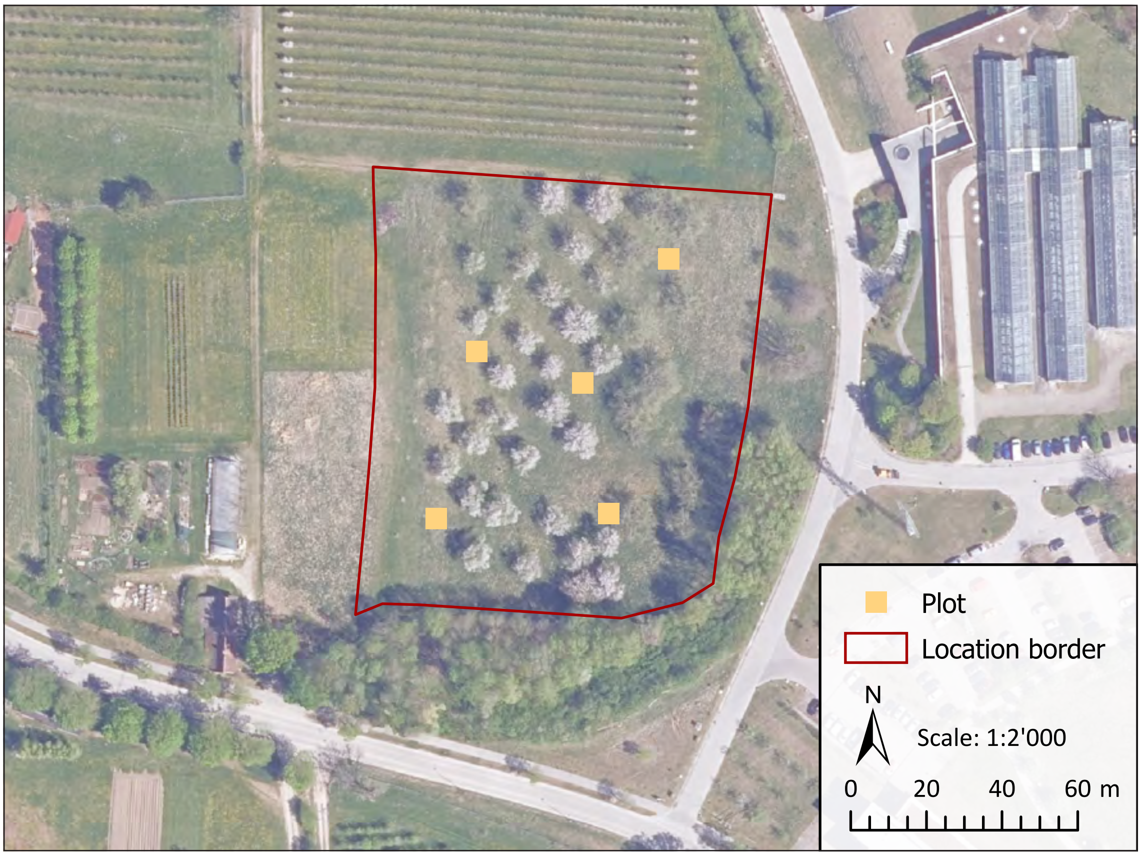


Figure 10 Overview of the orchard of the LfL including the position of the plots. Data source: LDBV (2020b)

Knautia arvensis (L.) J. M. Coult. s. str. are growing in the meadow. The orchard is exposed towards the east and has a stronger inclination in the westernmost quarter of the area. This part of the area is drier and has been managed differently for a couple of years (Kilian, 2021) which has led to a higher proportion of flowers compared to in the flatter parts. The regarded area is 1.1 ha large and has 43 middle aged (meaning in their full yield stage) as well as 21 young apple trees. The herb layer within the orchard consists of 13 different flowering species (see Figure 11). *Ranunculus acris* L. and *Medicago lupulina* L. are found on the entire area, but not very abundantly. The older trees have good nesting opportunities and there is one dead tree standing in the area. In addition, there is a big pile of branches at the upper side of the orchard. Furthermore, there was a track that was cut out and left behind bare ground. During data collection there were four temporary beehives from a local beekeeper (Kilian, 2021) located in the northern part of the area (see Figure 9). The meadow was mown and the hay was taken out of the area shortly after data collection in the middle of June.

Aegopodium podagraria L.	A
Cerastium holosteoides Fr.	A
Fragaria vesca L.	B
Galium mollugo agg.	A
Lotus corniculatus L.	B
Medicago lupulina L.	C
Ranunculus acris L.	C
Trifolium pratense L.	A
Trifolium repens L.	A
Veronica chamaedrys agg.	A
Vicia sativa L.	A
Vicia sepium L.	B
Vicia tetrasperma (L.) Schreb.	B

Figure 11 Plant species and category of abundance and pattern within the area of the orchard of the LfL. Categories found: A - sporadic, B - patchy, C - distributed, but rare.

Description gardens

Knollen & Co Bachinger Moos

The community garden Knollen & Co Bachinger Moos is located in Vötting, at the south-western border of Freising (see Figure 5). It is located in the northernmost part of the original extent of the Freisinger Moos (peatland area). The bordering neighbourhood consists of a few houses with big gardens that are not directly adjoining the rest of the settlement. The neighbourhood is surrounded by agriculturally used grasslands in the north, west and south. To the east there is a forest patch consisting of old, mainly native trees such as *Salix alba* L. and *Fraxinus excelsior* L.. On the western side of the garden the stream Moosach forms the border towards the grassland, while in the north and south the neighbouring gardens are adjoining (see Figure 13). Here, species such as *Betula pendula* Roth, *Corylus avellana* L., *Ligustrum vulgare* L., *Crataegus sp.* L., *Cornus florida* L., *Thuja sp.* L. and other native as well as non-native species can be found, both isolated or within hedges. Just like the surroundings, the garden itself is flat. It has an area of 0.2 ha that includes a small garden shed and two polytunnels that are open on both sides (see Figure 12). Furthermore, there are beehives at the eastern end of the area. The garden is divided into two parts by a gravel-road that serves as access for the neighbourhood. On the eastern part there are several raised beds, while on the western part the beds are in the ground. The garden offers diverse structures such as compost heaps, piles of old wood, small stone walls and areas that are not mown. Additionally, there are young as well as middle aged trees. This

Figure 12 Impressions of the garden Knollen & Co Bachinger Moos.

Figure 13 Overview of the garden Knollen & Co Bachinger Moos including the position of the plots. Data source: LDBV (2020b)

Alliaria petiolata (M. Bieb.) Cavara et Grande	A
Allium sp. L.	A
Aquilegia vulgaris L.	A
Bellis perennis L.	A
Capsella bursa-pastoris (L.) Medik.	A
Chelidonium majus L.	A
Cucurbita sp. L.	A
Dianthus sp. L.	A
Glechoma hederacea L.	A
Iris sp. L.	A
Lamium album L.	A
Lamium purpureum agg.	A
Lapsana communis L.	A
Matricaria chamomilla L.	A
Myosotis sp. L.	A
Phacelia tanacetifolia Benth.	A
Potentilla anserina L.	A
Potentilla sp. L.	A
Ranunculus acris L.	A
Rosa sp. L.	A
Silybum marianum (L.) Gaertn.	A
Sinapis arvensis L.	A
Solanum sp. L.	A
Stellaria media (L.) Vill.	A
Symphytum sp. L.	A
Taraxacum officinale agg.	A
Trifolium pratense L.	A
Trifolium repens L.	A
Tripleurospermum inodorum (L.) Sch. Bip.	A
Veronica persica Poir.	A
Vicia sp. L.	A
Weigela sp. Thunb.	A

Figure 14 Plant species and category of abundance and pattern within the area of the garden Knollen & Co Bachinger Moos. Categories found: A - sporadic.

includes 4 fruit trees (apple, cherry and plum), 3 young ashes (*Fraxinus excelsior* L.), a norwegian spruce (*Picea abies* (L.) Karst.) and some flowering shrubs such as roses, *Ligustrum vulgare* L. and *Syringa sp*. L.. Within the garden there are 32 different flowering species, all of which were found sporadically (see Figure 14). The garden is jointly managed by association members in general, but there is the opportunity to cultivate a plot by oneself (Knollen & Co. e.V., 2019). Increasing the resilience by cultivating regional species is one of the main aims of the gardeners. In addition to the production of organic vegetables for own consumption, the garden is also thought to be a meeting point for the members of the association and a source for new ideas and initiatives (Knollen & Co. e.V., 2019).

Ökogartenanlage

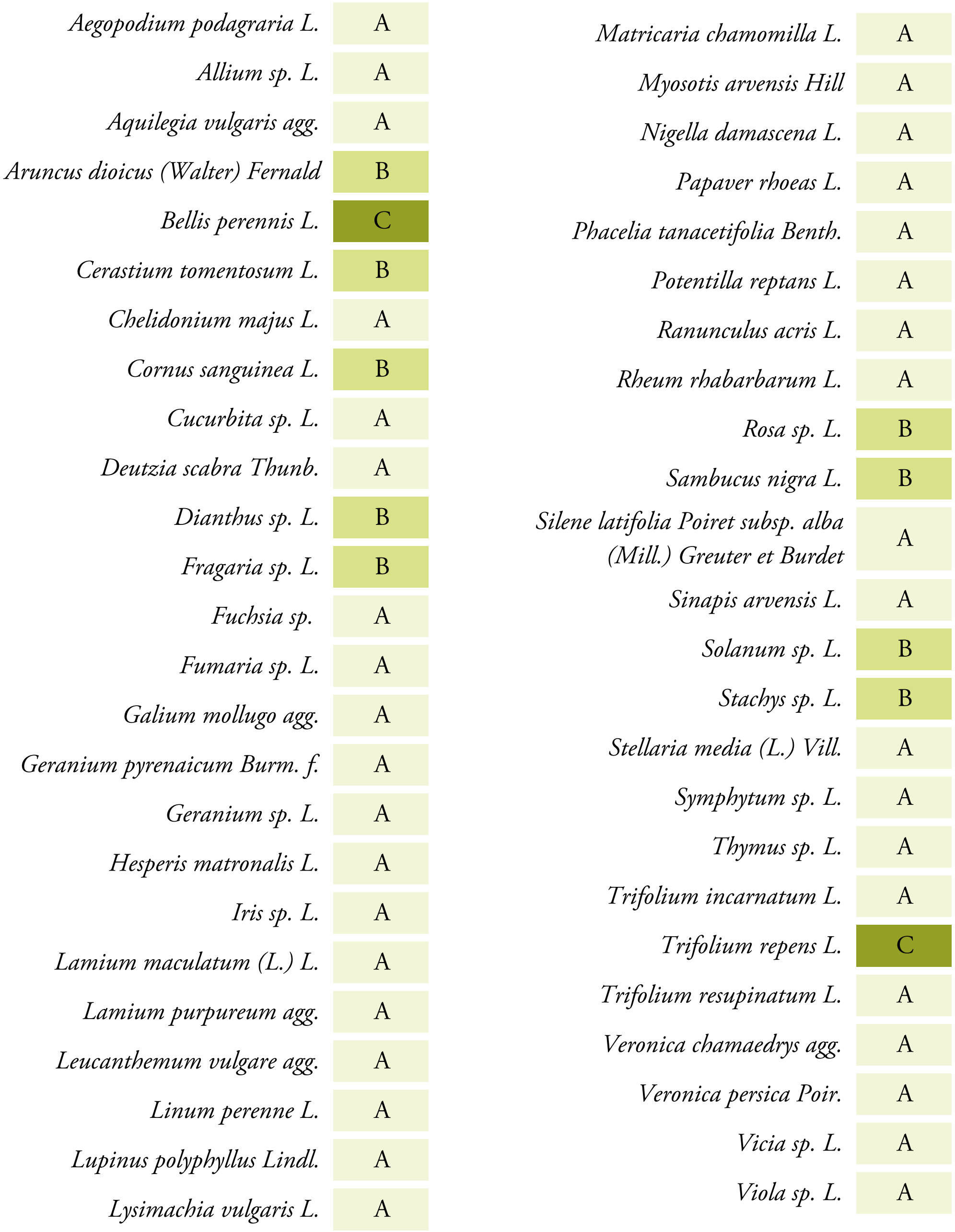
The „Ökogartenanlage“ is located in Vötting between the bridge leading over the Moosach in the north and the Vöttinger Weiher (pond) in the south (see Figure 5). The neighbourhood is characterised by allotment gardens, single-family houses and agricultural land, where the community garden forms the southernmost tip of the settlement structure. On the northern side the Mühlenangergraben, a mill stream, borders the garden area. A small path, leading along the stream, serves as a back entrance to the garden. A band of mainly native trees and shrubs surrounds the garden (see Figure 16). Species like *Prunus padus* L., *Fraxinus excelsior* L., *Sorbus aucuparia* L., *Betula pendula* Roth, *Sambucus sp.* L., *Cornus sp.* L., *Populus sp.* L. and *Salix sp.* L. can be found here. The garden held 49 flowering species, at the moment of data collection (see Figure 17). Most species were sporadic, while *Bellis perennis* L.

and *Trifolium repens* L. were distributed over the entire area, but not very abundantly either. Within the 0.8 ha large garden numerous structures can be found (see Figure 15). These include compost heaps, stone walls, cairns, bare ground, piles of branches, old plant stems, lying deadwood, nesting

Figure 15 Impression of the garden Ökogartenanlage.

Figure 16 Overview of the garden Ökogartenanlage including the position of the plots. Data source: LDBV (2020b)

aids and young and middle-aged trees and shrubs of diverse species. Also, there are different water sources to be found within the garden. The parcels are rented on a yearly basis and can be managed according to personal preferences (Lorenz, 2021). Many gardeners seem to keep their parcels for a long time. The owners of the garden aim for a sustainable management and cultivate their own parts as per permaculture rules. They try to inspire the other gardeners to do the same. In addition to the production of food for personal need, the needs of wild animals and insects are gaining attention from the gardeners (Lorenz, 2021).



