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Assessing wild bee fauna (Hymenoptera: Apoidea: Anthophila) in Calabria (southern Italy)

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Abstract
The ecological importance of wild bees as pollinators has become more widely recognized in recent years. However, knowledge regarding their diversity and distribution in numerous regions of Italy remains deficient in comparison to other Mediterranean countries. This study, conducted over a three-year period (2022–2024), surveyed eight sites in an area designated as a UNESCO (United Nations Educational, Scientific and Cultural Organization) Man and Biosphere Reserve in Calabria. The sampling methods included transect walks and pan traps, leading to the identification of 80 species, classified into 17 genera belonging to four families (Andrenidae, Apidae, Halictidae, Megachilidae). Among them, 16 species were documented for the first time in Calabria, i.e. *A. binominata*, *A.cineraria*, *A. fumida*, *A. gravida*, *A. haemorrhoa*, *A. lathyri*, *A. pandellei*, *A. polita* (Andrenidae); *Lasioglossum aeratum*, *L. transitorium*, *L. xanthopus*, *Sphecodes spinulosus* (Halictidae); *Hoplitis cristatula*, *Osmialigurica*, *O. scutellaris* (Megachilidae) and *Eucera nigrifacies* (Apidae). The study also documented bee–flora interactions, noting 40 plant genera from 21 families. New insights into the dietary preferences of *Seladonia seladonia* and *Andrena fumida* were obtained, alongside novel plant associations for several oligolectic species (*A. pandellei*, *A. agilissima*, *A. humilis*, *A. lagopus*, *A. russula*, *L. brevicorne*, *H. cristatula*, *O. leaiana*). These findings contribute to the knowledge about the distribution and ecology of the bee fauna in southern Italy, in particular, and in Europe in general.

Keywords: *Bumblebees*, *host-plant*, *mason bees*, *mining bees*, *sweat bees*

1. Introduction

Pollination is an important ecosystem service that sustains both wild and domesticated plants (Potts et al. 2016; Khalifa et al. 2021). Wild bees (Hymenoptera, Apoidea, Anthophila) are the most important group of plant pollinators (Winfree et al. 2008) and comprise more than 20,000 species worldwide (Michener 2007; Ascher 2017). Nevertheless, they are currently experiencing a decline caused by different stress factors such as climate change and land use (LeBuhn & Vargas Luna 2021). The diversity and abundance of wild bees appear to be primarily affected by factors such as habitat fragmentation, extensive use of pesticide, general environmental pollution, pests and pathogens (Potts et al. 2010). In recent years, monitoring research has been carried out at European, national and regional levels to improve knowledge on the causes and consequences of their decline and to develop effective management and conservation strategies (Patiny et al. 2009; Potts et al. 2016, 2024; Woodard et al. 2020; Breeze et al. 2021; Ghisbain et al. 2023; Reverté et al. 2023).

Despite the growing interest in wild bees (Rasmont et al. 2017; Ghisbain et al. 2023;

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Reverté et al. 2023), more than 50% of the documented species in the International Union for Conservation of Nature (IUCN) Red List for bees in Europe are reported as data deficient (Nieto et al. 2014). This suggests the importance of increasing ecological studies on the geographical distribution and species richness of communities. In Europe, the greatest diversity of bee species has been observed in Mediterranean countries (Nieto et al. 2015; Orr et al. 2021; Leclercq et al. 2022), which have served as important refuges for bees during glaciations (Dellicour et al. 2014, 2017). Italy, along with Greece and Spain, is one of the three countries with the highest species richness in bees, with more than 1000 species recorded (Reverté et al. 2023). Although important faunistic and ecological studies have been carried out in Italy (Quaranta et al. 2004; Comba 2019; Nobile et al. 2021; Bella et al. 2023; Wood et al. 2023; Cornalba et al. 2024; Fortini et al. 2024; Goglia et al. 2024a), the available data on the distribution of wild bees in certain geographical areas, such as Calabria (southern Italy), are either limited or lacking (Wood et al. 2023; Cornalba et al. 2024).

The aim of this study is to provide a preliminary report on wild bees in a central area of Calabria. The designated monitoring area falls within a UNESCO Man and Biosphere Reserve, which includes the Sila National Park, known for its importance in terms of biodiversity conservation. Furthermore, the interaction between the identified wild bees and the host plants was analysed and an overview of the knowledge on the ecological characteristics and conservation status of the identified species was provided.

2. Materials and methods

2.1. Study area

The sampling sites were chosen in an area (about 357,000 ha) which has been designated "UNESCO Man and Biosphere Reserve" since 2014 and includes the Sila National Park (Calabria, Italy). The Park covers approximately 77,000 ha of the Sila plateau, a large area of 170,000 ha at altitudes ranging from 1100 to 1900 m a.s.l. consisting of granitoids and metamorphic rocks (Muto et al. 2024). The area is classified as belonging to the oceanic temperate bioclimate, characterised by a pronounced summer drought, increasing precipitation with altitude and cold winters. It is characterised by the presence of water bodies, including small rivers, cold streams, and artificial lakes. Additionally, it exhibits a diverse range of vegetation, including both spontaneous and re-naturalised species, which have emerged because of reforestation efforts following repeated phases of intense deforestation. The vegetation consists of extensive meadows, pastures and forests of conifers (mainly *Pinus nigra* Arnold, 1785), silver firs (*Abies alba* Miller, 1759) and beech woods (*Fagus sylvatica* Linnaeus, 1753) (Scarciglia et al. 2020). Furthermore, the region has urban settlements and agricultural activities.

