DIVERSITY AND ABUNDANCE OF FLOWERING PLANTS AND POLLINATOR GROUPS IN A MEDITERRANEAN OPEN CANOPY CEDAR FOREST IN MOROCCO

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Abstract. Plant-pollinator interactions are crucial for ecosystem diversity and functionality. Although, these interactions are still less studied and known, a growing body of evidence is showing that pollinators populations across the world are declining and that affects severely these necessary interactions. This study investigates flowering plants and pollinators diversity, abundance and interactions in a Mediterranean cedar forest in Morocco using two common methods; *pan traps* and *observation plots*. From March to August 2023, 1627 insects were captured. *Hymenoptera* accounted for 35.34%, *Diptera* 40.14%, *Coleoptera* 22.62%, and *Lepidoptera* 1.90%. Bees comprised 85.57% of *Hymenoptera*, with *Andrena*, Lasioglossum, and *Panyrgus* as predominant genera. Beetles, mainly represented by *Tropinota*, *Anthaxia*, and *Melanthaxia*, showed fluctuating abundances within months. 1274 insect visits to 46 flowering plants were recorded, with solitary bees (24.73%), beetles (18.29%), Muscoid flies (10.20%), and honey bees (8.95%) being the most frequent visitors. The most visited plants were the *Asteraceae's Mantisalca salamantica*, *Cardus nutans*, and *Bellis selvestris*, the *Brassicaceae's Brassica napus, Erysimum grandiforum and Isatis tinctoria,* the *cistaceae*'s *Helianthemum hirtum*, and the Fabaceae's *Linaria sp*. This study highlights the diverse plant and pollinators communities in a Mediterranean preserved area in Morocco and gives insights in the distribution of pollinators among flowering plant species.
Keywords: *Mediterranean plant community, plant–pollinator interactions, pollination ecology, Middle Atlas*

Introduction

Pollination is essential for reproduction success of plants and intraspecific diversity (Faegri and Pijl, 1979; Willmer, 2011). Ollerton et al. (2011) estimates that 87.5% of flowering plants depend on biotic mediated pollination, which mainly implies insects. On the other hand, insects depend on flower products, mainly pollen and nectar, as energy and nutrients source for survival (Willmer, 2011). Plant-pollinators interactions are then among the key processes that generate and sustain biodiversity (Bascompte et al., 2006; Fontaine et al., 2006; Wei et al., 2021). The coevolutionary processes involved in animal pollination have helped to maintain the structure and function of entire communities and species' networks (Muschett and Fontúrbel, 2022). Pollinators also provide highly valuable ecosystem services to crops. More than 70% of the world's crops depend directly on insect pollination, making pollination a key to food security as well (Klein et al., 2007). Unfortunately, although, plants pollinators interactions are still less studied and understood, especially in certain countries like Morocco, an increasing body of evidence is showing that pollinators populations across the world are decreasing and pollinations communities are being modified in front of habitat destruction, land-use intensification, climate change and the spread of alien species and diseases (Deguines et al., 2016; Potts et al., 2010; Raven and Wagner, 2021; Thomann et al., 2013; Vanbergen et al., 2013). Sánchez-Bayo and Wyckhuys (2019) stated that insects across the world are facing a dramatic rate of decline that may lead to the extinction of 40% of species over the next few decades. More interest in pollination ecology is then necessary to understand basic biological and ecological processes and patterns involved in plants-pollinators interactions and how human activity and climate change affect these interactions. Furthermore, accumulative knowledge may help to developpe efficient strategies of remediation to pollinators decline at the local level.

Morocco is a country of unusually high diversity of climates, which in return result in a multitude of habitats hosting the second highest terrestrial biodiversity in the Mediterranean basin (Médail and Quézel, 1999). Additionally, Agriculture, is a key sector of Moroccan economy (Tounsi et al., 2013). Understanding plant-pollinators interactions within Moroccan plant communities is crucial for motivating scientific research in pollination ecology. By exploring this field, researchers can uncover the rich diversity of both wild pollinators and plants and the complexity of interactions between them. This knowledge will serve as a foundation for developing effective strategies to protect and conserve these vital compounds of ecosystems and ensuring crop production and food security in a future world of multiple challenges including drought and climate change.

In this context, this study aims to (1) investigate pollinators and flowering plants richness and abundance across 6 months from march to august in an open canopy cedar forest in the Middle Atlas of Morocco, and (2) to evaluate how pollinator functional groups are distributed across the occurring flowering plants.

