



Original article

Insect pollinator diversity in four forested ecosystems of southern Punjab, Pakistan

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ABSTRACT

This study investigated pollinator assemblage diversity and richness in four forested ecosystems of southern Punjab, Pakistan, with different landscape types. Pirowal is situated in the plains of irrigated Punjab, Lal Suhanra is part of a sandy desert ecosystem, Ghazi Ghat is part of the Indus River delta, and Fort Munro is located in dry hilly mountains. A yearlong survey of pollinator populations was carried out in these four forested ecosystems from January to December of 2010. Fortnightly hand netting was performed for collecting flower-visiting insects whereas, pan traps of three colors (white, blue, and yellow) were deployed for collecting the data. A total of 8,812 individuals from two orders (Lepidoptera and Diptera) were observed, including 22 families and 154 species. Bees were the most abundant, with 4,502 individuals, and the most species-rich taxa, with 70 species in five families, followed by flies having 2,509 individuals and 51 species in 10 families. Wasps were the least abundant with 1,801 individuals and 33 species in seven families. The assemblage structure of pollinator communities as visualized through rank abundance curves showed that there were many species with low abundance and only a few species with a much higher abundance. The most abundant species among the bees, in order, were *Nomia* sp.3, *Megachile bicolor*, and *Colletes* sp.3; among flies, *Syrphus* sp.2, *Calliphoridae* sp.1, and *Empididae* sp.4; and among wasps, *Tiphidae* sp.1, *Myziniinae* sp.2, and *Scelionidae* sp.1.

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1. Introduction

In nature, the majority of flowering plant species produce seeds only when arthropod pollinators transfer pollen from the anthers to the stigmas of flowers. Without this facility, many interconnected species and processes working within an ecosystem would fail. Approximately 80% of all flowering plant species are specialized for pollination by arthropods, mainly insects. The economic value of global pollination (commercial plus wild) differs broadly, ranging from \$112 to \$200 billion per year. In the United States

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alone, the contribution of wild pollination services has been projected at over \$3 billion per year (Losey and Vaughn, 2006).

The dependence on insect pollinators is even stronger in the tropics than the global average: more than 97% of all tropical lowland plants depend on insects for pollination. In the tropical forests of Central America, insects may be the only means for 95% of canopy tree pollinations and 50% of the understory plants rely on insects for pollination. Arid and mountainous ecosystems often have diverse groups of pollinators, with finely tuned variations to ensure that pollination is operative even when climatic conditions are erratic (Vamosi et al., 2006).

The principal flower-visiting insects are from the orders Hymenoptera and Diptera for the following reasons. Approximately 73% of the world's cultivated crops are dependent on pollination, of which 56.5% are pollinated by bees, 19% by flies, 6.5% by bats, 5% by wasps, 5% by beetles, 4% by birds, and 4% by butterflies and moths. The 25,000 different bee species differ greatly in their size and habit requirements and consequently, deviate in the plants they visit and fertilize. Though honey bees are vital pollinators of many crops and fruit plants (Shaheen et al., 2017; Khan et al., 2012), flies are also important pollinators of more than 100 cultivated plants, including economically important crops like mango, cashew, tea, cacao, apple, onions, and strawberries (Larson et al., 2001). Today, flies are the third largest and most diverse animal groups in the world (Skevington and Dang, 2002), comprising over 160,000 named species in approximately 150 families (Evenhuis et al., 2008). At least 71 families of flies comprise flower-visiting flies, and flies are pollinators of, or at least regular visitors to, at least 555 flowering plant species (Larson et al., 2001).

A decline in pollinator population abundance and diversity has been registered worldwide. Anthropogenic alterations in climates and habitats have resulted in reductions in the biodiversity of many pollinator families (Biesmeijer et al., 2006). Different factors, a-biotic and biotic, influence these parameters in the wild: predators, competitors, parasites, pathogens, and the availability of key resources (Kremen et al., 2007). Research on pollinators and plant-pollinator interactions has expanded greatly because studies have illustrated the negative effects of habitat fragmentation on the diversity of pollinators and the significance of wild pollinators to crop pollination (Ali et al., 2015; Bashir et al., 2015; Steffan-Dewenter and Westphal, 2008; Biesmeijer et al., 2006). The trend of an increasing decline in pollinator populations in recent years has raised concern and drawn the attention of experts on a global scale.

Fragmentation and the loss of natural and semi-natural habitats are considered as major threats to biodiversity in general (Steffan-Dewenter and Westphal, 2008). Human impact has modified the original landscape through degradation, destruction, and fragmentation of natural habitats. The change in land use practices has resulted in alterations in pollinator communities and overall pollination (Kremen et al., 2007). In general, species numbers and densities are expected to decline under such conditions whereas habitat or food specialists and higher trophic levels are more prone to this change (Steffan-Dewenter and Westphal, 2008).

