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Distribution Patterns of Insect Pollinator Assemblages at Deva Vatala National Park, Bhimber, Azad Jammu and Kashmir

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Key words
Pollinators, DVNP, Insect fauna, Biodiversity

ABSTRACT

Diversity and distribution patterns of pollinator assemblages were explored at Deva Vatala National Park (DVNP), Bhimber, AJK, Pakistan. Sampling was recorded fortnightly by using pan traps, sweep nets, and handpicking. A one-year survey of pollinator fauna was recorded from selected locales of DVNP from October 2019 to September 2020. We observed the same species richness in all three study sites, but a great difference was observed in species abundance. A total of 5565 individuals of 58 species belonging to 23 families and four orders were collected from DVNP. Barmala was reported as the highest abundant site (2815 individuals), followed by the Vatala (1832 individuals) and Deva (918 individuals). SIMPER analysis indicated an overall dissimilarity of Deva-Vatala (18.88%), Deva-Barmala (29.12%), and Vatala-Barmala (10.84%). The biological dissimilarity was evaluated and based on insect taxonomy indicated that *Coccinella septempunctata, Sceliphron madraspatanum, Aedes albopictus, Eristalis tenax, Crambus albellus, Zonitoschema melanarthra, Zonitoschema gibdoana, Camponotus vagus, Polistes carolira*, and *Episyrphus viridaureus* were the main contributing species in the community dissimilarity. Results showed significant differences between Vatala - Deva with higher Shannon value in Vatala (H' = 4.03) than Deva (H' = 3.92), Deva-Barmala with higher Shannon index in Barmala (H' = 4.05) than Deva (H' = 3.92) and Vatala-Barmala have a higher average value of Shannon diversity in Barmala (H' = 4.05) than Vatala (H' = 4.03). DVNP offers habitat and plentiful resources for the insect pollinator assemblages of four major insect orders, viz. Lepidoptera, Hymenoptera, Diptera, and Coleoptera. We detected variations in the abundance of different insect groups (orders, families, and species) during different seasons and study sites within DVNP. This study emphasizes the conduct of research work based on more explorative surveys in association with vegetation types.

INTRODUCTION

Insects represent the most abundant and diverse animal taxa, which provide a wide range of ecosystem services such as pollination, biological control of pests, decomposition, and conservation of biodiversity (Losey and Vaughan, 2006). Insect pollination contributes significantly to the ecological processes of all terrestrial ecosystems (Bohan *et al*., 2016). Insects are known to pollinate over 80% of wild plants and about 75% of cultivated species (Thomann *et al*., 2013; Sataral and Rustiawati, 2019). Insect pollinators diversity and ecological role directly or indirectly influence agriculture, human health, and natural resources (Scudder, 2017). For example, the ecological role of insect pollinators positively impacts the quality and quantity of crop yield by providing pollination services. Additionally, many insect pollinators are useful in environmental pollution monitoring, help in pest management, and have cultural and aesthetic significance (Katumo *et al*., 2022a).

Studies suggest a global decline in the diversity and densities of insect pollinators results in reduced pollination (Aizen *et al*., 2008; Aizen and Harder, 2009; Lautenbach *et al*., 2012; Polce *et al*., 2014). Global declines in the diversity of insect pollinators owes to many adverse factors including mainly adverse effects of climate change

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and habitat modifications (Didham *et al*., 1996; Siregar *et al*., 2016), mainly due to a decrease in food resources, nesting, oviposition, resting, and mating sites (Kevan, 1999). Additionally, recent shifts in land use, mainly converting natural habitats to croplands, may adversely affect species, which ultimately lower pollination services and consequently dent biodiversity (Astegiano *et al*., 2015; Klein *et al*., 2012; Kremen *et al*., 2002).

Several pollinator communities consist of many insect taxa but most of the pollinators insect species belong to four major insect orders: Coleoptera (beetles), Hymenoptera (bees and wasps), Diptera (flies), and Lepidoptera (moths and butterflies). Insect pollinators from these four major orders can provide pollination services to a variety of crops and plantations (Rader *et al*., 2016). These insects pollinate crops and wild plants which ensure biodiversity, provide food, form and improve habitats for many animals and provision of natural resources (Gill *et al*., 2016; Wardhaugh, 2015; Ollerton, 2017).