The study was conducted over a period of three-years (from 2022 to 2024). A total of eight sampling sites were selected, representing a range of different habitats (Figure 1). In detail, four sites were chosen in cultivated areas (S1: 39°28'06.6"N, 16° 30'04.5"E, 1051 m a.s.l.; S2: 39°21'54.0"N, 16° 31'09.9"E, 1175 m a.s.l.; S3: 39°26'52.5"N, 16° 29'04.2"E, 1122 m a.s.l; S4: 39°16'59.0"N, 16° 38'28.6"E, 1231 m a.s.l.). Three sites were pastures (S5: 39°16'51.4"N, 16°32'10.3"E, 1567 m a.s.l.; S6: 39°18'46.8"N, 16°32'28.8"E, 1430 m a.s.l.; S7: 39°31'08.33"N, 16°42'53.25"E, 1680 m a.s.l.). One site was a grassland located within the integral gated reserve area (S8: 39°23'40.8"N, 16° 36'01.6"E, 1284 m a.s.l.), which is crossed by the Cecita stream and surrounded by wooded areas with no crops present in proximity. Over the sampling period, the minimum temperature was approximately 15°C in May while the maximum temperature reached approximately 33°C in July (Arpacal, 2024).

2.2. Bee sampling

Sampling was carried out according to the guidelines of the Pollinator Monitoring Scheme (PoMS), a standardised monitoring programme designed to monitor pollinator populations across the European Union (Potts et al. 2021, 2024). Permanent transect walks were used to survey flying insects. These were corridors 250 m long and 2 m wide divided into five subunits of 50 m each. Each transect was observed for a maximum of 50 min (10 minfor each subsection) by a minimum of two operators in predefined time slots (from 09:00 to 16:00). Sampling periods were monthly from May to August over three years, totaling 12 sampling events. All specimens of wild bees observed on the flowers were captured and subsequently associated with the plant species that were visited at the time of observation.

In June 2022, pan traps were set to determine whether there were any differences in the wild bee fauna compared to those observed during the transect walks (Klaus et al. 2024). A group of three-coloured pan traps (white, blue, yellow) were located at the beginning, middle and end of each

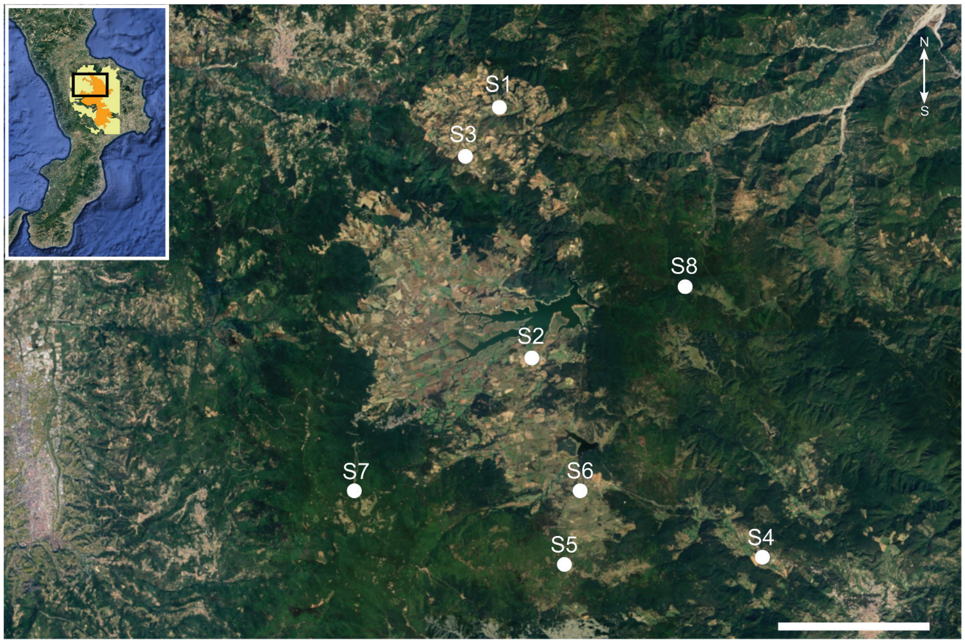

Figure 1. Map of the sampling area (from Google Earth). Insert: area of the Sila National Park (Calabria, Italy) (orange) included in area of the UNESCO Man and Biosphere Reserve (yellow); S1–S8: sampling sites. Scale bar: 7000 m.

transect at sites S2, S4 and S8 (nine triplets, Figure 1), chosen to represent differing degrees of management (cultivated area, pasture and a natural area). Each pan trap was filled with a solution of 200 mL of water and one drop of a common detergent and was left active for 48 h. All wild bee specimens were initially stored at a temperature of −20°C.

2.3. *Species identification and data analysis*

All specimens collected were identified to the species level (see reference of dichotomous keys in Michez et al. 2019) and preserved in the laboratory of Morphofunctional Entomology at the University of Calabria in Rende (Italy).