Aegopodium podagraria L.	A
Allium sp. L.	A
Aquilegia vulgaris agg.	A
Aruncus dioicus (Walter) Fernald	B
Bellis perennis L.	C
Cerastium tomentosum L.	B
Chelidonium majus L.	A
Cornus sanguinea L.	B
Cucurbita sp. L.	A
Deutzia scabra Thunb.	A
Dianthus sp. L.	B
Fragaria sp. L.	B
Fuchsia sp.	A
Fumaria sp. L.	A
Galium mollugo agg.	A
Geranium pyrenaicum Burm. f.	A
Geranium sp. L.	A
Hesperis matronalis L.	A
Iris sp. L.	A
Lamium maculatum (L.) L.	A
Lamium purpureum agg.	A
Leucanthemum vulgare agg.	A
Linum perenne L.	A
Lupinus polyphyllus Lindl.	A
Lysimachia vulgaris L.	A
Matricaria chamomilla L.	A
Myosotis arvensis Hill	A
Nigella damascena L.	A
Papaver rhoeas L.	A
Phacelia tanacetifolia Benth.	A
Potentilla reptans L.	A
Ranunculus acris L.	A
Rheum rhabarbarum L.	A
Rosa sp. L.	B
Sambucus nigra L.	B
Silene latifolia Poiret subsp. alba (Mill.) Greuter et Burdet	A
Sinapis arvensis L.	A
Solanum sp. L.	B
Stachys sp. L.	B
Stellaria media (L.) Vill.	A
Symphytum sp. L.	A
Thymus sp. L.	A
Trifolium incarnatum L.	A
Trifolium repens L.	C
Trifolium resupinatum L.	A
Veronica chamaedrys agg.	A
Veronica persica Poir.	A
Vicia sp. L.	A
Viola sp. L.	A

Figure 17 Plant species and category of abundance and pattern within the area of the garden Ökogartenanlage. Categories found: A - sporadic, B - patchy, C - distributed, but rare.

Rural locations

Description orchards

Figure 18 Impression of the orchard in Sent Nuns.

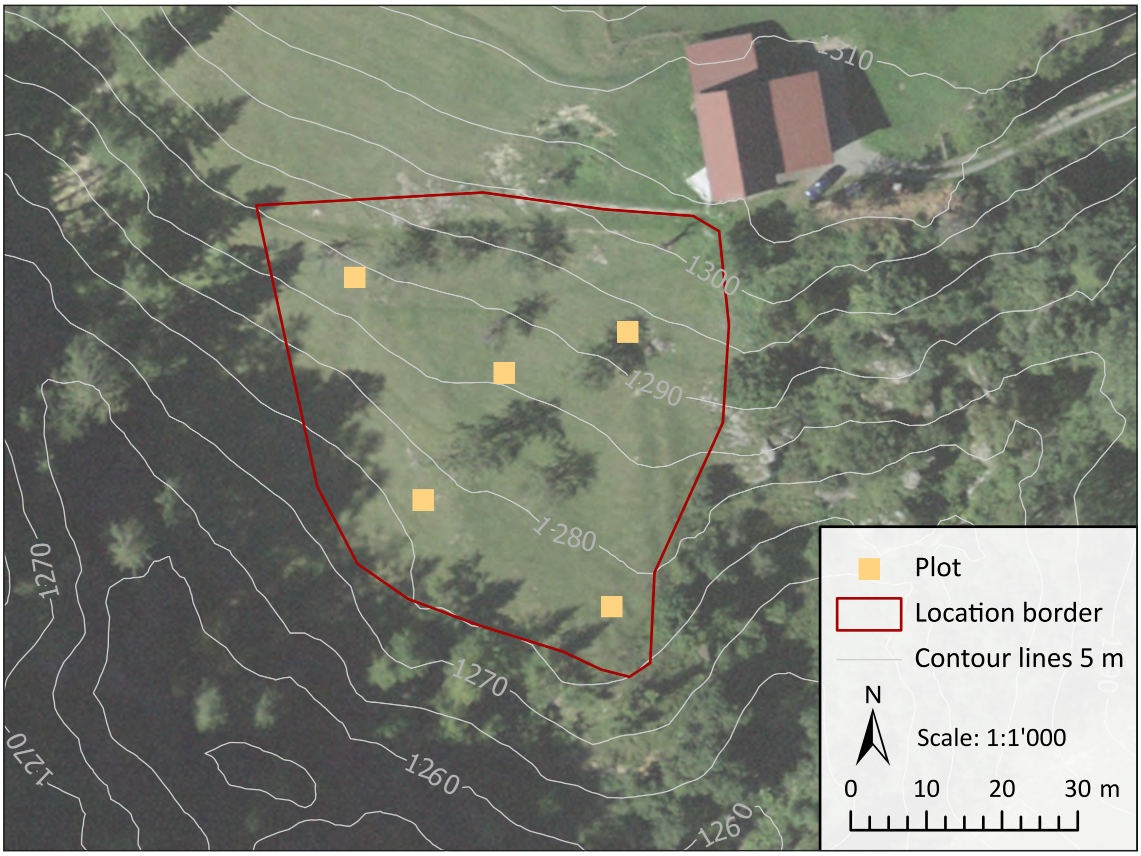


Figure 19 Overview of the orchard in Sent Nuns including the position of the plots. Data sources: swisstopo (2021b, 2020)

Sent Nuns

Nuns is located on a steep hillside of the Engadine valley, below the village of Sent, which belongs to the municipality of Scuol (see Figure 5). The area is limited by a forested gorge with a little stream to the west, while the landscape is more open on the slope towards the north, where the village is located (see Figure 19). To the south, the area ends at the edge of a much steeper slope that is overgrown with bushes. The eastern edge transitions into a bushy gorge that is less deep than the one to the west. An old farmhouse with an enclosed stable, which is used for the goats and sheep that pasture the orchard, is located on the area. The house can be reached by a gravel road. Unlike other orchards, where trees are planted in rows, the fruit trees are spread over the area unevenly. The trees are mainly in their old-growth stage, some of them are partially dead, others are left as standing deadwood in the area. In this project only the lower, steeper part of the orchard is regarded (see Figure 18). This almost 3,000 m^2 area had not been pastured by sheep for over one month at the point of data collection. Nevertheless, the vegetation was quite short, as goats are also kept in the area, moving around freely. In this area there are 10 fruit trees, mainly apple (*Malus domestica* Borkh.) and wild-cherry (*Prunus avium* (L.) L.). One of the cherry trees is standing deadwood. Additionally, there is one pear tree (*Pyrus communis* L.) in the area. During the fieldwork, the apple trees were still blooming. Additionally, there were 15 flowering species in the herb layer, where some were more abundant and regularly distributed than others (see Figure 20). As the orchard is very steep and exposed towards the south, it has a lot of small, warm patches with bare ground. Some break-off edges can also be found in the steepest parts of the area. Additionally, there is a long dry-stone wall separating the lower part of the orchard from the higher, flatter part (see Figure 18).

Anthriscus sylvestris (L.) Hoffm.	A
Arabis ciliata Clairv.	B
Bellis perennis L.	A
Campanula glomerata L.	A
Galium pumilum Murray	A
Helianthemum nummularium (L.) Mill.	A
Hieracium pilosella L.	B
Hippocrepis comosa L.	C
Leucanthemum vulgare agg.	A
Malus sp. Mill.	D
Medicago lupulina L.	A
Plantago media L.	C
Polygala vulgaris L.	A
Ranunculus bulbosus L.	C
Salvia pratensis L.	C
Veronica chamaedrys L.	A

Figure 20 Plant species and category of abundance and pattern within the area of the orchard in Sent Nuns. Categories found: A - sporadic, B - patchy, C - distributed, but rare, D - commonly distributed.

Ramosch Cumün

The second orchard in the Lower Engadine is in the village of Ramosch, which belongs to the municipality of Valsot (see Figure 5). The village is located on the south-oriented hillside of the valley about 150 m above the valley bottom. The orchard is situated at the eastern end of the village, forming a part of a bigger area that is partially planted with fruit trees and transitions to grasslands that surround the village (see Figure 22). While the orchard-like structure continues to the east and north, the orchard ends at a paved road to the south. Here, there are some more houses with their gardens. To the west, the orchard borders a small, gravelled path and a small square with a well and behind that the

Figure 21 Impression of the orchard in Ramosch Cumün.

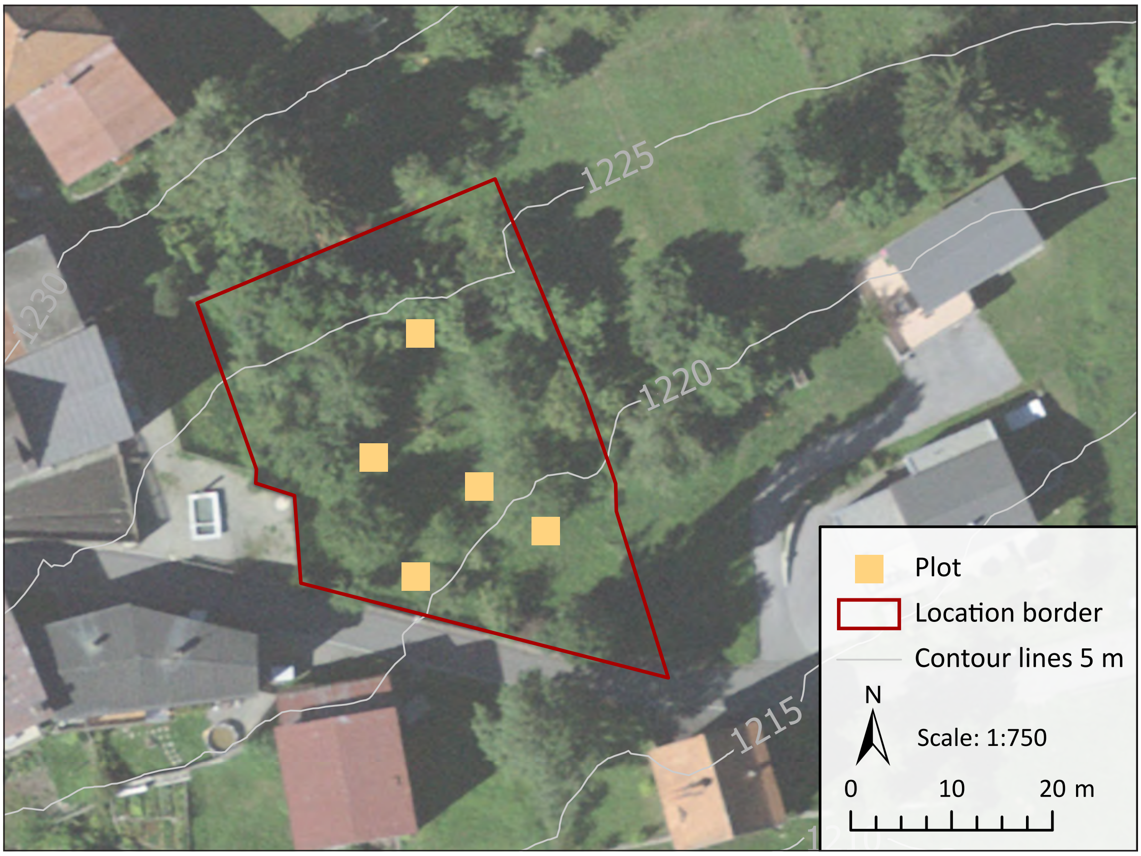


Figure 22 Overview of the orchard in Ramosch Cumün including the position of the plots. Data sources: swisstopo (2021b, 2020)

neighbouring house. The orchard is mainly surrounded by a wooden fence, even though it is on top of a wall in the southern and northern end in order to level out the differences towards the adjoining parcels of land (see Figure 21). On the adjoining parcel to the north, there is an apiary with honeybees. The 1,300 m^2 large orchard is slightly inclined towards the south-east, but quite flat in general. On the south-eastern edge there is a big pile of branches and a tall black poplar (*Populus nigra* L.). To the north and east, the area's border is hard to define, as trees, bushes, the wall and the fence have grown together into a thick, hedge-like structure. In general, the trees in the orchard are planted quite densely, with partially less than 3 m between the stems. Nevertheless, in the middle part of the orchard there is a more open area. The trees within the orchard are mainly apple trees (different sorts), two pear trees (*Pyrus communis* L.) and various trees from the *Prunus* genus, including some of the locally well-established subspecies *Prunus domestica ssp. insititia* (L.) Bonnier et Layens. Most of the trees are past their productive phase. Within the orchard 17 species were found flowering (see Figure 23). The area was dominated by *Anthriscus sylvestris* (L.) Hoffm., while *Rhinanthus alectorolophus* (Scop.) Pollich was less abundant. The other flowering species were not spread regularly. The orchard is managed very little. The meadow below the trees is mown twice a year, which resulted in vegetation that was up to 80 cm high during the fieldwork.

Anthriscus sylvestris (L.) Hoffm.	D
Bellis perennis L.	A
Buphthalmum salicifolium L.	A
Chelidonium majus L.	B
Crepis biennis L.	A
Geranium pyrenaicum Burm. f.	A
Heracleum sphondylium L.	B
Lamium album L.	B
Leucanthemum vulgare agg.	A
Myosotis arvensis Hill	B
Ranunculus acris L.	A
Ranunculus bulbosus L.	B
Rhinanthus alectorolophus (Scop.) Pollich	C
Silene dioica (L.) Clairv.	A
Silene vulgaris (Moench) Garcke	A
Taraxacum officinale agg.	A
Veronica chamaedrys L.	B

Figure 23 Plant species and category of abundance and pattern within the area of the orchard in Ramosch Cumün. Categories found: A - sporadic, B - patchy, C - distributed, but rare, D - commonly distributed.