Several factors influence the composition, diversity and abundance of pollinator species such as habitat composition, floral abundance, plant diversity, agricultural practices, pesticide exposure, parasites and pathogens (Dyola *et al*., 2022; Khan *et al*., 2014; Macdonald *et al*., 2018; Katumo *et al*., 2022b; Ganuza *et al*., 2022; Abrahamczyk *et al*., 2011; Plascencia and Philpott, 2017). Population dynamics of pollinators vary during seasons and in different landscapes (Bashir *et al*., 2015). Deva Vatala National Park (DVNP) has a great significance in the conservation of many animal and wild plant species by providing habitat with plentiful resources (Akrim *et al*., 2015; Umar and Hussain, 2023). Pollinators in this protected area help to maintain a healthy ecosystem by ensuring genetic diversity (Anwar *et al*., 2015). Despite its ecological significance and contribution in the biodiversity conservation, the diversity of insects in DVNP is threatened due to habitat degradation, human population pressure, intensive agricultural practices and use of pesticides (Anwar *et al*., 2015; Umar *et al*., 2021). Therefore, keeping in view the significance of insect pollinators in the protected areas, we explored the diversity of four major insect pollinator taxa (coleoptera, diptera, lepidoptera and hymenoptera) at DVNP, Bhimber, AJK. Additionally, we studied the patterns of distribution of diversity and abundance of these species in three main sites, *viz.* Deva, Vatala and Barmala.

MATERIALS AND METHODS

Study area

Deva Vatala National Park (DVNP), Bhimber (32°51-32°55 N, 74°16-74°24 E; an elevation of 267 to 536 m above sea level) covers an area of 2,993 ha was and it was declared as a National Park in 2007 (Umar *et al*., 2021). DVNP is characterized by sub-tropical semi-evergreen forests (Grimmett *et al*., 2008) and cultivated areas (Anwar *et al*., 2015) for wheat, maize, millet and mustard. Major plant species in the study area include *Acacia modesta*, *Dalbergia sissoo*, *Acacia nilotica, Ficus benghalensis, Mangifera indica, Dodonaea viscosa, Carissa opaca, Ziziphus nummularia, Cynodon dactylon, Desmostachya bipinnata*, *Butea monosperma, Lannea coromandelica, S. spontaneum, V. nilotica, Salvia* spp., *Senna occidentalis, Zanthoxylum armatum* and *Saccharum spontaneum* (Azam *et al*., 2007). We sampled insect pollinators during October 2019 to September 2020 from three main sites DVNP. These sites within DVNP were selected based on topography, anthropogenic activities, agricultural practices, access to the area and the significance of these sites to represent the DVNP (Umar *et al*., 2021) (Fig. 1).

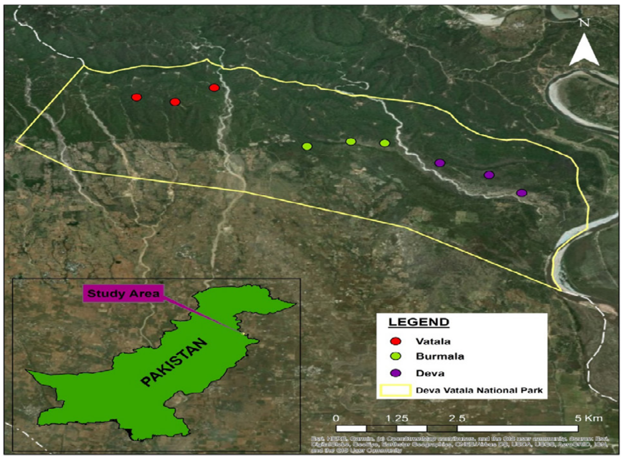

Fig. 1. Map showing study three sampling locations within each sampling site within Deva Vatala National Park (Umar *et al*., 2021).

The hilly forests of Barmala (32°52'58.7" N, 74°20'18.97" E; 350-411m asl) have seasonal streams and different vegetation layers. The forests of Deva (32°54'8.6" N, 74°21'29.7" E; 306-381m asl) is situated closer to the line of control (LoC) which is a military control line between the Indian and Pakistani controlled parts of the former princely state of Jammu and Kashmir, whereas Vatala (32°52'38.7" N, 74°17'44.7" E; 350-396 m asl) shares a similar plant community composition to the other sites (Umar *et al*., 2021).

Sampling methods

Sampling was performed fortnightly on bright sunny days by using pan traps, sweep nets and hand picking.

Surveys were conducted randomly in the mornings (08:00-10:00 h) and afternoons (16:00-18:00 h). We used different pan traps (blue, yellow, and white) to capture the diversity of floral visitors (Wilson *et al*., 2008). The traps were filled with soap water to reduce surface tension and were placed with alternate colors in saline in open and visible places. The traps were fixed in a selected area in the morning and removed in the afternoon to record all the insect visitors. Then, soap water in pan traps was strained to separate trapped specimens by passing through a net. Insect collections were stored in sealed plastic bags. While using sweep nets (about 30 cm in diameter), we swept randomly over vegetation by transect walks (El-Abdouni, 2022). We also performed sampling by observations and handpicking along the transect walk. Based on the general floral resources in the study area, we grouped monthly sampling efforts into summer (March-September) and winter (October-February) months to document seasonal shifts in the diversity and abundance of the insect pollinators species.

