



Revealing the diversity of wild bees (Hymenoptera: Apoidea: Anthophila) in flower strips in Mediterranean floodplains: which monitoring method fits best?

Oana Catalina Moldoveanu¹ · Martino Maggioni^{2,3,1} · Daniele Vergari⁴ · Francesca Romana Dani^{1,3}

Received: 27 December 2024 / Revised: 13 May 2025 / Accepted: 16 May 2025
© The Author(s), under exclusive licence to Springer Nature B.V. 2025

Abstract

The ongoing pollinator decline may threaten and compromise the resilience of terrestrial ecosystems. Implementing conservation action requires monitoring pollinator populations. Since more than 55% of European bee species are classified as “Data Deficient” by the IUCN, monitoring their populations is very important. However, although crucial, the results of bee monitoring are strongly dependent on the applied methods. Here, we compared different monitoring methods to evaluate wild bee biodiversity in lowland areas enriched with entomophilous flowers to support pollinating insects in a Mediterranean environment. We sampled wild bees for two years using hand netting, pan traps and artificial nests. We compared species richness and abundance among these methods with a particular focus on how flowering coverage affects the results of walking transects and pan traps and discussed the attractiveness of the different colours of pan traps. Hand netting captured a higher number of wild bee specimens and species than the other two methods. Artificial nests captured fewer specimens and species. Bee assemblages were significantly different between pan traps and hand netting and pan trap attractiveness was negatively influenced by the increase of flowering coverage. As for other studies, the three sampling methods were complementary in reaching the final species assemblages and although time-consuming, the juxtaposition of several monitoring methods appears essential to reveal species with different ecological traits.

Keywords Biodiversity · Anthophila · Pan traps · Trap nests · Monitoring schemes

Oana Catalina Moldoveanu and Martino Maggioni contributed equally to this work.

Communicated by Jens Dauber.

✉ Francesca Romana Dani
francescaromana.dani@unifi.it

¹ Department of Biology, University of Florence, Florence, Italy

² Terrestrial and Marine Sciences Department, University of Palermo, Palermo, Italy

³ National Future Biodiversity Centre, Palermo, Italy

⁴ Consorzio di Bonifica Medio Valdarno 3, Florence, Italy

Introduction

Pollinator biodiversity and decline

The complexity and resilience of terrestrial ecosystems are highly related to pollinators (Bascompte et al. 2006). The dependence of angiosperm species on animal pollination is estimated to vary from 78% in temperate systems to about 94% in tropical areas (Ollerton et al. 2011). At the same time, many crops important for a healthy human diet largely depend on animal pollination (Klein et al. 2007; Potts et al. 2010). The steady decline of pollinators globally is well documented and the need for actions to counter it is clear and accepted (Dunn et al. 2009; Klien et al. 2007; Potts et al. 2010). The loss of pollinator diversity can be particularly relevant in regions with a Mediterranean climate, known as important hotspots for wild bees (Orr et al. 2021). Among pollinator species, bees are considered to be the most efficient group due to their great species richness and functional diversity (Michener 2007). The European continent counts 2.138 species of wild bees (Ghisbain et al. 2023), and the Mediterranean region has the greatest species diversity (Quaranta et al. 2018). Yet, the IUCN Red List of Bees classified more than 55% of the species as “Data Deficient” (Nieto et al. 2014). The deficiencies that persist in many countries affect decisions about conservation actions and also the refining of monitoring methods is essential to ensure that pollinator status can be accurately documented (Nieto et al. 2014; Potts et al. 2016, 2024). The European Union is introducing multiple measures to reverse the trend of pollinator decline both in natural and human-modified ecosystems (Moldoveanu et al. 2024). These are condensed in the recently published document “A new deal for pollinators” (EU Communication, 2023). To overcome the lack of data on the trends of wild bee populations, improvements in the monitoring efforts are highly needed. Still, unlike for the butterfly species (e.g. BMS, Sevilleja et al. 2019; Potts et al. 2024), there is little consensus among the best standard monitoring method. Yet, monitoring schemes for wild bees are important to understand how populations respond to stressors and how they may develop in time on local and global scales (Breeze et al. 2021).

Monitoring methods for wild bees

According to several assessments (IPBES 2016; IUCN 2014; Reid et al. 2005) and researchers (Bell et al. 2023; Hutchinson et al. 2021; Klaus et al. 2024; O’Connor et al. 2019), there is a clear need for standardised methods of monitoring pollinators through a wide range of habitats and many geographical areas. The monitoring methods usually adopted for pollinators, particularly suitable for assessing wild bees, are divided into passive and active methods (Westphal et al. 2008). Active methods include primarily walking transects and observation plots (Cane et al. 2006; Dafni et al. 2005) whereas passive methods are numerous: pan traps (Rhoades et al. 2017; Westphal et al. 2008), malaise traps (Geroff et al. 2014), vane traps (Hall et al. 2018), and trap nests (Staab et al. 2018). According to the work of Westphal et al. (2008) and Potts et al. (2024), standardised transects are vegetated corridors, permanently or not, of length 250 m or 500 m, respectively, $\times$ 4 m that can be divided into subunits. The duration of transects should not exceed 50 min to avoid running into the same individual several times (Potts et al. 2024; Westphal et al. 2008). Active methods are often time-consuming and heavily dependent on observers'expertise in species determination, but

they allow the collection of much more information about plant-pollinator interactions (Bell et al. 2023; Westphal et al. 2006).

Pan traps are usually plastic bowls of 400–500 mL volume that are coloured with UV-reflecting varnishes, usually in blue, white and yellow, and contain water with a few drops of liquid soap to reduce the surface tension (Westphal et al. 2008). Vane traps are similar to pan traps, but they are made of a transparent glass jar topped with a plastic-coloured (UV-reflecting) funnel that traps insects in the jar (Stephen and Rao 2005). Usually, both types of traps are left in the field for up to 24 h (Stephen and Rao 2005; Westphal et al. 2008).

Passive methods are less time-consuming and independent of the sampler's knowledge in the first instance, but they may be affected by vegetation height and distribution (Cane 2001; Westphal et al. 2008). Despite their similarity, pan traps sample mainly small-sized bees while vane traps were first designed for the sampling of large-bodied bee species (Stephen and Rao 2005; Westphal et al. 2006). Plastic tubes of 10 cm diameter and 20 cm length, filled with common reed (*Phragmites australis*) with diameters up to 10 mm are the most employed trap nests (Gathmann et al. 1994), but book-like structures may also be employed (MacIvor 2017). Trap nests are highly biased to sample cavity-nesting bee species (Dafni et al. 2005), and their design may vary among researchers (Klaus et al. 2024). Trap nests are placed in the field usually in the late winter season and then are analysed after the autumnal months; this allows researchers to collect data over a whole flight period with relatively low sampling effort and to gather additional information such as that from pollen analysis and trophic interactions with associated parasitic fauna (Prendergast et al. 2020; Staab et al. 2018).

Since bee species richness can be relatively high and even within a same environment, species can exhibit great ecological diversity, many studies (Chamorro et al. 2023; Hutchinson et al. 2021; Prado et al. 2017) recommend a combination of different sampling methods to achieve efficient monitoring and an exhaustive characterisation of the wild bee community. The most used combination of sampling methods is vane traps, pan traps and standard transects (Bell et al. 2023; Wilson et al. 2008). Furthermore, several studies have compared monitoring methods to understand their pros and cons (Bell et al. 2023; Hutchinson et al. 2021; Nielsen et al. 2011; Thompson et al. 2021) but comparing active and passive methods may be difficult.