Description gardens

Ramosch Sot Döss

The garden in Ramosch is located in Sot Döss, which is on the valley bottom south of Ramosch (see Figure 5). It is located on the plain between the river Inn (140 m away) and the steep south-oriented hillside. The close surroundings are mainly cultivated grasslands, partially used as pasture only. The landscape is quite small-structured and holding hedgerows, dry-stone walls and embankments (see Figure 25). On the steep parts of the hillside, there are some break-off edges as well as open ground.

Furthermore, the access to the garden is a road that is partially gravel and partially paved. The hillside on the other side of the valley is mainly forested, while the surrounding of the village Ramosch is a mainly open, terraced landscape. The garden Sot Döss itself is surrounded by hedges consisting of diverse, mainly native tree species, such as *Sorbus aucuparia* L., *Prunus padus* L., *Sambucus nigra* L..

Figure 24 Impression of the garden in Sot Döss.

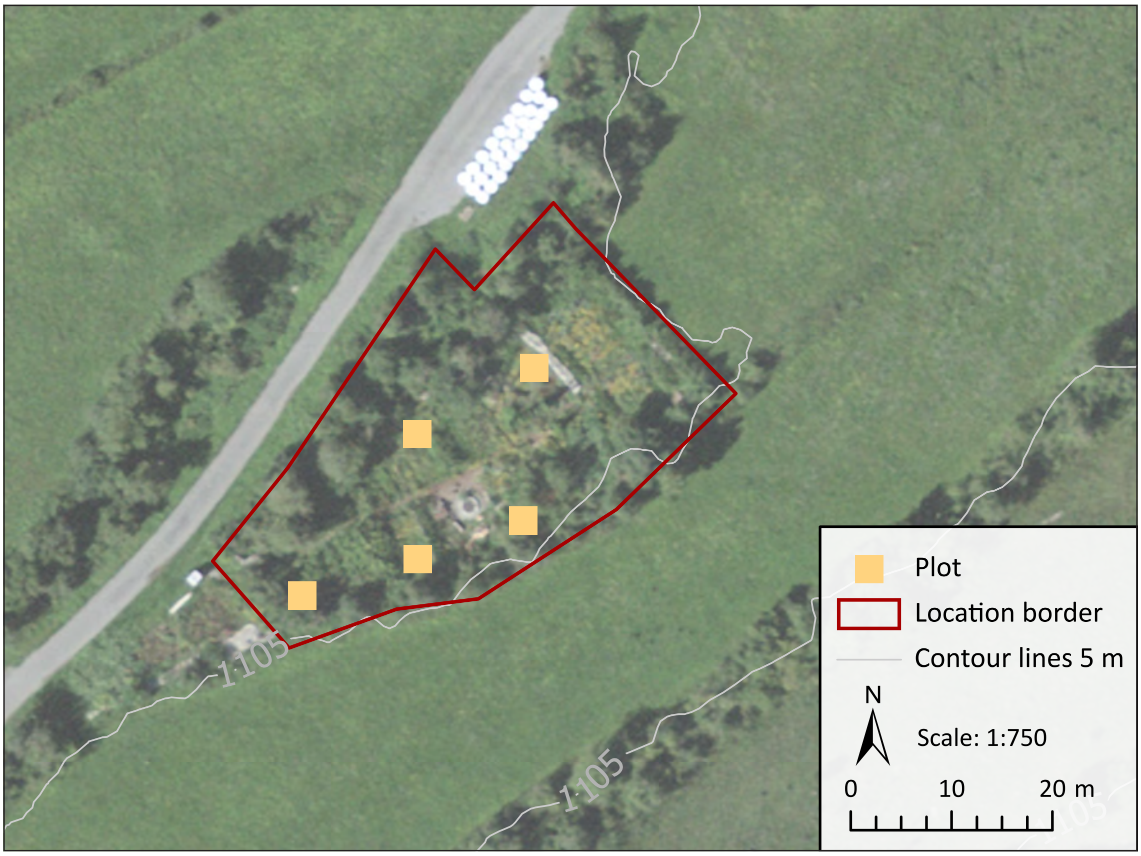


Figure 25 Overview of the garden in Sot Döss including the position of the plots. Data sources: swisstopo (2021b, 2020)

Within this hedgerow-structure there is standing and lying deadwood, stone-structures and piles of branches. The very same diversity of structures can also be found within the 1,100 m^2 large garden: dry-stone walls, a little pond, compost heaps, berry bushes, woven willow and different structures of old wood (see Figure 24). Furthermore, the paths within the garden are either soil, covered by plant materials (weeds), mulch, wooden panels or flat stones. During the fieldwork 23 different plant species were found flowering (see Figure 26). Except for *Glechoma hederacea* L. the species were not spread over the entire area, but sporadic or patchy in their occurrence. The garden is owned and managed by a family from Ramosch. The usage is mainly production of food for their own subsistence but also for recreational purposes. In addition to the reproduction of local and regional species, the owners are also actively trying to grow species and crossings from other places that might fit the local conditions.

Allium sp. L.	A
Anchusa officinalis L.	A
Anthriscus sylvestris (L.) Hoffm.	A
Aquilegia vulgaris L.	A
Capsella bursa-pastoris (L.) Medik.	A
Chelidonium majus L.	A
Euphorbia sp. L.	A
Fragaria sp. L.	B
Geranium sylvaticum L.	A
Glechoma hederacea L.	C
Lamium album L.	A
Lamium purpureum L.	A
Lunaria annua L.	A
Omphalodes verna 'alba'	A
Polemonium caeruleum L.	A
Potentilla sp. L.	A
Primula veris L.	A
Prunus padus L.	A
Pulmonaria sp.	A
Taraxacum officinale agg.	A
Veronica sp. L.	A
Viola sp. L.	B
X Sorbaronia fallax "Titan"	A

Figure 26 Plant species and category of abundance and pattern within the area of the garden in Sot Döss. Categories found: A - sporadic, B - patchy, C - distributed, but rare.

Cruschada

The garden in Crusch is called Cruschada – üert alpin. “Cruschada” means crossing, while “üert alpin” says what it actually is: an Alpine garden. Crusch is a small settlement that belongs to the municipality of Scuol and consists of 5 houses and a stable. It is located at the crossing where the road from Sent meets the main road of the valley (see Figure 5). Although the village is located in the hillside, the garden itself is relatively flat (see Figure 27). Directly around it, the area is used as a pasture for horses, containing 11 young fruit trees (see Figure 28). The surroundings on the south-oriented hillside are characterised by embankments and hedgerows holding native species like *Berberis vulgaris* L., *Corylus avellana* L., *Lonicera xylosteum* L., *Crataegus sp.* L., *Rhamnus sp.* L. and *Viburnum sp.* L.. In the lower part of the settlement there is an orchard as well as pastures that are partially very steep and therefore managed with goats. Here, break-off edges can be found. The garden with an area of 690 m^2 is enclosed by a wire fence with wooden posts. On the inside, there is a hut for the tools as well as a small paved terrace. In the western part there are two compost heaps and in the middle part

Figure 27 Impression of the garden Cruschada.

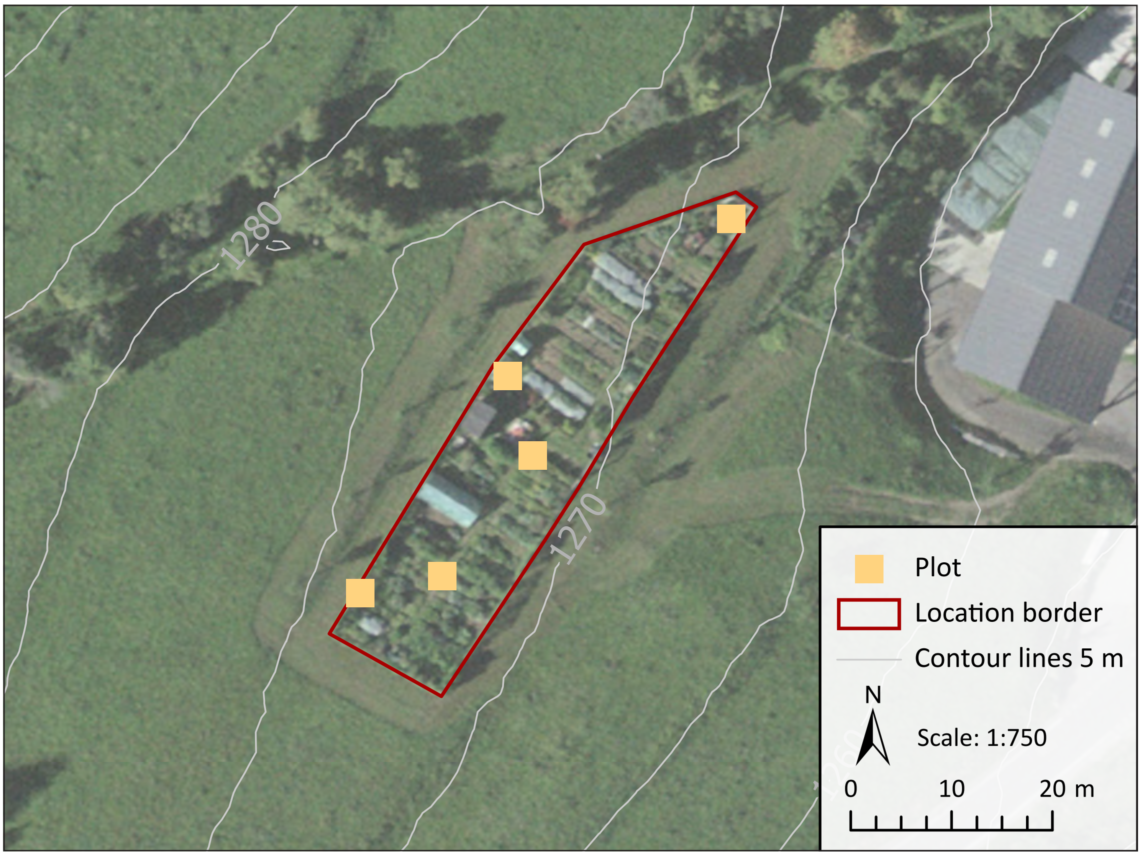


Figure 28 Overview of the garden Cruschada including the position of the plots. Data sources: swisstopo (2021b, 2020)

there are beds that are coverable (see Figure 27). At some of the beds the edge to the path is vertical and around 10-20 cm high. During the data collection many beds were covered with nonwoven fabric. Also, on the second date, the sprinklers were on, leaving the vegetation and soil wet during data collection. Within the garden, 18 species were found flowering during the fieldwork. The occurrence was rare, for all of the species, but some of them were found to occur in patches (see Figure 29). Cruschada is a garden used for organic food production, managed by a gardener who is part of the farming family in Crusch (Rauch et al., 2021). The products are for their own subsistence, but are also sold in different ways. One method is the so-called long-distance garden, where the customer gets a parcel that is planted after her/his own wishes, gets updates about the growth and gets the harvest. Another method is to buy the products based on a subscription method, where the customer can pick up a bag of vegetables every second week during the summer months. Lastly, there is an old wooden trailer at the roadside, where everyone is welcome to stop and buy vegetables, herbs or flowers from the garden (Rauch et al., 2021).

Allium sp. L.	A
Aronia melanocarpa (Michx.) Elliott	A
Bellis perennis L.	B
Bergenia sp. Moench	A
Capsella bursa-pastoris (L.) Medik.	A
Euphorbia sp. L.	A
Fragaria sp. L.	B
Geranium pyrenaicum Burm. f.	A
Lamium album L.	A
Mentha sp. L.	A
Myosotis sp. L.	B
Papaver croceum Ledeb.	A
Ranunculus bulbosus L.	A
Silene dioica (L.) Clairv.	A
Solanum sp. L.	A
Taraxacum officinale agg.	B
Veronica arvensis L.	A
Viola sp. L.	B

Figure 29 Plant species and category of abundance and pattern within the area of the garden Cruschada. Categories found: A - sporadic, B - patchy.

5. Results

Additional influences on pollinator abundance

In this study wind speed and cloud coverage did not provide an explanation for the number of pollinators observed in the plot. Here, the regression resulted in $F_{1,78} = 0.02$, $p = 0.9$ for wind speed and $F_{1,78} = 1.61$, $p = 0.21$ for cloud coverage. Thus, these results are not significant. The only weather variable that had a slight effect on pollinator numbers landing on flowers was the temperature ($F_{1,78} = 4.2$, $p = 0.04$), showing that less pollinators were observed at higher temperatures. A closer look into the data, differentiating between honeybees, wild bees and non-bee pollinators, showed that the difference related to temperature was mainly influenced by non-bee abundance ($F_{1,78} = 4.76$, $p = 0.03$). Neither honeybee, nor wild bee numbers showed a significant association with temperature changes. In the t-test comparing the two regions a significant difference between the temperature was found, showing a 3.48 °C higher mean temperature in Freising ($t_{39} = 10.83$, $p < 0.01$). The weather variables did not show any interactions in their effect on pollinator abundance.

Furthermore, the data analysis revealed no differences between data collected in the morning and data collected in the afternoon (mean difference of -0.53 pollinators), although this result is not significant ($t_{39} = -1.32$, $p = 0.2$). An influence of vegetation height on the number of pollinators was not found either ($F_{1,73} = 0.6$, $p = 0.44$). This test was run with a smaller sample of the data, dropping the counts where vegetation height was not measured. The t-test for difference of means between pollinator counts in gardens or orchards with beehives and locations without hives, had a non-significant result ($t_{6} = -0.61$, $p = 0.56$). The mean number of honeybees of the group with beehives was 0.18 higher than the mean of the group without beehives. However, the standard deviation was larger in the group without beehives (sd = 0.49) than in the group with beehives (sd = 0.3).

