Pakistan J. Zool., pp 1-15, 2024. DOI: https://dx.doi.org/10.17582/journal.pjz/20240218031246

Communities of Arid Bees as Affected by Weather Factors and Foraging Resources in Southern Punjab, Pakistan

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Article Information
Received 18 February 2024
Revised 05 March 2024
Accepted 17 March 2024
Available online 05 September 2024 (early access)

Authors' Contribution
WA and AS conceived the research, conducted experiments and collected data. AS and MA designed the experiments. WA, AS and MKR collected and prepared the materials. AS supervised the experiments. HK, AS, MA and MKR analyzed the data. WA, AS, MA, HK and MKR wrote the manuscript. All authors have read the final version of the manuscript.

Key words
Bee diversity, Habitat type, Seasonality, Environmental factors, Plant species abundance

ABSTRACT

A year-long study was carried out to assess the impact of weather factors (i.e., temperature, relative humidity, wind speed and solar radiation) and foraging resources (i.e., number of plant species at flowering) on the species richness and abundance of arid bees in four distinct seasons and five different anthropogenic land use types of subtropical Bahawalpur. Species richness and diversity were the highest in autumn while abundance was highest in spring. Winter was the most stressed season of the year. Both the richness and abundance were the highest in agricultural landscapes whereas diversity was the highest in semi-natural landscapes. The two wild honey bee species i.e., *Apis dorsata* and *Apis florea* were the most abundant in all the seasons and landscapes. Species richness was significantly affected by solar radiations in agricultural and natural landscapes during spring season while it was significantly affected by the abundance of flowering plant species in only agricultural landscape during autumn and summer seasons. On the other hand, bee abundance was significantly affected by solar radiations and the abundance of flowering plant species only in the agricultural landscape. Understanding how density dependent and independent factors affect species richness and abundance of native bees in different seasons and land use types is imperative to device effective ecosystem management planning. The current study is a first such account from the arid region of Pakistan. This will help support in ecosystem management planning and act as a baseline for further research in the area.

INTRODUCTION

Pollination is the most important ecosystem service mostly provided by the bees that pollinate approximately 2/3rd of the global crop species and are therefore crucial in food production (Biesmeijer *et al*., 2006; Klein *et al*., 2007). Solitary bees are considered an important component of ecosystem functioning and efficient pollinators of cultivated and native plants (Kevan *et al*., 1990; Tylianakis *et al*., 2005; Fleming and Muchhala, 2008). The diversity and population of these hymenopterous pollinators are also used as bioindicators as they are sensitive to environmental disturbances i.e., changes in the availability of food resources and in microclimate (Tylianakis *et al*., 2006; Buschini and Woiski, 2008). Unfortunately, the population of bees is declining and their decline causes pollination crisis as well as a negative effect on crop productivity (Kremen *et al*., 2007; Ricketts *et al*., 2008; Giannini *et al*., 2015).

There are several factors that affect the bee abundance and richness i.e., habitat loss or conversion of agricultural land, changes in environmental or microclimatic conditions like temperature and air humidity, seasonality, availability of nesting resources, diversity of floral resources and extensive use of chemicals (Tscharntke *et al*., 2005; Tylianakis *et al*., 2006; Teodoro *et al*., 2009; Stangler

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0030-9923/2024/0001-0001 $ 9.00/0

et al., 2015). One of the major drivers of bee decline is habitat change/loss (Decourtye *et al*., 2010). Various types of land-use present different patterns of abiotic and biotic factors which are essential for solitary bees and therefore may affect their density and distribution (Batista Matos *et al*., 2013; Stangler *et al*., 2015).

Paradoxically, agriculture that not only affects the richness of bees but also ruins the functioning and structure of ecological communities; considered as one of the major threats to bees as it causes habitat loss or fragmentation, changes in land use, introduction of non-native harmful organisms and extensive use of pesticides (Steffan-Dewenter *et al*., 2005; Garibaldi *et al*., 2011). Therefore, bees are delimited to utilize food and habitats around the crop lands which serve as dispersion corridors, providing the necessary resources for their survival (Tilman *et al*., 2001; Ockinger and Smith, 2007). Though, such semi-natural and natural habitats apparently do not provide enough resources to maintain bee populations as evidenced by their reported decline in agroecosystems (Williams *et al*., 1991).

Oertli *et al*. (2005) have shown that changes in the season have a marked effect on the ecological patterns shown by bee assemblages. Seasonality affects the diversity, distribution and abundance of bees i.e., diversity is high in wet and warm months as compared to dry and hot or cold seasons (Michener, 2007; Abrahamczyk *et al*., 2011). Temporally, species richness and bee abundance can vary widely on a diurnal, seasonal and annual basis. Temporal variations can be the outcome of environmental factors and life history traits of bees (Oertli *et al*., 2005). Bees are mostly diurnal and their daily activities significantly affected by environmental factors (like temperature, humidity, wind speed and solar radiations) (Cane *et al*., 2006) and biotic factors like availability of floral resources that varies with seasons (Gurr, 1957; Abrahamczyk *et al*., 2011). However, little is known about the effect of seasonal changes on abundance and species richness of bees.