Materials and methods

Study area

This study was conducted in the natural reserve of *Moudmam* located in the National Parc of Ifrane (NPI) in the middle Atlas of Morocco (33°23'57.48"N, 5°11'0.87"W)

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between Azrou and Timahdit (see *Fig. 1*). The study area is a cedar open canopy forest (see *Fig. 3*) of 25 ha with an important herbaceous plant diversity. The natural reserve was closured in 2003 to protect cedar populations, enhance their natural regeneration and provide an adequate habitat to many fauna and flora species including several rare and threatened species (HCEFLCD, 2007). Altitude is comprised between 1800 and 1880 m, and the slope is low (≤15°). The study region is characterized by a humid Mediterranean climate with an average annual rainfall of 963.69 ± 363 mm, and the alternance of a humid period that extend from October to May and a dry period from Jun to September (see *Fig. 2*) (HCEFLCD, 2007).

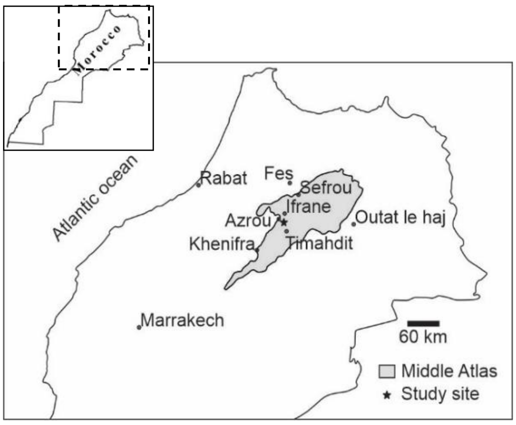

Figure 1. *Geographic position of the study site in the Middle Atlas of Morocco*

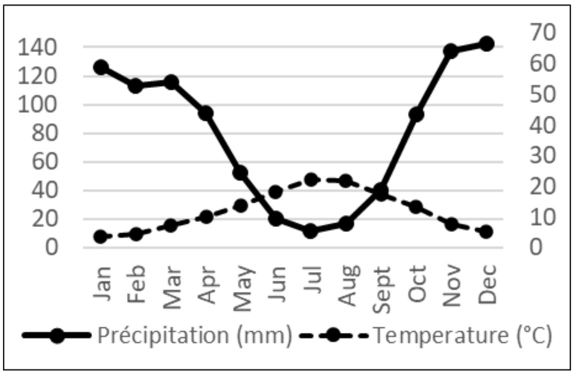

Figure 2. *Last 30 years (1991–2021) average of monthly rainfall (mm) and temperature (°C) in the study region (produced from a dataset obtained from the meteorological station of Ifrane)*

Insect survey

Pan traps

To sample insect pollinators, colored pan traps were used (Gibb and Oseto, 2020; Popic et al., 2013; Westphal et al., 2008). Sampling occurred in 6 months from March to August 2023. Within each sampling period, five 50 meters transects were placed randomly in the study area. Within each transect, 11 clusters of 6 pan traps of three different colors (white, yellow and blue) were placed 5 m apart (see *Fig. 3*). Colored pan traps were filled to two-thirds of their volume with a mixture of water and an

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odorless detergent and left in the field for 24 h. Sampling occurred when the meteorological conditions were adequate for insect's activity (Fijen and Kleijn, 2017). Collected specimens were transferred to plastic vials containing ethanol 70% and sent for processing. Samples were processed according to the protocol described by (Droege, 2015). Processed specimens were classified to morphospecies, identified to the lowest possible taxonomic level and pinned to voucher collections held at the laboratory LBGN, Faculty of Sciences Dhar el Mehraz, Fes.

Observation plots

To study pollinators visitation to plants species, we used observation plots method. Within each sampling period, 10 observation plots of 2 × 1 m each were placed randomly in the study area with a minimum separation among plots of 5 m. In each plot, we observed pollinators visitation to plant species for 12 min for each observation period (Mahon and Hodge, 2022). Observations occurred when the meteorological conditions were adequate for insect activity (i.e., temperature beyond 22°C, low wind speed and low sky cover) (Fijen and Kleijn, 2017). A flower visitation is counted when the insect sets on the reproductive organs of the flower (Lázaro et al., 2008). We categorized each visitor into 10 pollinator functional groups. Pollinator functional groups are defined as groups of insects that behave in similar ways on a flower and exert similar pressures, which in turn generate correlations among floral traits (Fenster et al., 2004; Waser et al., 1996). The functional groups included Bumblebees (*Bombus sp*.), honey bee (*Apis melifera*), solitary bees (*Andrenidae*, *Halictidae*, *Megachilidae*, *Apida (Bombus sp.*, and *Apis melifera* excluded*)* and *Melitidae*), ants, wasps (mainly *Scoliidae*, *Ichneumonidae*, *Pompilidae* and *Vepidae*), Muscoid flies (mainly *Anthomiidae*, *Muscidae*, *Tachinidae*, *Asilidae* and others), hoverflies (*Syrphidae*), butterflies, beeflies (*Bombylus sp*.), and beetles.