Abundance of pollinator groups in peri-urban and rural orchards and gardens

What is the abundance of different pollinator groups in peri-urban and rural orchards and gardens?

During this study a total of 603 insects were counted within the plots. 313 of them, were visiting flowers. In the analysis, only these flower-visiting insects were taken into account. With a total number of 169 individuals, the non-bee pollinator category represented slightly more than half of the counts (54 %). However, looking at the single classes (see Figure 30), solitary bees made up the biggest part of the total counts (22.7 %), followed by flies (20.5 %) and honeybees (19.5 %). Within the group of non-bee pollinators, beetles (15 %) and hoverflies (14.4 %) followed the flies in order of abundance. Bugs, butterflies, wasps and sphecoid-wasps accounted for less than 2 % each. Similarly, the bumblebees made up only 3.8 % of the totally counted insects.

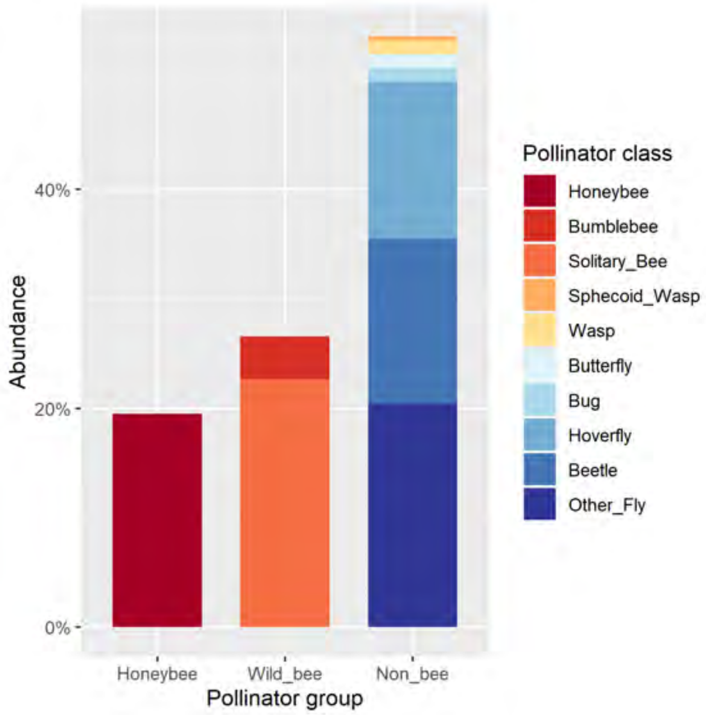


Figure 30 Abundance of counted flower visitations of pollinators within different groups and classes.

Comparing the abundances between the orchards and gardens in the rural and peri-urban regions, the peri-urban orchards clearly showed the lowest number of pollinators in this study (see Figure 32). Out

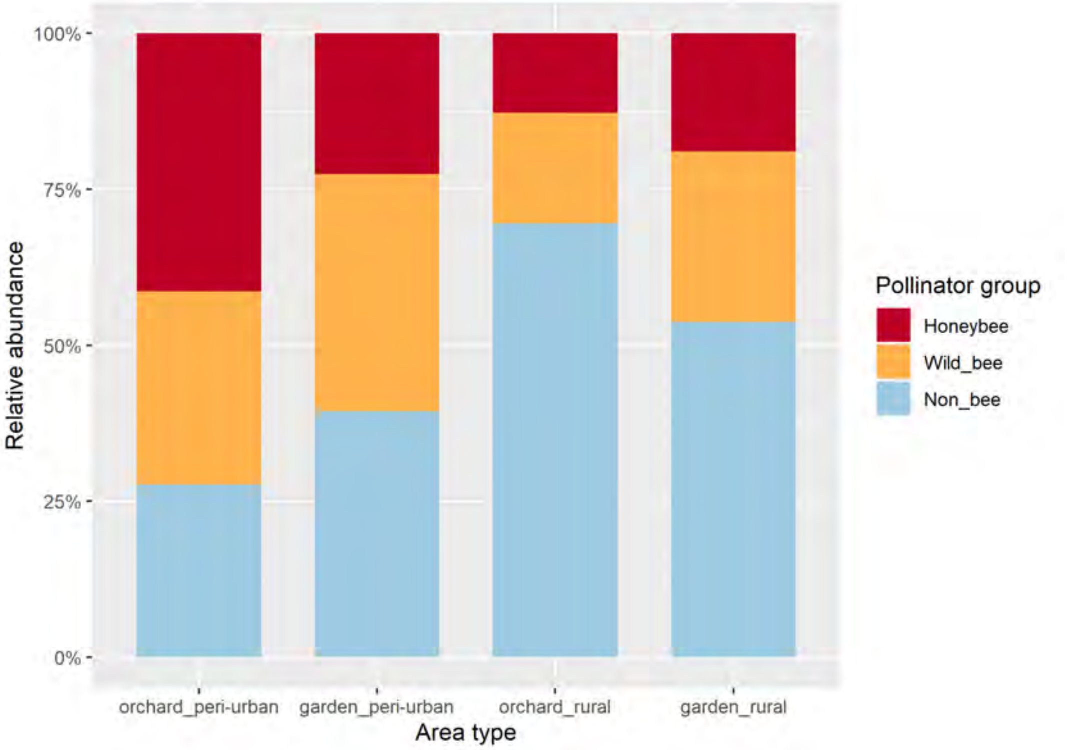


Figure 31 Relative abundance of pollinator groups within different area types.

of the total counts, only 9.3 % pollinators were counted within peri-urban orchards. This proportion was composed of 41.4 % honeybees, 31 % wild bees and 27.6 % non-bee pollinators (see Figure 31). Peri-urban orchards were the only areas where non-bee pollinators made up the least proportion of the total pollinator abundance. Nevertheless, the abundance and proportion of the non-bee group compared to bees was generally higher in rural surroundings, showing the highest relative abundance in rural orchards, where 69.5 % of the total counted individuals were non-bee insects (see Figure 31). The highest total as well as relative abundance of wild bees was found in peri-urban gardens with 27 counted individuals, contributing 38 % to the totally counted insects in these locations. Compared to rural gardens this was only one wild bee more, but the relative abundance in rural gardens was smaller (27.4 %). Flower visits of honeybees were registered most often in rural gardens (18), while 16 individuals were counted in peri-urban gardens and 15 in rural orchards. However, peri-urban gardens had a higher relative abundance of honeybees (22.5 %) compared to the rural areas (19 % in gardens and 12.7 % in orchards). The type of areas hosting most pollinators in this study were the rural orchards, holding 37.7 % of the total counted pollinators. This equals a total abundance of 118 individual pollinator counts in these areas.

To compare the main effects as well as the interaction of ecosystem type and rurality on total pollinator abundance, a two-way ANOVA was conducted. The results showed a significant interaction between the two explanatory variables ($F_{1,76} = 9.62$, $p < 0.01$). Looking closer, in a pairwise comparison the peri-urban orchards were significantly different in terms of pollinator abundance, compared to the other area types ($p < 0.01$) (see Figure 32).

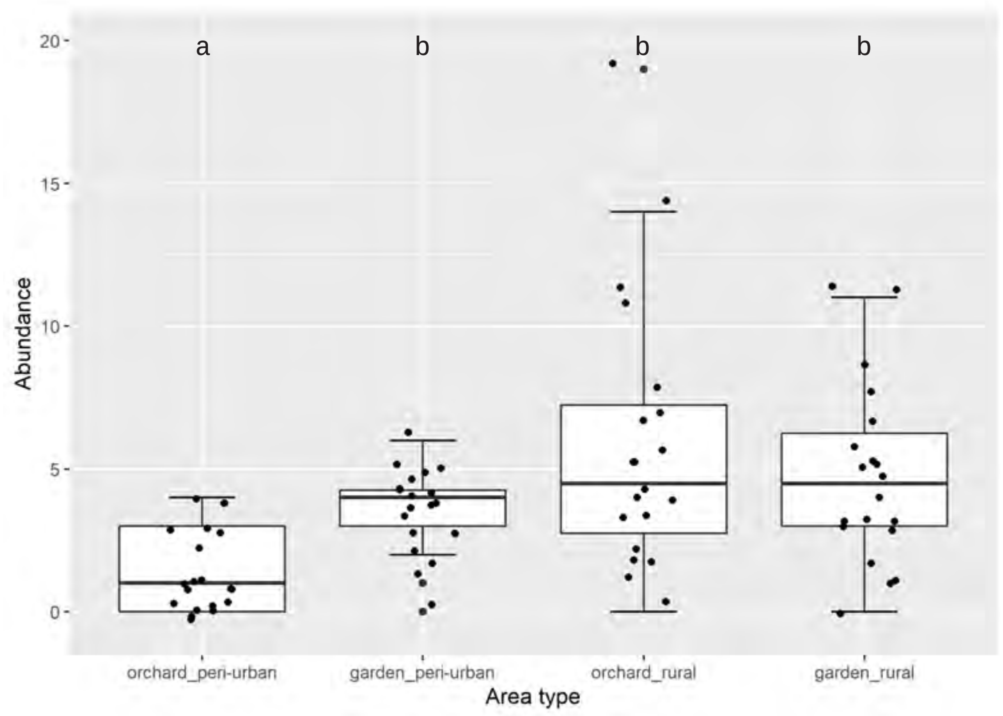


Figure 32 Differences of abundance of pollinators within different area types tested with an ANOVA. Letters indicate significant ($p < 0.05$) differences. Black dots indicate samples.

Feeding and nesting resources and their influence on pollinator abundance

What are the available feeding and nesting resources for pollinators in orchards and gardens and how do these resources influence pollinator abundance?

Within the feeding resources, the estimated flower coverage reached the highest mean in rural gardens with a mean coverage of 18.25 % (sd = 11.04 %) over the two repetitions of the 10 plots within this category. The plot with the highest coverage, belonging to the same area type, was in the garden Cruschada. This plot had an estimated coverage of 50 %. The lowest flower coverage was found within peri-urban orchards with a mean of 4.75 % (sd = 4.72 %). Peri-urban gardens and rural orchards had a similar mean flower coverage with 15.75 % (sd = 9.63 %) and 15.25 % (sd = 12.92 %) respectively.

Just like the flower coverage, rural gardens showed the highest mean Shannon diversity index with 1.07 (sd = 0.23), while peri-urban orchards had the lowest index with 0.66 (sd = 0.39) averaged over all the plots within this category. Peri-urban gardens and rural orchards showed a similar mean index, with rural orchards having a slightly higher diversity of 0.9 (sd = 0.28) compared to peri-urban gardens with 0.86 (sd = 0.4). Nevertheless, the plot with the highest diversity index (1.7) was in the peri-urban Ökogartenanlage in Freising.

Looking at the number of different flowering species, peri-urban gardens showed the highest numbers with a mean of 40.5 (sd = 8.72) species. Again, the Ökogartenanlage in Freising had the highest diversity with 49 flowering plant species registered (see Figure 17). This is almost double the number of species found in rural gardens (mean = 20.5, sd = 2.56). The orchards had a lower species diversity, counting a mean of 16.5 (sd = 0.51) species in rural and 11 (sd = 2.05) species in peri-urban orchards. Looking at the recorded categories, most species in all the locations were sporadic (category A) (see Figure 3). Indeed, the category D, explaining high abundance and a regular pattern, was not recorded in any of the gardens. The species recorded in gardens as distributed, but rare (category C), were common herbaceous species like *Trifolium repens* L., *Bellis perennis* L., *Glechoma hederacea* L.. In contrast, most orchards showed at least one species that was frequently found in the entire area. The orchard at the LfL is the only exception, showing no commonly distributed species (see Section 4.3).

Nesting structures on plot level were measured by the proxy of bare ground coverage. Generally speaking, gardens showed a higher ratio of bare ground than orchards. Rural gardens showed the highest coverage with 36.5 % (sd = 20.2 %), while peri-urban gardens showed a mean of 21.5 % (sd = 24.39 %) bare ground coverage per plot. The difference between peri-urban and rural orchards was much lower, with a mean bare ground coverage of 6 % (sd = 8.97 %) in peri-urban and 8.75 % (sd = 13.27 %) in rural orchards. Even though the means showed differences between the locations, the standard deviation showed that bare ground is not spread evenly on the location. Indeed, the peri-urban garden with the highest coverage within a plot (80 %) also included a plot with 0 % coverage of bare ground. Only the two gardens in the Lower Engadine showed bare ground in all their plots, while there was at least one plot with 0 % bare ground in all the other study locations.