Parallel diversity reductions in pollinating insects and insect-pollinated flowering plants have been reported, suggesting a functional coupling and interdependence between them. Plant-visiting insects depend on plant diversity, but a reduction in flower variety may cause decreases in pollinator diversity; thus, there are positive correlations between species richness on several scales (Fründ et al., 2010). At first, observations of the pollinator crisis mainly arose from the recorded declines in crop-pollinating insects. Habitat alteration and intensification in agriculture are definitely the primary causes of this (Carvalho et al., 2010). In a geographical context, the spatial structure of variation in pollinator abundance and community composition can also have important implications

for plant reproductive performance and ultimately floral evolution (Gomez et al., 2007). This spatial variation in pollinator communities remains poorly documented.

In the present study, the focus was on forest ecosystems, which are the least disturbed by humans and livestock. In general, earlier studies only considered the pollinators of cultivated plant species because this problem was recognized as critically important to agriculture (Latif et al., 2014; Ali et al., 2011; Sajjad et al., 2009; Roubik, 1995; Sihag, 1990; Sihag, 1986). However, little is known about the diversity and abundance of insect pollinators in natural forest habitats in this area.

The focus of this study was on two of the most important groups of pollinators, bees, and flies. Wild native pollinators were considered in the study because all of them contribute to overall pollination in forested ecosystems. The current study serves as a baseline for future conservation programs regarding sustainable agriculture and forest management in the region.

2. Material and methods

2.1. Study area

The study area comprised four widely isolated forest reserves (at least 100 km from each other), each situated in a different type of landscape in southern Punjab, Pakistan. Pirowal (a part of the district Khanewal) is a wildlife sanctuary, with naturally growing trees, herbs, and shrubs along with some agro-forestry. Ghazi Ghat (district Muzaffar-garh) is a wetland extending parallel to both sides of the Indus River or even within the river-bed. Fort Munro (district Dera Ghazi Khan) is a hilly mountainous area with an elevation up to 6470 feet above sea level and the vegetation over hills is sparse. Lal Suhanra (district Bahawalpur) is one of the largest national parks in the country and a desert ecosystem.

2.2. Sampling methods

The research was performed from January to December 2010 and data were fortnightly collected from each location on clear sunny days. Cloudy and rainy days were avoided. A fortnightly census of pollinators was performed throughout the year by using two standardized protocols, i.e., colored pan traps (white, yellow, and blue) and hand netting. Hand netting was performed for only those insects attending flowers during anthesis. Collected insects were pinned and labeled indicating locality (GPS position), date, and host flora (in the case of hand netting). Family-level identification was done using the keys of Borror et al. (1981). The bee (Hymenoptera) genera were identified using the keys of Michener (2007). For species level identification, specimens were sent to relevant local and international experts. Specimens which were not identified at any taxonomic level were morphotyped.

2.3. Statistical analysis

Two traits of the pollinator assemblage were analyzed in this study, including abundance (total number of pollinators) and diversity (Magurran, 2004). Assessment of diversity was calculated by species richness, diversity, evenness, and dominance. Species richness is the number of pollinator species in each location. Dominance (D) was calculated as the relative abundance of the most abundant visitor species. Diversity was calculated by using the Shannon-Wiener index and the evenness index that combines the two mechanistic factors affecting diversity, i.e., dominance and species abundance, which itself is the complement of the Simpson index (1-D).

To measure the sampling efforts, individual-based rarefaction curves were used to estimate the 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). For a detailed comparison of species composition among the four locations, a comprehensive list of pollinators was maintained showing composition percentage at three different levels, i.e., family, order, and overall pollinators on the basis of their abundance. Tukey's test for paired comparisons was applied for statistical comparison of the different pollinator groups.

3. Results

A total of 8812 specimens of 154 species in 22 families and 2 orders (Diptera and Hymenoptera) were collected. Pollinators were broadly categorized into three major groups, bees, wasps, and flies. Bees comprised the highest proportion of the total pollinator species and were most abundant (70 species, 45%; 4502 individuals, 51%) followed by flies (51 species, 33%; 2509 individuals, 28%) and wasps (33 species, 22%; 1801 individuals, 21%).

The diversity of different pollinator communities was evaluated using three different diversity indices, in addition to dominance. The Shannon-Weiner index (H) tend to be more sensitive to rare species, the Simpson index (1-D) emphasizes more common species, whereas evenness describes the relative distribution of individuals among the groups such that the higher the evenness value, the more equally distributed individuals are across categories (Hill, 1973).

The dominance (D) value was the highest for wasps, followed by bees, and flies. Similarly, the Simpson index was in reverse order, i.e. it was highest for flies followed by bees and wasps, or it can be stated that the probability that two randomly selected samples belonging to the same species was higher in flies, followed by bees and wasps. The value of the Shannon-Wiener index and evenness was greater for flies, followed by bees and wasps (Table 1).

The rarefaction curves of the three pollinator groups, based on an individual rarefaction method using the expected number of species as a function of sample size, revealed that the sampling efforts for flies and bees were sufficient to represent the maximum number of species, whereas it was not sufficient for wasps because it did not reach an asymptote (Fig. 1).