Most studies have primarily compared pan traps and vane traps (Bell et al. 2023; Rhoades et al. 2017). Even if several researchers demonstrated that pan traps capture the greatest abundance of bees, mostly small-sized and ground-nesting species (Thompson et al. 2021; Westphal et al. 2008), others found that vane traps capture the highest number of specimens (Bell et al. 2023; Rhoades et al. 2017; Prendergast et al. 2020). In general, it was demonstrated that vane traps, especially the blue-coloured ones, capture a higher abundance of species and are more effective across different habitats (Bell et al. 2023; Hall 2018; Packer and Darla-West 2021). The reasons for the diverse attractiveness of colours are still debated (Gibbs et al. 2017; Hall 2018). According to several studies (Chamorro et al. 2023; Krahner et al. 2021; O'Connor et al. 2019; Thompson et al. 2021), there are other concerns about the effectiveness of pan traps, especially because they seem to be appropriate only for open sampling areas and for habitats with a low abundance of flowers. Some authors demonstrated that pan traps compete with flowers for pollinators' attractiveness, showing that the number of captured bees decreased when the flowering surface increased, although this result did not affect the number of sampled species (Kuhlman et al. 2021). Ortiz-San-

chez and Aguirre-Segura (1992) also demonstrated that pan traps are biased by the vertical height of sampling, unlike vane traps. Moreover, trapped specimens are usually immersed in soapy water, therefore they must be washed and dried and this may be very time-consuming and damaging to the exemplars, hindering the identification by morphological characters (Prendergast et al. 2020). Additionally, if comparing passive and active methods, multiple elements need to be considered, including differences in sampling effort (Bell et al. 2023; Krahner et al. 2021). Hand netting may also allow to capture parasitic bees that are just sporadically patrolling flowers but usually are not detected by passive sampling methods (Popic et al. 2013; Thompson et al. 2021). These are also useful when assessing wild bee species richness or investigating the structure of wild bee communities (Nielsen et al. 2011; O'Connor et al. 2019; Thompson et al. 2021). Finally, many authors show agreement in suggesting that the choice of sampling methods must consider primarily the objectives of the experiment (Bell et al. 2023; Klaus et al. 2024) and the life-history traits of the target species (Hall 2018), but also which monitoring method is more suitable to the habitat features (de Assis et al. 2021; O'Connor et al. 2019). Since different sampling methods may produce very different results, here we aimed to compare the species diversity assessed by pan traps, walking transects and artificial nests in two different, but similar and quite close study areas. Both areas are found in floodplains in Tuscany (Central Italy) and were recently undergone to massive earth-moving works and then partially sown with commercial mixtures of nectariferous and polleniferous herbaceous plants developed for agroecosystems to support wild pollinator insects. The study duration, high monitoring frequency, high resolution of specimen identification, and quite homogeneous features of the sampling surface contribute to a fine and reliable comparison of the sampling method results.

Material and methods

Study areas and area description

The project focused on two study areas in Tuscany (Central Italy). Both areas are found in floodplain zones of two major tributaries of the Arno River and are 9 km apart in a beeline (Fig. 1 and Fig. 2). The first area is named “Castelletti”, and it is enclosed by an elbow of the Ombrone River in the municipality of Carmignano (PO), the second area, named “Bramasole”, is found in the municipality of Montelupo Fiorentino (FI) along the Pesa River (Fig. 1). The first area has a surface of about 6.5 ha, the second is about 5 ha. Both study areas are located in a periurban context and have undergone large-scale soil remodelling for the construction of embankments and expansion basins; they are therefore areas disturbed by the passage of large-scale tillage machinery and mainly dominated by grasses. Moreover, the context in which they are found is also perfluvial, with the presence of numerous tree species, reed thickets and small ponds as well as open grassland areas, so they are areas characterised by many different niches. These same areas were included in an environmental improvement project started in 2022 due to the paucity of flowering plants. In this project, mixtures of entomophilous herbaceous plants were sown to provide trophic support for local pollinators focusing on wild bee species preferences. Each study area was divided into experimental plots of 0.33 ha that were sown with three different mixtures of entomophilous plants to increase trophic resources for pollinating insects since these areas

Fig. 1 The study area of “Bramasole” in Montelupo Fiorentino (FI) with details of the sown flowering species in early spring (2024)



had a paucity of flowers. In both study areas, sowing took place in the early spring of 2022 in two experimental plots and then in the autumn of 2022 for two additional plots. Between each sown plot there was a control plot of the same width and extent as the sown ones. This kind of landscape may be very suitable for solitary bees due to a wide range of nesting sites, including the embankment slopes, highly preferred by many ground-nesting species (Heneberg et al. 2012).

Bee sampling methods and data collection

Sampling was carried out from 2022 to 2024 in “Castelletti” and from 2023 to 2024 in “Bramasole”. The two periods of sampling are mismatched due to the seeding works and maintenance requirements of the areas by the competent managing authority (Consorzio di Bonifica 3 Medio Valdarno). We used three different methods of sampling: *i.* hand netting (or standardised walking transects); *ii.* pan traps; *iii.* artificial trap nests (Fig. 3). Trap nests

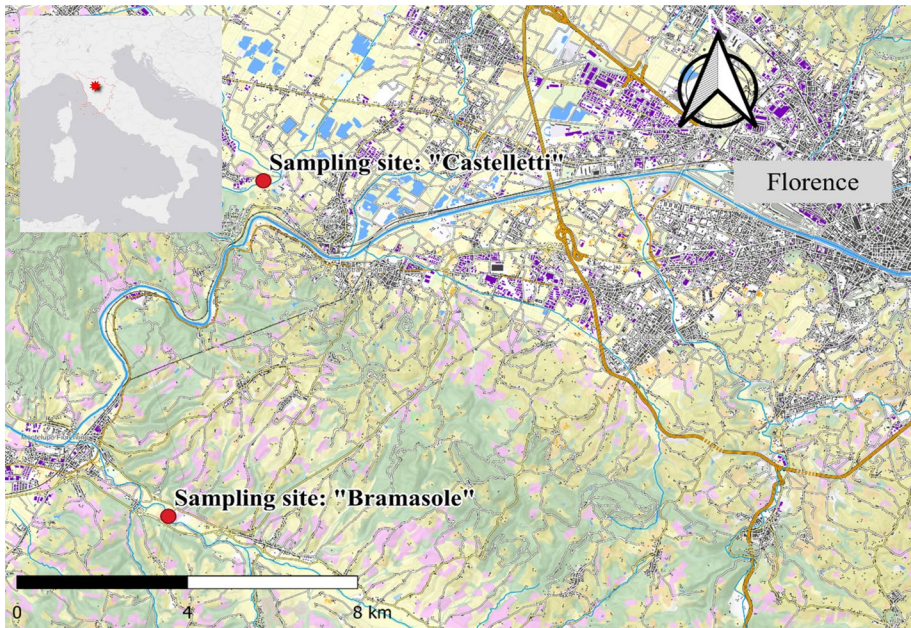


Fig. 2 Location of the two sampling areas (Tuscany, Italy; map from <https://www.regione.toscana.it/-/geoscopio>)

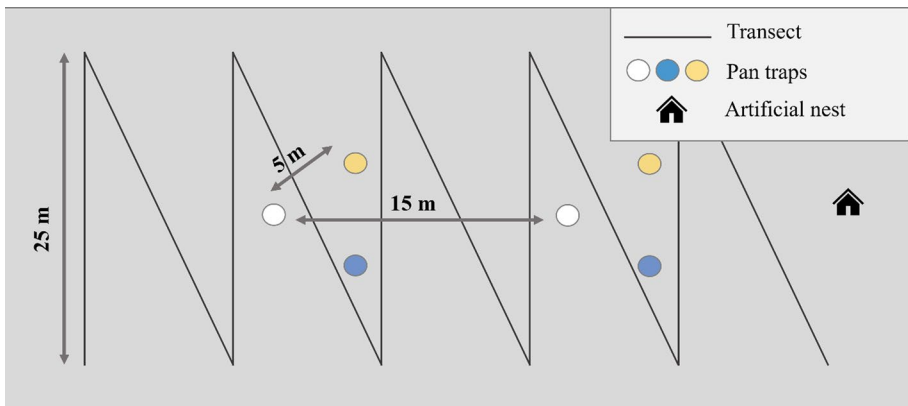


Fig. 3 Graphical scheme of a plot (in grey) showing the monitoring setup: the walking transect as a zig-zag corridor divided into ten 25 m long sections, two triplets of pan traps 15 m apart, and the artificial nest