To distinguish the different species within the genus *Bombu*s, a genetic analysis was carried out based on the following protocol. The hind legs of all specimens were isolated and stored at −20°C for subsequent molecular analysis, which was carried out on 20 randomly selected samples using the DNA barcoding approach, which involves amplification of the mitochondrial cytochrome c oxidase subunit I (COI) gene. Total DNA was extracted from the leg of each insect using a Chelex-proteinase K protocol as described by Gebiola et al. (2009). The COI gene was amplified using the primer BeeCox1F1 (TAGTCAACAAATCATAAAGATATTGG) andBeeCox1R2 (CCAAATCCTGGTAGAATTAAAATATA) (Bleidorn & Henze 2021). As reported in Goglia et al. (2024b), polymerase chain reaction (PCR) amplification was carried out using 50 µL PCR master mix with 5 µL 10X Taq buffer, 3 µL 1.5 mm $MgCl_2$, 2 µL of 5 mm dNTP, 2.5 µL of 10 µM of each primer, 1.25 U Taq DNA polymerase recombinant (Thermo Fisher Scientific) and 1 µL genomic DNA. PCR thermal cycling parameters included: initial denaturation at 94°C for 2 min; 40 cycles of denaturation at 94°C for 30 s, annealing at 50°C for 45 s, extension at 72°C for 60 s; final extension for 10 min at 72°C (Bleidorn & Henze 2021). PCR amplification was checked on a 1% agarose gel. Amplicons were sequenced using the Sanger sequencing service provided by Macrogen Europe (Amsterdam, Netherlands). The resulting chromatograms were analysed and edited with Chromas v. 2.6.4 (Technelysium, South Brisbane, Queensland, Australia). Amplified sequences were matched with known sequences available in the GenBank database using the BLAST tool (https://blast.ncbi.nlm.nih.gov/Blast.cgi) and in the BOLD database (https://v4.boldsystems.org/index.php).

Species were scored according to their conservation status as reported on the European International Union for Conservation of Nature (IUCN) Red List of Bees (EN – Endangered, VU – Vulnerable, NT – Near Threatened, LC –

Least Concern, DD – Data Deficient) (Nieto et al. 2014). The recently published checklist of the wild bees of Europe (Ghisbain et al. 2023) was consulted for the nomenclature. New species for Calabria were checked by comparing data with references provided in Table I. The specimens recovered from the pan traps were categorised according to the colour plate on which they were found. The proportion of specimens from each colour plate was calculated, for both the total number of specimens and the three most abundant groups.

During the sampling in the transect walks, plant–pollinator interactions were recorded, and the resulting network was generated using the R package "circlise" (Gu et al. 2014). Plant species were identified at the genus level using the PlantNet tool.

3. Results and discussion

3.1. *Sampled species*

A total of 922 specimens, belonging to 69 species, were collected during transect walks, and an additional 174 specimens from 34 species were obtained using pan traps (Table S1). The combined data from the two methods led to the identification of 80 species across 17 genera and four families (Table I). The genus *Andrena* exhibited the greatest diversity, with 28 species, followed by *Lasioglossum* with 15 species, and *Bombus* with 11 species. According to previous studies (see references in Table S1), most censed species are solitary and ground-nesting. Species displaying eusocial and cleptoparasitic behaviour, as well as cavity-nesting habits, were also identified. Great variability was also found in their current conservation status, i.e., 54 species were classified as LC by the IUCN, 20 species as DD, six species as NT, and one species, *Lasioglossum subfasciatum*, as EN (Table S1). The species identified in the present study are, in general, distributed throughout Europe, with some species extending to North Africa, the Caucasus region and Asia (see Table I for further details and references; also see the Atlas Hymenoptera website 2025). In addition, *A. ranunculorum* and *A. tomora* were reported in Italy in a limited number of records (Comba 2019; Wood et al. 2023), making their actual Italian distribution uncertain. Moreover, *L. subfasciatum*, categorised as EN, was reported in a previous study (Vommaro et al. 2024). These results highlight the rich bee diversity in Calabria and raise important considerations regarding the conservation status of certain species.

The study also identified 16 species that represent new records for the Calabria region: eight species belonging to Andrenidae, four species belonging to Halictidae, three species belonging to Megachilidae and one species belonging to Apidae (Table I; Table S3). Twelve of these (*Andrena cineraria*, *A. gravida*, *A. pandellei*, *A. lathyri*, *A. polita*, *Lasioglossum aeratum*, *L. transitorium*, *L. xanthopus*, *Osmia ligurica*, *O. scutellaris*, *Eucera nigrifacies* and *Hoplitis cristatula*) were previously known in different Italian regions, from north to south. *Sphecodes spinulosus* has been recorded in the central (Emilia Romagna, Abruzzo) and southern regions (Basilicata and Sicily); *A. haemorrhoa* has been recorded only in northern regions and this finding agrees with the cold climate character of the Sila plateau, which harbours several disjointed populations of northern species. Finally, *A. fumida* has been recorded in southern regions (Campania and Sicily), while *A. binominata* has only been reported in Sicily (Comba 2019). These new records significantly expand the understanding of the regional species composition and emphasise the need for further investigation into the distribution of these bees in Calabria.

The molecular analysis confirmed the identity of the *Bombus* species with a high degree of accuracy, showing over 99% sequence similarity to existing databases such as BOLD and NCBI (National Center for Biotechnology Information). For species like *B. lapidarius*, *B. lucorum*, and *B. terrestris*, a 100% match was achieved, further validating the reliability of the morphological identifications. The genetic confirmation of species identities adds an important layer of confidence to the study's findings, providing a robust basis for future research and comparisons.