Flowering plant species relative abundance assessment

Within each sampling period, 90 quadrats of 2 * 2 m were placed randomly within the study area to assess plant species occurrence and relative abundance (Kent, 2012). In each plot, the number of individuals of occurring flowering plants species was counted in every sampling period. Data collected was used to calculate relative abundance (RA) applying *Equation 1*:

$$RA = \frac{N_i}{N} * 100 \qquad \text{(Eq.1)}$$

N_i: total number of individuals of the species i, and N: total number of individuals of all species occurred in the study area.

Data analysis

Collected data was processed using R program (version 4.3.1). Plant species relative abundance and insect groups visitation proportions were calculated, and results were exploited using "*ggplot2"* (version 3.5.0) package in the R program to create summary heatmaps. Collected insects counts of each identified taxon in each sampling period were presented in a summary.

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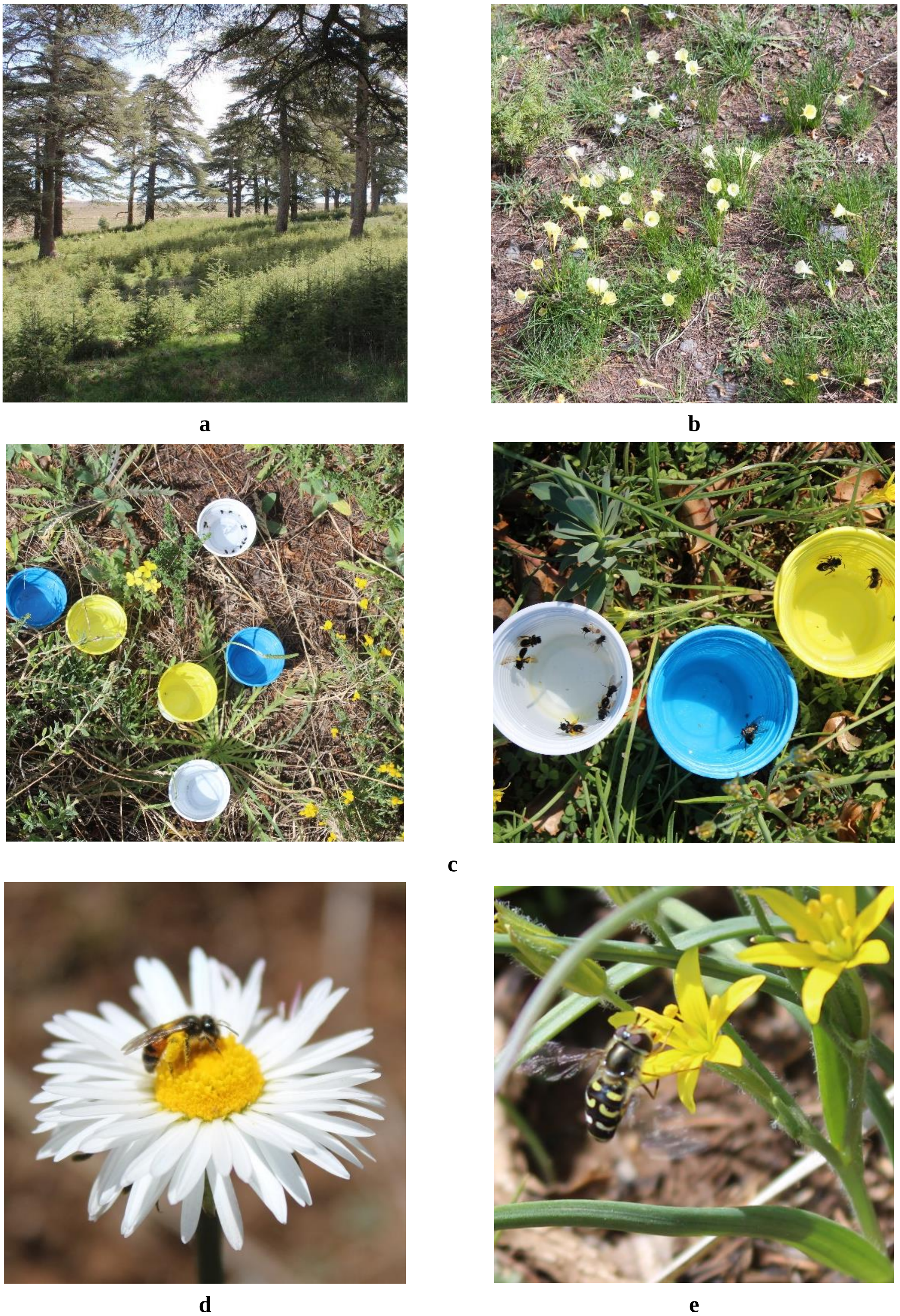

Figure 3. *Photos from the study site. (a) A view from the study area. (b) Examples of flowers occurring in March (Narcissus bulbocodium (yellow flowers) and Romulea bulbocodium (purple flowers)). (c) Colored pan traps used in the sampling of pollinators. (d) An Andrena bee collecting pollen from an Asteraceae capitula (Bellis selvestris). (e) A hoverfly feeding on a Gagea liotardi flower*

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Results

Insect groups abundance

In total, 1627 insects were sampled. The *Hymenoptera* group accounted for 577 individuals, representing 35.34% of the entire insect community. *Diptera* accounted for 653 individuals, representing 40.14%, and *Coleoptera* accounted for 368 individuals, representing 22.62%. *Lepidoptera*, though less abundant, constituted only 1.90% of the entire insect community (see *Table 1*).