Among the bees, five families, i.e. the Andrenidae, Apidae, Colletidae, Halictidae, and Megachilidae were recorded. Halictidae was the most species-rich and abundant family (29 species and 1,827 individuals). In contrast, Andrenidae was the least abundant (77 individuals) whereas Colletidae was the least species-rich family (three species). To visualize species by their relative abundance, we used rank abundance curves, which showed that there were many species with low abundance but few with a much higher abundance (Figs. 2 and 3). The three most abundant species among the bee species were, in order, *Nomiasp.3*, *Megachile bicolor*, and *Colletes sp.3*.

Table 1

Diversity profile of pollinator groups (bees, wasps and flies) in four forested ecosystems of southern Punjab, Pakistan.

Indices	Overall	Bees	Wasps	Flies
Richness	154	70	33	51
Abundance	8812	4502	1801	2509
Dominance (D)	0.04	0.09	0.26	0.06
Simpson's index (1 - D)	0.96	0.91	0.74	0.94
Shannon-Wiener index	3.97	3.09	2.22	3.18
Evenness	0.34	0.32	0.21	0.40

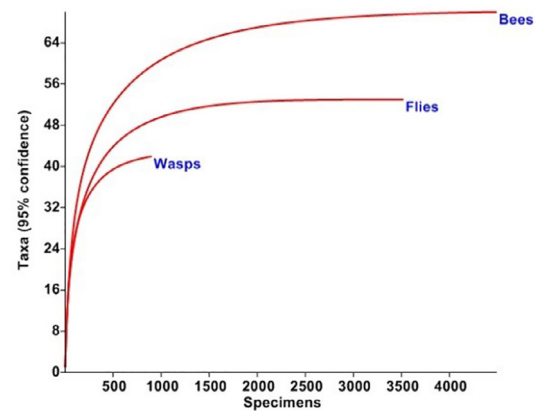


Fig. 1. Individual-based rarefaction curves of three pollinator groups (bees, flies, and wasps) showing the expected number of taxa as a function of sample size.

In the case of flies, ten different families (Calliphoridae, Syrphidae, Asilidae, Anthomyiidae, Bombyliidae, Tephritidae, Sarcophagidae, Muscidae, Stratiomyidae, and Sepsidae) were recorded throughout the study period. The results showed that Syrphidae was the most species rich and abundant family (21 species and 1459 individuals), whereas Sepsidae and Stratiomyidae were the least species rich families (1 species each). On the other hand, Stratiomyidae was also the least abundant family (i.e., 6 individuals). The rank abundance curve of flies also followed the same trend as that of bees, i.e., most species with a low abundance but few with a much higher abundance. The three most abundant species among flies were *Sarcophaga sp.2*, *Syrirta sp.1*, and *Empididae sp.4*.

Wasps belonged to seven different families, i.e., the Chrysididae, Mutillidae, Philanthidae, Pompilidae, Scelionidae, Sphecidae, Tiphidae, and Vespidae. The maximum number of species with the highest abundance was recorded in the family Vespidae (12 species and 144 individuals). The minimum number of species (2) was recorded in the family Tiphidae, whereas the minimum number of individuals (18) was recorded in the family Chrysididae. The rank abundance curve clearly suggests *Tiphidae sp.1*, *Myzininae sp.2*, and *Scelionidae sp.1* are the most abundant species.

When the pooled data of all the three pollinator groups subjected to visualization of their rank abundance curve, *Nomia sp.3*, *Megachile bicolor*, *Sarcophaga sp.1*, *Syrirta sp.1*, and *Colletes sp.3* appeared to be the most abundant species. For studying species composition, a list of pollinators was systematically arranged, mentioning the abundance of each pollinator along with its proportion with reference to its family, order, and overall pollinator abundance (Table 2). Results showed that the order Hymenoptera constituted 60.47% of the total pollinator abundance, whereas Diptera constituted 39.53%.

Among the 22 observed families of pollinators, Halictidae, Apidae, and Syrphidae comprised the highest proportions (20.08%, 18.09%, and 10.88%, respectively) among total pollinator abundance, whereas the Chrysididae, Tephritidae, and Mutillidae comprised the lowest proportion of total pollinator abundance (0.35%, 0.47%, and 0.98%, respectively). On the other hand, and at the species level, *Nomia sp.3*, *Megachile bicolor*, and *Syrirtasp.1* had the highest proportional percentage at 10.37%, 10.34%, and 4.39% respectively. Similarly, *Pseudapis sp.2*, *Mutillinae sp.3*, and *Mutillinae sp.9* had the lowest proportional percentage (0.01% for each).