3.2. *Plant–pollinator interaction*

In terms of plant–pollinator interactions, a total of 40 plant genera, representing 21 families, were recorded as visited by the sampled bee species (Figure 2). Asteraceae was the most frequently visited plant family, comprising 15 genera. Among the pollinator genera, *Bombus* and *Andrena* showed the broadest foraging patterns, with *Bombus* interacting with 22 plant genera across 14 families, and *Andrena* visiting 18 plant genera from 11 families. This reflects their generalist foraging strategies. Moreover, new information was obtained about the dietary preferences of two species for which no prior evidence was documented in the existing literature: *Seladonia seladonia* foraging on *Tolpis* sp. and *Cirsium* sp., and *A. fumida* observed on *Asphodelus* sp. Furthermore, this study provided new insights into the plant preferences of eight species that were typically regarded as oligolectic (Table S1). The following species were observed foraging on plants outside their previously documented

Table I. List of species found throughout the three-year (2022–2024) sampling period, and their geographical distribution.

Family	Genus	Subgenus	Species	Distribution
Andrenidae	*Andrena*	*Agandrena*	*A. agilissima* (Scopoli, 1770)	South-western and central Europe; North Africa (Rasmont et al. 2013)
		Biareolina	*A. lagopus* Latreille, 1809	South-western Europe; North Africa (Rasmont et al. 2013)
		Carandrena	*A. binominata*⋆ Smith, 1853	Sicily, Spain and Maghreb region (Rasmont et al. 2013)
		Charitandrena	*A. hattorfiana* (Fabricius, 1775)	Throughout Europe; Caucasus region and Asia Minor (IUCN 2013; Rasmont et al. 2013)
		Chlorandrena	*A. cinerea* Brullé, 1832	Southern Europe; North Africa, Caucasus and Asia Minor (Rasmont et al. 2013)
		Chlorandrena	*A. humilis* Imhoff, 1832	Throughout Europe; North Africa, Caucasus, Asia Minor and Far East (Rasmont et al. 2013)
		Fumandrena	*A. fumida*⋆ Pžrez, 1895	In Europe only known from Sicily; Maghreb (Rasmont et al. 2013)
		Fumandrena	*A. tomora* Warncke, 1965	Albania, Greece, Turkey, Italy (Wood et al. 2023)
		Lepidandrena	*A. pandellei*⋆ Pérez, 1895	Mediterranean (IUCN 2013; Comba 2019)
		Melandrena	*A. cineraria*⋆ (Linnaeus, 1758)	Throughout Europe; Caucasus region and Asia (Rasmont et al. 2013)
		Melandrena	*A. morio* Brullé, 1832	Southern and central Europe, Caucasus region, North Africa, south-western and Central Asia (Rasmont et al. 2013)
		Melandrena	*A. nigroaenea* (Kirby, 1802)	Throughout Europe; Caucasus region, North Africa, Asia Minor and Central Asia (Rasmont et al. 2013)
		Melandrena	*A. nitida* (Müller, 1776)	Throughout Europe; Caucasus region, North Africa, south-western and Central Asia and west Siberia (Rasmont et al. 2013)
		Melandrena	*A. thoracica* (Fabricius, 1775)	Throughout Europe; North Africa, Russia, south-western and Central Asia and to the far east of China and Korea (Rasmont et al. 2013)
		Micrandrena	*A. minutula* (Kirby, 1802)	Throughout Europe;l Caucasus region, North Africa, Asia Minor and central and east Asia (Rasmont et al. 2013)
		Micrandrena	*A. simontornyella* Noskiewicz, 1939	Southern and central Europe; North Africa (Rasmont et al. 2013)
		Plastandrena	*A. pilipes* Fabricius, 1781	Throughout Europe; widespread globally (IUCN 2013)
		Poecilandrena	*A. labiata* Fabricius, 1781	Throughout Europe; Caucasus region, Asia Minor and central and east Asia (IUCN 2013)
		Poliandrena	*A. polita*⋆ Smith, 1847	Central and southern Europe (Rasmont et al. 2013)
		Simandrena	*A. dorsata* (Kirby, 1802)	Throughout Europe; North Africa and south-western Asia (Rasmont et al. 2013)
		Taeniandrena	*A. afzeliella* (Kirby, 1802)	Throughout Europe; Caucasus region and North Africa (Praz et al. 2022)
		Taeniandrena	*A. lathyri*⋆ Alfken, 1899	Throughout Europe; Asia Minor and Far East Russia (Rasmont et al. 2013)
		Taeniandrena	*A. numida* Lepeletier, 1841	In Europe, found only in Italy and Sicily; Caucasus and North Africa (Rasmont et al. 2013)
		Taeniandrena	*A. ranunculorum* Morawitz, 1877	Rare species, locally distributed across the middle of Europe; Caucasus (Rasmont et al. 2013)
		Taeniandrena	*A. russula* Lepeletier, 1841	Throughout Europe; Caucasus (Praz et al. 2022)
		Trachandrena	*A. haemorrhoa*⋆ (Fabricius, 1781)	Throughout Europe; Caucasus region, North Africa, Asia Minor and central Asia and the Far East to Kamchatka and Japan (Rasmont et al. 2013)
		Zonanadrena	*A. flavipes* Panzer, 1799	Throughout Europe; North Africa, Middle East, Asia Minor and Central Asia eastwards to India, Nepal and China (IUCN 2013; Rasmont et al. 2013)
		Zonanadrena	*A. gravida*⋆ Imhoff, 1832	Throughout Europe; Asia Minor and central Asia (Rasmont et al. 2013)
	Panurgus	*Panurgus*	*P. calcaratus* (Scopoli, 1763)	Throughout Europe; Caucasus region (Patiny 2012)
Apidae	*Anthophora*	*Anthophora*	*A. crinipes* Smith, 1854	Mediterranean region; North Africa (Rasmont 2014)
	Bombus	*Bombus*	*B. lucorum* (Linnaeus, 1761)	Throughout Europe, in the southern countries, it remains in the hills and the mountains, never reaching the Mediterranean coast (Rasmont & Iserbyt 2014)