Suitable abiotic conditions i.e., weather factors and topography is also crucial for bee survival. Previous researches have shown that temperature, rainfall, light intensity and wind velocity may change the behavior of bees (Rajkhowa and Deka, 2013; Akram *et al*., 2019; Hennessy *et al*., 2020; Akram and Sajjad, 2022). Different species of bees have different weather preferences and also take less than a minute to react to weather changes (Riessberger and Crailsheim, 1997).

The accessibility and abundance of floral resources have been identified as the major factor limiting the population of wild bees (Roulston and Goodell, 2011). Different species of bees have different phenologies (Wcislo and Cane, 1996) e.g., social bees have longer life cycles than solitary bee species. Various studies have shown that a limited period of activity (one or two months during the year) of several solitary bee species often corresponds with the host flowering plants (Westphal *et al*., 2008). The temporal variations in bee fauna occur over time and the highest densities correspond to the peak flowering seasons (Wolfe and Barrett, 1988). The knowledge about how seasons, land use types and biotic and abiotic factors affect abundance and richness of native bee species is rare.

The present study was aimed to assess that how weather factors and foraging resources influence the species richness and abundance of arid bees in four distinct seasons and five different anthropogenic land use types of subtropical Bahawalpur? The study hypothesized that (a) maximal bee diversity will be recorded from various landscapes (agricultural, natural and semi-natural) and seasons (spring, summer, autumn and winter) at certain ranges of environmental factors (temperature, relative humidity, wind speed and solar radiation) and the number of flowering plant species and deviations from such ranges would have detrimental effects, (b) the effect of environmental factors on bee diversity is not uniform across various habitat types and seasons and (c) increase in the number of flowering plant species would positively influence bee diversity.

MATERIALS AND METHODS

Study area

The experiment was carried out for a period of one year i.e., September 2020 to August 2021 at District Bahawalpur (29.3544°N, 71.6911°E; 181 m above sea level), Punjab, Pakistan. Bahawalpur is comprised of a variety of landscapes including ornamental grassy plots, naturally occurring desert, agricultural land, planted forests, a river, canals, roads and buildings etc. Five types of landscapes were selected i.e., agricultural land, desert, planted forest, road verges and canal verges. We categorized agricultural land into the agricultural landscape, desert and forest into natural landscape and road and canal verge into semi-natural landscape. We selected five sites in each landscape. In agricultural and natural landscapes, each site was constituted of at least 20 hectares, at least 5 km apart. In semi-natural landscapes, each site was constituted of a road or canal verge of 1 km, at least 5 km apart. However, during data analysis, we pooled the data of all the five sites.

The climate of the area is arid with hot summers and cold winters. The mean daily maximum and minimum temperatures are 33.5°C and 18.8°C, respectively with the average annual rainfall is 83 to 218mm (Ahmad *et al*., 2019). This region is blessed with four different seasons i.e., spring (March to May), summer (June to September), pre-winter or autumn (October to November) and winter (December to February) (Sajjad *et al*., 2017).

Sampling unit and floral abundance

To assess the seasonality of native bees, all the available plant species at the flowering stage in three landscapes were observed for bee visitation on fortnightly basis. Since plant species belonged to different categories i.e., trees, shrubs, weeds, etc. and had different types of inflorescences i.e., heads, umbels, etc., therefore, the sampling unit of each plant species was defined separately i.e., m^2 area on a plant, the entire plant, specific number of branches/trees, etc. Floral unit abundance was also recorded for each plant species. For this purpose, five individuals of each plant species were randomly selected and tagged and floral units i.e., individual flowers, a bunch of inflorescences, umbel, head, etc. were counted fortnightly (Sajjad *et al*., 2019).

Data collection

Data was recorded on clear sunny days and cloudy or rainy days were avoided. Five individuals of each plant species were randomly selected for observation and each individual was observed for 120 sec. During each census, there was a total of ten minutes of observation per plant species. For each plant, the number of visiting individuals of each bee species was counted by visual observation. Few specimens of each bee species were collected with the help of an entomological sweep net and all the bee species were morphotyped. The keys of Michener (2007) were used to identify the bee species up to family, genus or subgenus level. Specimens of bees were sent to specialists for species level identification.

Data analysis

To measure sampling efforts, individual-based rarefaction curves were used for the estimation of number of species (S) expected in a random sample of 'n' individuals, taken from a larger collection made up of 'N' individuals and 'S' species (Gotelli and Entsminger, 2005). The diversity of bees in all the landscapes was assessed by using Shannon-Wiener index, Simpson Index (1-D), Evenness index and Chao 1 index. We also used rank abundance curve plots (using log series) as a way to find out the community structure (Magurran, 2004). Non-parametric hierarchal cluster analysis was used to see the similarity among landscapes and seasons on the basis of abundance of 101 bee species on 173 plant species using Bray and Curtis distance as input formula, as many cells in the data were zero. The analysis was performed by using computer software 'PAST' (Hammer *et al*., 2001).

Generalized Linear regression model (GLM) was used to measure the abundance and richness of bees as affected by the weather factors (i.e., temperature, relative humidity, wind speed and solar radiation) and floral resources (i.e., number of plant species at flowering) in different landscapes and seasons. As the abundance and richness of bees were the number of k*th* events in an experiment, so its distribution is considered as negative binomial distribution. Moreover, the abundance and richness of bees are count and over dispersed as recommended by Biggeri (2005) and Yang and Berdine (2015) a count variable which is over dispersed as compared to passion process- has negative binomial distribution and for modeling, negative binomial regression model should be used for that variable. Thus, we used negative binomial log link function in GLM. The GLM was performed by using SPSS statistical software.