Among the Hymenoptera families, Halictidae, Megachilidae, and Apidae were the species-richest families with proportional abundances of 33.21%, 29.92%, and 8.64%, respectively, with respect to the total pollinator population. The Chrysididae, Mutillidae, and Sphecidae, on the other hand, were the families having

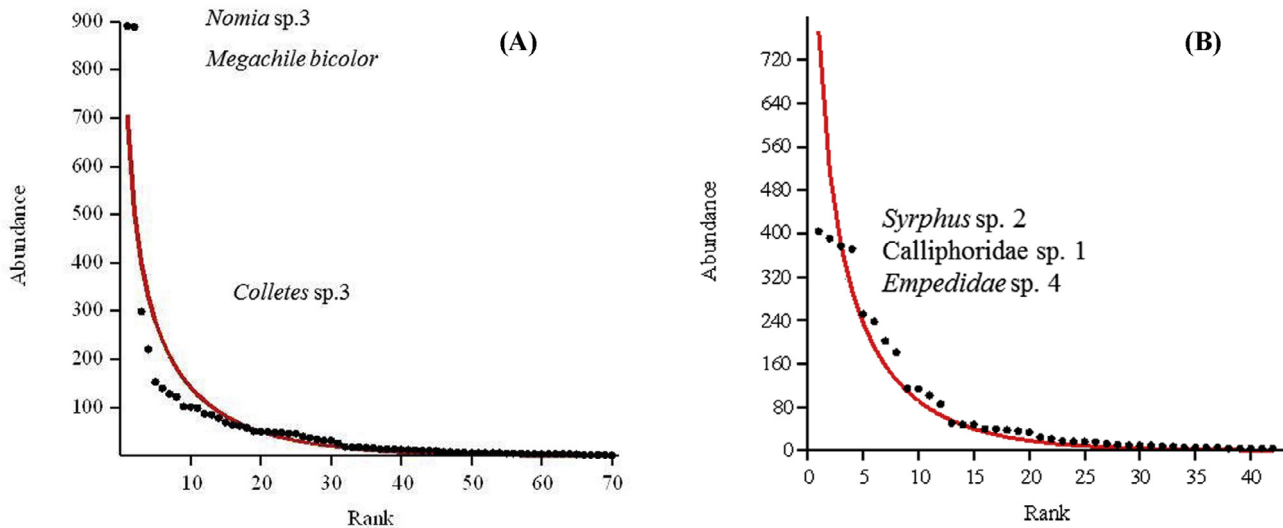


Fig. 2. Rank abundance curves of (A) bees and (B) flies. The three most abundant species are named.

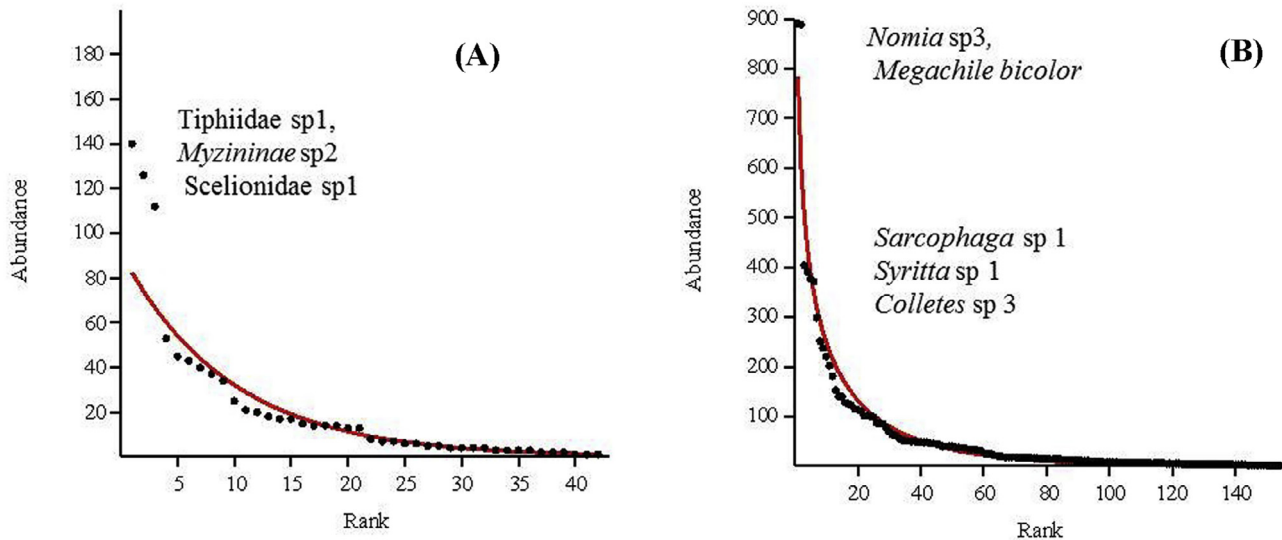


Fig. 3. Rank abundance curves of (A) wasps and (B) overall pollinators. The most abundant pollinators are named.

the lowest proportional abundances of 0.35%, 0.98%, and 1.10%, respectively. The species *Nomia sp.3* (10.37%), *Megachile bicolor* (10.34%), and *Colletes sp.3* (3.48%) comprised the highest fraction of total pollinator abundance, whereas *Pseudapis sp.2*, *Mutillinae sp.3*, and *Mutillinae sp.6* comprised the lowest (0.01% each).