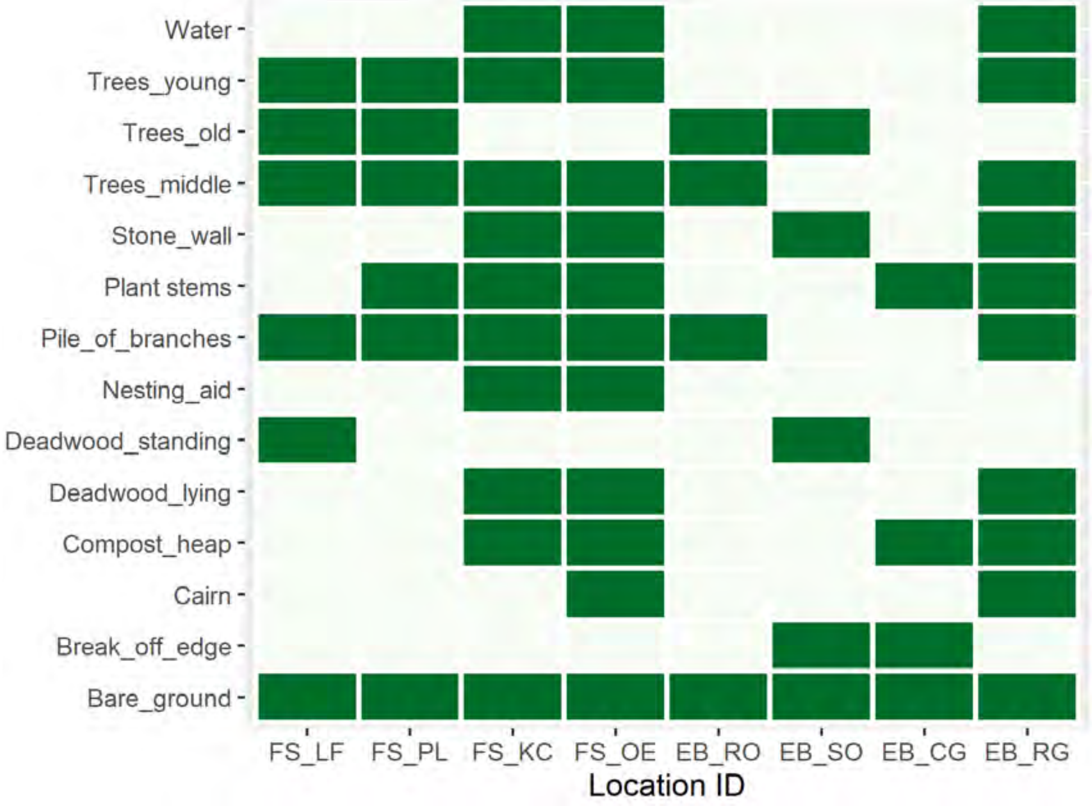


Figure 33 Availability of nesting resources within the different study locations. Dark green indicates availability, light green indicates lack of the resource. Locations are ordered by peri-urban orchards and gardens, followed by rural orchards and gardens (left to right). Location abbreviations: FS_LF Orchard LfL, FS_PL Orchard Plantage, FS_KC Garden Knollen&Co, FS_OE Garden Ökogartenanlage, EB_RO Orchard Ramosch Cumün, EB_SO Orchard Sent Nuns, EB_CG Garden Cruschada, EB_RG Garden Sot Döss.

Additional nesting structures to bare ground are shown in Figure 33. Gardens tended to have a greater variety of nesting structures than orchards, even though one garden in the Lower Engadine did not match this picture (Cruschada). A structure found in all gardens and in none of the orchards were compost heaps. Similarly, lying deadwood, plant stems, dry-stone walls and water structures were mostly found in gardens. Two exceptions were the orchard at the Plantage, where plant stems were recorded, and the rural orchard in Nuns which includes a long dry-stone wall. Cairns were found in gardens only, but have only been recorded twice in total. A structure that seemed to be universal in both peri-urban and rural as well as gardens and orchards was the formation of piles of branches. The only two locations that did not have this structure were the orchard in Sent, which is very steep and the garden in Crusch, which does not include any trees. In terms of deadwood, orchards tended to show standing, instead of lying deadwood. Here, two orchards, one rural and one peri-urban, included standing deadwood in addition to old trees, which were recorded in all the orchards. Middle-aged trees, forming most of the orchards (exception Nuns), were also recorded in all the gardens that included trees at all. Young trees, in contrast, were more frequently found in the peri-urban study locations. Similarly, nesting aids were found in peri-urban gardens only. In contrast, break off edges were only recorded in two of the rural sites.

The results from the Principal Component Analyses showed two general trends (see Figure 34). Firstly, more available bare ground and a higher feeding diversity was related to higher pollinator abundance. Secondly, gardens showed a higher amount of both resources and pollinators. This was very clear on both the plot (see Figure 34 a) and the location scale (see Figure 34 c) with total pollinator abundance, where the first dimension explained 42.1 % and 59.7 % of the variation respectively. Along this dimension, the mean of gardens was on the positive side, while the mean of orchards was on the negative side. The analysis of the abundance within each pollinator group on the plot level showed a much wider dispersal of the data then the other plots (see Figure 34 b). Here, the two dimensions explained only 54.3 % of the variation of the data together, indicating that the trends found here are not very strong. On the location level, the trends found for total pollinator abundance were also valid for the abundance of the pollinator groups (see Figure 34 d).

Significant correlations between pollinator abundance and bare ground or flowering diversity were not found (see Table 3). Nevertheless, the resources were generally positively correlated with pollinator abundance. On the plot level, total pollinator abundance was slightly stronger correlated with bare ground ($rs_{78} = 0.22$, $p = 0.05$) than with flower diversity ($rs_{78} = 0.18$, $p = 0.11$) (see Table 3 a). This was also found for the bee groups, while the correlation coefficients were not different between the two resources for the non-bee pollinators. However, the non-bee pollinator abundance showed a stronger correlation to both resources than both bee group abundances. On the location level, the correlation of total pollinator abundance was stronger with flower diversity ($r_6 = 0.43$, $p = 0.28$), than with bare ground ($r_6 = 0.2$, $p = 0.64$) (see Table 3 b). Here, the result was the same for non-bee abundance. Meanwhile, both bee groups showed stronger correlations with bare ground, compared to flower diversity. Comparing the bee groups, both resources showed stronger correlations with wild bee than with honeybee abundance. Looking at the correlations between pollinator groups, honeybees were significantly correlated with wild bees on the location level ($r_6 = 0.9$, $p < 0.01$). Non-bee abundance showed a positive, but weaker and non-significant relation with both bee group abundances. On the plot level, the correlation between non-bee and wild bee abundance was significant, but not very strong ($rs_{78} = 0.24$, $p = 0.04$).

A summary of the pollinator data and the feeding and nesting resources can be found in Appendix B.

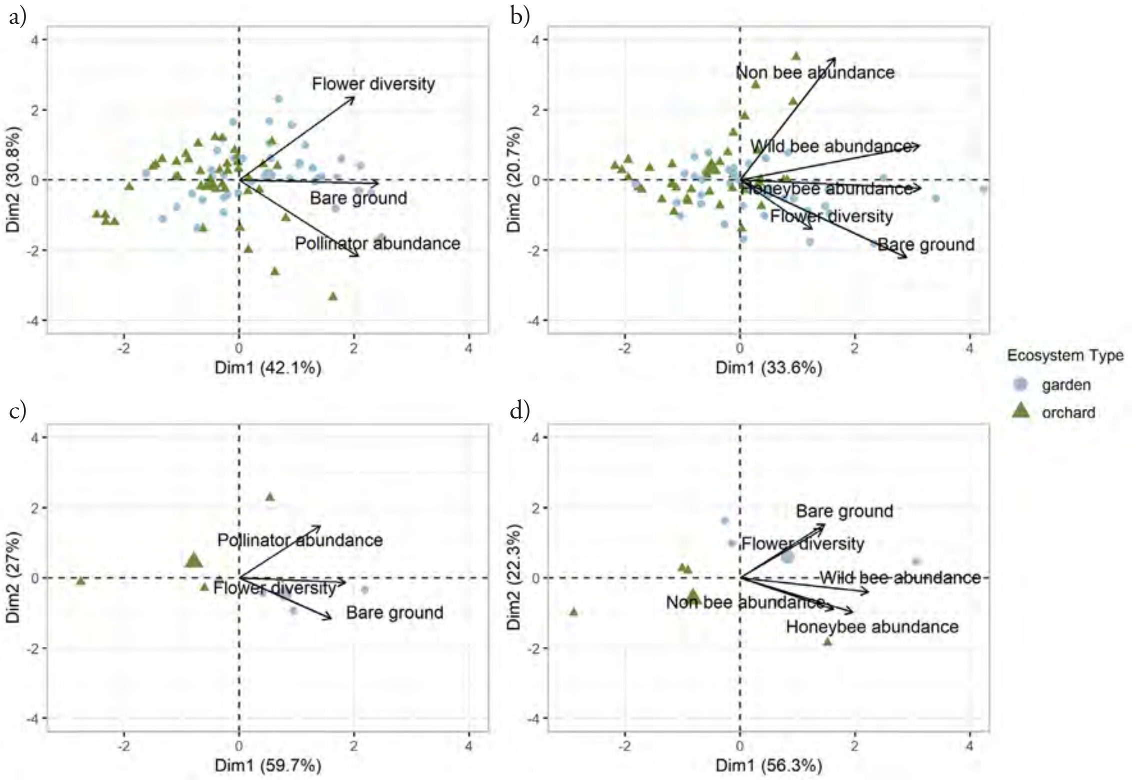


Figure 34 PCA biplots showing the relationship of feeding and nesting resources and pollinator abundance in orchards and gardens. The variables were standardised before calculation. The bigger symbols of each ecosystem type represent the mean. **a)** Total pollinator abundance and resources on the plot level, **b)** Pollinator group abundance and resources on the plot level, **c)** Total pollinator abundance and resources on the location level, **d)** Pollinator group abundance and resources on the location level

Table 3 Correlations between pollinator abundance and nesting (bare ground) and feeding (flower diversity) resources. Variables were standardised before calculation. No significant correlations were found. **a)** Spearman correlation coefficients on the plot level, **b)** Pearson correlation coefficients on the location level

a) Plot

	Bare ground	Flower diversity
Honeybee abundance	0.12	0.02
Wild bee abundance	0.15	0.08
Non bee abundance	0.21	0.21
Pollinator abundance	0.22	0.18

b) Location

	Bare ground	Flower diversity
Honeybee abundance	0.36	0.11
Wild bee abundance	0.53	0.39
Non bee abundance	0.01	0.44
Pollinator abundance	0.20	0.43

Landscape context and its influence on pollinator abundance

How do different landscape contexts influence pollinator abundance in orchards and gardens?

The landscape around the sites in the peri-urban and rural regions differ in the percentage of impervious area as well as the percentage of different land use classes (see Figure 35 & see Appendix C). Within one region the three buffer ranges (300 m, 500 m, 1 km) showed very little differences in imperviousness. The differences of mean percentage of built-up area between the smallest and the largest buffer were within 2 % in both regions. The impervious area around the study sites in the peri-urban region was around 10 % bigger than in the rural region. In the smallest buffer, the peri-urban locations were surrounded by a mean of 15.49 % (sd = 9.74 %) built-up area, while rural locations showed only 5.92 % (sd = 6.91 %). In other words, the built-up area was more than double in the peri-urban region compared to the rural. This means that a total ratio of 84.51 % and 94.08 % of the peri-urban and rural areas respectively was categorised as pervious within the smallest buffer. The pervious areas can again be split up into several land use classes. Here, there were more differences between the buffer sizes. Looking at rural areas, the percentage of grassland decreased, while the forest increased, with size of the buffer area. A similar trend was seen in peri-urban areas, where cropland and grasslands decreased, and forest increased with buffer size. Nevertheless, the increase in forest was much lower in the region of Freising (+6.21 %) than in the Lower Engadine (+13.36 %). Comparing the two regions, the most obvious difference is in cropland, which was almost absent in the Lower Engadine with a maximum mean of 1.34 % (sd = 2.54 %) within the smallest buffer, compared to 19.11 % (sd = 14.68 %) within

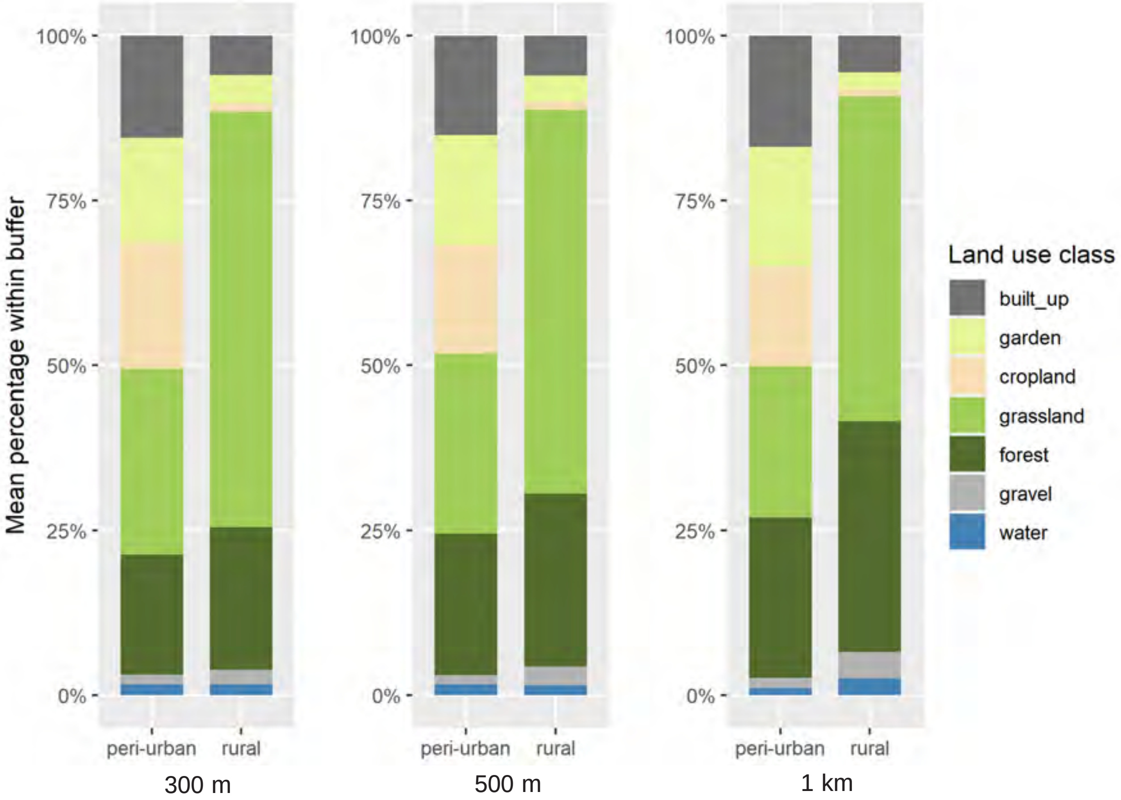


Figure 35 Mean percentage of land use classes within different buffer sizes (300 m, 500 m, 1 km) in the peri-urban and rural region.

the same buffer in Freising. The smaller area used for cropland and infrastructure (built-up) in the rural region, was found to be compensated by a higher amount of grassland and forest. In the 300 m buffer the grassland took up 63 % (sd = 4.23 %) of the area, while forest was recorded in 21.62 % (sd = 11.34 %) of the rural area. In the peri-urban surroundings, grasslands constituted 28.13 % (sd = 20.21 %) and forests 18.15 % (sd = 19.02 %) of the total area within the small buffer. In general, the land use classes had a similar distribution within the different categories in the peri-urban area ranging from about 15 % to 27 % each (besides water and gravel that were both lower than 2 %). In the rural area, forests (mean = 21.62 % and 34.98 %, sd= 11.35 % and 14.15 %) and grasslands (mean = 63 % and 49.31 %, sd = 4.23 % and 14.03 %) were dominant in both the smaller and the larger buffer. The other land use and vegetation types represented less than 6 % each in these two buffers (see Figure 35).