RESULTS

From September 2020 to August 2021 a total of 4479 individuals of bee species were recorded representing five families i.e., Apidae, Andrenidae, Colletidae, Halictidae and Megachilidae, 23 genera and 98 morphospecies. Out of these 98 morphospecies, 23 were identified to species level (Table I). Only 13 species were found in all the four seasons i.e., *Apis dorsata*, *A. florea*, *Amegilla mucorea*, *Amegilla* (Zonamegilla) sp.1, *Ceratina smaragdula*, *Ceratina* sp.1, *Xylocopa basalis*, *X. fenestrata*, *Lasioglossum albescens*, *Lasioglossum* sp.3, *Lasioglossum* sp.4, *Lasioglossum* sp.6 and *Pseudapis* sp.4. Out of these 13 species, three were recorded from all the landscapes i.e., *A. dorsata*, *A. florea* and *A. mucorea*. Three species i.e., *Lipotriches fulvinerva*, *L. fervida* and *Megachile lanata* were found only in agricultural landscape. *Lipotriches fulvinerva* was found only in summer while *L. fervida* and *M. lanata* in Autumn season (Table I). The occurrence of different bee species in three landscapes across four seasons is presented in Table I.

Species richness of native bees was higher in autumn season followed by summer, spring and winter. Abundance of native bees was higher in spring season followed by winter, spring and autumn season. Dominance_D index was higher in winter season followed by spring, summer and autumn season. Simpson_1-D, Shannon_H, Evenness_e^H/S and Chao-1 indices were higher in autumn season followed by summer, spring and winter season (Table II). Species richness, abundance and Chao-1 index of native bees were higher in agricultural landscape followed by semi-natural and natural landscape. Dominance_D index was also higher in agricultural landscape followed by natural and semi-natural landscape. Simpson_1-D and Evenness_e^H/S indices were higher in semi-natural landscape followed by natural and agricultural landscape. Similarly, Shannon_H index was also higher in semi-natural landscape followed by agricultural and natural landscape (Table II).

Table I. The seasonal occurrence and abundance of bees in all the three landscapes at Bahawalpur, Pakistan from September, 2020 to August, 2021.

Species	Spring			Summer			Autumn			Winter			Total
	A	SN	N	A	SN	N	A	SN	N	A	SN	N	
Family: Apidae													
Apis dorsata	+	+	+	+	+	+	+	+	+	+	+	+	1384
Apis florea	+	+	+	+	+	+	+	+	+	+	+	+	1593
Apis mellifera	+	+	-	+	-	-	-	-	-	+	-	-	59
Amegilla mucorea	+	+	+	+	+	+	+	+	+	+	+	+	86
Amegilla sp.1	-	-	-	-	-	-	-	-	+	-	-	-	1
Amegilla (Zonamegilla) sp.1	+	+	+	+	+	+	+	+	+	+	-	-	26
Amegilla (Zonamegilla) sp.2	-	-	-	-	+	-	-	-	+	-	-	-	2
Anthophora sp.1	+	-	-	-	-	-	-	-	-	-	-	-	2
Braunsapis mixta	+	+	-	+	+	-	-	-	-	-	-	-	10
Ceratina smaragdula	+	+	-	+	-	-	+	+	-	+	-	-	51
Ceratina sp.1	+	+	+	-	+	-	+	+	-	+	+	+	38
Ceratina sp.2	+	+	+	+	-	-	+	+	+	-	-	-	50
Ceratina sp.3	+	+	+	+	+	-	-	-	-	-	-	+	35
Eucera sp.1	+	+	+	-	-	-	-	-	-	-	-	-	10
Nomada sp.1	+	-	-	-	-	-	-	+	-	+	+	-	6
Nomada sp.2	-	-	-	-	-	-	-	-	-	+	-	-	5
Thyreus sp.1	-	-	-	+	-	+	-	+	+	-	-	-	4
Xylocopa basalis	-	+	-	+	-	-	+	-	-	-	+	-	10
Xylocopa fenestrata	+	+	-	+	+	+	+	+	+	+	+	-	55
Xylocopa pubescens	+	+	-	-	-	-	-	+	-	-	-	-	7
Family: Andrenidae													
Andrena savignyi	-	-	-	-	-	-	+	-	-	+	-	-	146
Andrena sp.1	-	-	-	-	-	-	-	-	+	-	-	+	5
Andrena sp.2	-	-	-	-	-	-	-	-	-	-	-	+	1
Family: Colletidae													
Hylaeus sp.1	-	-	-	-	-	-	-	+	-	-	-	-	1
Family: Halictidae													
Ceylalictus sp.1	+	+	-	+	-	+	-	-	-	-	-	-	14
Ceylalictus sp.2	+	+	-	+	+	+	-	-	-	+	-	-	24
Ceylalictus sp.3	+	-	-	-	+	-	-	+	-	-	-	-	6
Ceylalictus sp.4	-	-	-	+	+	+	-	+	+	-	+	-	30
Ceylalictus sp.5	+	-	-	-	-	+	-	-	-	+	-	-	6
Halictus sp.1	-	-	-	-	-	+	-	-	-	-	-	-	1

Table continued on next page..........