Within the *Hymenoptera* group, bees constituted the majority, representing 85.57% of the total (492 individuals), while wasps constituted the remaining 14.43% (83 individuals). 13 bee genera belonging to 5 families were sampled. The most abundant genera were *Andrena* and *Lasioglossum* (239 and 141 individuals respectively). *Apis*, *Panurgus* and *Halictus* exhibited moderate abundances (47, 29 and 14 individuals respectively) and the remaining genera were rare (n < 10 individuals). Captured wasps belonged to six families. The *Scoliidae* family, represented mainly by *Dasyscolia ciliata*, constituted more than 50% of total wasps. *Vespidae*, *Pompilidae*, *Chrysididae*, *Crabronidae* and *Ichneumonidae* wasps were captured in low numbers (see *Table 1*).

Within the Coleoptera group, 19 genera were captured belonging to 10 families. *Buprestidae's Melanthaxia* and *Anthaxia*, *Scarabaeidae's Tropinota*, and *Melyridae's Falsomelyris* were the most abundant genera in the study area (24.72%, 22.82%, 18.47% and 11.14% respectively). Theremaining genera were less abundant (n < 20 individuals) (see *Table 1*).

In the *Diptera* order, various families were present, with the highest abundance found in *Anthomyiidae*, *Muscidae*, *Calliphoridae*, and others, constituting together 72.12% of the entire Flies group. *Asilidae* ranks second, accounting for 17.45% of all captured flies. Hoverflies (*Syrphidae*) account for 5.66%, and *Tachinidae* for 4.74%.

In terms of temporal variations in insect groups abundance, bee's abundance varied in a unimodal curve achieving its peak abundance in May. Wasps were the most abundant in May too, but beetles continued to increase until Jun. flies were remarkably abundant in April and May, then their abundance decreased considerably in the next months (see *Fig. 4*). More details about temporal variation in each identified taxon abundance is found in *Table 1*.

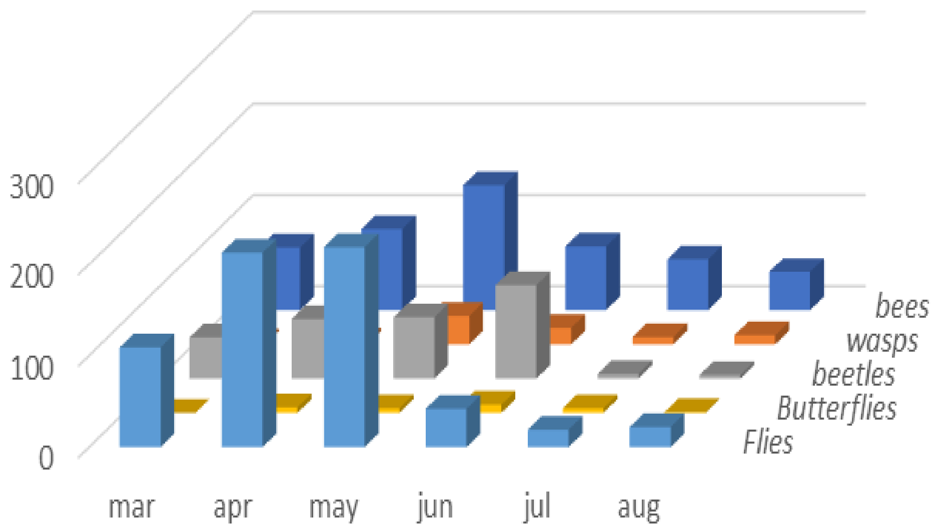

***Figure 4.** Insect groups total abundance variation across months (from March to August)*

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Table 1. *Insects abundance across months (only captured insects by pan traps were included)*