Preservation and identification of specimens

The specimens were preserved in absolute alcohol (Schauff, 2001) and were identified using taxonomic identification keys up to species level (Perveen and Ahmad, 2012; Perveen and Fazal, 2013).

Statistical analysis

The species relative abundance was calculated to compare the species abundance in three sites. Species richness measures biodiversity by providing the number of species in each area, which depends greatly on sampling size and effort (Hussain *et al*., 2021; Magurran, 2004). Species abundance, dominance, richness and evenness were measured by using Shannon–Wiener index (Shannon and Weaver, 1949). We also applied Two-way ANOVA to determine the significance between means of the insects within each order among the three sites. We also determined the differences between insect pollinator species by using Analysis of Similarities (ANOSIM) by comparing the three study sites using PAST software. For ANOSIM, the data were pre-treated with square root transformation to down-weight the effect of the most abundant species (Umar *et al*., 2021). The contribution of each species (%) to the dissimilarity between sites was calculated using SIMPER (similarity percentages) analysis.

RESULTS

Relative abundance of four pollinator orders of insects at DVNP

We reported 58 species belonging to 23 families within four insect orders: Coleoptera, Diptera, Lepidoptera, and Hymenoptera. A total of 5565 insects were collected, the maximum number of individuals belonged to the order Lepidoptera which was significantly different from Hymenoptera, Diptera, and Coleoptera (Fig. 2).

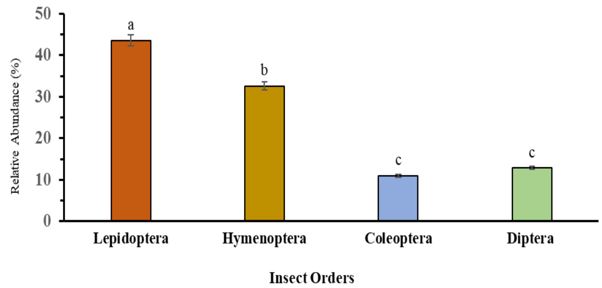

Fig. 2. Relative abundance (%) of different insect orders in Deva Vatala National Park, Bhimber, AJK. Small letters above the column bars indicate significance between orders within each site but no significant differences were found between orders across the three sites. Error bars indicate ± 95% CI.

Comparison of means between three sites using ANOVA indicated significant differences number of individuals of insects belonging to four orders ($F_{(2, 162)}$ = 215.5840, $p < .0001$). The data also showed differences in relative abundance between the three sites: Deva (48.02 %), Vatala (31.88%) and Barmala (16.69%). Interestingly, we observed non-significant differences in the means between individuals of different orders ($F_{(3, 162)}$ = 2.14, p = 0.079).

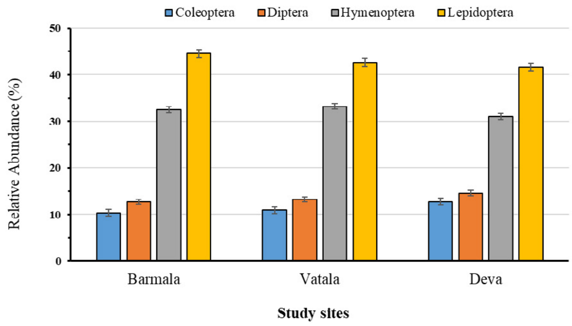

Fig. 3. Relative abundance (%) of four insect orders: Lepidoptera, Hymenoptera, Diptera, and Coleoptera quantified in the three sampling sites in the Deva Vatala National Park, Bhimber, AJK. Error bars indicate±95% CI.

Seasonal abundance of insects at DVNP

ANOVA results showed significant differences in the means between summer and winter ($F_{(3, 324)}$ = 15.50, $p < 0.0001$).Data presented in Figure 3 showed lepidoptera was the most abundant insect order across the three sites. The highest relative abundance (%) of Lepidoptera was recorded in Barmala (44.51%) followed by Vatala (42.63%) and then in Deva (41.61%). Hymenoptera showed almost similar relative abundance in all three sites (Fig. 3). Coleoptera and Diptera showed relatively lower abundance though the difference between these orders was significant ($F_{(2, 162)} = 215.58$, $p = .0001$).