(*Continued*)

Table I. (Continued).

Family	Genus	Subgenus	Species	Distribution
		Bombus	*B. terrestris* (Linnaeus, 1758)	Throughout Europe; Caucasus and North Africa (Rasmont & Iserbyt 2014)
		Kallobombus	*B. soroeensis* (Fabricius, 1776)	West Palaearctic region (Rasmont & Iserbyt 2014)
		Megabombus	*B. hortorum* Linnaeus, 1761	West Palaearctic region (Rasmont & Iserbyt 2014)
		Megabombus	*B. ruderatus* (Fabricius, 1775)	Western Europe, especially Mediterranean zone (Rasmont & Iserbyt 2014)
		Melanobombus	*B. lapidarius* (Linnaeus, 1758)	Central Europe; Morocco and Caucasus (Rasmont & Iserbyt 2014)
		Psithyrus	*B. barbutellus* (Kirby, 1802)	Western Europe (Rasmont & Iserbyt 2014)
		Psithyrus	*B. sylvestris* (Lepeletier, 1832)	Central Europe (Rasmont & Iserbyt 2014)
		Thoracobombus	*B. humilis* Illiger, 1806	Throughout Europe (Rasmont & Iserbyt 2014)
		Thoracobombus	*B. pascuorum* (Scopoli, 1763)	The most abundant bumblebee species in the West Palaearctic (Rasmont & Iserbyt 2014)
		Thoracobombus	*B. sylvarum* (Linnaeus, 1761)	West Palaearctic region (Rasmont & Iserbyt 2014)
	Ceratina	*Ceratina*	*C. cucurbitina* (Rossi, 1792)	Mediterranean (Terzo & Rasmont 2011)
		Euceratina	*C. dentiventris* Gerstäcker, 1869	Thermo-Mediterranean zone (Terzo & Rasmont 2011)
	Eucera	*Pteneucera*	*E. nigrifacies** Lepeletier, 1841	South Europe; From North Africa to the Middle East (IUCN 2013; Comba 2019)
	Melecta	*Melecta*	*M. albifrons* (Forster, 1771)	The most widespread species of the genus in Europe (IUCN 2013)
	Nomada	*Heminomada*	*N. fucata* Panzer, 1798	Europe, North Africa, the Near East and Asia (IUCN 2013)
		Gestamen	*N. femoralis* Morawitz, 1869	Central and southern Europe and Asia Minor; extinct in Czechia (IUCN 2013)
		Holonomada	*N. basalis* Herrich-Schäffer, 1839	South-eastern Europe; northern Africa, the Near East and Asia; extinct in Czechia, Slovenia and Switzerland (IUCN 2013)
	Xylocopa	*Xylocopa*	*X. violacea* (Linnaeus, 1758)	Western and central Europe, very abundant in the Mediterranean region; extinct in Poland (IUCN 2013)
Halictidae	*Halictus*	*Halictus*	*H. quadricinctus* (Fabricius, 1776)	Throughout Europe; Morocco; extinct in the Netherlands (IUCN 2013)
		Hexataenites	*H. scabiosae* (Rossi, 1790)	Western Europe, Mediterranean region (Pauly 2011a)
		Tytthalictus	*H. asperulus* Pérez, 1895	South-western palearctic (Pauly 2011a)
		Tytthalictus	*H. maculatus* Smith, 1848	West Palearctic; extinct in the United Kingdom (Pauly 2011a)
	Seladonia	*Seladonia*	*S. seladonia* (Fabricius, 1794)	Steppe zones of Eurasia (Pauly 2011b)
		Seladonia	*S. subaurata* (Rossi, 1792)	Warm localities of the West Palaearctic (Pauly 2011b)
	Lasioglossum	*Dialictus*	*L. aeratum** (Kirby, 1802)	Sporadically in Euro-Siberian zone (IUCN 2013)
		Hemihalictus	*L. brevicorne* (Schenck, 1870)	Throughout Europe; North Africa, Caucasus (IUCN 2013)
		Hemihalictus	*L. crassepunctatum* (Blüthgen, 1923)	Steppe zones of Eurasia (IUCN 2013)
		Hemihalictus	*L. griseolum* (Morawitz, 1872)	Europe, throughout the Mediterranean; Caucasus; extinct in Czechia (IUCN 2013)
		Hemihalictus	*L. parvulum* (Schenck,1853)	Southern and eestern Europe; Caucasus (Pauly 2011c)
		Hemihalictus	*L. pauperatum* (Brullé,1832)	Western Europe; Maghreb (Pauly 2011c)
		Hemihalictus	*L. puncticolle* (Morawitz, 1872)	Western, central and south-eastern Europe; North Africa (IUCN 2013)
		Hemihalictus	*L. transitorium** (Schenck, 1868)	Sporadically throughout the Mediterranean; North Africa (Pauly 2011c)
		Hemihalictus	*L. villosulum* (Kirby, 1802)	Throughout Europe; Middle East and Asia IUCN (2013)
		Lasioglossum	*L. laterale* (Brullé, 1832)	Mediterranean (IUCN 2013)
		Lasioglossum	*L. subfasciatum* (Imhoff, 1832)	Western Europe; Caucasus; extinct in Belgium (IUCN 2013)
		Lasioglossum	*L. xanthopus** (Kirby, 1802)	Sporadically throughout Europe; northern Africa and Asia (IUCN 2013)
		Leuchalictus	*L. leucozonium* (Schrank, 1781)	Throughout the whole Holarctic region (IUCN 2013)
		Sphecodogastra	*L. interruptum* (Panzer, 1798)	Eastern and central Europe; North Africa (IUCN 2013)
		Sphecodogastra	*L. pauxillum* (Schenck, 1853)	Western and central Europe and south-eastern Europe; North Africa, the Middle East, and Central Asia (IUCN 2013)