Taxons		Total	March	April	May	June	July	August
HYMENOPETRA		***575***						
BEES		***492***						
Andrenidae	*Andrena*	**239**	66	52	101	16	2	0
	Panurgus	**29**	0	0	2	1	26	0
Apidae	*Anthophora*	**2**	0	1	0	0	0	1
	Eucera	**3**	0	0	1	2	0	0
	Bombus terrestris	**9**	0	0	0	0	0	4
	Apis melifera	**47**	0	0	0	16	19	5
	Xylocopa	**2**	0	0	0	0	0	0
Halictidae	*Halictus*	**14**	2	1	7	0	2	1
	Lasioglossum	**141**	1	34	26	36	6	29
Megachilidae	*Anthidium*	**1**	0	1	0	0	0	0
	Megachile	**3**	0	0	0	1	0	2
	Heriades	**1**	0	0	0	1	0	0
Melitidae	*Dasypoda*	**1**	0	0	0	0	1	0
WASPS		***83***						
Scoliidae	*Dasyscolia ciliata*	**48**	2	1	23	15	1	0
	Scolia hortorum	**2**	0	0	0	0	2	0
Pompilidae		**10**	0	2	1	3	2	1
Chrysididae		**3**	0	0	3	0	0	0
Crabronidae		**8**	0	0	2	4	2	0
Ichneumonidae		**2**	0	0	1	0	1	0
Vespidae		**12**	0	0	1	0	2	9
COLEOPTERA **(Beetles)**		***368***						
Apionidae	*Aspidapion*	**1**	0	0	0	1	0	0
Buprestidae	*Melanthaxia*	**91**	37	9	28	10	1	0
	Anthaxia	**84**	0	0	3	60	2	0
	Acmaeodera	**19**	0	0	0	13	0	0
Prionoceridae	*Lobonyx*	**2**	0	2	0	0	0	0
Chrysomelidae	*Cryptocephalus*	**9**	0	0	3	3	0	1
	Exosoma	**2**	0	0	0	2	0	0
Coccinellidae	*Coccinella*	**6**	2	1	3	0	0	0
Dermestidae	*Attagenus*	**9**	0	0	0	7	0	0
Elateridae	*Cardiophorus*	**1**	0	0	0	0	0	0
Melyridae	*Falsomelyris*	**41**	2	4	12	18	0	0
	Divales	**12**	0	0	7	3	0	0
	Clanoptilus	**6**	0	0	0	6	0	0
Mordellidae	*Stenalia*	**3**	0	0	0	0	2	1
	Mediimorda	**2**	0	0	0	0	0	2
Scarabaeidae	*Oxythyrea*	**2**	0	1	0	1	0	0
	Tropinota	**68**	4	48	11	3	0	0
	Phyllopertha	**7**	0	0	0	7	0	0
	Protaetia	**3**	0	0	0	0	0	0
DIPTERA **(Flies)**		**653**						
Anthomiidae, Muscidae, Calliphoridae and others		**471**	109	196	107	24	12	8
Asilidae		**114**	0	3	77	16	5	6
Syrphidae (Hoverflies)		**37**	0	7	15	3	2	8
Tachinidae		**31**	0	7	20	4	0	0
LEPIDOPTERA **(Butterflies)**		***31***	0	6	5	9	5	1

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Flowering plant species diversity and relative abundance

During the entire study period, a total of 46 flowering plant species were observed and assessed with a peak richness and relative abundance (RA) in June (31 species, see *Fig. 5*). These species belong to 23 different families. The *Asteraceae* family was the most prominent, with 13 species, followed by the *Caryophyllaceae* and *Fabaceae* families, represented by 5 and 4 species each respectively. The *Brassicaceae* family had three species, while the *Apiaceae* and *Malvaceae* families each had two species. The remaining families were represented by one species only (*Amaryllidaceae*, *Asparagaceae*, *Boraginaceae*, *Caprifoliaceae*, *Cistaceae*, *Euphorbiaceae*, *Campanulaceae*, *Geraniaceae*, *Hypericaceae*, *Iridaceae*, *Lamiaceae*, *Liliaceae*, *Plantaginaceae*, *Ranunculaceae*, *Resedaceae*, *Rosaceae* and *Scrophulariaceae)*.