were used from 2022 to 2023 in both areas. Transects and pan traps were used from March to September every sampling year. Transects were walked biweekly during sunny and no-wind days, or once a month in case of prolonged unsuitable weather. We walked one transect for each sown and control plot. Experimental plots within the same area were walked on the same day and used as replicates. The plots of the other area were walked the day after or within a few days. Each transect was 250 m long, with a zig-zag pattern, divided into 10

sections of 25 m each, and was walked for 50 min. Transects were conducted by the same person in both study areas and for all sampling events. Bees were sampled one meter ahead, one meter on the left and right and one meter high. We sampled only bees that could not be identified in the field. For each plot, field forms were filled with information about atmospheric temperature, cloud cover and wind force indexes, and flowering coverage. Most specimens were determined up to the genus level in the field and the visited plant species were recorded for each observation. The time required to transfer the insect from the net to the Falcon tube was short, so it was considered irrelevant. Whenever there were snags and longer processing times, the lost time was recovered. Vegetation and flower coverage were recorded for each transect as the average percentage of the values estimated by three operators. Netted specimens were placed into 15 mL Falcon tubes, anaesthetised with acetic ether, then placed at -20°C in the laboratory. Subsequently, they were processed and conserved in entomological boxes. Pan traps were positioned on the same days as transects. Two triplets were placed 15 m away along the transect path and positioned at the same height as the surrounding flowering vegetation. Each triplet was composed of a blue, white, and yellow bowl and was left in the field for 24 h. Each bowl of the triplet was arranged as the vertices of an equilateral 5 m-side triangle (Westphal et al. 2008). Bowls were 15 cm in diameter, had a capacity of 500 mL and were coloured with UV-reflecting paints (Spray-Color GmbH; Westphal et al. 2008).

Sampled specimens were put in 15 mL Falcon tubes and conserved at -20°C in the laboratory. Later, they were quickly rinsed in water, dried in the air by gently shaking them in a small bag containing small pieces of blotting paper and processed the same way as described for the netted specimens.

Trap nests were placed in spring and removed in winter both in year 2022 and 2023. Three trap nests were placed for each study area. Trap nests were made of a wood frame filled with drilled wooden logs and river reeds (*Arundo donax* L.). Both wooden logs and river reeds were 20 cm long, the diameters of the reeds ranged from 0.5 cm to 2.5 cm, and the holes in the logs were 10 cm deep and 0.4 cm in diameter. During winter, trap nests were taken to the laboratory and incubated to let cavity-nesting specimens emerge. Specimens from trap nests were processed the same way as the netted specimens. Artificial nests capture cavity-nesting bee species, mainly from the Megachilidae family, that are only a fraction of the bee community. Therefore, we decided to analyse data from trap nests only as a focus on this family.

Species identification

Only specimens of the superfamily Apoidea, clade Anthophila (Hymenoptera:Apoidea:Anthophila) (Michener 2007), were considered during sampling. *Apis mellifera* was recorded but not considered for the analysis. This study focused on wild and non-managed species, so honeybees, which are considered as a managed species, were not considered for analysis. In the present study, we identified all specimens at the species level unless necessary identification characters were missing or unrecognizable. We used dichotomous keys (see Supplementary Materials “Keys”) for both genus and species identification. In addition to morphological identification, species were confirmed by DNA barcoding performed by the Canadian Center for DNA Barcoding (CCDB, University of Guelph 50 Stone Rd E, Guelph, ON). Molecular identification only considered percentages of similarity greater than 99%.

If there were discrepancies between morphological and molecular identifications, the specimen was re-identified and compared with specimens from a reference collection (“Vittorio Nobile” Collection at the Natural History Museum “La Specola” in Florence).

Data analysis

For the sake of homogeneity and data consistency, the analyses considered the two study areas separately and the data were pooled over two years (2023 and 2024). To understand how hand netting and pan trapping captured the α -diversity of the study areas as the number of sampled specimens increased, we performed rarefaction curves for each study area over two years (2023 and 2024). Rarefaction curves were run using the iNext package (Hsieh et al. 2016). The number of sampled specimens and sampled species were used as proxies to compare active and passive methods in terms of effectiveness and sampling effort. To compare the number of species captured by walking transects and pan traps we run GLM(M)s with Poisson distribution and log link function and chose the one as most parsimonious according to lower AIC. We used the lme4 package (Bates et al. 2015) and added date, site and temperature as random factors. To understand whether the abundance of flower coverage influenced the performance of each sampling method, we computed GLM(M)s with Poisson family link function on the abundance of sampled specimens by walking transects and pan traps. According to the lowest AIC, we chose the one with date, site, temperature, cloud and wind as random factors (see Supplementary Materials). All GLM(M)s were tested for the assumption to fixed effects and random factors using the DHARMA package and residuals analysis (Hartig et al. 2017). To address differences in the composition of wild bee communities between hand netting and pan traps in each study area, we used “adonis2” function with 999 permutations to perform a distance-based (Bray–Curtis dissimilarities) multivariate analysis of variance (PERMANOVA). We evaluated multivariate dispersion using the betadisper function for both sampling methods. For those analyses, we used the vegan package (Oksanen et al. 2024). The attractiveness of different pan trap colours was tested with the Kruskal–Wallis rank sum test, and the Bonferroni method was used for p-value adjustment. The VennDiagram package was used to show the difference in the genera captured by the pan traps of different colours. Singletons were excluded from this analysis. ggplot2 package was used for the design of boxplots and barplots. Finally, we focused on the Megachilidae family as it includes both ground-nesting and cavity-nesting species, sampleable by all three methods and performed a ternary plot using the ggtern package (Hamilton et al. 2018). All analyses were run in R 4.4.0 (R Core Team 2024).

Results

We collected wild bees from 32 genera (about 51% of all genera in the Italian territory) from all six families present in Italy (Table 1), for a total of 3,532 specimens in both study areas. Hand netting captured 29 genera, approximately 90.6% of all genera collected, among which 7 genera were not present in the pan traps. Pan traps sampled 23 genera, about 71.8% of all collected genera and 2 that were not observed with hand netting. Artificial nests trapped 4 genera, about 12.5% of all collected genera, with one genus not captured by the other two methods. Altogether we sampled 6 genera of parasitic bees (cuckoo bees): one

Table 1 Number of specimens (abundance) and species of each bee family and genus revealed through the three sampling methods in 2022, 2023 and 2024 considering both study areas: Hand netting, Pan traps and Artificial nests. * are parasitic genera

Family	Genus	Abundance			Number of species		
		Hand netting	Pan traps	Artificial nest	Hand netting	Pan traps	Artificial nest
Andrenidae	<i>Andrena</i>	448	33		29	17	
	<i>Panurgus</i>	1	9		1	1	
Apidae	<i>Amegilla</i>	2	2		1	1	
	<i>Anthophora</i>	11			6		
	<i>Bombus</i>	591	12		5	3	
	<i>Ceratina</i>	5	2		3	2	
	<i>Epeolus</i> *	1			1		
	<i>Eucera</i>	397	115		10	7	
	<i>Habropoda</i>	9			1		
	<i>Melecta</i> *	2			2		
	<i>Pasites</i> *	1			1		
	<i>Nomada</i> *	6	4		3	5	
	<i>Tetralonia</i>		1			1	
	<i>Xylocopa</i>	20	3		2	2	
Colletidae	<i>Hylaeus</i>	20	9		6	6	
Halictidae	<i>Halictus</i>	154	63		4	5	
	<i>Lasioglossum</i>	461	158		18	18	
	<i>Nomiapis</i>	25	3		1	1	
	<i>Seladonia</i>	133	37		4	5	
	<i>Sphecodes</i> *	12	4		4	2	
	<i>Systropha</i>	6	11		1	1	
Megachilidae	<i>Anthidiellum</i>	219			1		
	<i>Anthidium</i>	6		46	4		2
	<i>Chelostoma</i>	2	3		2	1	
	<i>Coelioxys</i> *			1			1
	<i>Hoplitis</i>	7	27		3	2	
	<i>Megachile</i>	225	7	10	10	6	5
	<i>Osmia</i>	13	7	67	4	3	5
	<i>Protosmia</i>		1			1	
	<i>Pseudoanthidium</i>	22			1		
	<i>Rhodanthidium</i>	83	12		1	1	
	<i>Trachusa</i>	1			1		
Melittidae	<i>Dasypoda</i>	1	2		1	1	

genus (*Coelioxys*) with artificial nests, two (*Nomada* and *Sphecodes*) with pan traps and 5 (*Epeolus*, *Melecta*, *Nomada*, *Pasites*, and *Sphecodes*) by hand netting. Artificial nests and hand netting caught 1 and 3 unique genera of parasitic bees, respectively.