Among the fly families, Syrphidae, Calliphoridae, and Muscidae had the highest proportion in overall abundances of 27.52%, 24.57%, and 15.98%, respectively, whereas the Tephritidae and Stratiomyidae had the lowest overall abundances of 0.47% and 2.15%, respectively. Out of the 51 species of flies, *Syritta sp.1*, *Muscidae sp.3*, and *Bombyliidae sp.3* contributed the most to the overall abundance of pollinators, at 10.95%, 7.42%, and 7.00%, respectively.

The results indicated that the abundance of bees, flies, and wasps were significantly different (DF = 2, 22; F = 4.14; P = 0.029) between the sampling sites. However, bees were the most abundant and wasps were less abundant (Table 1). The richness of the three groups was highly significantly different (DF = 2, 22; F = 20.03; P = 0.000), with flies having the highest richness followed by bees and wasps (Table 3).

4. Discussion

In this study, the Hymenoptera comprised the highest proportion (51%) of the total abundance of pollinators followed by the Diptera (28%). Previously, few recent studies have reported the profiles of pollinator communities in the study locations though their prime focus was plant and pollinator interactions in natural and agricultural lands. Sajjad et al. (2012) studied the spatial variations in pollinator communities and their impact on plant reproductive performance in the Pirowal Wildlife Park and the Chak Katora forest reserve (District Bahawalpur). They recorded 77 species in four orders with the Hymenoptera and Diptera being the most dominant at 41% and 17%, respectively. Similarly, Saeed et al. (2012) reported bitter melon pollinators in ten families with the Apidae and Syrphidae being the most dominant. Similar findings have also been observed in the case of canola (Ali et al., 2011) and pumpkin crops (Ali et al., 2014). In all the three aforementioned studies, two social bee species, *Apis dorsata* and *A. florea*, comprised the highest fraction of the overall pollinator

Table 2

Proportions of pollinator abundance within their orders and families and with respect to overall pollinator abundance. Data was pooled for all the four locations, including Pirowal, Ghazi Ghat, Lal Suhanra, and Fort Munro, in southern Punjab, Pakistan.