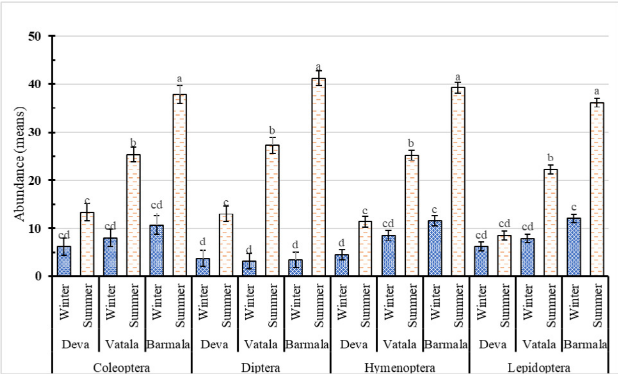

Fig. 4. Comparison of means of different insect orders during summer and winter in Deva Vatala National Park, Bhimber, AJK.

Overall comparison of means across three sites indicated significant differences between winter and summer season (Fig. 4). We observed that higher mean values in summer across all three sites. Coleoptera in summer demonstrated highest mean individuals in Barmala followed by Vatala and Deva. Similar pattern of mean abundance was observed for Diptera, Hymenoptera and Lepidoptera (Fig. 4).

Diversity of insect pollinator families

Data presented in Table I shows the relative abundance (%) of insect orders, families, and species in Deva, Vatala, and Barmala. Results indicated that out of the four insect pollinator orders, the maximum number of families belonged to order Lepidoptera (ten families) followed by Hymenoptera (seven families), Diptera (three families), and Coleoptera (three families). within Hymenoptera order, we observed maximum species in vespidae (six) followed by Formicidae (five) and Apidae (three). However, the highest abundance was shown by *Polistes carolira* (2.83 %) in Deva (Table I). We recorded three families in order diptera with maximum number species belonged to the family syrphidae (six) with highest abundance showed by *Episyrphus viridaureus* (2.94 %) in Deva (Table I). We documented ten families from order Lepidoptera with greater number of species were detected in Pieridae (six) followed by Nymphalidae (five). In order Coleoptera, three species belonged to Meloidae followed by Coccinellidae (two species).

Table I. Relative abundance (%) of orders, families, and species in Deva, Vatala, and Barmala from Deva Vatala National Park (DVNP), Bhimber, AJK.

Order/Family	Species	Relative abundance (%)			
		Deva	Vatala	Barmala	Overall DVNP
Order: Coleoptera (10.13 %)					
Cantharidae (1.39)	*Rhagonycha fulva*	1.42	1.47	1.28	1.39
Coccinellidae (3.40)	*Adalia bipunctata*	1.2	1.09	1.24	1.18
	Coccinella septempunctata	2.61	2.07	1.99	2.22
Meloidae (6.54)	*Mylabris postulate*	2.07	2.02	1.99	2.03
	Zonitoschema gibdoana	2.51	2.02	1.81	2.11
	Zonitoschema melanarthra	2.94	2.24	2.02	2.40
Order: Diptera (13.19 %)					
Culicidae (2.07)	*Aedes albopictus*	2.40	2.02	1.78	2.07
Muscidae (2.73)	*Musca domestica*	1.42	1.58	1.53	1.51
	Ophyra spinigera	0.97	1.36	1.31	1.21
Syrphidae (8.72)	*Episyrphus viridaureus*	2.94	2.02	1.74	2.23
	Eristalis arbustorum	1.09	1.31	1.46	1.29
	Eristalis nemorum	0.65	1.26	1.35	1.09
	Eristalis tenax	2.61	1.91	1.85	2.12
	Paragus annandalei	2.51	1.8	1.67	1.99