(*Continued*)

Table I. (Continued).

Family	Genus	Subgenus	Species	Distribution
	Sphecodes	*Sphecodes*	*S. ephippius* (Linnaeus, 1767)	Throughout Europe; North Africa (IUCN 2013)
		Sphecodes	*S. spinulosus*⋆ von Hagens, 1875	Sporadically throughout Europe; North Africa to Asia (IUCN 2013; Comba 2019)
Megachilidae	*Chelostoma*	*Chelostoma*	*C. florisomne* (Linnaeus, 1758)	Throughout Europe; northern Africa and south-western Asia (IUCN 2013)
	Heriades	*Heriades*	*H. truncorum* (Linnaeus, 1758)	Throughout Europe; northern Africa and northern and south-western Asia (IUCN 2013)
	Hoplitis	*Anthocopa*	*H. cristatula*⋆ (van der Zanden, 1990)	Southern Europe, Mediterranean countries; northern Africa, northern and south-western Asia (IUCN 2013)
	Megachile	*Xanthosarus*	*M. lagopoda* (Linnaeus, 1761)	Throughout Europe (IUCN 2013)
	Osmia	*Helicosmia*	*O. leaiana* (Kirby, 1802)	Throughout Europe; northern Africa and from south-western to northern Asia (IUCN 2013)
		Helicosmia	*O. niveata* (Fabricius, 1804)	Throughout Europe; northern Africa and from south-western to northern Asia (IUCN 2013)
		Hoplosmia	*O. ligurica*⋆ Morawitz, 1868	Southern Europe, Mediterranean; northern Africa and south-western Asia; extinct in Switzerland (IUCN 2013)
		Hoplosmia	*O. scutellaris*⋆ Morawitz, 1868	Southern Europe, Mediterranean; northern Africa and south-western Asia (IUCN 2013)

” >(⋆) first report in Calabria.

preferences: (a) *A. pandellei*, previously reported as strictly oligolectic on *Campanula* spp. (Campanulaceae) (Michez et al. 2019), was observed to forage on *Taraxacum* sp. (Asteraceae); (b) *A. agilissima*, reported as oligolectic on Brassicaceae (Westrich 1989), was found on *Cirsium* sp. (Asteraceae); (c) *A. humilis*, reported as oligolectic on Asteraceae (Franzén & Larsson 2007), was observed on *Asphodelus* sp. (Asphodelaceae), *Ranunculus* sp. (Ranunculaceae), and *Armeria* sp. (Plumbaginaceae); (d) *A. lagopus*, oligolectic on *Salix* sp. (Michez et al. 2019), was observed foraging on *Sinapis* sp.; (e) *A. russula*, reported as oligolectic on Fabaceae (Praz et al. 2022), was observed foraging on *Bellis* sp. (Asteraceae); (f) *L. brevicorne*, reported as oligolectic on Asteraceae (Westrich 1989), was observed on *Asphodelus* sp.; (g) *O. leaiana*, reported as oligolectic on Asteraceae (Michez et al. 2019), was also observed foraging on *Ranunculus* sp.; (h) *H. cristatula*, reported as oligolectic on Malvaceae (Ferton 1892) was observed foraging on *Achillea* sp. (Asteraceae). This expansion of known floral hosts suggests that, despite previous categorisation as oligolectic, these species may adapt their foraging strategies in response to environmental variables such as the availability of resources or specific plant phenology. As the chemical composition of pollen and nectar is highly variable across floral species (Fowler et al. 2016), our findings suggest that the relative dietary breadth of these species might be more related to metabolic needs or timing conditions, such as the necessity to collect pollen (providing protein) for larval feeding (Barraud et al. 2022).

Additionally, the widespread presence of honey bees at all study sites raises questions about potential competition and resource overlap between honey bees and wild pollinators. Given the intensive beekeeping activity in the region, it is crucial to examine how honey bees may influence the foraging behaviour of wild bee species. This interaction warrants further investigation, particularly concerning how honey bees may impact the diversity and behaviour of native pollinators.