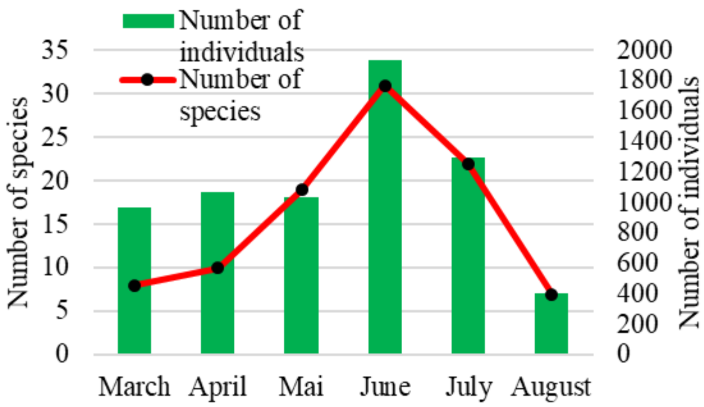

Figure 5. *Flowering plants richness and abundance across months*

Early spring (March and April) was characterized by the abundance of geophytes likes *Narcissus bulbocodium*, *Romulea bulbocodium* and *Gagea liotardi* and the *Asteracea Bellis selvestris* in close values of relative abundances. Mid-spring, although more specious, was characterized by the blooming of *Genista tridentata* which occupied the entire area (RA > 50% in June). The remaining species were less abundant (ie. *Erodium cicutarium*, *Helianthemum hirtum*, *Hypochaeris radicata*, *Linaria sp*, *Cerastium arvense*, *Catananche caerulea*). By the late spring, species number decreased, and new species invaded the study area like the Asteraceae *Mantisalca salamantica*, the Apiacea *Pimpinella tragium* and *Silaum silaus*. More details about each species occurrence and relative abundance within months can be found in the heatmap (see *Fig. 6*).

Insect visitations to different plant species

1274 insect visits were recorded. Solitary bees were the most abundant group, comprising 24.73% of total visits, followed by beetles (18.29%), Muscoid flies (10.20%), and honey bees (8.95%). The remaining groups made up less than 10% of total visits each. The *Asteraceae* family received the highest number of visits (43.80%), with beetles and solitary bees being the primary contributors. Within *Asteraceae*, *Mantisalca Zsalamantica* was the most visited, followed by *Cardus nutans*, *Taraxacum officinale* and *bellis selvestris*. The *Brassicaceae* ranked second with 15% of total visits, largely attributed to solitary bees as well, honey bees, and beetles. *Fabaceae*, *Cistaceae*,

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and *Plantaginaceae* families also received notable visits, with specific species attracting different insect groups. *Caryophyllaceae* family received 5.10% of visits, mainly by solitary bees, muscoid flies, beetles, and bumblebees. Other families received fewer visits, with *Iridaceae Romulea bulbucodium*, *Boraginaceae Cynoglossum creticum*, and *Gentinaceae Centaurium tenuiflorum* being visited only by solitary bees. More details about visitation proportions of different insect groups to different plant species are presented in *Figure 7*.

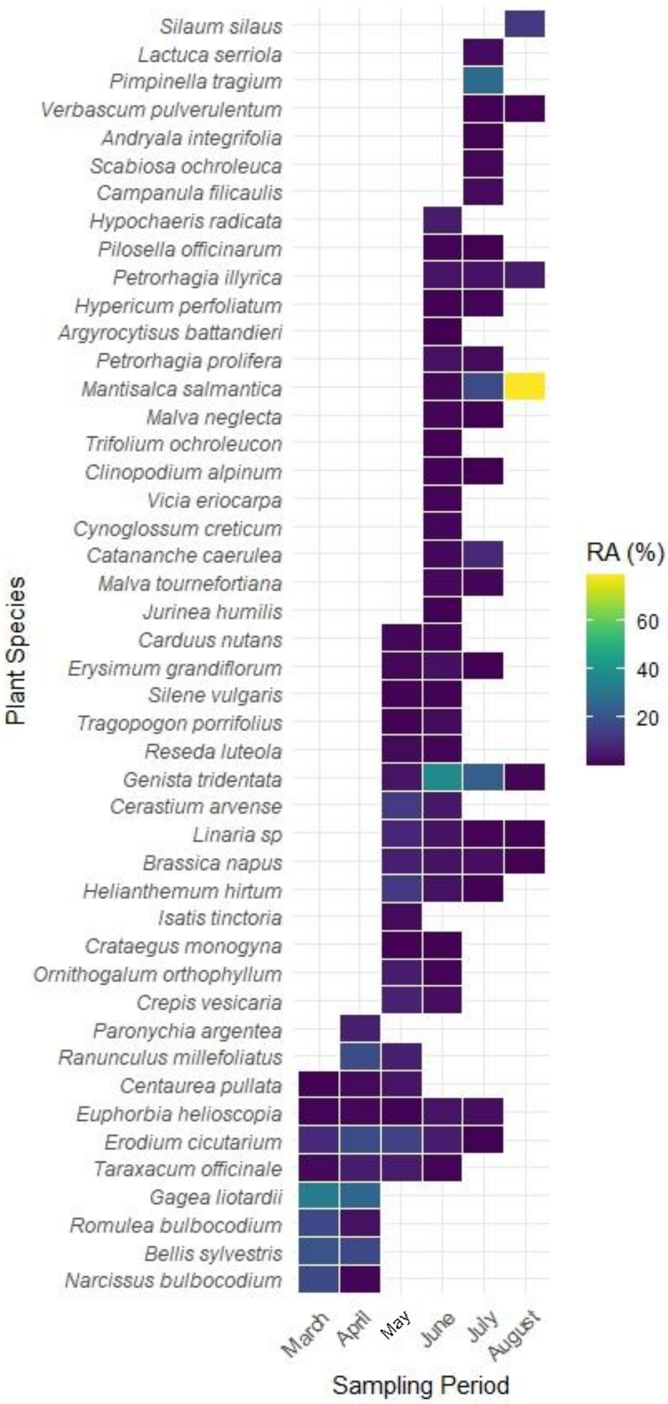

Figure 6. *Relative abundance (RA) of flowering plant species occurred in the study area across six months*