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

Order/Family	Species	Relative abundance (%)			
		Deva	Vatala	Barmala	Overall DVNP
Order: Hymenoptera (32.47 %)					
Apidae (6.17)	*Amegilla punctifrons*	1.96	1.75	1.85	1.85
	Apis dorsata	2.4	2.29	2.06	2.25
	Apis mellifera	2.18	1.97	2.06	2.07
Crabronidae (1.07)	*Trypoxylon californicum*	0.44	1.31	1.46	1.07
Eumenidae (1.70)	*Anterhynchium flavomarginatum*	2.07	1.42	1.6	1.70
Formicidae (8.74)	*Camponotus pennsylvanicus*	0.33	1.2	1.46	1.00
	Camponotus vagus	1.53	1.86	1.81	1.73
	Lasius nigar	1.96	1.97	1.85	1.93
	Solenopsis invicta	2.18	2.07	1.95	2.07
	Tapinoma sessile	2.18	2.02	1.85	2.02
Masaridae (1.23)	*Celonites hermon*	0.65	1.47	1.56	1.23
Sphecidae (2.35)	*Sceliphron madraspatanum*	2.51	2.4	2.13	2.35
Vespidae (10.98)	*Allorhynchium argentatum*	0.76	1.58	1.56	1.30
	Anterhynchium abdominale	0.65	1.09	1.21	0.98
	Delta conoideum	2.51	2.18	1.99	2.23
	Polistes carolira	2.83	2.51	2.13	2.49
	Polistes wattii	2.06	2.07	1.99	2.04
	Vespa tropica	1.84	2.02	1.95	1.94
Order: Lepidoptera (43.41 %)					
Crambidae (5.14)	*Cnaphalocrocis medinalis*	2.4	1.91	1.95	2.09
	Crambus albellus	2.61	2.13	2.02	2.25
	Spoladea recurvalis	0.11	0.98	1.31	0.80
Erebidae (8.63)	*Aloa lactinea*	1.74	1.64	1.74	1.71
	Amata phegea	2.4	1.8	1.63	1.94
	Creatonotos gangis	1.53	1.47	1.56	1.52
	Pyrrharctia isabella	1.53	1.64	1.78	1.65
	Spilosoma obliqua	0.11	1.09	1.39	0.86
	Spirama retorta	0.22	1.15	1.49	0.95
Geometridae (1.76)	*Lomographa vestaliata*	1.74	1.8	1.74	1.76
Lycaenidae (1.65)	*Azanus natalensis*	1.53	1.64	1.78	1.65
Nymphalidae (8.74)	*Pseudergolis wedah*	1.53	1.86	1.88	1.76
	Danaus chrysippus	2.4	1.91	1.85	2.05
	Junonia orithya	2.06	1.8	1.74	1.87
	Parage aegeriatircis	2.4	1.97	1.95	2.11
	Ypthima inica	0.11	1.36	1.39	0.95
Papilionidae (1.64)	*Papilio polytes*	1.53	1.69	1.71	1.64
Pieridae (10.80)	*Belenois aurota*	1.73	1.69	1.81	1.74
	Catopsilia pomona	1.74	1.75	1.81	1.77
	Catopsilia pyranthe	1.53	1.64	1.78	1.65
	Eurema hecabe	2.4	1.75	1.74	1.96
	Pieris brassicae	1.73	1.69	1.81	1.74
	Pieris canidia	2.4	1.64	1.78	1.94
Pyralidae (2.08)	*Plodia interpuntella*	2.4	1.92	1.92	2.08
Saturniidae (1.55)	*Antheraea pernyi*	1.52	1.58	1.56	1.55
Sphingidae (0.92)	*Hippotion celerio*	0.22	1.15	1.39	0.92

Table II. Relative abundance (%) of families in three sites (Deva, Vatala and Barmala) and in DVNP (overall) during summer (March- September) and winter (October-February).

Family	Deva		Vatala		Barmala		DVNP	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Apidae	6.17	6.72	6.26	5.92	7.04	5.67	6.59	5.91
Chantharidae	1.30	1.48	2.32	1.21	0.82	1.41	1.41	1.35
Coccinellidae	5.19	3.11	2.55	3.35	3.27	3.22	3.48	3.25
Crabronidae	1.30	0.00	2.32	1.00	2.13	1.27	2.00	1.00
Crambidae	6.82	4.26	6.03	4.71	6.71	4.90	6.52	4.74
Culicidae	0.97	3.11	0.93	2.36	0.49	2.13	0.74	2.35
Erebidae	10.06	6.23	9.05	8.71	10.47	9.35	9.93	8.68
Eumenidae	1.95	2.13	0.70	1.64	1.31	1.68	1.26	1.73
Formicidae	6.49	9.02	9.98	8.85	9.33	8.80	8.89	8.85
Geometridae	2.27	1.48	2.32	1.64	1.96	1.68	2.15	1.64
Lycaenidae	1.95	1.31	1.86	1.57	2.29	1.63	2.07	1.57
Masaridae	0.00	0.98	1.62	1.43	1.64	1.54	1.26	1.42
Meloidae	5.52	8.52	6.26	6.28	6.38	5.67	6.15	6.29
Muscidae	2.27	2.46	2.09	3.21	1.15	3.31	1.70	3.16
Nymphalidae	8.77	8.36	10.44	8.42	9.82	8.53	9.78	8.47
Papilionidae	1.95	1.31	2.09	1.57	1.96	1.63	2.00	1.57
Pieridae	14.61	10.00	10.44	10.06	12.60	10.21	12.37	10.13
Pyralidae	2.92	2.13	1.86	1.93	2.13	1.86	2.22	1.92
Saturniidae	1.95	1.31	1.62	1.57	1.31	1.63	1.56	1.57
Sphecidae	1.62	2.95	1.86	2.57	1.64	2.27	1.70	2.47
Sphingidae	0.65	0.00	1.62	1.00	1.80	1.27	1.48	1.00
Syrphidae	6.49	11.48	2.78	9.99	2.78	9.53	3.63	9.96
Vespidae	8.77	11.64	12.99	10.99	10.97	10.80	11.11	10.98