Order	Family	Species	Abundance	Family Level	Order Level	Overall
Hymenoptera	Andrenidae	<i>Andrena</i> sp. 1	50	28.09	0.06	0.05
		<i>Andrena</i> sp. 2	6	3.37	0.03	0.02
		<i>Andrena</i> sp. 3	4	2.25	0.79	0.58
		<i>Andrena</i> sp. 4	101	56.74	0.10	0.07
		<i>Andrena</i> sp. 5	11	6.18	0.06	0.05
		<i>Andrena</i> sp. 6	4	2.25	1.60	1.18
		<i>Andrena</i> sp. 7	2	1.12	0.17	0.13
		Family Total	178		2.82	2.07
	Apidae	<i>Amegilla mucorea</i>	21	4.68	0.33	0.24
		<i>Apis dorsata</i>	69	15.37	1.09	0.80
		<i>Apis florea</i>	46	10.24	0.73	0.54
		<i>Ceratina</i> sp. 1	3	0.67	0.05	0.03
		<i>Ceratina sexmaculata</i>	51	11.36	0.81	0.59
		<i>Thyreus</i> sp. 1	62	13.81	0.98	0.72
		<i>Apidae</i> sp. 1	6	1.34	0.10	0.07
		<i>Apidae</i> sp. 2	14	3.12	0.22	0.16
		<i>Apis</i> sp. 3	4	0.89	0.06	0.05
		<i>Apis mellifera</i>	26	5.79	0.41	0.30
		<i>Tetralonia</i> sp. 1	5	1.11	0.08	0.06
		<i>Thyreus</i> sp. 2	14	3.12	0.22	0.16
		<i>Apidae</i> sp. 4	4	0.89	0.06	0.05
		<i>Apis</i> sp. 4	2	0.45	0.03	0.02
		<i>Ceratina</i> sp. 2	10	2.23	0.16	0.12
		<i>Amegilla</i> sp. 1	2	0.45	0.03	0.02
		<i>Xylocopa</i> sp. 1	102	22.72	1.62	1.19
		<i>Xylocopa</i> sp. 2	8	1.78	0.13	0.09
		Family Total	449		7.12	5.22
		Colletidae	<i>Colletes</i> sp. 1	85	21.85	1.35
	<i>Colletes</i> sp. 2		5	1.29	0.08	0.06
	<i>Colletes</i> sp. 3		299	76.86	4.74	3.48
	Family Total		389		6.17	4.53
	Halictidae	<i>Agapostemon</i> sp. 1	7	0.41	0.11	0.08
		<i>Halictidae</i> sp. 1	2	0.12	0.03	0.02
		<i>Halictidae</i> sp. 2	40	2.32	0.63	0.47
		<i>Halictidae</i> sp. 3	18	1.04	0.29	0.21
		<i>Halictidae</i> sp. 4	12	0.70	0.19	0.14
		<i>Halictidae</i> sp. 5	48	2.78	0.76	0.56
		<i>Halictidae</i> sp. 6	6	0.35	0.10	0.07
		<i>Halictidae</i> sp. 7	3	0.17	0.05	0.03
		<i>Halictidae</i> sp. 8	4	0.23	0.06	0.05
		<i>Halictidae</i> sp. 9	48	2.78	0.76	0.56
		<i>Halictus</i> sp. 1	32	1.85	0.51	0.37
		<i>Halictus</i> sp. 2	11	0.64	0.17	0.13
		<i>Halictus</i> sp. 3	4	0.23	0.06	0.05
		<i>Halictidae</i> sp. 10	17	0.98	0.27	0.20
		<i>Halictidae</i> sp. 11	34	1.97	0.54	0.40
		<i>Halictidae</i> sp. 12	7	0.41	0.11	0.08
<i>Halictidae</i> sp. 13		16	0.93	0.25	0.19	
<i>Halictidae</i> sp. 14		87	5.04	1.38	1.01	
<i>Halictidae</i> sp. 15		153	8.86	2.43	1.78	
<i>Lasioglossum</i> sp. 1		19	1.10	0.30	0.22	
<i>Lasioglossum</i> sp. 2		50	2.90	0.79	0.58	
<i>Nomia</i> sp. 1		6	0.35	0.10	0.07	
<i>Nomia</i> sp. 2		13	0.75	0.21	0.15	
<i>Nomia</i> sp. 3		891	51.62	14.14	10.37	
<i>Nomia</i> sp. 4		64	3.71	1.02	0.74	
<i>Nomia</i> sp. 5		37	2.14	0.59	0.43	
<i>Nomia</i> sp. 6		2	0.12	0.03	0.02	
<i>Pseudapis</i> sp. 1		99	5.74	1.57	1.15	
<i>Pseudapis</i> sp. 2		1	0.06	0.02	0.01	
Family Total		1726		27.38	20.08	
Megachilidae	<i>Icteranthidium</i> sp. 1	58	3.73	0.92	0.67	
	<i>Icteranthidium</i> sp. 2	4	0.26	0.06	0.05	
	<i>Megachile</i> sp. 1	12	0.77	0.19	0.14	
	<i>Megachile</i> sp. 2	32	2.06	0.51	0.37	
	<i>Megachile</i> sp. 3	14	0.90	0.22	0.16	
	<i>Megachile</i> sp. 4	8	0.51	0.13	0.09	
	<i>Megachile</i> sp. 5	78	5.02	1.24	0.91	
	<i>Megachile</i> sp. 6	140	9.00	2.22	1.63	
	<i>Megachile</i> sp. 7	18	1.16	0.29	0.21	
	<i>Megachilidae</i> sp. 1	6	0.39	0.10	0.07	

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Table 2 (continued)