Over the three years, in both study areas, we collected about 17% of the Italian bee species. The number of species collected by the two methods was significantly different (Table 2) and on average was higher for hand netting (Table 1, Table 2, Fig. 4). In “Bramasole”, we sampled 71 and 24 unique species, respectively, by hand netting and pan traps

Table 2 Parameter estimates of the GLM(M), glmer function with Poisson distribution and log link function as most parsimonious according to lower AIC, explaining the influence of the different sampling methods (pan traps and hand netting) on the captured number of species with date, site and temperature as random factors

Fixed effects	Estimate	Std. Error	z-value	p-value
Species of wild bees	2.61	0.09	27.78	< 2E-16***
Methods of monitoring	-0.53	0.11	-4.87	1.11E-06***
Random effects	Variance	Std. Dev		
Date	8.42E-02	2.90E-01		
Site	1.04E-08	1.02E-04		
Temperature	2.96E-02	1.72E-01		

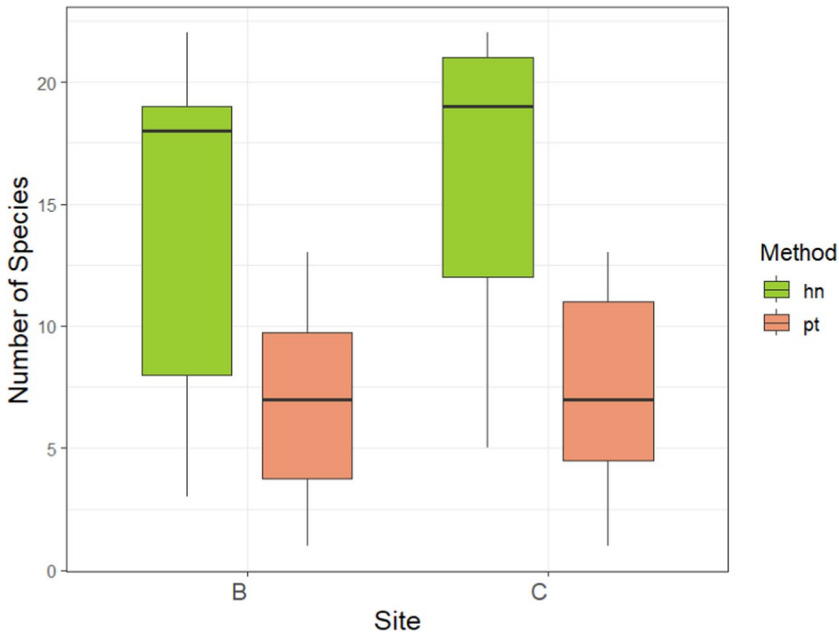


Fig. 4 Species sampled by hand netting and pan traps over 2023 and 2024 in “Bramasole” (B) and “Castelletti” area (C)

whereas in “Castelletti”, we sampled 94 and 21 exclusive species by hand netting and pan traps.

Species rarefaction curves (Fig. 5), cumulative over the sampling years in the two sampling areas, show that pan traps revealed fewer species than hand netting basing on the final sample size, although the curves increase more rapidly for pan traps. The effect of flowering coverage on sampling methods (in Supplementary Materials), showed that pan traps tend to capture more species at lower flowering coverage.

Wild bee assemblage differed between the two sampling methods in both areas (Fig. 6, $p < 0.001$), and variability was higher for pan traps in both study areas (Fig. 6, betadisper $p > 0.05$).

In both areas, the colours of the pan traps were not significantly different attractive on either species richness or abundance of trapped specimens (Fig. 7, Kruskal–Wallis $p > 0.05$).

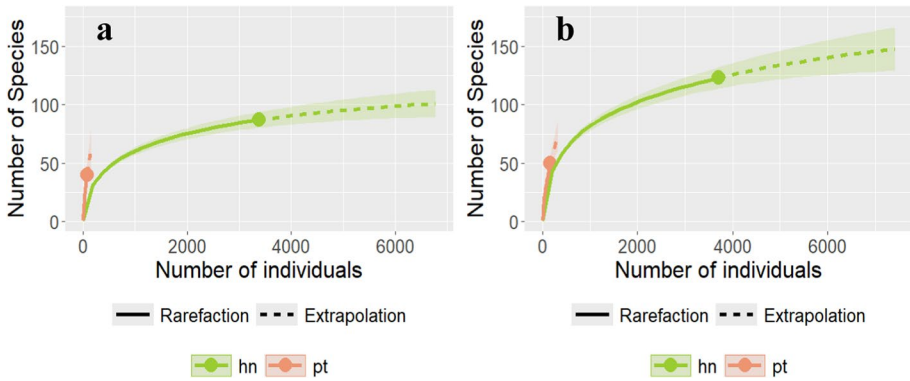


Fig. 5 Species rarefaction and extrapolation curves built on the samplings of both 2023 and 2024 in “Bramasole” (a) and “Castelletti” (b) areas

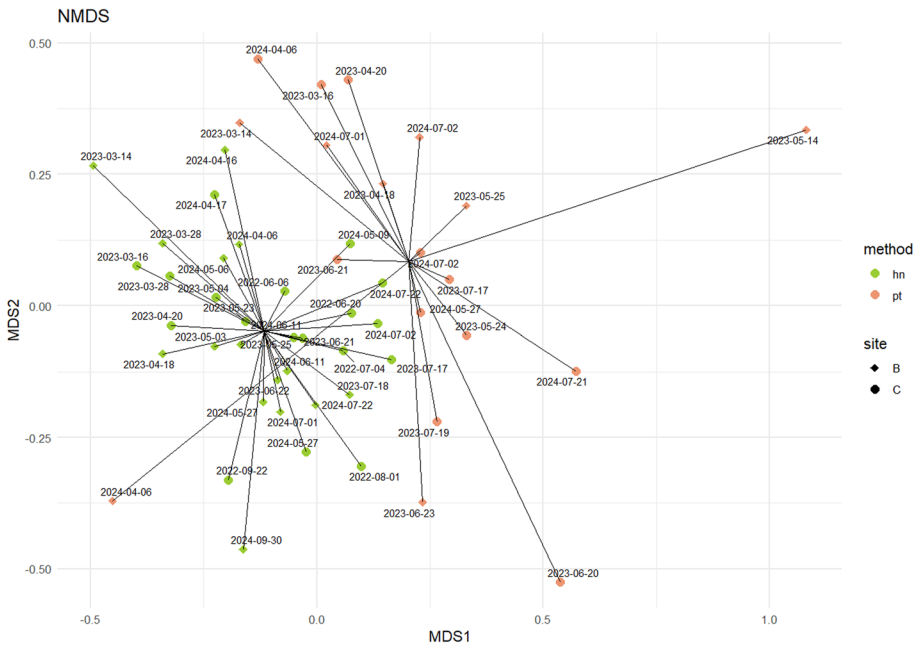


Fig. 6 Non-metric multidimensional scaling (NMDS, stress = 0.216) plot of wild bee community according to sampling dates, study areas and methods. Green dots represent communities sampled by hand netting, orange dots those sampled by pan traps; the shape of dots represent the two study areas, B is “Bramasole” and C is “Castelletti”. The wild bee communities described by the two methods were found to be significantly different (PERMANOVA, $p < 0.001$). The distance within samples for each group is similar but larger for pan traps (Beta Dispersion Analysis, $p > 0.05$)