Based on the general floral resources in the study area, we grouped monthly sampling efforts into summer (March-September) and winter (October-February) months to document seasonal shifts in the diversity and abundance of insect pollinators species. The relative abundance of insect pollinator families indicated significant differences between winter and summer ($F_{(1, 44)}$ = 239.66, p = .0001). The comparison of means indicated significant differences in the means of families between winter and summer. The relative abundance of few insect pollinator families varied greatly between the two seasons such as Crabronidae, Sphecidae, Sphingidae, Pieridae and Erebidae (Table II). Higher relative abundance of Crambidae, Erebidae, Geometridae, Nymphalidae, Pieridae and Sphingidae was observed in winter. We also detected higher abundance of Culicidae, Meloidae, and Syrphidae in summer.

Diversity and abundance of pollinator species

Our results indicated higher abundance of pollinator assemblages at Barmala as compared to other two sites, but we did not observe a single species to be present uniquely in any of the three sites. Insect pollinator communities were significantly different in composition across all three sites (ANOSIM; *R* = 0.331, *P*= 0.0001). All pairwise comparisons of insect pollinator communities between sites were significantly different (Barmala-Deva, *R* = 0.573, *P* = 0.006; Barmala-Vatala, *R* = 0.178, *P* = 0.0135); Deva-Vatala, *R* = 0.5162, *P* = 0.0003).

For assessing the contribution of these species in the diversity of different sites, we calculated similarity percentages (SIMPER) of these species at deva, Vatala and Barmala. The results of SIMPER analysis indicated an average dissimilarity ranged between Barmala-Vatala (30.94%), Deva-Vatala (37.46%), and Deva-Barmala (42.01%).

Table III. SIMPER Analysis indicating species contributing to dissimilarities of communities between three sites: Deva, Vatala and Barmala. Only the top ten contributing species are listed for each pairwise comparison. Analysis is based on pre-treated square-root transformed abundance (Clarke and Warwick, 2001).

Species	Overall dissimilarity	Mean abundance		Mean dissimilarity	% Contribution	Cumulative
		Deva	**Vatala**			
Ypthima inica	37.46 %	0.08	1.44	1.03	2.76	2.76
Coccinella septempunctata		0.78	1.52	1.00	2.66	5.42
Camponotus vagus		0.66	1.59	0.87	2.31	7.73
Trypoxylon californicum		0.17	1.26	0.86	2.29	10.02
Aedes albopictus		0.99	1.51	0.83	2.21	12.22
Allorhynchium argentatum		0.49	1.54	0.82	2.19	14.41
Celonites hermon		0.39	1.41	0.81	2.16	16.58
Adalia bipunctata		0.47	1.23	0.79	2.10	18.68
Eristalis tenax		1.24	1.35	0.79	2.10	20.79
Spirama retorta		0.12	1.19	0.78	2.07	22.86
		Deva	**Barmala**			
Spirama retorta	42.01 %	0.12	1.77	1.04	2.46	2.46
Coccinella septempunctata		0.78	1.92	1.02	2.44	4.90
Spilosoma obliqua		0.08	1.69	0.98	2.32	7.22
Ypthima inica		0.08	1.69	0.97	2.31	9.53
Spoladea recurvalis		0.08	1.64	0.94	2.24	11.77
Camponotus pennsylvanicus		0.25	1.74	0.94	2.23	14.00
Trypoxylon californicum		0.17	1.65	0.91	2.17	16.18
Camponotus vagus		0.66	1.90	0.91	2.17	18.34
Hippotion celerio		0.12	1.62	0.90	2.14	20.48
Celonites hermon		0.39	1.78	0.89	2.12	22.61
		Vatala	**Barmala**			
Episyrphus viridaureus	30.94%	1.52	1.60	0.72	2.33	02.33
Eristalis tenax		1.35	1.85	0.69	2.23	04.55
Paragus annandalei		1.36	1.63	0.68	2.21	06.76
Sceliphron madraspatanum		1.69	1.98	0.67	2.17	8.93
Zonitoschema gibdoana		1.51	1.73	0.67	2.16	11.10
Aedes albopictus		1.51	1.74	0.66	2.14	13.23
Crambus albellus		1.59	1.94	0.65	2.10	15.33
Pieris canidia		1.29	1.88	0.64	2.07	17.40
Danaus chrysippus		1.54	1.80	0.64	2.06	19.45
Eurema hecabe		1.46	1.74	0.63	2.03	21.48

Ypthima inica was the highest contributing species (2.76%) whilst *Spirama retorta* was the least contributing species (2.07%) towards dissimilarity between Deva-Vatala. An overall dissimilarity of 42.01% was observed between Deva-Barmala. *Spirama retorta* (2.46%) was the highest contributing species while *Celonites hermon* (2.12%) was the least contributing species towards dissimilarity between Deva - Barmala. Similarly, an overall dissimilarity of 30.94% was observed between Vatala and Barmala. *Episyrphus viridaureus* (2.33%) was the highest contributing species while, *Pyrrharctia isabella* (2.03%) was the least contributing species towards dissimilarity between the two sites (Table III).