Order	Family	Species	Abundance	Family Level	Order Level	Overall
		<i>Megachile</i> sp. 8	46	2.96	0.73	0.54
		<i>Megachilidae</i> sp. 2	128	8.23	2.03	1.49
		<i>Megachile</i> sp. 9	122	7.85	1.94	1.42
		<i>Megachile bicolor</i>	889	57.17	14.10	10.34
		Family Total	1555		24.67	18.09
	Chrysididae	<i>Chrysidinae</i> sp. 1	4	22.22	0.06	0.05
		<i>Chrysidinae</i> sp. 2	8	44.44	0.13	0.09
		<i>Chrysidinae</i> sp. 3	6	33.33	0.10	0.07
		Family Total	18		0.29	0.21
	Crabronidae	<i>Crabronidae</i> sp. 1	140	37.04	2.22	1.63
		<i>Crabronidae</i> sp. 2	112	29.63	1.78	1.30
		<i>Crabronidae</i> sp. 3	126	33.33	2.00	1.47
		Family Total	378		6.00	4.40
	Mutillidae	<i>Mutillinae</i> sp. 1	2	3.92	0.03	0.02
		<i>Mutillinae</i> sp. 2	14	27.45	0.22	0.16
		<i>Mutillinae</i> sp. 3	1	1.96	0.02	0.01
		<i>Mutillinae</i> sp. 4	2	3.92	0.03	0.02
		<i>Mutillinae</i> sp. 5	14	27.45	0.22	0.16
		<i>Mutillinae</i> sp. 6	1	1.96	0.02	0.01
		<i>Mutillinae</i> sp. 7	2	3.92	0.03	0.02
		<i>Mutillinae</i> sp. 8	14	27.45	0.22	0.16
		<i>Mutillinae</i> sp. 9	1	1.96	0.02	0.01
		Family Total	51		0.81	0.59
	Scelionidae	<i>Scelionidae</i> sp. 1	43	35.83	0.68	0.50
		<i>Scelionidae</i> sp. 2	37	30.83	0.59	0.43
		<i>Scelionidae</i> sp. 3	40	33.33	0.63	0.47
		Family Total	120		1.90	1.40
	Sphécidae	<i>Sphécinae</i> sp. 1	15	26.32	0.24	0.17
		<i>Sphécinae</i> sp. 2	3	5.26	0.05	0.03
		<i>Sphécinae</i> sp. 3	4	7.02	0.06	0.05
		<i>Sphécinae</i> sp. 4	13	22.81	0.21	0.15
		<i>Sphécinae</i> sp. 5	4	7.02	0.06	0.05
		<i>Sphécinae</i> sp. 6	5	8.77	0.08	0.06
		<i>Ammophilinae</i> sp. 1	3	5.26	0.05	0.03
		<i>Ammophilinae</i> sp. 2	17	29.82	0.27	0.20
		<i>Ammophilinae</i> sp. 3	5	8.77	0.08	0.06
		Family Total	57		0.90	0.66
	Tiphiidae	<i>Myzininae</i> sp. 1	34	25.76	0.54	0.40
		<i>Myzininae</i> sp. 2	45	34.09	0.71	0.52
		<i>Tiphiidae</i> sp. 1	53	40.15	0.84	0.62
		Family Total	132		2.09	1.54
	Vespidae	<i>Delta dimidiatipenne</i>	6	4.17	0.10	0.07
		<i>Delta esuriens</i>	3	2.08	0.05	0.03
		<i>Delta</i> sp.1	21	14.58	0.33	0.24
		<i>Delta</i> sp. 2	17	11.81	0.27	0.20
		<i>Delta</i> sp. 3	7	4.86	0.11	0.08
		<i>Vespa orientalis</i>	4	2.78	0.06	0.05
		<i>Vespa</i> sp. 1	20	13.89	0.32	0.23
		<i>Vespa</i> sp. 2	18	12.50	0.29	0.21
		<i>Vespa</i> sp. 3	3	2.08	0.05	0.03
		<i>Vespa</i> sp. 4	7	4.86	0.11	0.08
		<i>Vespidae</i> sp. 1	13	9.03	0.21	0.15
		<i>Vespidae</i> sp. 2	25	17.36	0.40	0.29
		Family Total	144		2.28	1.68
Order Hymenoptera Total			6303			60.47
Diptera	Calliphoridae	<i>Calliphoridae</i> sp. 1	17	2.04	0.50	0.20
		<i>Stomorhina</i> sp. 1	18	2.16	0.53	0.21
		<i>Calliphoridae</i> sp. 2	44	5.27	1.29	0.51
		<i>Euphumosia</i> sp.1	87	10.42	2.56	1.01
		<i>Stomorhina</i> sp. 2	87	10.42	2.56	1.01
		<i>Calliphoridae</i> sp. 3	121	14.49	3.56	1.41
		<i>Calliphoridae</i> sp. 4	223	26.71	6.56	2.59
		<i>Calliphoridae</i> sp. 5	115	13.77	3.38	1.34
		<i>Calliphoridae</i> sp. 6	123	14.73	3.62	1.43
		Family Total	835		24.57	9.71
	Syrphidae	<i>Eristalinus</i> sp. 1	6	0.64	0.18	0.07
		<i>Eristalinus</i> sp. 2	102	10.91	3.00	1.19
		<i>Ischiodon</i> sp. 1	4	0.43	0.12	0.05
		<i>Eristalis</i> sp. 1	36	3.85	1.06	0.42
		<i>Syritta</i> sp.1	372	39.79	10.95	4.33

Table 2 (continued)

Order	Family	Species	Abundance	Family Level	Order Level	Overall
		<i>Eristalinus</i> sp. 3	38	4.06	1.12	0.44
		<i>Sarcophaga</i> sp. 1	377	40.32	11.09	4.39
		Family Total	935		27.52	10.88
	Asilidae	<i>Asilidae</i> sp. 1	34	20.24	1.00	0.40
		<i>Asilidae</i> sp. 2	10	5.95	0.29	0.12
		<i>Asilidae</i> sp. 3	4	2.38	0.12	0.05
		<i>Asilidae</i> sp. 4	114	67.86	3.35	1.33
		<i>Asilidae</i> sp. 5	6	3.57	0.18	0.07
		Family Total	168		4.94	1.95
	Anthomyiidae	<i>Anthomyiidae</i> sp. 1	11	3.58	0.32	0.13
		<i>Anthomyiidae</i> sp. 2	6	1.95	0.18	0.07
		<i>Anthomyiidae</i> sp. 3	202	65.80	5.94	2.35
		<i>Anthomyiidae</i> sp. 4	40	13.03	1.18	0.47
		<i>Anthomyiidae</i> sp. 5	48	15.64	1.41	0.56
		Family Total	307		9.03	3.57
	Bombyliidae	<i>Bombyliidae</i> sp. 1	48	16.22	1.41	0.56
		<i>Bombyliidae</i> sp. 2	10	3.38	0.29	0.12
		<i>Bombyliidae</i> sp. 3	238	80.41	7.00	2.77
		Family Total	296		8.71	3.44
	Tephritidae	<i>Tephritidae</i> sp. 1	16	100.00	0.47	0.19
	Sarcophagidae	<i>Sarcophagidae</i> sp. 1	104	46.22	3.06	1.21
		<i>Sarcophagidae</i> sp. 2	121	53.78	3.56	1.41
		Family Total	225		6.62	2.62
	Muscidae	<i>Muscidae</i> sp. 1	181	33.33	5.33	2.11
		<i>Muscidae</i> sp. 2	110	20.26	3.24	1.28
		<i>Muscidae</i> sp. 3	252	46.41	7.42	2.93
		Family Total	543		15.98	6.32
	Stratiomyidae	<i>Stratiomyidae</i> sp. 1	73	100.00	2.15	0.85
	Sepsidae	<i>Sepsidae</i> sp. 1	56	100.00		39.53
Order Diptera Total			2509			39.53