Species	Spring			Summer			Autumn			Winter			Total
	A	SN	N	A	SN	N	A	SN	N	A	SN	N	
Halictus sp.2	+	+	+	+	+	-	-	-	-	+	-	-	8
Halictus sp.3	+	-	-	-	+	-	+	-	-	-	-	-	5
Halictus sp.4	-	-	-	-	-	-	+	-	-	-	-	-	1
Halictus sp.5	-	-	-	-	-	-	-	-	+	-	-	-	1
Halictus sp.6	-	-	-	+	-	-	-	-	-	-	-	-	4
Halictus sp.7	-	-	-	+	-	-	-	-	-	-	-	-	3
Lasioglossum albescens	+	+	+	+	+	-	+	+	-	+	+	+	73
Lasioglossum sp.1	-	-	-	-	-	-	+	+	+	+	-	-	8
Lasioglossum sp.2	-	-	-	-	-	-	-	-	-	+	-	+	2
Lasioglossum sp.3	+	-	-	+	-	+	+	+	+	+	+	-	11
Lasioglossum sp.4	+	-	-	+	+	-	+	+	+	+	+	+	40
Lasioglossum sp.5	-	-	-	-	+	-	+	+	-	-	-	-	5
Lasioglossum sp.6	+	-	-	+	-	-	+	+	+	+	-	-	13
Lasioglossum sp.7	-	-	-	-	-	-	-	+	-	-	-	-	1
Lasioglossum sp.8	-	-	-	-	+	-	+	+	-	-	-	-	4
Lasioglossum sp.9	-	-	-	+	+	-	-	+	-	-	-	-	4
Lasioglossum sp.10	-	-	-	-	-	-	+	+	-	-	+	-	6
Lasioglossum sp.11	-	-	-	-	-	-	-	+	-	+	+	-	3
Lasioglossum sp.12	-	-	-	-	-	-	-	+	-	-	-	-	1
Lasioglossum sp.13	-	-	-	-	-	-	-	-	-	-	+	-	1
Lasioglossum sp.14	+	-	-	-	-	-	-	-	-	-	-	-	6
Lasioglossum sp.15	+	-	-	+	-	-	-	-	-	-	-	-	2
Lipotriches fervida	-	-	-	-	-	-	+	-	-	-	-	-	21
Lipotriches fulvinerva	-	-	-	+	-	-	-	-	-	-	-	-	1
Lipotriches pilipes	-	-	-	+	+	-	+	+	+	-	-	-	25
Lipotriches sp.1	-	-	-	+	-	-	-	-	-	-	-	-	1
Lipotriches sp.2	-	-	-	+	-	+	+	+	-	-	-	-	5
Lipotriches sp.3	-	-	-	-	-	-	+	+	+	-	-	-	8
Lipotriches sp.4	-	-	-	-	-	-	+	-	-	-	-	-	1
Lipotriches sp.5	-	+	-	-	-	-	+	-	-	-	-	-	5
Lipotriches sp.6	-	-	-	-	-	-	-	+	-	-	-	-	1
Nomioidinae sp.1	+	+	+	-	-	-	-	-	-	-	-	-	33
Nomia curvipes	-	-	-	+	+	+	+	-	+	-	-	-	38
Nomia interstitialis	-	-	-	+	-	-	+	+	-	-	-	-	12
Nomia westwoodi	-	-	-	+	+	+	+	+	-	-	-	-	29
Nomia sp.1	-	-	-	+	-	-	-	+	-	-	-	-	7
Nomia sp.2	-	-	-	+	-	-	+	-	-	+	-	-	8
Nomia sp.3	-	-	-	+	-	-	+	-	-	-	-	-	3
Nomioides sp.1	+	+	+	+	+	+	-	+	+	-	-	-	97
Nomioides sp.2	-	-	-	-	+	-	-	-	-	+	-	-	3

Table continued on next page..........