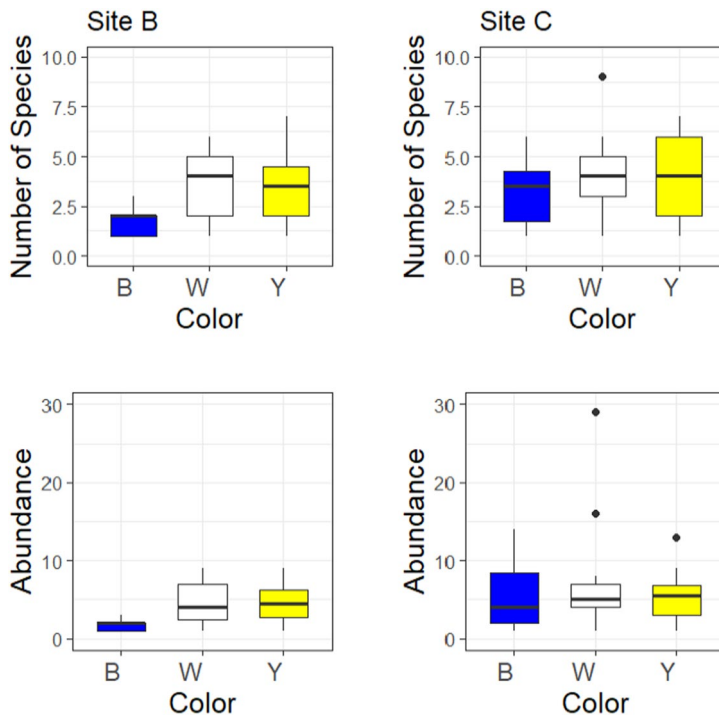


Fig. 7 Number of species and abundances of specimens trapped by the pan traps of the three different colours in the two sampling areas, Site B stands for “Bramasole, Site C stands for “Castelletti” (Kruskal-Wallis test, $p > 0.05$)

In both areas, the distribution of the most abundant genera was similar between the three colours (Fig. 8a and b) and, species captured by blue pan traps were a subsample of the white and yellow traps (Fig. 8c and d).

Focusing on the species of the Megachilidae family, collected in both study areas, we found 11 genera (about 30% of all sampled genera) and 44 species (about 18% of Italian Megachilidae fauna) with one genus, represented by one single species, the cuckoo bee *Coelioxys mandibularis* Nylander, 1848. The ternary plot (Fig. 9) of the Megachilidae species collected with each method (in 2023 in both areas) showed that many species cluster for each monitoring method, as they tend to be sampled exclusively or mostly by hand netting and artificial nests. We did not find species that were captured by all three methods.

Discussion

According to the IUCN Red List of European Bees (Nieto et al. 2014), 56.7% of wild bee species cannot be classified in a risk category due to insufficient data. Although attempts and proposals to standardise pollinator monitoring methods at the European level have been made, wild bees remain a difficult group to monitor due to their great specific and ecological diversity (Potts et al. 2024).

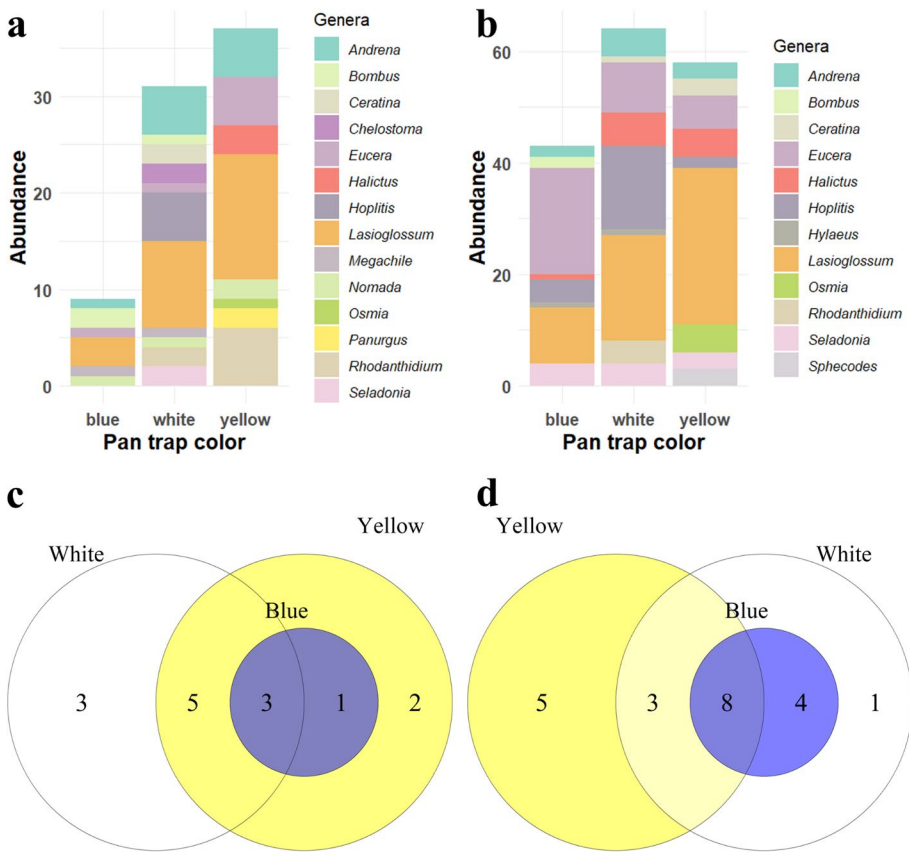


Fig. 8 Barplot and Venn Diagram showing respectively genera and species attracted by each pan trap colour for study area "Bramasole" (a, c) and "Castelletti" (b, d)

As many studies state (Klaus et al. 2024; Krahner et al. 2021; Potts et al. 2024; Westphal et al. 2008) different monitoring methods can sample the bee community of a particular area quite differently. Heterogeneous habitats may host a greater richness and diversity of wild bee species (Papanikolaou et al. 2017), and therefore exhaustive monitoring of these communities can be challenging as each monitoring method targets a particular group of species (Montgomery et al. 2021). Our study areas can be seen as particularly heterogeneous (as described in the Materials and Methods section) and the presence of sown entomophilous plant further enhances heterogeneity, thus possibly increasing the diversity of the bee species. A single monitoring method would not have been exhaustive for sampling all bee species diversity, whereas the use of three complementary methods was found to be a more suitable scheme for both the type of areas studied and the target species. The recent introduction of mixtures of plant species is also reflected in changes to the environment on a short time scale, as the mixtures take a few years to establish a stable lawn (Hussain et al. 2022; Sanderson 2010). This element is also a further variability factor in the performance of monitoring methods, as the presence of extensive flowering leads pan traps to lose efficiency (see Supplementary Materials), while the turnover of flowering species with different

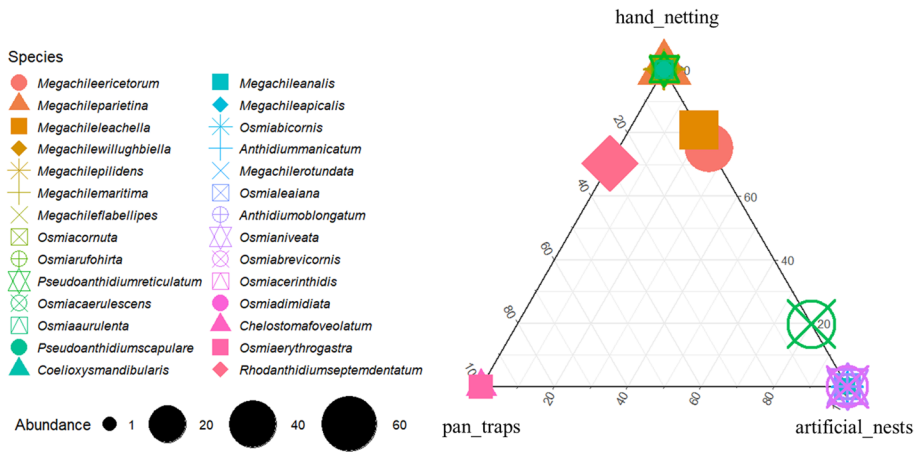


Fig. 9 The distribution of each megachilid species among the three monitoring methods in both study areas in 2023: the position of each shape indicates, for each species, the percentage of specimens captured with each sampling method; the size indicates the abundance of specimens per species