Table 3

Abundance and richness of different taxonomic groups in forested ecosystems of southern Punjab, Pakistan.

Serial No.	Group	Abundance	Richness
1	Bees	371.42 A	11.0B
2	Flies	282.25 AB	20.0 A
3	Wasp	75.0B	6.75B

abundance making the Hymenoptera more abundant than the Diptera.

In this study, the values of both the Simpson and Shannon-Wiener indices of diversity were the highest for flies followed by bees and wasps. The Simpson index is basically a dominance index and in this study, it is presented in two forms, including (i) Simpson's index of dominance (D), the probability that two individuals randomly selected from a sample will belong to the same species and (ii) Simpson's index of Diversity ($1 - D$), the probability that two individuals randomly selected from a sample will belong to different species. The latter is the opposite of dominance (D) and is more sensitive to changes in common species and weighted towards more abundant species. The Shannon-Wiener index in contrast, is more sensitive to changes in rare species (Leinster and Cobbold, 2012).

In this study, the individual-based rarefaction curves showed that wasps did not reach an asymptotic level. In practice, achieving an asymptote is routinely impossible in natural ecosystems where species diversity is high and most species are rare. This is also evident from the rank abundance curves in this study, in which there were many species with very low abundance and only a few species with much higher abundance. A 30-year assemblage of communities of ants at La Selva, Costa Rica, has still not reached an

asymptote in species richness (Longino et al., 2002). However, flies in this study reached an asymptote.

Among the bees in this study, the family Halictidae was the most species-rich and most abundant, whereas the family Andrenidae was the least species-rich and least abundant. Halictid bees are more abundant than most other bees except for *Apis* (honey-bees) species (Michener, 2007). A few studies from Pakistan have also shown similar trends, i.e., comparatively high species richness of Halictid bees in agricultural ecosystems. However, *Apis dorsata* and *A. florea* had superiority in terms of abundance (Ali et al., 2014, 2011; Saeed et al., 2012). Halictid bees display the most diverse gradation in social behavior as the species can be solitary, communal, semi-social, or eusocial. Some species exhibit solitary or eusocial behavior depending on the time of year, geographic location, altitude, and other unknown factors (Michener, 2007). The genus *Lasioglossum* in Halictidae is one of the largest genera of bees worldwide, with an incredibly diverse array of behaviors. Most of its species are polylectic, gathering floral resources from multiple plant species. Most Halictid bees nest underground. Nests that are built in rotting wood usually resemble ground nests (Eickwort and Eickwort, 1973), or if that species is a parasite of other bees, then nests are not built at all. Despite usually nesting in the ground, nesting behavior is otherwise highly variable between the species.

The family Syrphidae, on the other hand, proved to be the most species-rich and abundant family among the Diptera, followed by the families Calliphoridae and Empididae. Family Syrphidae perhaps is the most widely studied fly family in Pakistan. Several authors have reported syrphid flies as regular visitors of several agricultural and wild plant species in Punjab, Pakistan (Ali et al., 2014, 2011; Sajjad et al., 2012; Sajjad and Saeed, 2010). Hoverflies are a characteristic fly during the spring (March–April) in this part

of Pakistan. Sajjad et al. (2010) reported interactions of 14 hover fly species with 59 plant species throughout the year, whereas Saeed et al. (2012, 2008) and Ali et al. (2011) reported the relative effectiveness of different syrphid flies for the pollination of onion, canola, and bitter gourd crops.

5. Conclusion

The current study provides a baseline survey of species composition and assemblage structure of flower-visiting Hymenopteran and Dipteran insects for the first time from four widely isolated nature reserves in southern Punjab, Pakistan. The study also identifies the most species-rich and most abundant families of bees, wasps, and flies. This baseline study will provide basic information to ecologists for opening new investigations regarding the complexity of species interactions, i.e., plant and pollinator interactions, and devising management and conservation strategies.

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