We also compared diversity by calculating Shannon-Wiener index for species and applied t-test between sites to determine statistical significance. The results showed significant differences between Vatala - Deva ($t = -7.31$, d.f. = 1199.5, $P < 0.00001$) with higher average value of

Shannon diversity in Vatala (H' = 4.03) than Deva (H' = 3.92). Similarly, we recorded significant differences between Deva - Barmala (t = -8.43, d.f. = 1013, P< 0.0001) with higher average value of Shannon diversity in Barmala (H' = 4.05) than Deva (H' = 3.92). Vatala had a higher average value of Shannon diversity (H' = 4.03) compared to Barmala (H' = 4.05) but the difference was not statistically significant (P= 0.071).

Rank abundance curves

We also plotted rank abundance curves of species for three sites. The shallow gradient of rank abundance curve for Barmala and Vatala indicated that species were evenly distributed in these areas whereas, the steep curve for Deva indicated less dispersion of species at this study site (Fig. 5).

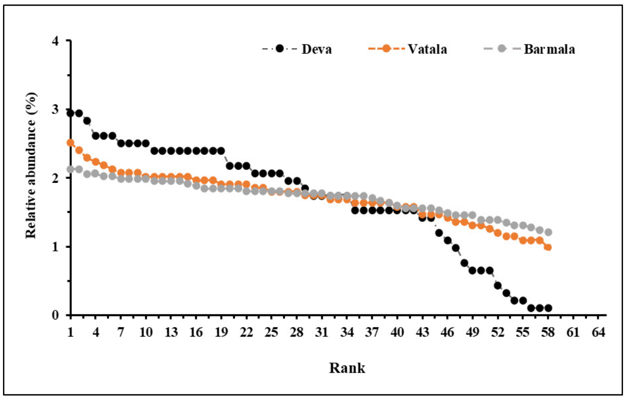

Fig. 5. Rank abundance curves of species representing Deva, Vatala, Barmala.

DISCUSSION

Our study provides a first comprehensive estimation of species richness and the relative abundance of insect pollinators in DVNP. We documented the relative contribution of species belonging to four major insect orders in Deva, Vatala and Barmala. Results showed variations in the species richness and relative abundance of in family groups of four major insect orders. Our results demonstrated variable contributions of four major groups of insect pollinator communities in the descending order: Lepidoptera > Hymenoptera > Diptera > Coleoptera.

Several important features of communities like diversity of species, seasonal pattern of abundance, number of individuals and their relative proportion at three sites were observed. These may be attributed to the variations in the landscape features, vegetation type and the anthropogenic activities associated with these sites. For example, Barmala has the hilly forests with seasonal streams and is relatively undisturbed area though impacted by livestock grazing, cutting wood for fuel, and grass collection and burning all impact upon the area (Umar *et al*., 2021). This would have contributed to the lower number of individuals in Barmala. Similarly in Deva, human population density is lower than in Vatala and has the luxury of field crops and seasonal flowering flora maintained in the nurseries. With higher population density, among these sites, Vatala has the highest human disturbance mainly due to the army deployment, summer visitors, and stone quarrying and livestock grazing. This area may have lesser floral diversity to be exploited by insect pollinators resulting in the lower levels of the insect pollinator species diversity and abundance.

Four major groups of insect pollinators with higher relative abundance of Lepidoptera (butterflies) followed by Hymenoptera (mainly bees, wasps, ants), and Diptera (flies and mosquitoes). Insect pollinators may benefit different resources to maintain their density at relatively higher numbers. A large number of species in different families of Lepidoptera, Hymenoptera and Diptera owes to variations in exploitation of floral resources in different landscapes are pollinators of global importance (Mawdsley, 2003).

Insect pollinators including bees, flies, beetles, moths, and butterflies have been associated with the crops and wild plants (Rader *et al*., 2009; Jauker and Wolters, 2008; Blanche and Cunningham, 2005; Jarlan *et al*., 1997a, b; Kendall and Solomon, 1973). Insect belonging diptera, lepidoptera, and coleoptera have been reported to pollinate different field crops of Brassicaceae family (Shakeel *et al*., 2015, 2019; Chaudhary, 2001).