3.3. *Pan traps versus transect walks*

The combined use of the pan trap and transect walk sampling techniques in June 2022 showed the great efficiency of the former, with 33 species caught at sites S2, S4 and S8, five of which were also collected during the transect walk (*Andrena cinerea*, *A. russula*, *Bombus terrestris*, *Halictus scabiosae*, *Panurgus calcaratus;* Table S1). In contrast, only two (*Bombus lapidarius*, *Lasioglossum crassepunctatum*) of the collected species were found exclusively during the transect walk (Figure 3(a)). Although the two methods are not comparable in terms of collection effort and taxonomic outcomes (Westphal et al. 2008; Krahner et al. 2021; Packer & Darla-West 2021), the passive pan trap method proved to be advantageous for sampling species not observed during the transect.

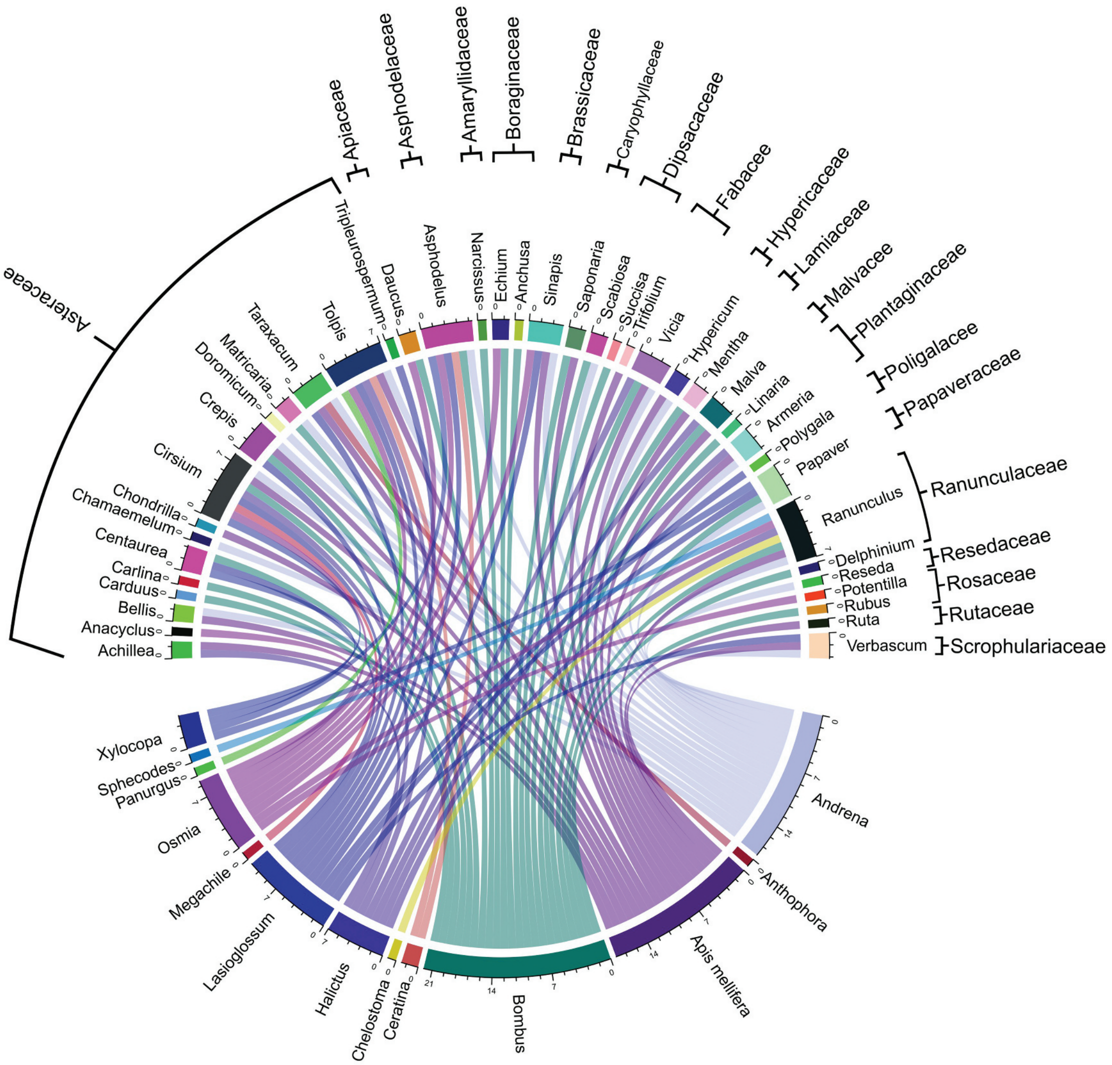

Figure 2. Chord diagram illustrating the plant–pollinator interaction recorded during transect walks in the sampling period (2022, 2023, 2024); the genera of Apoidea (bottom) are related to plant genera (top) grouped by family (black open square brackets).

Indeed, 11 species collected using pan traps were not detected at any of the sites during the transect surveys over the three-year sampling period (Table S1). Pan traps and transects are methods well known to provide different results in sampling pollinator communities, depending on several factors (Wood et al. 2015; O'Connor et al. 2019) such as the frequency of sampling, the phenology of the species, the abundance and type of flower species (Westerberg et al. 2021), and the timing of sampling (Saunders & Luck 2013). Despite the valuable insights gained from transect walks in terms of understanding bee–plant interactions, this method may not be sufficient to accurately estimate solitary bees. Indeed, the presence of Euro-Mediterranean Colletidae species in Italy and the Calabria region was documented by Comba (2019), although we found no evidence of this wild bee family during our survey. The presence of species belonging to Melittidae cannot be ruled out either. This underlines the importance of using multiple sampling techniques to cover the full diversity of wild bee species (Hutchinson et al. 2022), as some species may be missed by active observation, especially those with more specialised or cryptic foraging habits. In this way, issues can be solved concerning both the the ability of the observer to discern all the species present at the sampled site and the variations in the daily flowering activity of the various species, thus reducing the underestimation of local (site) diversity.