The Principal Component Analyses on the land use categories and the pollinators showed clearer differences between the ecosystem types and the regions with increasing buffer size (see Figure 36). Within the largest buffer (1 km radius) the rurality was mainly described by the first dimension (see Figure 36 e & f). Peri-urban and rural gardens were not only different on the first, but also on the second dimension, which was also found for orchards. The main contributions to the first dimension derived from the built-up and the garden class on the negative side and pollinators on the positive side, while the second dimension, describing 24.1 % of the variance, was mainly influenced by the forest class. This suggests more built up and garden area in the peri-urban environment and a difference in the amount of forest between gardens and orchards of each region. Within the different pollinator groups, non-bee abundance contributed the most to the first dimension, suggesting higher abundances in rural areas (see Figure 36 f). In the plots of the 500 m buffer, a similar picture was found, even though it was less clear (see Figure 36 c & d). Comparing with the 300 m buffer, there was a trend for the data to group differently with decreasing buffer size. This grouping showed a difference between peri-urban orchards and the other three area types (peri-urban gardens, rural orchards and rural gardens). However, the variance of the data within the plots of the smallest buffer (see Figure 36 a & b) was not as clearly explained, as the larger buffer's data variance.

Looking at the correlation matrix resulting from the three buffers, a significant correlation between total pollinator abundance and a land use category was only found on the largest buffer (see Table 4 c). Here, built-up area was negatively correlated with pollinator abundance ($rs_6 = -0.71$, $p = 0.05$). The garden and cropland classes showed similar negative coefficients, however not significant ($rs_6 = -0.69$, $p = 0.06$ with garden and $rs_6 = -0.62$, $p = 0.1$ with cropland). Within the two smaller buffer sizes these three classes showed negative correlations with pollinator abundance (see Table 4 a & b). However, the strength decreased, the smaller the buffer size got. A positive correlation of pollinator numbers with grasslands was found in all the buffer sizes, even though it was not significant. Forest, gravel and water were not correlating with total pollinator abundance on any scale, except for water on the largest scale ($rs_6 = 0.6$, $p = 0.12$). Significant correlation between a land use class and the

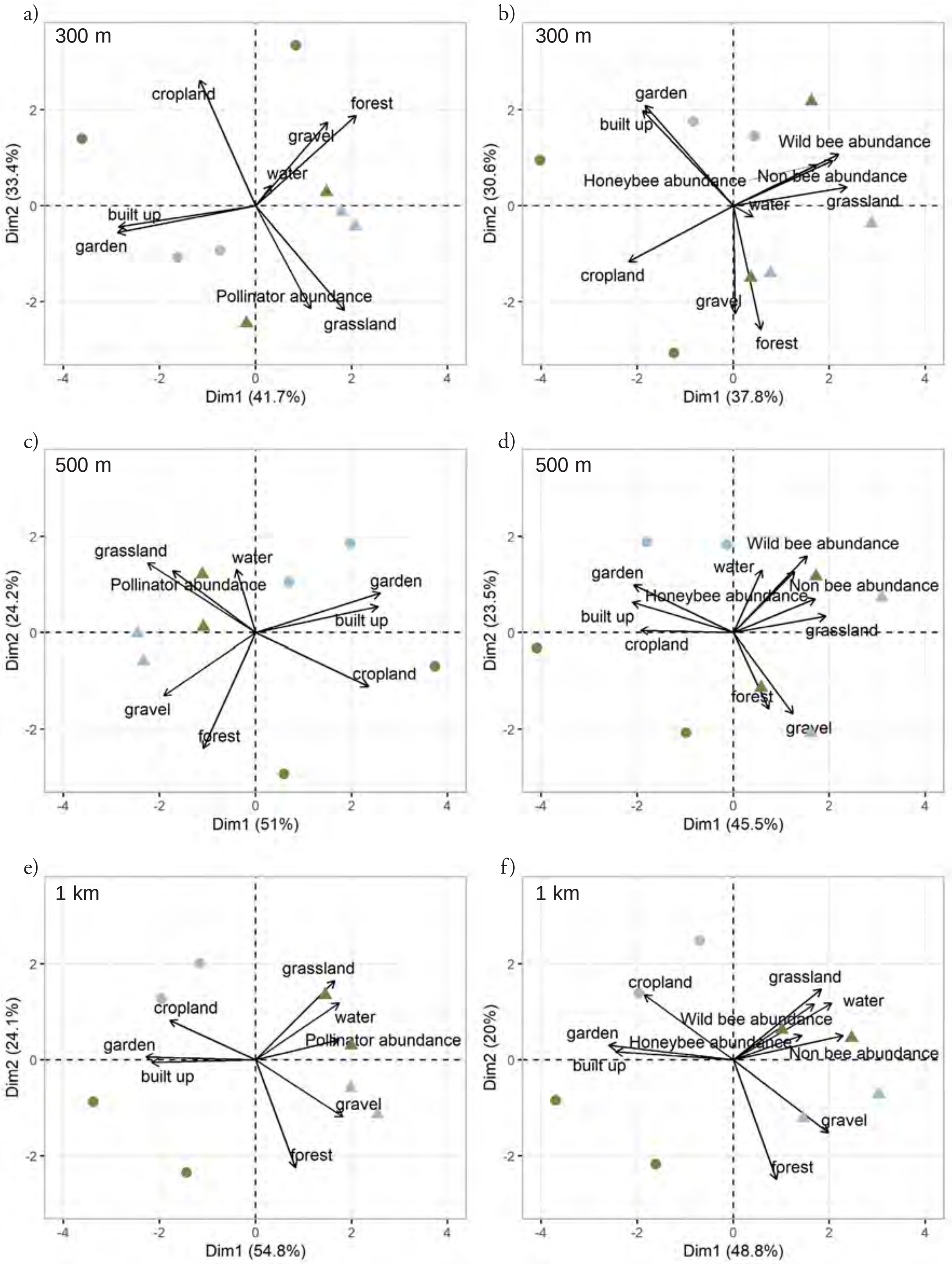


Figure 36 PCA biplots showing the relationship of different land use classes and pollinator abundance in different area types and buffer sizes. **a)** Total pollinator abundance - 300 m, **b)** Pollinator group abundance - 300 m, **c)** Total pollinator abundance - 500 m, **d)** Pollinator group abundance - 500 m, **e)** Total pollinator abundance - 1 km, **f)** Pollinator group abundance - 1 km

abundance of a single pollinator group was only found for the non-bee abundance. On all three scales, this pollinator group was significantly negatively correlated with cropland (300m buffer: $rs_6 = -0.82$, $p = 0.02$, 500 m buffer: $rs_6 = -0.76$, $p = 0.03$ and 1 km buffer: $rs_6 = -0.83$, $p = 0.01$). Furthermore, non-bee abundance was correlated negatively with the built-up ($rs_6 = -0.83$, $p = 0.01$) and the garden

Table 4 Correlations between pollinator abundance and different land use classes. Variables were standardised before calculation. All the correlations were calculated using Spearman correlation. Bold font indicates significance ($p < 0.05$). **a)** Correlations on the 300 m buffer, **b)** Correlations on the 500 m buffer, **c)** Correlations on the 1000 km buffer

a) 300 m

	built up	cropland	forest	garden	grassland	gravel	water
Honeybee abundance	-0.07	0.05	-0.07	-0.06	-0.13	-0.25	0.41
Wild bee abundance	-0.29	-0.21	0.10	-0.28	0.17	-0.38	0.50
Non bee abundance	-0.36	**-0.82**	0.12	-0.52	**0.83**	-0.07	-0.40
Pollinator abundance	-0.26	-0.68	0.02	-0.40	0.69	-0.31	-0.30

b) 500 m

	built up	cropland	forest	garden	grassland	gravel	water
Honeybee abundance	-0.15	0.33	0.08	-0.06	-0.25	-0.32	0.15
Wild bee abundance	-0.29	-0.04	-0.01	-0.16	0.08	-0.29	0.44
Non bee abundance	-0.52	**-0.76**	0.21	-0.57	**0.79**	0.26	0.07
Pollinator abundance	-0.38	-0.55	0.05	-0.40	0.62	-0.02	0.14

c) 1 km

	built up	cropland	forest	garden	grassland	gravel	water
Honeybee abundance	-0.06	-0.16	0.18	-0.10	-0.33	-0.08	0.08
Wild bee abundance	-0.28	-0.23	-0.01	-0.32	-0.01	-0.04	0.40
Non bee abundance	**-0.83**	**-0.83**	0.12	**-0.81**	**0.71**	0.48	**0.71**
Pollinator abundance	**-0.71**	-0.62	-0.05	-0.69	0.60	0.21	0.60

class (rs_6 = -0.81, p = 0.01) on the largest buffer. This was also true for the smaller buffers, although not significant. Positive correlations with non-bee abundance were found with grasslands in the surrounding reaching significance at all scales (300 m buffer: rs_6 = 0.83, p = 0.01, 500 m buffer: rs_6 = 0.79, p = 0.03 and 1 km buffer: rs_6 = 0.71, p = 0.05). On the largest scale, non-bee abundance was further positively correlated to water (rs_6 = 0.71, p = 0.05). However, this correlation was not found on smaller scales. The results from both bee groups were not significant on any scale and the calculated correlation coefficients were very weak for most land use classes, showing very little trends. While the correlation coefficients with different land use classes varied a lot between the three buffer scales with honeybee abundance, wild bee abundance showed some trends with certain land use types. Built-up area, cropland and garden classes were correlated negatively, while water was correlated positively with wild bee abundance on all scales. The remaining land use types showed high fluctuations in their correlation with wild bee numbers comparing the three buffer-sizes.

6. Discussion

This study aimed to compare pollinators in peri-urban and rural orchards and gardens and to find explanations for different abundances. The results shall contribute to a better understanding of the needs to protect and promote pollinators. The method chosen aimed for an easy implementation, while still producing results that can contribute to current research.

6.1 Main findings

What is the abundance of different pollinator groups in peri-urban and rural orchards and gardens?

One main finding of this study is that peri-urban orchards differed from peri-urban gardens as well as rural orchards and gardens in terms of their pollinator abundance. As both gardens and orchards are considered important habitats for wild bees (Kay et al., 2020; Potts et al., 2003; Zurbuchen & Müller, 2012), a difference between the two was not expected. However, differences in pollinator abundances and group compositions along the urbanisation gradient were reported from different places (Ahrné et al., 2009; Baldock et al., 2015; Geslin et al., 2013). Whether the abundance is higher or lower with a higher degree of urbanisation depends on the surrounding landscape (e.g. low pollinator abundance in intensively used agricultural landscapes) as well as the availability and quality of urban green spaces (Wenzel et al., 2020). Thus, the local availability of feeding and nesting resources, as well as landscape scale effects of different land use types, could be explanations for the lower number of pollinators in peri-urban orchards. These effects are discussed in the two following questions.

Generally, non-bee pollinators represented a bigger part of the total pollinators in rural, than in peri-urban areas. A study in the UK found higher abundance of hoverflies in farmland and nature reserves than in urban areas (Baldock et al., 2015), supporting the differences found between peri-urban gardens and rural locations in this study. This is further supported by the experimental study by Geslin et al. (2013) who reported less pollinators from the groups of hoverflies, other flies, beetles and solitary bees, with a higher degree of urbanisation. The corresponding effect on wild bees was only partially seen in this study, as peri-urban gardens showed a high total as well as relative abundance, while peri-urban orchards did not. Similarly, Baldock et al. (2015) found no differences in bee abundance between the landscape types studied (farmland, nature reserves and urban areas). Daniels et al. (2020) found that pollinator abundance in community gardens is different from other urban park types and very similar to the rural reference within the study. In another study, residential and community gardens were found to be hotspots within the urban context (Baldock et al., 2019). An underlying reason is that the management and availability of feeding and nesting resources within different sites are crucial factors for pollinator abundance (Ayers & Rehan, 2021; Hülsmann et al., 2015; Levé et al., 2019). This supports the difference between the two peri-urban ecosystem types as well as the similarity between the rural locations and the peri-urban gardens found in the present study.

Summing up, the abundance of pollinators in this study was higher in rural than in peri-urban orchards. Gardens did not show an effect of urbanisation in the total pollinator abundance. However, non-bee pollinator numbers were generally higher in rural than in peri-urban areas, regardless of the ecosystem type.

What are the available feeding and nesting resources for pollinators in orchards and gardens and how do these resources influence pollinator abundance?

All the feeding resources measured showed the lowest scores in peri-urban orchards. On the location scale, the feeding diversity was higher in gardens than in orchards. However, this difference was not seen on the plot scale neither in flower coverage nor diversity of flowering species (see section 6.2). Both garden groups showed high diversity and richness in nesting and feeding resources, suggesting relatively good habitat quality (Zurbuchen & Müller, 2012). Meanwhile, orchards, especially the ones in Freising, showed less availability of these resources. A difference of nesting resource availability between peri-urban and rural sites was not noted. The integration of these location scale variables into the statistical analysis would have been beneficial, as discussed in the section 6.2.