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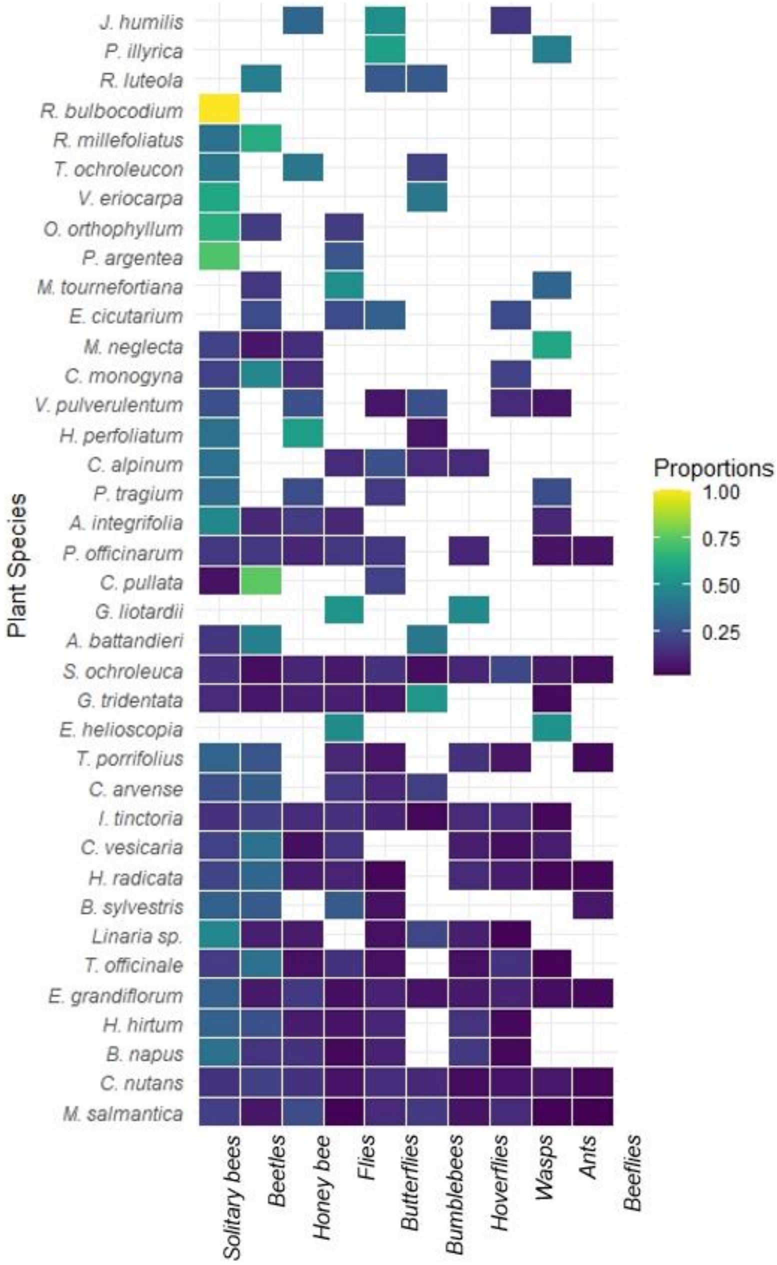

Figure 7. *Proportions of visits of different insect groups to different plant species (plant species that were visited less than six times were excluded from the calculation). Plant species and insect group are ordered in a decreasing order of total visits*

Discussion

The study area as with other mountainous Mediterranean plant communities is characterized by the abundance of flowering species in spring and their scarcity throughout the rest of the year (Bosch et al., 1997; Thompson, 2020). In parallel, insects' pollinators communities were more diverse and abundant in flowering period, as they depend on flowers as energy and nutrients resources. The flower composition of the studied plant community is dominated by a few very abundant species, while the remaining species were scarcer and their contribution to the flower density of the study area is low.