Species	Spring			Summer			Autumn			Winter			Total
	A	SN	N	A	SN	N	A	SN	N	A	SN	N	
Nomioides sp.3	+	-	-	+	+	-	+	-	-	-	-	-	18
Nomioides sp.4	+	-	-	+	+	-	+	+	-	+	-	-	30
Nomioides sp.5	+	-	-	-	-	-	-	-	-	-	-	-	2
Nomioides sp.6	-	-	-	-	-	-	-	+	-	-	-	-	1
Nomioides sp.7	-	-	-	-	-	-	-	+	-	+	-	-	2
Pseudapis bispinosa	+	+	-	+	-	-	+	-	-	-	-	-	24
Pseudapis oxybeloides	+	+	-	+	+	+	+	+	+	-	-	-	44
Pseudapis sp.1	-	-	-	+	+	+	+	+	+	-	-	-	13
Pseudapis sp.2	+	-	-	+	-	+	+	+	-	-	-	-	10
Pseudapis sp.3	-	-	-	-	-	+	-	-	-	-	-	+	6
Pseudapis sp.4	+	-	-	+	+	+	+	+	+	+	-	+	21
Pseudapis sp.5	-	-	-	-	+	-	-	-	-	-	-	-	1
Pseudapis sp.6	-	-	-	-	+	-	+	+	+	-	-	-	9
Sphecodes sp.1	+	+	-	-	-	-	-	+	-	+	-	-	5
Sphecodes sp.2	+	-	-	-	-	-	-	-	-	+	+	-	4
Sphecodes sp.3	+	-	-	-	-	-	-	-	-	-	-	-	1
Family: Megachilidae													
Coelioxys sp.1	-	-	+	+	-	-	-	-	-	-	-	-	3
Heriades sp.1	-	+	-	-	-	-	-	-	-	-	-	-	2
Icteranthidium sp.1	-	-	-	-	-	-	-	-	+	-	-	+	2
Icteranthidium sp.2	-	-	-	-	-	-	-	-	+	-	-	-	1
Lithurgus sp.1	-	-	-	-	-	-	-	-	-	-	+	-	4
Megachile bicolor	+	-	-	-	-	-	+	+	-	-	-	-	26
Megachile cephalotes	+	+	-	+	+	+	+	-	-	-	-	-	32
Megachile creusa	+	+	-	+	+	+	-	+	+	-	-	-	31
Megachile lanata	-	-	-	-	-	-	+	-	-	-	-	-	7
Megachile sp.1	+	-	-	+	-	-	-	-	-	-	-	-	3
Megachile sp.2	+	-	-	+	-	+	-	-	+	-	-	-	6
Megachile sp.3	+	-	-	-	-	-	-	-	-	-	-	-	3

Table II. Diversity of native bees in different seasons and landscapes at Bahawalpur, Pakistan from September, 2020 to August, 2021.

	Seasons				Landscapes		
	Spring	Summer	Autumn	Winter	Agriculture	Semi-natural	Natural
Species richness	49	58	65	39	79	68	46
Abundance	1518	1005	903	1052	2847	974	657
Dominance_D	0.2557	0.218	0.1876	0.2844	0.2524	0.188	0.2293
Simpson_1-D	0.7443	0.782	0.8124	0.7156	0.7476	0.812	0.7707
Shannon_H	2.022	2.402	2.568	1.723	2.197	2.554	2.139
Evenness_e^H/S	0.1541	0.1904	0.2006	0.1437	0.1139	0.189	0.1846
Chao-1	56.33	64.11	91.25	45.6	87.67	85	67.86

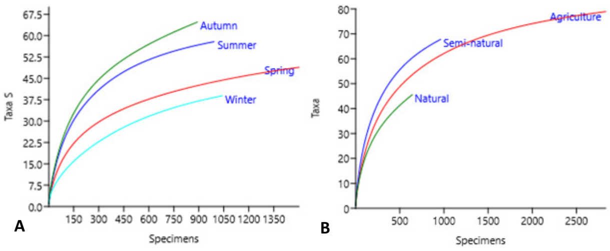

Fig. 1. Individual based rarefaction curves of the bee community in (A) seasons and (B) landscapes at Bahawalpur, Pakistan from September, 2020 to August, 2021

The individual based rarefaction curves showed that sampling was not enough in all the seasons and landscapes as all the curves are not asymptote. This shows that with the increase in sample size the probability of encountering new species is still there in all the seasons and landscapes (Fig. 1A, B).

The hierarchical cluster analysis (using Bray and Curtis distance as input formula) of four seasons on the basis of native bee abundance grouped summer and autumn seasons while winter and spring seasons were the diverse (Fig. 2A). Whereas, the hierarchical cluster analysis of three landscapes on the basis of native bee abundance grouped semi-natural and natural landscapes while the agricultural landscape was diverse (Fig. 2B).

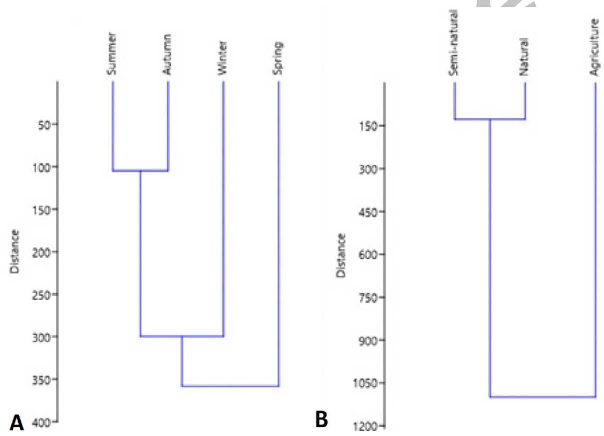

Fig. 2. Hierarchical cluster analysis (Similarity based) for (A) seasons and (B) landscapes at Bahawalpur, Pakistan from September, 2020 to August, 2021.

Rank abundance curves of all the four seasons showed that majority of the bee species were lower in abundance but there were only few species with much higher abundance. The top three most abundant pollinator species are presented in each graph (Fig. 3). These includes *A. florea*, *A. dorsata* and *Nomioides* sp.1 in spring (Fig. 3A), *A. florea*, *A. dorsata* and *Nomia curvipes* in summer (Fig. 3B), *A. florea*, *A. dorsata* and *A. mucorea* in Autumn (Fig. 3C) and *A. dorsata*, *A. florea* and *Andrena savignyi* in winter season (Fig. 3D).