flower symmetries attracts bee species with different ecological features that can be more easily sampled with a different monitoring method. For example, the presence of Fabaceae attracts many Megachilidae specimens, which are more easily sampled by transects and trap nests (see Fig. 9); the presence of patches of bare soil or with little vegetation attracts more generalists and ground-nesting species such as those of the genera *Andrena*, *Lasioglossum* and *Eucera*, which are more easily sampled by pan traps (see Table 1 and Fig. 8). Moreover, this study contributes to data on Italian bee species distribution that is very poor (Quaranta et al. 2018). We demonstrated the complementarity of different methods since, despite the high frequency of sampling, each method collected quite a relevant number of unique species. Moreover, our work draws attention to several key factors to be considered when developing a monitoring scheme. Several studies point out the use of trapping, especially pan traps, as the most efficient monitoring method, as these can attract both more specimens and more species than other methods (Krahner et al. 2021; Nielsen et al. 2011; Stephen and Rao 2005; Westphal et al. 2008). However, the use of pan traps raises doubts regarding the effect of their repetitive and extensive use on the bee communities and bycatches of other insect groups (Gezon et al. 2015); as well as on the relative lack of standardisation due to the influence of vegetation (Kuhlman et al. 2021; LeBuhn et al. 2013). The effectiveness of pan traps is highly dependent on the height of the vegetation and thus on the heights at which the traps are placed to be competitive with the surrounding vegetation (Westphal et al. 2008). Furthermore, as we also found, pan traps can lose effectiveness when flowering coverage is abundant since, in addition to colour, many pollinators are attracted by other factors that characterise flowers but not pan traps (O'Connor et al. 2019). Finally, pan trap effectiveness is affected by weather phenomena which may impact the variability of the results, and to interferences by large animals, with consequent loss of sampled specimens (Kuhlman et al. 2021; LeBuhn et al. 2013; O'Connor et al. 2019). Our results are consistent with those of Cane et al. (2000) and Thompson et al. (2021), who reported that generally, hand netting captured more specimens and species than pan traps. In our study, the different performances of the two methods are confirmed by the fact that in both study areas, rarefaction

curves display the same trend. However, the effectiveness of pan traps and walking transects are differently affected by the flower coverage (see Supplementary Materials, Table S1 and Figure S1). While the effectiveness of pan traps is high at low flowering coverage, as shown by the rarefaction and extrapolation curves of the “Castelletti” area for the year 2022 (when flowering was scarce due to the recent seeding, Supplementary Materials, Figure S2 and S3), we observed that at high flowering coverage pan traps are less effective than walking transects (Supplementary Materials, Figure S1). Still, walking transects are strongly dependent on the presence of blooms on which to observe and net specimens. Therefore, our results confirm those by O'Connor et al. (2019) showing that pan traps and transects are inversely affected by flower coverage and are consistent with those by Kuhlman et al. (2021) about the seasonal and flower richness patterns on the effectiveness of pan traps and hand netting. The total rarefaction and extrapolation curves are in line with the results of other studies in indicating the great potential of pan traps in attracting a high diversity of bee species at very low sample size (Hall 2018; Krahner et al. 2021; Nielsen et al. 2011; O'Connor et al. 2019) because pan traps catch many more singletons than transects. However, transects revealed a higher number of species when considering the actual final sampling size, suggesting that an ideally exhaustive sampling, based solely on pan traps, would require a greater sampling effort than hand netting in terms of sampling sessions and personnel time. Finally, pan traps tend to catch a more variable community of bees than hand netting which instead samples more consistent communities over time (Fig. 6). In our case, hand netting was also crucial for collecting parasitic genera that can sometimes be found feeding on some flowering species but are rarely attracted to pan traps (Lezzeri et al. 2024). Still an important aspect when choosing between the two methods is the expertise of the operators since while pan traps do not require any expertise during field work, transects are largely based on taxonomic expertise and ideally the very same operator should perform all the surveys, to favour the consistency of the results. The wild bee communities sampled by hand netting and pan traps were distinctive between the two monitoring methods, confirming, as already seen in other studies (Nielsen et al. 2011; O'Connor et al. 2019), that these two methods are highly complementary. Finally, artificial nests as an exclusive monitoring method targets only cavity-nesting bee species and their associated cuckoo bees. As in Nielsen and colleagues (2011), nests captured the fewest specimens and species.

Regarding pan traps colours, some studies (Hall 2018; Stephen and Rao 2005) support the hypothesis of a strong preference for the blue colour of traps for most of the wild bee fauna. On the contrary, in our study the species captured by blue traps were a subsample of the white and yellow traps. According to Hall (2018) in the northern hemisphere the blue-coloured traps have greater attractiveness because of a greater abundance of bumblebees that prefer this colour. This study took place in a Mediterranean and lowland habitat, and although bumblebees are, from an abundance point of view, the dominant genus in the walking transects, very few specimens were caught by both blue and white traps. A possible explanation may also be that we used pan traps and not vane traps, unlike Hall (2018). The lower abundance of bumblebees sampled with pan traps is consistent with the results of Bell and colleagues (2023), who demonstrated that vane traps are more efficient at catching bumblebees than pan traps. The white traps attracted more *Systropha curvicornis* (Scopoli, 1770) specimens, a short-ligula species reported to be monoleptic for the Convolvulaceae (Michener 2007, <https://www.beewatching.it/>). Finally, yellow traps attracted many specimens of the genus *Lasioglossum*. Although the species of this genus are largely

polylectic, they are often found foraging on yellow-coloured Asteraceae (Michener 2007). These patterns indicate, according to the literature (Kuhlman et al. 2021; Nielsen et al. 2011; Rhoades et al. 2017), that the most suitable sampling method is extremely influenced by the studied habitat and by the local composition of the bee fauna. Therefore, if interested in monitoring a particular group of bees, it is necessary to assess beforehand the best method or combination of methods to capture the diversity of the entire group. In the Megachilidae family, we find genera and species with diverse trophic and nesting habits (Danforth et al. 2019; Michener 2007). For example, several *Osmia* and *Megachile* species nest in hollow stems and holes in wood, while others nest in the ground or in shells (Danforth et al. 2019; Michener 2007). The trophic habits are also different; while the genus *Megachile* is known to be related to Fabaceae, the genus *Chelostoma* prefers Ranunculaceae and Asteraceae species (<https://www.beewatching.it/>). These ecological differences do not allow a single sampling method to be used. Our results showed that all three monitoring methods are strongly complementary. Furthermore, the use of artificial nests also makes it possible to investigate parasites, parasitoids and hyperparasites of the nesting species, which make up a significant fraction of the biodiversity of an ecosystem (Klaus et al. 2024). Indeed, the only parasitic species among the Megachilidae family was captured using artificial nests.

Conclusions

Mediterranean areas are a hotspot for the biodiversity of wild bees. We found that in a very limited and frequently sampled area, different monitoring methods described quite different bee communities. Hand netting caught a higher abundance of specimens and species richness, but pan traps had greater attractiveness when flowering coverage was low. Artificial nests only sampled a smaller fraction of species but were fundamental to reveal the presence of several Megachilidae species, including the parasitic ones. In conclusion, we recommend the use of multiple highly complementary methods when addressing a comprehensive assessment of a wild bee community's biodiversity.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10531-025-03097-8>.

Acknowledgements Not applicable.

Author contributions O.C.M., M.M. and F.R.D. authors contributed to the monitoring work; D.V. supported the agronomic fieldwork; O.C.M. conceived the study; O.C.M. and M.M. identified the specimens, performed data analysis and wrote the paper; all authors read, commented and approved the manuscript.