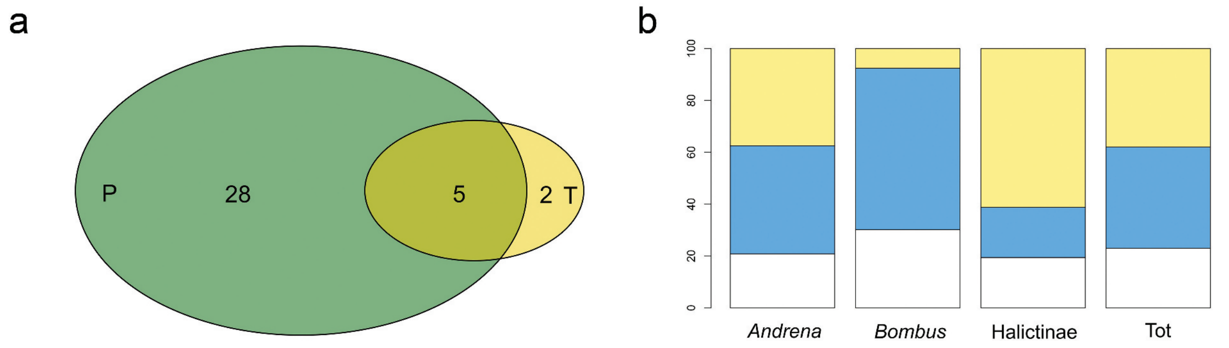

Figure 3. (a) Venn diagram illustrating the number of species found using the pan trap (P, green), during the transect walks (T, yellow) and five species found using both techniques in June 2022. (b) Bar plot illustrating the relative abundance as a percentage of the number of species found in the different colour plates of the pan trap cluster (yellow, blue, white) for the genera *Andrena*, *Bombus* and the subfamily halictinae (*Halictus*, *Lasioglossum* and *Sphecodes*). Tot: preferences of the 34 species found (number of specimens = 174).

The species caught in pan traps showed different patterns of colour preference. *Bombus* species exhibited a strong preference for blue (62.26%), while species from the subfamily Halictinae (*Halictus*, *Lasioglossum*, and *Sphecodes*) preferred yellow (61.19%). *Andrena* species showed no differences in the preference rate for blue (41.67%) and yellow (37.5%) traps (Figure 3(b)). This finding is consistent with other studies showing differences in colour preference (Krahner et al. 2024; Coelho et al. 2025) with blue (Acharya et al. 2021) traps being particularly attractive to wild bees. These highlights suggest that visual cues play an important role in the foraging behaviour of these bees, with certain colours likely being associated with more rewarding floral resources in the habitat (Saunders & Luck 2013).

Cleptoparasitic species, such as *Melecta albifrons* and various *Nomada* species, were also found (Table S1). These species are parasitic on other bee species, such as *Anthophora plumipes* and *Andrena* species, and their presence indirectly indicates the presence of their host species in the sampled area (Comba 2019; Michez et al. 2019). The identification of seven cleptoparasitic species further underlines the complexity of the bee community, where parasitic interactions provide insights into the ecology of both the parasites and their host species.

4. Conclusion

This study significantly enriches the understanding of bee diversity in the Calabria region, providing new records, documenting novel foraging behaviours, and expanding knowledge of cleptoparasitic relationships, although this study focused on a few sites in a limited area. The combination of transect walks and pan traps proved essential for documenting a wide range of species, and molecular identification further confirmed the accuracy of the findings. However, the bee fauna of Calabria remains poorly documented, and further research is needed to fully elucidate the diversity of species present and the ecological interactions among them.

The number of species found confirms the need for further research on wild bees in Italy to gain a comprehensive understanding of their distribution and status. Moreover, the findings of this study provide evidence of the importance of protected areas in biodiversity conservation. They serve to enhance our understanding of the ecological habits of these hymenopterans, which are necessary for the efficient design of conservation and protection programmes for pollinators.

Supplementary material

Supplemental data for this article can be accessed online at https://doi.org/10.1080/24750263.2025.2517360.

Author contributions

Maria Luigia Vommaro: writing – review and editing, validation, methodology, investigation, data curation, conceptualisation. **Martina Lento**: writing – review and editing, visualisation, investigation, data curation. **Denis Michez**: investigation, methodology, writing – review and editing. **Simone Flaminio**: investigation, writing – review and editing. **Serafino Flori**: resources. **Ilario Treccosti**: resources. **Gennaro Di Prisco**: investigation, methodology, writing – review and editing. **Lorenzo Goglia**: investigation, writing – review and editing. **Pietro Brandmayr**: investigation, methodology, writing –

review and editing. **Anita Giglio**: writing – original draft and writing – review and editing, writing – original draft, resources, methodology, investigation, funding acquisition, data curation, conceptualisation, supervision.

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