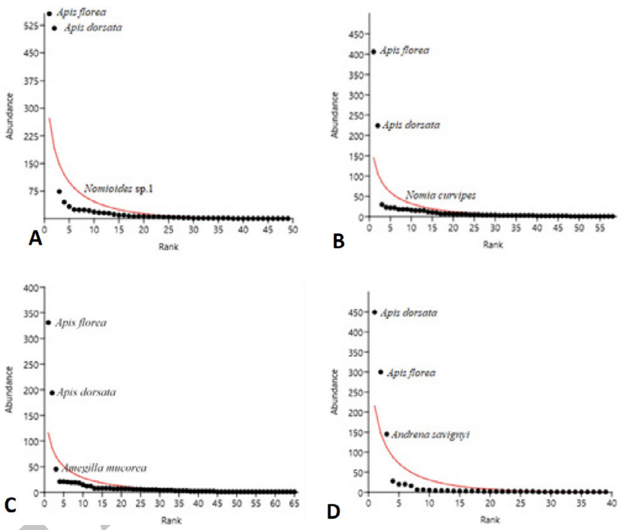

Fig. 3. Rank abundance curves of bees in (A) spring, (B) summer, (C) autumn and (D) winter at Bahawalpur, Pakistan from September, 2020 to August, 2021. The top three most abundant bee species are mentioned in each season.

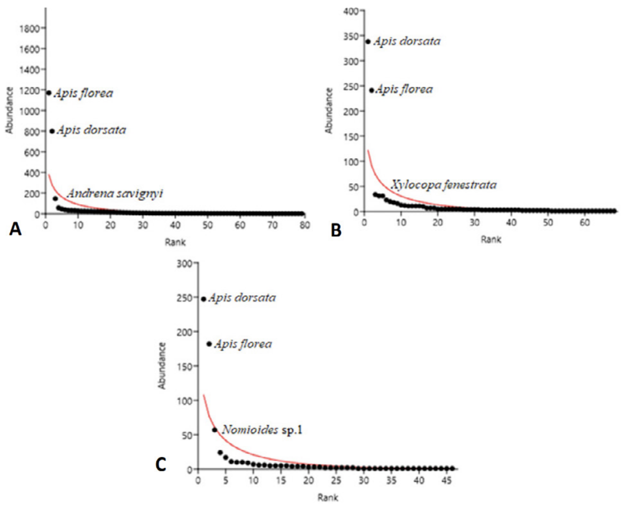

Fig. 4. Rank abundance curves of bees in (A) agricultural, (B) semi-natural and (C) natural landscapes at Bahawalpur, Pakistan from September, 2020 to August, 2021. The top three most abundant bee species are mentioned in each landscape.

Rank abundance curves of all the three landscapes showed that majority of the bee species were lower in abundance but there were only few species with much higher abundance. The top three most abundant pollinator species are presented in each graph (Fig. 4). These includes *A. florea*, *A. dorsata A. savignyi* in agricultural landscape (Fig. 4A), *A. dorsata*, *A. florea*, and *X. fenestrata* in semi-natural landscape (Fig. 4B) and *A. dorsata*, *A. florea*, and *Nomioides* sp.1 in natural landscape (Fig. 4C).

The results of generalized linear regression model showed that bee richness was significantly affected by solar radiations in agricultural and natural landscapes. Bee richness had also a significant interaction with solar radiations during spring season. Bee richness was also significantly affected by the abundance of flowering plant species in agricultural landscape during autumn and summer seasons. On the other hand, bee abundance was significantly affected by solar radiations and the abundance of flowering plant species in the agricultural landscape only (Table III).

DISCUSSION

In the present study, a total of 98 morphotyped species in five families and 23 genera of bees were reported from Southern Punjab, Pakistan. Saeed *et al.* (2019) also reported these five families i.e., Apidae, Andrenidae, Colletidae, Halictidae and Megachilidae from this part of Pakistan. We could identify 23 bee genera in this study i.e., *Apis, Andrena, Anthophora, Amegilla, Ceratina, Halictus, Icteranthidium, Lasioglossum, Megachile, Nomia, Nomioides, Pseudapis, Thyreus*, *Xylocopa*, *Braunsapis, Ceylalictus, Coelioxys, Eucera, Heriades, Hylaeus, Lipotriches, Lithurgus* and *Nomada*. The first 14 listed genera have already been reported from Southern Punjab (Ali *et al*., 2011, 2014; Sajjad *et al*., 2017; Akram *et al*., 2019; Akram and Sajjad, 2022) while the later nine genera are reported for the first time.

Table III. Generalized linear regression model of species richness and abundance of bees as affected by weather factors and floral resources at Bahawalpur, Pakistan from September, 2020 to August, 2021.