Funding Open access funding was provided by Università degli Studi di Firenze within the CRUI-CARE Agreement. O.C.M. acknowledges the support of Programma Operativo Nazionale Ricerca e Competitività. F.R.D. and M.M. acknowledge the support of the NBFC to the University of Florence, funded by the Italian Ministry of University and Research, PNRR, Missione 4 Componente 2, “Dalla ricerca all’impresa”, Investimento 1.4, Project CN00000033.

Data availability All data analysed for this paper are available in the Supplementary Materials and on request.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Bascompte J, Jordano P, Olesen JM (2006) Asymmetric coevolutionary networks facilitate biodiversity maintenance. *Science* 312:431–433. <https://doi.org/10.1126/science.1123412>
- Bates D, Mächler M, Bolker B, Walker S (2015) Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, 67(1), 1–48. <https://doi.org/10.18637/jss.v067.i01>
- Bell C, Tronstad L, Hotaling S (2023) Tailoring your bee sampling protocol: Comparing three methods reveals the best approaches to capturing bees. *Agric for Entomol* 25(3):477–488. <https://doi.org/10.1111/afe.12569>
- Breeze TD, Bailey AP, Balcombe KG, Brereton T, Comont R, Edwards M, Garratt MP et al (2021) Pollinator monitoring more than pays for itself. *Journal of Applied Ecology* 58:44–57. <https://doi.org/10.1111/1365-2664.13755>
- Cane JH, Minckley RL, Kervin LJ, Roulston TH, Williams NM (2006) Complex responses within a desert bee guild (Hymenoptera: Apiformes) to urban habitat fragmentation. *Ecological Applications: a Publication of the Ecological Society of America* 16(2):632–644. [https://doi.org/10.1890/1051-0761\(2006\)016\[0632:crwadb\]2.0.co;2](https://doi.org/10.1890/1051-0761(2006)016[0632:crwadb]2.0.co;2)
- Cane JH (2001). Habitat Fragmentation and Native Bees: a Premature Verdict? *Conservation Ecology*, 5(1). <http://www.jstor.org/stable/26271798>
- Cane JH, Minckley RL, Kervin LJ (2000) Sampling Bees (Hymenoptera: Apiformes) for Pollinator Community Studies: Pitfalls of Pan-trapping. *Journal of the Kansas Entomology Society* 73(4):225–231
- Chamorro FJ, Faria CMA, Araújo FS, Freitas BM (2023) Elevated pan traps optimise the sampling of bees, including when the availability of floral resources is high. *Insect Conservation and Diversity* 16(1):16–32. <https://doi.org/10.1111/icad.12621>
- Dafni A, Kevan PG, Husband BC (2005) *Practical Pollination Biology*. Enviroquest Ltd.
- Danforth BN, Minckley RL, Neff JL (2019) *The Solitary Bees*. Princeton University Press, Biology, Evolution, Conservation
- de Assis JC, Toppa RH, Martines MR, Arena MVN, da Silva SM, Carneiro LT, Oliveira LF, da Silva-Zacarin ECM (2021) The influence of climate and seasonality on bee communities: a complementary method for bee sampling in forest patches of an anthropic matrix. *Int J Trop Insect Sci* 41:711–723. <https://doi.org/10.1007/s42690-020-00261-1>
- Dunn RR, Harris NC, Colwell RK, Koh LP, Sodhi NS (2009) The sixth mass coextinction: are most endangered species parasites and mutualists? *Proceedings Biological Sciences* 276(1670):3037–3045. <https://doi.org/10.1098/rspb.2009.0413>
- Gathmann A, Greiler HJ, Tscharnkte T (1994) Trap-Nesting Bees and Wasps Colonizing Set-Aside Fields: Succession and Body Size, Management by Cutting and Sowing. *Oecologia*, 98(1): 8–14. <http://www.jstor.org/stable/4220660>
- Geroff RK, Gibbs J, McCravy KW (2014) Assessing bee (Hymenoptera: Apoidea) diversity of an Illinois restored tallgrass prairie: methodology and conservation considerations. *J Insect Conserv* 18:951–964. <https://doi.org/10.1007/s10841-014-9703-z>
- Gezon ZJ, Wyman ES, Ascher JS, Inouye DW, Irwin RE (2015) The effect of repeated, lethal sampling on wild bee abundance and diversity. *Methods Ecol Evol* 6:1044–1054. <https://doi.org/10.1111/2041-210X.12375>
- Ghisbain G, Rosa P, Bogusch P, Flaminio S, Divelec RL, Dorchin A, Kasperek M, Kuhlmann M et al. (2023) The new annotated checklist of the wild bees of Europe (Hymenoptera: Anthophila). *Zootaxa*, 5327(1):1–147. <https://doi.org/10.11646/zootaxa.5327.1.1>
- Gibbs J, Joshi NK, Wilson JK, Rothwell NL, Powers K, Haas M, Gut L, Biddinger DJ, Isaacs R (2017) Does Passive Sampling Accurately Reflect the Bee (Apoidea: Anthophila) Communities Pollinating Apple and Sour Cherry Orchards? *Environ Entomol* 46(3):579–588. <https://doi.org/10.1093/ee/nvx069>
- Hall M (2018) Blue and yellow vane traps differ in their sampling effectiveness for wild bees in both open and wooded habitats. *Agric for Entomol* 20:487–495. <https://doi.org/10.1111/afe.12281>
- Hamilton NE, Ferry M (2018) ggtern: Ternary Diagrams Using ggplot2. *Journal of Statistical Software, Code Snippets* 87(3):1–17. <https://doi.org/10.18637/jss.v087.c03>