Solitary bees emerged as the predominant visitor group to plant species in our study, underscoring their significant abundance. However, it is noteworthy that the diversity of solitary bees' genera in our study area is much lower than the national diversity, as highlighted by Lhomme et al. (2020). Altitude is a recognized factor influencing bee's richness and abundance, often attributed to physiological constraints associated with lower temperatures (Chesshire et al., 2021). In our study area, *Andrena* and *Lasioglossum* were identified as the most abundant genera, a finding consistent with other regions, including agronomic habitats (El Abdouni et al., 2022). Notably, *Andrena* species seem to play a pivotal role in ecosystem functioning, displaying high efficiency in pollinating a diverse array of species across various plant families (Larkin et al., 2008; Tang et al., 2019). The honey bee (*Apis mellifera*) and bumblebee (*Bombus terrestris*) did not show until June but persisted until August, contributing significantly to the pollination of numerous flowers during this period. However, our study area appeared less invaded by honey bees compared to other regions, possibly due to the absence of beekeeping activities in the vicinity. This contrasts with findings in other Mediterranean communities (Ropars et al., 2020). Among other bee genera, including *Xylocopa*, *Eucera*, *Anthrophora*, *Anthidium*, *Heriades*, *Dasypoda*, and *Megachile*, rarity was observed (n < 5). While some of these genera, such as *Megachile*, *Eucera*, and *Xylocopa*, exhibited higher abundance in other studies, the remaining genera consistently appeared less abundant (El Abdouni et al., 2022; Ropars et al., 2020).

Despite being less specious and abundant, many studies have shown the importance of wasps in providing a variety of ecosystemic services, not only as pollinators, but also as parasites, predators, biological indicators, decomposers and seed dispersers (Brock et al., 2021). The most abundant wasp in our study area which is *Scoliida*'s *Dasyscolia ciliate* have been shown to have a specific relationship with blue *Orchid* flowers like *Orphys miroir* which highly mimic the wasp's hairiness and pheromones (Paulus and Salkowski, 2007). In our study area, no orchid flowers occurred, but this wasp was captured mainly by blue traps and occasionally visited yellow Asteraceae flowers.

Flower beetles represented 22.61% of all captured insects and emerged as the second most abundant visitor of plant species. this insect group seem to play an important role in pollinating several flowers especially *Asteraceae* flowers as they spend long periods of time on these flowers. Several studies have described specific relationships between flowers and beetles. Therefore, some plant families have developed specific floral traits to attract beetles as specific pollinators (i.e. specific odors) (Gottsberger, 1990; Saravy et al., 2021).

Hoverflies constitute an important pollinator group that visit many flowers. Doyle et al. (2020) stated that hoverflies visit over 70% of animal pollinated wildflowers. In our study area, Hoverflies performed about 7% of recorded insect visits on several plant species especially the Liliaceae *Gagea liotardii*, yellow *Asteraceae* capitula, and the *Brassicaceae's Brassica napus* and *Isatis tinctorial*. A recent study evolved that hoverflies can in some plant species be more efficient in pollination and seed set than wild bees (Baumann et al., 2021).

The low abundance obtained in butterflies and absence of beeflies is probably related to the sampling method used which seem to be less efficient for this insect groups (Gibb and Oseto, 2020). In terms of visitation, butterflies performed 8.95% of total visits and beeflies performed only 1.26% (16 visits observed). These two groups characterized with a prolongated proboscis seem to act as nectar robbers and have less efficiency in pollen removal and deposition (Barrios et al., 2016). However, another study has,

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surprisingly, shown that moths, which act as nocturnal pollinators, in the other hand participated in pollen deposition more than all diurnal pollinators in bramble (*Rubus fruticosus* agg.), a common and widespread plant species across Europe (Anderson et al., 2023).

Muscoid flies were the most abundant insect group in the study area. However, in terms of visitation, these insects performed only 10% of total visits. Although, flies tend to be less effective than other groups in depositing pollen, in some instances, flies appear to be responsible for more pollen deposition due to their higher abundance and visitation rates (Borkent and Harder, 2007; Kearns and Inouye, 1994).

Ants performed 5% of total visits recorded and visited different plant species. The most visited plants by this insect group were *Euphorbia helioscopia*, *Malva neglecta*, *Carduus nutans* and *Pimpinella tragium*. A similar result was obtained by (Lázaro et al., 2008) in which ants performed a low proportion of visits compared to other insect groups. In contrast, a study by (Bosch et al., 1997) in a Mediterranean grassland, concluded that ants were the dominant flower-visiting insect group performing 58% of total visits to 88% of studied plant species flowers. Which suggest that ants can be an important pollinator in some ecosystems (Bosch et al., 1997; Das and Das, 2023; Gómez et al., 1996).

Conclusion

In this study, we used two common sampling methods to assess pollinators diversity, abundance and interaction with flowering plant species across 6 months of spring from March to August in an open canopy Mediterranean cedar forest. Our results highlighted the diversity in pollinators and flowering plants taxa and the variation of diversity and abundance within spring months in a north African plant community. Also, we showed the importance of certain plant species in providing feeding resources to insect communities and insect groups proving pollination service to the plant community, two facets of plants-pollinators interactions which are essential to ecosystems and biodiversity preservation. Future research is needed to assess these interactions at the species level to elaborate comprehensive plant pollinators interaction networks.

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