Models/ variables	Species richness				Abundance			
	B	S.E.	Wald test	p-value	B	S.E.	Wald test	p-value
Weather factors								
(Intercept)	3.227	1.811	3.174	0.075	6.393	2.223	8.272	0.004
Agricultural landscape	0.473	0.137	11.927	0.001	1.225	0.232	27.774	0.000
Natural landscape	-0.402	0.175	5.302	0.021	-0.240	0.199	1.454	0.228
Semi-Natural landscape	0^a				0^a			
Autumn season	0.368	0.318	1.335	0.248	0.012	0.385	0.001	0.975
Spring season	1.243	0.517	5.787	0.016	0.931	0.756	1.516	0.218
Summer season	-0.348	0.651	0.286	0.593	-0.731	0.772	0.897	0.344
Winter season	0^a				0^a			
Temperature ˚C	0.005	0.033	0.027	0.869	-0.005	0.043	0.015	0.903
Humidity %	-0.013	0.010	1.722	0.189	-0.025	0.013	3.676	0.055
Wind km/h	-0.093	0.051	3.384	0.066	-0.086	0.073	1.380	0.240
Solar Radiation W/m^2	0.003	0.001	12.261	0.000	0.003	0.001	4.280	0.039
Floral resources								
(Intercept)	1.000	0.276	13.153	0.000	2.867	0.525	29.782	0.000
Agricultural landscape	0.308	0.093	10.920	0.001	1.106	0.202	30.121	0.000
Natural landscape	0.057	0.171	0.112	0.738	0.279	0.269	1.080	0.299
Semi-Natural landscape	0^a				0^a			
Autumn season	0.389	0.112	11.986	0.001	-0.194	0.220	0.778	0.378
Spring season	0.079	0.108	0.525	0.469	0.133	0.215	0.382	0.537
Summer season	0.410	0.123	11.112	0.001	-0.102	0.239	0.182	0.670
Winter season	0^a				0^a			
No. of plant species at flowering	0.050	0.007	45.392	0.000	0.050	0.014	12.873	0.000

[a], Set to zero because this parameter is redundant.

In the present study we could identify 22 bee species in 11 genera. Ascher and Rasmussen (2010) and Ascher and Pickering (2020) reported 319 bee species from entire Pakistan. All the 22 identified species of present study are present in that list i.e., *Apis dorsata, A. florea, Amegilla mucorea, Andrena savignyi, Ceratina smaragdula, Megachile bicolor, M. cephalotes, M. lanata, Pseudapis oxybeloides, P. bispinosa, Xylocopa basalis, X. fenestrata*, *X. pubescens, Braunsapis mixta, Lasioglossum albescens, Lipotriches fervida, L. fulvinerva, L. pilipes, M. creusa, Nomia curvipes, N. interstitialis* and *N. westwoodi*. The first 11 listed species have already been reported from Southern Punjab (Sajjad *et al*., 2017, 2019; Akram *et al*., 2019; Bashir *et al*., 2019; Akram and Sajjad, 2022; Rauf *et al*., 2022) while the later 11 species are reported for the first time.

In the present study, *A. dorsata*, *A. florea* and *A. mucorea* was found in all the three landscapes across all the four seasons. Bees require suitable nesting and floral resources for survival and successful reproduction (Westrich, 1996). Honeybees built their nests where water and adequate food resources are available (Oldroyd *et al*., 2008). *Apis dorsata* build their nests on branches of tall trees, vertical rock faces and tall manmade structures i.e., buildings and water towers whereas *A. florea* makes their nests on branches of shrubs and hidden places in manmade structures (Hepburn and Radloff, 2011). *Amegilla* bees usually prefer sandy loam soil for nests construction (Michener, 1960; Cardale, 1968; Greco et al., 2006). Since the soil of Bahawalpur district is sandy to sandy loam in texture which suits well to *Amegilla*.

All the three species are generalist in feeding preferences; *A. dorsata* and *A. florea* are broadly polylectic whereas *A. mucorea* are narrowly polylectic (Michener, 2007). A recent study suggests that *A. dorsata* and *A. florea* remain active throughout the year in the arid to semi-arid neighboring district "Multan", yet with the considerable population fluctuations (Sajjad *et al*., 2017). On the other hand, *A. mucorea* is a solitary bee and remained active in low abundance throughout the year as compared to honeybees. Previous studies suggest that social bees comprise 27 to 97 percent of the total bee community in arid and semi-arid regions (Ali *et al*., 2011, 2014, 2015; Saeed *et al*., 2012; Zameer *et al*., 2017).

Three species i.e., *L. fulvinerva*, *L. fervida* and *M. lanata* were found only in the agricultural landscapes. Species of genus *Lipotriches* collect pollen grains only from grassy crops i.e., Sorghum, millet, maize, etc. The pollen gathering activity of these bees is usually rigorous on the wild plants and agricultural crops closer to their nests (Immelman and Eardley, 2000). In the present study, *L. fulvinerva* was found solely in summer while *L. fervida* and *M. lanata* in autumn. Contrarily to our findings, Immelman and Eardley (2000) found that species of the genus *Lipotriches* remained active from December to May in Kruger Nation Park, South Africa. *Megachile lanata* is solitary, polylactic bee that nests in pre-existing cavities, old nests of sphecid wasps, and trap-nests (Gonzalez *et al*., 2019). This species was also introduced in the North and South America from Pakistan. It is also found in tropical climate of West Indies and Cuba where it remains active throughout the year (Genaro, 1996; Raw, 2007; Meurgey, 2016).

In the present study, species richness and abundance of native bees were the maximum in summer and spring, respectively. Bashir *et al*. (2015) also recorded the maximum abundance of bees in the spring season in the same geographical area. Ambient temperature and relative humidity mainly predict the seasonal fluctuation of bee abundance and diversity (Tylianakis *et al*., 2005; Bashir *et al*., 2015; Matos *et al*., 2016). Besides physical factors, plant species richness in terms of floral resource heterogeneity (nectar and pollen) also predicts pollinator species richness (Potts *et al*., 2003; Ghazoul, 2006).