- Hartig F. (2017) DHARMA: residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.15.
- Hsieh TC, Ma KH, Chao A (2016) iNEXT: an R package for rarefaction and extrapolation of species diversity (Hill numbers). *Methods Ecol Evol* 7:1451–1456. <https://doi.org/10.1111/2041-210X.12613>
<https://www.beewatching.it/>
- Hussain RI, Brandl M, Maas B, Krautzer B, Frank T, Moser D (2022) Establishing new grasslands on crop fields: short-term development of plant and arthropod communities. *Restor Ecol* 30(8):e13641. <https://doi.org/10.1111/rec.13641>
- Hutchinson LA, Oliver TH, Breeze TD, O'Connor RS, Potts SG, Roberts SPM, Garratt MPD (2021) Inventorying and monitoring crop pollinating bees: Evaluating the effectiveness of common sampling methods. *Insect Conservation and Diversity* 15(3):299–311. <https://doi.org/10.1111/icad.12557>
- IPBES (2016). The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 552 pages. <https://doi.org/10.5281/zenodo.3402856>
- Klaus F, Ayasse M, Classen A, Dauber J, Diekötter T, Everaars J, Fornoff F et al (2024) Improving wild bee monitoring, sampling methods, and conservation. *Basic Appl Ecol* 75:2–11. <https://doi.org/10.1016/j.baec.2024.01.003>
- Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings Biological Sciences* 274(1608):303–313. <https://doi.org/10.1098/rspb.2006.3721>
- Krahner A, Schmidt J, Maxiner M, Porten M, Schmitt T (2021) Evaluation of four different methods for assessing bee diversity as ecological indicators of agro-ecosystems. *Ecol Ind* 125:107573. <https://doi.org/10.1016/j.ecolind.2021.107573>
- Kuhlman MP, Burrows S, Mummey DL, Ramsey PW, Hahn PG (2021) Relative bee abundance varies by collection method and flowering richness: Implications for understanding patterns in bee community data. *Ecological Solutions and Evidence* 2:e12071. <https://doi.org/10.1002/2688-8319.12071>
- LeBuhn G, Droege S, Connor EF, Gemmill-Herren B, Potts SG, Minckley RL, Griswold T, Jean R, Kula E, Roubik DW, Cane J, Wright KW, Frankie G, Parker F (2013) Detecting insect pollinator declines on regional and global scales. *Conserv Biol* 27(1):113–120. <https://doi.org/10.1111/j.1523-1739.2012.01962.x>
- Lezzeri M, Lozano V, Brundu G et al (2024) Standardized transect walks outperform pan traps in assessing wild bee community in a Mediterranean protected area (Asinara National Park, Italy). *Biodiversity Conservation* 33:1–16. <https://doi.org/10.1007/s10531-024-02850-9>
- MacIvor JS (2017) Cavity-nest boxes for solitary bees: a century of design and research. *Apidologie* 48:311–327. <https://doi.org/10.1007/s13592-016-0477-z>
- Michener CD (2007) The bees of the world. The Johns Hopkins University Press. <https://doi.org/10.56021/9780801885730>
- Moldoveanu OC, Maggioni M, Dani FR (2024) Environmental ameliorations and politics in support of pollinators. Experiences from Europe: A review. *Journal of Environmental Management*, 362:121219. <https://doi.org/10.1016/j.jenvman.2024.121219>
- Neumann P, Carreck LN (2010) Honeybee colony losses. *J Apic Res* 49(1):1–6. <https://doi.org/10.3896/IBRA.1.49.1.01>
- Montgomery GA, Belitz MW, Guralnick RP, Tingley MW (2021) Standards and best practices for monitoring and benchmarking insects. *Front Ecol Evol* 8:579193. <https://doi.org/10.3389/fevo.2020.579193>
- Nielsen A, Steffan-Dewenter I, Westphal C, Messinger O, Potts SG, Roberts SPM et al (2011) Assessing bee species richness in two Mediterranean communities: importance of habitat type and sampling techniques. *Ecology Research* 26:969–983. <https://doi.org/10.1007/s11284-011-0852-1>
- Nieto A, Roberts SPM, Kemp J, Rasmont P, Kuhlmann M, García Criado M et al. (2014) European Red List of bees. Luxembourg: Publication Office of the European Union. <https://data.europa.eu/doi/> <https://doi.org/10.2779/51181>
- O'Connor RS, Kunin WE, Garratt MPD, Potts SG, Roy HE, Andrews C et al (2019) Monitoring insect pollinators and flower visitation: The effectiveness and feasibility of different survey methods. *Methods Ecol Evol* 10:2129–2140. <https://doi.org/10.1111/2041-210X.1329>
- Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R et al. (2024). *vegan: Community Ecology Package*. R package version 2.7–0, <https://github.com/vegandevs/vegan>, <https://vegandevs.github.io/vegan/>
- Ollerton J, Winfree R, Tarrant S (2011) How many flowering plants are pollinated by animals? *Oikos* 120:321–326. <https://doi.org/10.1111/j.1600-0706.2010.18644.x>
- Orr MC, Hughes AC, Chesters D, Pickering J, Zhu CD, Ascher JS (2021) Global patterns and drivers of bee distribution. *Curr Biol* 31(3):451–458. <https://doi.org/10.1016/j.cub.2020.10.053>

- Ortiz-Sanchez FJ, Aguirre-Segura A (1992) Comparison of the effectiveness of different heights in order to capture bees with the employ of Moericke traps (Hymenoptera, Apoidea). *Graellsia* 48:35–43
- Packer L, Darla-West G (2021) Bees: how and why to sample them. In: Santos JC, Fernandes GW (eds) *Measuring Arthropod Biodiversity*. Springer Nature, Switzerland, pp 55–83. <https://doi.org/10.1007/s10841-017-0018-8>
- Papanikolaou AD, Kühn I, Frenzel M, Schweiger O (2017) Landscape heterogeneity enhances stability of wild bee abundance under highly varying temperature, but not under highly varying precipitation. *Landscape Ecology*, 32, 581–593. <https://doi.org/10.1007/s10980-016-0471-x>, https://doi.org/10.1007/978-3-030-53226-0_3
- Popic TJ, Davila YC, Wardle GM (2013) Evaluation of common methods for sampling invertebrate pollinator assemblages: net sampling out-perform pan traps. *PLoS ONE* 8(6):e66665. <https://doi.org/10.1371/journal.pone.0066665>
- Potts S, Imperatriz-Fonseca V, Ngo H, Aizen MA, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J, Vanbergen AJ (2016) Safeguarding pollinators and their values to human well-being. *Nature* 540:220–229. <https://doi.org/10.1038/nature20588>
- Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE (2010) Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution*, 25(6):345–353. <https://doi.org/10.1016/j.tree.2010.01.007>
- Potts SG, Bartomeus I, Biesmeijer K, Breeze T, Casino A, Dauber J et al (2024) Refined proposal for an EU pollinator monitoring scheme. Publications Office of the European Union, Luxembourg,. <https://doi.org/10.2760/2005545>
- Prado SG, Ngo HT, Florez JA et al (2017) Sampling bees in tropical forests and agroecosystems: a review. *J Insect Conserv* 21:753–770. <https://doi.org/10.1007/s10841-017-0018-8>
- Prendergast KS, Menz MH, Dixon KW, Bateman PW (2020) The relative performance of sampling methods for native bees: an empirical test and review of the literature. *Ecosphere*, 11. <https://doi.org/10.1002/ec.2.3076>
- Quaranta M, Cornalba M, Biella P, Comba M, Battistoni A, Rondinini C, Teofili C (2018) Red list IUCN of the Italian threatened bees [Lista Rossa IUCN delle api italiane minacciate]. Comitato Italiano IUCN e Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma.
- Reid W, Mooney H, Cropper A, Capistrano D, Carpenter S, Chopra K (2005) Millennium Ecosystem Assessment. Ecosystems and human well-being: synthesis.
- Rhoades P, Griswold T, Waits L, Bosque-Pérez NA, Kennedy CM, Eigenbrode SD (2017) Sampling technique affects detection of habitat factors influencing wild bee communities. *J Insect Conservation* 21:703–714. <https://doi.org/10.1007/s10841-017-0013-0>
- Sanderson MA (2010) Stability of production and plant species diversity in managed grasslands: a retrospective study. *Basic Appl Ecol* 11:216–224. <https://doi.org/10.1016/j.baec.2009.08.002>
- Sevilleja CG, van Swaay CAM, Bourn N, Collins S, Settele J, Warren MS, Wynhoff I, Roy DB (2019) Butterfly Transect Counts: Manual to monitor butterflies. Report VS2019.016, Butterfly Conservation Europe & De Vlinderstichting/Dutch Butterfly Conservation, Wageningen. <https://butterfly-monitoring.net/>
- Staab M, Pufal G, Tscharnke T, Klein A-M (2018) Trap nests for bees and wasps to analyse trophic interactions in changing environments—A systematic overview and user guide. *Methods Ecol Evol* 9:2226–2239. <https://doi.org/10.1111/2041-210X.13070>
- Stephen WP and Rao S (2005) Unscented Color Traps for Non-Apis Bees (Hymenoptera: Apiformes). *Journal of the Kansas Entomological Society*, 78(4): 373–80. *JSTOR*, <http://www.jstor.org/stable/25086288>
- Thompson AH, Frenzel M, Schweiger O, Musche M, Groth T, Roberts SP, Kuhlmann M, Knight TM (2021) Pollinator sampling methods influence community patterns assessments by capturing species with different traits and at different abundances. *Ecological Indicators*, 132. <https://doi.org/10.1016/j.ecolind.2021.108284>
- Westphal C, Bommarco R, Carré G, Lamborn E, Morison N, Petanidou T, Potts SG, Roberts SPM, Szentgyörgyi H, Tscheulin T, Vaissière BE, Woyciechowski M, Biesmeijer JC, Kunin WE, Settele J, Steffan-Dewenter I (2008) Measuring bee diversity in different European habitats and biogeographical regions. *Ecol Monogr* 78:653–671. <https://doi.org/10.1890/07-1292.1>
- Westphal C, Steffan-Dewenter I, Tscharnke T (2006) Foraging trip duration of bumblebees in relation to landscape-wide resource availability. *Ecological Entomology* 31(4):389–394. <https://doi.org/10.1111/j.1365-2311.2006.00801.x>
- Wilson JS, Griswold T, Messinger OJ (2008) Sampling bee communities (Hymenoptera: Apiformes) in a desert landscape: are pan traps sufficient? *J Kans Entomol Soc* 81(3):288–300. <https://doi.org/10.2317/JKES-802.06.1>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.