Bare ground and feeding diversity showed a very clear positive connection with pollinator abundance in this study, even though the correlation matrices did not show significant correlations. Thus, the detailed relations between each of the resources and the abundances of the pollinator groups are not very clear on neither of the two scales (plot and location). The correlations on the location level suggest a higher reliance on bare ground than on flower diversity for both bee group abundances. The correlations were stronger for wild bee than for honeybee abundance with both resources. This suggests a stronger benefit for wild bees from a diverse habitat with ground nesting possibilities and diverse feeding plants, compared to honeybees. Many wild bee species need bare ground as a nesting resource, which could therefore influence wild bee abundance in a specific location (Antoine & Forrest, 2021). Honeybees in contrast, are not relying on bare ground as they are living in beehives and taken care of by beekeepers (Zurbuchen & Müller, 2012). The stronger correlation with flower diversity for wild bee compared to honeybee abundance was also found in a study about flower strips in orchards, where additional flowers, thus a higher diversity and abundance, boosted wild bee, but not honeybee abundance (Campbell et al., 2017). Non-bee pollinator numbers showed a stronger correlation with flower diversity than with bare ground. This is supported by Jauker et al. (2009), suggesting that hoverflies, as part of the non-bee pollinators, are less dependent on specific habitat conditions in comparison to wild bees, due to the different lifecycles and dependencies of different species. Furthermore, bare ground is not a specifically needed nesting resource for hoverflies, while they are relying on flowering diversity, as adult hoverflies feed on both nectar and pollen (Bartsch et al., 2009).

Nesting and feeding resources were more abundant in gardens than in orchards and can thus provide an explanation for the higher pollinator abundances found in these ecosystems within this study. The result indicates, that gardens are an important habitat for pollinators, offering bare ground as a nesting possibility as well as a high flower diversity as a feeding resource. These local resources showed positive relations with pollinator abundance. Several studies found that gardens can overcome negative effects on pollinators of the surrounding environment (especially impervious area) (Ayers & Rehan, 2021; Levé et al., 2019), explaining the difference between peri-urban orchards and gardens found here. However, the results have to be interpreted with caution, as the dataset of this study was very small resulting in non-significant results. Also, correlations do not imply causation, suggesting that the found differences between area types could be caused by aspects which were not studied, while still correlating with the resources regarded. Furthermore, bare ground is not a suitable nesting resource for all the pollinators included in the study and some possible underlying effects, like management were not taken into account (see section 6.2).

How do different landscape contexts influence pollinator abundance in orchards and gardens?

Land use types showed different effects on pollinator abundances, with clearest results on the largest buffer scale (1 km). As found in other studies (Burdine & McCluney, 2019; Levé et al., 2019; Wenzel et al., 2020), the results showed a negative trend for pollinator abundance, the more built-up an area is. Specifically, wild bee and non-bee abundances showed these negative correlations. The effect of urbanisation, using proportion of impervious surface as an indicator, was studied by Geslin et al. (2016), who found negative effects on wild bee abundance, especially for ground nesting species. For flies (Diptera), Lagucki et al. (2017) found similar negative trends with increase of built-up area, suggesting underlying mechanisms like habitat loss and physiological changes of the surroundings.

Further negative trends for total pollinator abundance, but specifically for non-bee and wild bee abundance were found with the garden land use category. Other studies, that took into account gardens in the surrounding area of pollinator habitats reported positive effects of this land use, even though these results were found on a much smaller scale (>140 m) (Levé et al., 2019; Samnegård et al., 2011). As the garden category within this study included different types of green space (see Table 2), these might have different qualities for pollinators (Ayers & Rehan, 2021). Assuming high habitat quality in the areas categorised as garden, pollinators could be attracted into these habitats, as gardens are often showing concentrated richness of resources and the small-scale character is beneficial for pollinators (Zurbuchen & Müller, 2012). The consequence could be a decreased pollinator density as the same number of insects would be spread over more available habitats. This would suggest that gardens do not have a negative impact on pollinators per se, but do decrease the density in the single habitats. Nevertheless, the quality of the habitats within the garden category could be low, leading to a lack of resources in the entire area and thus low numbers of pollinators. Summing up, the negative impact of gardens remains weakly understood and requires further research.

The third land use type that showed negative correlations with total pollinator, wild bee and non-bee abundance, was cropland. Pfister et al. (2018) found similar negative effects on flower visitation by bees with increased cropland. Nevertheless, other studies found differing effects, depending on scale, crop and pollinator group (Mogren et al., 2016) or no effects from the land use type at all (Mallinger et al., 2016). The effect of cropland on pollinators is not well understood and is often not taken into account in pollinator studies (Garibaldi et al., 2011; Petersen & Nault, 2014; Taki et al., 2010). Here, I suggest further research.

A very clear positive correlation with total pollinator abundance was found with grasslands. This land use type is often counted as semi-natural habitat and associated with positive effects on pollinator abundance (Garibaldi et al., 2011; Jauker et al., 2009; Meyer et al., 2009; Petersen & Nault, 2014; Pfister et al., 2018; Xie & An, 2014). However, the positive relation was only found with abundance of non-bee pollinators, while both bee groups did not show clear results for this land use. The result for non-bee pollinators goes in line with the review by Rader et al. (2016) and results from other studies (Meyer et al., 2009; Taki et al., 2010). Meanwhile, the fluctuations within the results of wild bee abundances on the different scales could be related to the diversity of grasslands within the category, which was not taken into account in this study. The type and intensity of use have a high influence on the availability of feeding and nesting resources and are therefore relevant for wild bees (Klein et al., 2012; Zurbuchen & Müller, 2012).

In addition to the grasslands, positive correlations with water were found in the largest buffer. This is valid for total pollinator abundance as well as non-bee and wild bee abundance. Wild bee numbers were positively correlated with water on all the buffer scales. However, these results were not significant. Meanwhile, non-bee abundance was positively correlated to water on the largest scale only. Some hoverfly species are relying on water resources (existing at least temporary) (Bartsch et al., 2009), which approves the correlation found within this study. Even though positive correlation with water was partially found in other studies (Pfister et al., 2018; Stewart et al., 2017), Mogren et al. (2016) did not find any effects of aquatic habitats on pollinators. Like (Stewart et al., 2017) suggest, further research on the effects of water habitats on pollinators is needed, especially to identify if it is water-associated habitat or the aquatic habitat itself, that favours pollinators and to better understand the underlying reasons for reliance on water habitats of different pollinators.

The forest and gravel categories did not show clear correlations with any of the pollinator groups, suggesting that these land use classes do not have an influence on pollinators. However, these results were not significant.

In contrast to non-bee and wild bee abundances, the honeybee numbers did not show clear correlations with any of the land use classes. This could be related to the fact, that honeybees are not relying on nesting resources in the landscape and are thus dependent on the feeding availability only (Zurbuchen & Müller, 2012). Földesi et al. (2016) found the same independence of honeybees in their study on the influence of landscape contexts on pollination success in orchards, suggesting the larger flying ranges of honeybees compared to wild bees as an underlying reason. In general, the increasing clarity of results with increasing buffer size suggests that land use effects are more relevant on the larger scale, while the abundance of pollinators cannot be explained by the surroundings on the small scale. Other studies have found strong influences of landscape context on pollinators on lager scales (3 km) (Bartholomée et al., 2020; Mogren et al., 2016; Moreira et al., 2015), which could not be considered in this study (see section 6.2). Calculating the correlations separately for orchards and gardens would allow to draw more specific conclusions, as the results are indicating that the local feeding and nesting resources might be more important than the close surroundings. Thus, comparing the effect of land use classes on pollinator abundance between locations with different local resources could give further insights. However, the dataset was too small to conduct this analysis (see section 6.2).

In this study, built-up area, garden and cropland showed negative correlations with pollinator abundance, while grassland was correlated positively. The results were especially clear for non-bee pollinators, providing a possible explanation for the low numbers within the peri-urban region. The influence of the land use classes was clearer on a larger scale, while on the local scale, the available feeding and nesting resources were more relevant.

6.2 Limitations and further research

Study design

In the frame of a bachelor thesis, the limited time to conduct a study is connected to some compromises that had to be taken. The data-collection could only be repeated once on every plot, which means that the results presented here are a snapshot of the current situation, while temporal continuity is an important factor for pollinators (Nicholson et al., 2021; Zurbuchen & Müller, 2012). Also, studies found that the variation of composition of pollinator communities becomes greater over time, than when compared between sites, suggesting studies over multiple seasons (Russo et al., 2015). The timeframe also limited the possibilities to include further aspects of the pollination service, especially related to the actual flow. Even though counting of flower visitations is a common method used to estimate pollination service supply, the relations of flower visitation to pollination success and the benefit for harvest for human consumption is not very well understood and needs further research (Bartholomée & Lavorel, 2019) which was not possible within this thesis.

Furthermore, the time limited the number of gardens and orchards that could be included in the study. The limits resulting from the small data set were visible in the landscape analysis, where the difference between gardens and orchards could not be taken into account. Several studies suggest that high local qualities can be more relevant to pollinators than their surroundings (Ayers & Rehan, 2021; Baldock, 2020; Daniels et al., 2020; Hülsmann et al., 2015; Levé et al., 2019; Majewska & Altizer, 2020). The distinction between orchards and gardens in the landscape analysis would therefore be important to improve reliability. Similarly, studies found different effects on pollinators between management types (Ayers & Rehan, 2021; Klein et al., 2012; Levé et al., 2019), which were not included in this study. In order to include management as a fixed variable in the models, the locations should either be similar (cf. Ahrné et al. (2009)) or more numerous (cf. Klein et al. (2012)).

Additionally, the two study regions were very different in terms of the progression of the season. In general, the plots in gardens in the Lower Engadine included more bare ground, as the season was not as far progressed as in Freising, when the data was collected. This means that gardens in the Lower Engadine had less vegetation in general and also a smaller amount of species flowering (see Figure 27) . The consequences were visible in the flower diversity and flower coverage of the plots, where the rural gardens showed quite high numbers, while the number of species on the location level was lower than in peri-urban gardens. Even though the diversity index does not represent the number of species only, but also includes the abundance, this comparison shows the discrepancies of the different scales, resulting from the different progression of the season. The high diversity and flower coverage in rural gardens is related to the fact that plots had to be placed where flowers were available. This does not necessarily reflect the entire area. As the observation method used relies on flowers where the pollinators can land, this might have influenced the results. Therefore, the use of a completely randomised design was not possible.

Study regions and landscape analysis

In addition to the limited time, the choice of locations was connected to feasibility and relied on established contacts. A more profound choice of the regions as well as the specific gardens and orchards could have been beneficial, as compromises had to be taken here as well. Wenzel et al. (2020) found in their review that pollinator declines due to urbanisation were mostly found in sites, where the imperviousness is above 50%. In this study, the average of imperviousness around the study locations reached a maximum of 17 %, suggesting a little grade of urbanisation. Thus, this study only mirrors the beginning of the urbanisation gradient, while the results could become much clearer, setting the locations along this gradient (cf. Ahrné et al., 2009) or making sure that the two regions are on either end of the gradient (urban and rural) with clear differences of impervious area. Additionally, the landscape buffers overlapped, inducing a certain dependency and limiting the buffer size to 1 km, while other studies found effects on pollinators on a 3 km scale (Bartholomée et al., 2020; Mogren et al., 2016; Moreira et al., 2015). Zuckerberg et al. (2020) state that concerns about overlapping buffers violating test assumptions of independency are common among researchers, eventhough the concern is not justified according to studies investigating the topic. However, testing spatial autocorrelation in studies about landscape effects on different scales is an important step to check independency, which was not considered in the present thesis.

A second limitation from the choice of regions is that the study locations were not only rural and peri-urban, but also Inner-Alpine and at the outer border of the Alps. This suggests not only different sets of diversity (Kormann, 2002) and different progress in season, but also differences in the landscape surrounding the studied location, where effects of rurality and Alpine location intertwine. As an example, the little amount of cropland in the Lower Engadine is not due to its rural character, but rather a question of appropriate use of land. An additional difficulty that emerged during the GIS analysis are the high changes in altitude within the landscape buffer (up to 360 m from the center). Even though a study found, that pollinators do surmount heights of up to 135 m elevation, there is a certain cost connected to it (Zurbuchen et al., 2010a). Thus, land uses in flat regions might have different effects than land uses on the hillsides of an Inner-Alpine valley. The cost for pollinators connected to differences in altitude still needs to be better understood.

An additional finding that could be related to the Inner-Alpine location of the Lower Engadine was an association of temperature and non-bee taxa, showing less pollinators with higher temperatures. The temperatures were significantly different from each other between the two regions, showing cooler temperatures in the Lower Engadine. Thus, the lower abundances of non-bee in the peri-urban region could be both related to temperature as well as caused by other factors, such as the surrounding landscape. However, research about the relation of non-bee pollinators and temperature is very scarce, indicating the need for further investigation.

In addition to these location related difficulties, the decision to look at the effect of different land use classes also led to some information of the landscape matrix being lost. In the peri-urban area, there is no specific land use that dominates the surrounding, while the rural locations are characterised by their large total area of grasslands and forested patches. This does not mean that the landscape is less structured in the Lower Engadine, as these numbers are totals. For example, the forest category included hedgerows, which could separate several grassland parcels, structuring the landscape. The inclusion of a structure variable such as indices on diversity, isolation or heterogeneity would be a possibility to keep such information in the analysis. Such variables are often used in other studies (cf. Bartholomée et al. (2020); Földesi et al. (2016); Moreira et al. (2015); Viana et al. (2012)). As the small-scaled structure of the landscape and the ecological connectivity play an important role for pollinators (Zurbuchen & Müller, 2012), this could help to better understand the differences between the peri-urban and the rural locations. Nevertheless, the effect of different land use classes on pollinators is not well understood yet, especially for the categories water, cropland, garden and gravel surrounding pollinator habitats. Here, further research is needed.