In the present study, Dominance_D index was higher in winter whereas lower in the autumn season. Simpson_1-D, Shannon_H, Evenness_e^H/S and Chao-1 indices were higher in autumn season but lower in winter season. Shannon-Wiener index estimates species richness and species evenness and gives more weight to species richness. Simpson index also estimates species richness and species evenness but gives more weight to species evenness. Chao-1 however, is an abundance-based estimator of species richness (Kim *et al*., 2017). Because the Chao-1 richness estimator gives more weight to the low abundant species, therefore this index is particularly useful for data sets skewed toward the low-abundance species (Chao, 1984). The association between species evenness and richness among communities remains an unrequited issue in ecology from both the theoretical and practical viewpoints, which shows that these two factors are the discrete constituents of biodiversity. This relationship is mostly led by organismal and environmental properties (Soininen *et al*., 2012).

In the present study, species richness, abundance, Chao-1 and Dominance_D index of native bees were higher in agricultural landscape than semi-natural and natural. Simpson_1-D, Shannon_H and Evenness_e^H/S indices were higher in semi-natural landscape than natural and agricultural landscape. Several habitats may offer a greater number of niches and possibilities for resource exploitation (Silva *et al*., 2008). For example, uncultivated natural areas may provide resources to the species that are rare in cultivated areas i.e., alternate sources of nectar and pollen, permanent vegetation coverage, shelter and nesting places (Tscharntke *et al*., 2007; Sobek *et al*., 2009). The agricultural landscape, on the other hand, generally has a high abundance of floral resources at certain times of the year which may favor the population of arthropods (Tscharntke *et al*., 2005, 2007). Therefore, different types of land use in a region may complement each other, contributing to the maintenance of insects i.e., bees and solitary wasps and consequently maintaining the environmental services provided by them (Tscharntke *et al*., 2005, 2007; Kremen, 2005).

The rank abundance curves of all the four seasons and landscapes in the present study showed that there were so many species with very low abundance but there were only few species with much high abundance. This is the characteristic feature of any natural ecosystem not only in terms of pollinators (Bashir *et al*., 2015) but also other biological groups i.e., natural enemies, soil arthropods etc. (Sajjad *et al*., 2016).

In the present study, *A. dorsata* and *A. florea* were the most abundant in all the four seasons and three landscapes. The results of present study are in agreement with (Bashir *et al*., 2015) who reported that both the bees remained active throughout the year in the southern plain of Punjab, Pakistan. They also reported highest diversity of bees at temperature 30 °C to 40 °C. Sajjad *et al*. (2017) also reported that *A. dorsata* and *A. florea* remained abundant throughout the year. Michener (1990) also reported that honey bees are generalist feeder and floral visitors and remain active throughout the year.

In the current study, bee richness was affected by solar radiations in agricultural landscape, natural landscape and spring season. Bee richness was also affected by the abundance of flowering plant species in agricultural landscape, autumn season and summer season. Moreover, bee abundance was affected by solar radiations and the abundance of flowering plant species only in the agricultural landscape. Majority of the studies have documented those types of landscapes (Carre *et al*., 2009; Ayers and Rehan, 2021) and seasons (Oertli *et al*., 2005; Bashir *et al*., 2015; Escobedo-Kenefic *et al*., 2020) greatly influence the bee richness and abundance.

In agro-ecosystems, the abundance of pollinator has been positively related to floral species richness (Holzschuh *et al*., 2007; Ebeling *et al*., 2008; Kennedy *et al*., 2013) and it is also reported that cultivated plants provide an alternative source of food and nutrition for pollinators during the hotter and drier months of the year, when wild plant floral richness is low and pollinators are under stress. In our region, the agricultural landscape consists of various types of plants i.e., agricultural crops, orchards, medicinal plants, vegetables and weeds at the sides of canal or water channels. This type of landscape provides adequate floral resources to the bees that ultimately affect their diversity (Guezen and Forrest, 2021).

CONCLUSION

The highest species richness during autumn and abundance during spring in the agricultural landscapes indicate that this landscape offers variety of nesting opportunities for the native bees including water course and road verges, mud and brick walls and the use of reeds for the construction of animal sheds. This provides an ideal on-farm habitat for the bees. However, indiscriminate use of pesticides and ever-increasing intensification in agriculture may pose some threats to them. Therefore, there is need to monitor the populations of native bees and promote ecological intensification besides a supporting policy for the conservation and utilization of native bees.

DECLARATIONS

Acknowledgement

We are thankful to John S. Ascher for the identification of bees up to subgenus and species level.

Funding

This research was funded by the Agricultural Linkages Program (ALP) of Pakistan Agriculture Research Council (PARC) under project "Conservation of native bees through ecosystem approach for enhanced crop pollination".

IRB approval

The study was approved by the departmental research committee of the Department of Entomology, Faculty of Agriculture and Environment, The Islamia University of Bahawalpur.

Ethical statement

This research is the authors' own original work and analyzed in a truthful and complete manner. The paper properly credits the meaningful contributions of co-authors and co-researchers. All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

Statement of conflict of interest

The authors have declared no conflict of interest.

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