Further investigations about aspects that impact pollinators along the urbanisation gradient is needed to improve promotion and protection. In their review, (Wenzel et al., 2020) point out the need for further research on possible urban drivers like air and light pollution. These suggestions go in line with other researchers' claims for further research on the concurrence of honeybees and wild bees, the effect of chemicals and pollutants, the need for non-flower resources of wild bees and the effect of climate change (Baldock, 2020; Geldmann & González-Varo, 2018; Giavi et al., 2021; Knop et al., 2017; Mallinger et al., 2017; Mogren & Lundgren, 2016; Requier & Leonhardt, 2020; Ropars et al., 2019).

Fieldwork method

The choice of method setup was aiming for possible implementation by citizens, creating a tool for garden owners to get more familiar with the pollinators in their area. This is why an observational study was chosen. The most commonly used sampling methods for pollinators are pan trapping and aerial netting (Bartholomée & Lavorel, 2019). Studies comparing these two methods found that the methods complement, rather than replace, each other. Even though Gezon et al. (2015) found that the use of pan traps does not induce changes on the community level over a period of trapping of three years, Gibbs et al. (2017) registered signs of local overtrapping over the same period length. Therefore, these methods should be used carefully (Gibbs et al., 2017). Meanwhile, observational methods are much more cautious (Bartholomée & Lavorel, 2019).

A downside of this method is, however, that the identification to species level is often not possible. This means that the within group diversity is not measured. It is known that pollinators are very different in their needs (Rader et al., 2016; Westrich, 2018; Zurbuchen & Müller, 2012). Also, landscape or local effects might differ in their effect on different species, on the diversity of the community or the abundance. In their study on bumblebees along an urbanisation gradient in Stockholm, Ahrné et al. (2009) found that species diversity is more affected by the urbanisation grade, while the abundance was most related to the local management e.g. flower abundance. Not only does this suggest different reactions to environmental factors, but also points towards different needs of species. These different needs were not taken into account in this study. Even though a higher resolution in terms of genus and species would allow a more specific network of plants and pollinators to be drawn, the knowledge and resources necessary for this are very high and not the objective of this study. However, a differentiation of the classes within the groups could be beneficial for a better interpretation of the results, especially for the non-bee pollinators. This closer look had to be bypassed as a consequence of time limitation.

Additionally, some further examination especially in terms of feeding resources could help improve understanding of the results. The plant species could be categorised after their relevance for different pollinators, or by different traits. For example, Geslin et al. (2013) show in their study that open flowers and their related pollinators, being mostly hoverflies and solitary bees, are more sensitive to urbanisation than the pollinators associated with tubular flowers. This step was also bypassed due to limited time. The integration of the location level feeding and nesting resources could further improve the understanding, as the different pollinator groups rely on different resources for feeding and nesting (Ahrné et al., 2009; Bartsch et al., 2009). However, to include these resources in tests, a different data collection approach or a much larger dataset would be needed. Additionally, the method used to measure local feeding resources turned out to be difficult. Especially in locations with little overview, some of the flowering species could easily be missed. Nevertheless, the amount of plant species in the data reflects the differences between the locations, even if some species might be missing (especially in the Ökogartenanlage). Furthermore, the study method had a stronger focus on feeding than nesting, as the pollinators were counted on flowers only. Thus, pollinators were counted while collecting pollen and nectar and not while building and filling their nests. Many studies focus on the feeding, while the needs for nesting are not well understood yet, which calls for further research (Zurbuchen & Müller, 2012).

An advantage related to the little resolution on the pollinator species, however, is that this allows for more different groups to be included. Several reviews stated a strong focus on bees within the pollination topic, while non bee pollinators are underrepresented, leading to a lack of knowledge (Bartholomée & Lavorel, 2019; Rader et al., 2016; Senapathi et al., 2017). Thus, including the wide range of pollinator groups into studies could be an important contribution to the current research gap around non-bee pollinators. Here, an implementation of the method used in this study over a longer time period and a broader scale would increase reliability. As the method is appropriate for beginners, a citizen science approach, like the ongoing project in Switzerland (Gloor et al., 2021), would be possible and of great importance (Kremen et al., 2011). This could help increase the knowledge and awareness around pollinators and thereby also change peoples' attitude towards pollinators (Levé et al., 2019; Locritani et al., 2019; Peter et al., 2019). The willingness to contribute to similar studies was shown in the study by Pawelek et al. (2009). Therefore, I conclude that the method used here could be implemented in a larger study with citizen scientists, which would enhance the time and spatial scale along with further benefits.

7. Conclusion

In this study, differences in pollinator abundance and community composition related to rural and peri-urban contexts as well as ecosystem type were found. Here, peri-urban orchards showed a lower pollinator abundance than rural areas, suggesting negative impacts related to built-up area. This effect was especially clear for non-bee pollinators, where the positive correlation with grasslands offered an additional explanation, why this group was represented stronger in rural, than in peri-urban areas. Meanwhile, indications that gardens could overcome general negative impacts of urbanisation by offering relatively good feeding and nesting resources on the local scale were found. These resources are very important to wild bee abundance, while non-bee pollinators are found to be more dependent on the feeding than the nesting resources on the local scale. In contrast to these two pollinator groups, honeybees seem less reliant on both local and landscape resources. This study suggests, that both landscape and local characteristics need to be taken into account for pollinator protection and promotion.

8. References

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Declaration of Authentic Work

Surname:	Abderhalden
First Name:	Bigna Lu
Date of birth:	17.11.1998

I hereby declare that I have prepared this thesis independently without the unauthorised assistance of third parties and without the use of other than the indicated aids. Data and concepts taken directly or indirectly from other sources are identified with a valid reference to the literature citation. This also applies to drawings, sketches, pictorial representations, tables and the like as well as to sources from the Internet and unpublished sources.

The work has not yet been submitted to another examination authority in the same or similar form, either in Germany or abroad, and has not previously been part of a course or examination performance.

Freising, 08.09.2021

Location, Date

B. Abderhalden

Signature

Appendix

A Data collection forms

Specific ID.: ______________
Region_Location_PlotNR_Round

Data collection form (within 1m^2 plot)

Study location: ________________ Plot Nr.: _______ Round: __________

Date/ Time: _______________ Overview-Photo Nr.: _______

Mark position on map

Weather:
Cloud coverage (%): ______
Temperature: _____ Windspeed: _____

Pollinators:
(10min observation)

Insect-Group	Genus/ Species	Amount on flower	Ground/ Leaves/ Air
Honeybee	*Apis mellifera*		
Bumblebee	*Bombus sp.*		
Solitary bee	-		
Hoverfly	-		
Fly	-		
Wasp	-		
Sphecoid Wasp	-		
Butterfly	-		
Beetle	-		
Bug	-		

Specific ID.: _______________
Region_Location_PlotNR_Round

Feeding and nesting aspects:

Coverage (%): Bare ground: _________ Flowering plants: _________

Height of vegetation: ______________

Flowers

Species	Amount (estimated nr. of inflorescences)

Other comments:

____

____

____

____

____

____

____

____

____

____

Specific ID.: _______________

Region_Location

Data collection form (study location) (1x)

Photo Nr.: from _____ to ______

Feeding resources:

Flowering plants:

Categories:

A – sporadic

B – patchy

C – rare, but distributed

D – commonly distributed

Species	Category	Comment

Specific ID.: _______________
Region_Location

Nesting resources:

Structure	Yes	No	Comment
Compost heap			
Stone wall			
Cairn			
Bare ground			
Break-off edges (ground)			
Pile of branches			
Plant stems			
Lying deadwood			
Standing deadwood			
Young trees			
Middleaged trees			
Old trees (partially dead)			
Nesting aid			
Water			
Beehive			

Number of trees (total): ________________

Other factors

Other comments: (Management, Exposition, Slope etc.)

____

____

____

____

Specific ID.: _______________

Region_Location

Description of surroundings

Photo Nr.: from ________to__________

Structures:

○ Water ○ Hedgerow ○ Wood-Edges ○ Gravel road ○ Fence

Plant species around the location:

B Pollinator data, feeding and nesting resources

			Cruschada	Sot Döss	Ramosch Cumün	Sent Nuns	Knollen & Co	Ökogartenanlage	LfL	Plantage
		Region	rural				peri-urban			
		Ecosystem type	garden		orchard		garden		orchard	
Mean pollinator abundance	Pollinator class	Honeybee	0.40	1.40	1.10	0.40	1.10	0.50	0.50	0.70
		Bumblebee	0.00	0.10	0.20	0.00	0.50	0.40	0.00	0.00
		Solitary bee	0.60	1.90	1.30	0.60	1.10	0.70	0.20	0.70
		Wasp	0.10	0.00	0.20	0.00	0.00	0.00	0.10	0.00
		Hoverfly	1.00	1.30	0.70	0.40	0.20	0.70	0.00	0.20
		Other fly	0.60	0.70	3.40	0.30	0.60	0.40	0.00	0.40
		Butterfly	0.00	0.00	0.20	0.10	0.10	0.00	0.00	0.00
		Beetle	0.30	1.10	1.30	1.20	0.60	0.10	0.00	0.10
		Bug	0.00	0.00	0.10	0.20	0.00	0.10	0.00	0.00
		Sphecoid wasp	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
	Pollinator group	Honeybee	0.40	1.40	1.10	0.40	1.10	0.50	0.50	0.70
		Wild bee pollinators	0.60	2.00	1.50	0.60	1.60	1.10	0.20	0.70
		Non-bee pollinators	2.00	3.10	5.90	2.30	1.50	1.30	0.10	0.70
		Total pollinators	3.00	6.50	8.50	3.30	4.20	2.90	0.80	2.10
Standard deviation (sd) of pollinator abundance	Pollinator class	Honeybee	0.70	1.65	0.57	0.52	0.99	0.53	0.85	0.67
		Bumblebee	0.00	0.32	0.42	0.00	1.08	0.52	0.00	0.00
		Solitary bee	1.07	1.66	0.95	0.97	0.74	0.48	0.42	0.67
		Wasp	0.32	0.00	0.42	0.00	0.00	0.00	0.32	0.00
		Hoverfly	0.67	0.95	0.82	0.97	0.42	0.82	0.00	0.42
		Other fly	0.70	0.67	3.24	0.48	0.70	0.97	0.00	0.70
		Butterfly	0.00	0.00	0.42	0.32	0.32	0.00	0.00	0.00
		Beetle	0.48	1.10	1.57	1.03	0.97	0.32	0.00	0.32
		Bug	0.00	0.00	0.32	0.63	0.00	0.32	0.00	0.00
		Sphecoid wasp	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00
	Pollinator group	Honeybee	0.40	1.40	1.10	0.40	1.10	0.50	0.50	0.70
		Wild bee pollinators	1.07	1.63	0.97	0.97	0.97	0.88	0.42	0.67
		Non-bee pollinators	1.25	0.99	5.11	1.95	0.97	1.57	0.32	0.82
		Total pollinators	1.76	3.31	5.17	2.45	0.79	1.73	1.03	1.66
Feeding		Mean Shannon index	1.09	1.06	0.95	0.84	0.64	1.07	0.42	0.90
		sd Shannon index	0.25	0.23	0.34	0.21	0.26	0.42	0.38	0.19
Nesting		Mean bare ground %	30.00	43.00	2.00	15.50	24.00	19.00	1.00	11.00
		sd bare ground %	15.81	22.75	3.50	16.06	25.58	24.24	2.11	10.49

C Land use data

		Cruschada	Sot Döss	Ramosch Cumün	Sent Nuns	Knollen & Co	Ökogartenanlage	LfL	Plantage
	Region	rural				peri-urban			
	Ecosystem type	garden		orchard		garden		orchard	
300 m	% built-up	4.70	0.55	15.97	2.46	14.76	15.23	27.90	4.08
	% cropland	0.04	5.15	0.16	0.00	7.43	5.45	30.69	32.87
	% forest	21.90	24.93	6.25	33.41	16.85	7.10	3.29	45.37
	% garden	1.11	0.80	13.97	1.17	11.92	22.30	27.32	2.25
	% grassland	69.24	60.30	62.03	60.42	45.66	45.53	8.89	12.46
	% gravel	3.02	2.16	1.61	1.84	0.52	0.62	1.92	2.96
	% water	0.00	6.12	0.01	0.70	2.85	3.77	0.00	0.00
500 m	% built-up	3.42	1.28	10.51	9.00	10.59	16.52	26.72	6.41
	% cropland	0.01	3.72	0.90	0.45	14.22	10.47	21.41	19.38
	% forest	26.42	35.20	20.87	22.18	12.65	5.70	17.32	49.99
	% garden	1.62	0.68	7.88	5.27	11.24	24.87	23.49	7.73
	% grassland	62.54	51.69	58.52	60.21	48.12	37.51	9.21	14.05
	% gravel	4.46	3.25	1.32	2.48	0.81	0.96	1.55	2.32
	% water	1.53	4.17	0.00	0.41	2.38	3.96	0.30	0.12
1 km	% built-up	2.36	6.59	6.16	7.24	9.08	22.33	22.78	13.40
	% cropland	1.23	0.97	0.97	1.03	26.63	10.27	15.09	8.85
	% forest	40.07	47.37	37.83	14.65	5.61	9.02	27.51	55.31
	% garden	0.94	2.52	2.59	3.90	10.41	24.15	24.56	13.04
	% grassland	48.46	33.37	47.85	67.57	45.94	30.54	8.18	6.80
	% gravel	4.72	6.25	2.25	3.01	0.80	1.07	1.59	2.53
	% water	2.23	2.94	2.35	2.62	1.52	2.61	0.29	0.08