In our study, Lepidoptera was dominant order in all three sites with species contributed differently to the dissimilarity. This may be attributed to the heterogeneity of the three habitats. Lepidopterans are important pollinators of flowering plants both in wild ecosystems and managed systems such as parks (Ostiguy, 2011). Lepidopterans are identified as an important group of insects pollinating plant species in almost all terrestrial ecosystems across the world (Macgregor *et al*., 2015).

Individual Lepidopterans have varied morphological and behavioural adaptations for pollination such as papilionids, pierids, and groups of nymphalids have long proboscis to reach nectar in specialized flowers (Corbet, 2000; Tiple *et al*., 2009; Mertens *et al*., 2021; Webb, 2008). Lepidoptera has shown the highest diversity and abundance at DVNP that indicates the variety of floral resources in the study area. Lepidopterans have been reported for having attraction towards bright colors. The variety of flora in the study area offered such a plentiful variations in the color of flowers and this may be the reason of high number of lepidoptera than other insect orders (Shakeel *et al*., 2019).

Many hymenopterous insects like bees and wasps are designated as key pollinators of many wild plants and cultivated crops. Hymenopteran showed as the highest abundance among pollinator species with *A. mellifera* was recorded as most prominent insect pollinator species (Shakeel *et al*., 2019). We collected some species collected are known specialists on other plant taxa, suggesting they may be tourist species (Parys *et al*., 2020).

We observed Hymenoptera as second dominant order in our study. Hymenopterans have been reported to be attracted to flowers having high amount of nectar like *Brassica* spp. and many wild plants. The reason could be high amount of nectar secretions in the wild plants and cultivated crops like Brassica (Shakeel *et al*., 2019; Silva and Dean, 2000). Bees and other pollinators of Hymenoptera like to visit the flower with high sugar and nectar. This could be the one reason for their higher diversity and abundance. *A. dorsata* was also reported as pollinator of forest plantations at Sarawak (Momose *et al*., 1998). *T. californicum* showed higher abundance in Barmala and Vatala than Deva which demonstrates its preference for habitat. Many members of superfamily Apoidea including bees and wasps pollinate many food and feed crops of agricultural importance (Lorenzo-Felipe *et al*., 2020). Many hymenopterous insects like social bees are usually found in higher densities near the tree plantations than cropped areas which could be due to the availability of suitable nesting sites and greater foraging opportunities in the adjacent agroecosystems.

Dipterous syrphid flies in both agricultural landscapes and natural ecosystems contribute to the pollination of crops and plantations (Saleem *et al*., 2001; Sajjad *et al*., 2010; Khan and Hanif, 2016). Dipterous flies are an important group of pollinators of agrobiodiversity and plant biodiversity (Ssymank *et al*., 2008). Many dipterans such as syrphid flies are important generalized pollinators which visit many of the same flowers as hymenopterous bees and lepidopterous butterflies. Similar results were reported other parts of the world such as 43 species belonging to hymenoptera, diptera, and lepidoptera from Agricultural lands of Jambi, Sumatra (Siregar *et al*., 2016). Similarly, higher number of pollinators species belonging to Lepidoptera, Coleoptera, Hymenoptera, and Diptera was reported from other parts of the world (Wardhaugh, 2015; Ollerton, 2017).

We found higher relative abundance in summer for example in Syrphidae as compared to winter. Similarly, we recorded higher abundance of Crabronidae, Pieridae, Crambidae, Nymphalidae, and Erebidae in winter than summer. This suggests that different floral resources have contributed to the abundance of the individuals of these species in DVNP.

Similar finding was communicated in a study which reported 11 of Coleopteran pollinator species (Mawdsley, 2003). Earlier studies reported that pollinator diversity varies between habitats (Mudri-Stojnić *et al*., 2012). Hymenopterous pollinators like honeybees, wasps and ants were abundant in Deva but A. dorsata was dominant in Vatala. Bees are the most important generalist insect pollinators for many crops (Bawa *et al*., 1985) and essential pollinators for some crops and wild plants (Aebi *et al*., 2012). In central Sumatera, the study reported that bees visited 73.5% of flowers and *A. dorsata* was recorded in high abundance.

Surprisingly, we detected only six species of Coleoptera with an overall 10.13% contribution in the abundance. Only three species of Meloidae and two species of Coccinellidae were observed in the study area. However, we are uncertain about the possible factors that may have contributed in the lower coccinellid population observed in our study. This lower diversity and abundance of coccinellid assemblages may be attributed to their global decline in their population. mainly due to use of farm inputs like the use of insecticides in the cropped areas for pest management lowering prey density in addition to direct hazardous effects. Many native and ornamental plants in tropical and temperate areas rely on beetles for pollination (Saravy *et al*., 2021). Earlier studies have reported six species of Coleoptera from Israel pollinating mangoes (Dag and Gazit, 2000). Coleoptera is ranked as fourth among pollinators importance after hymenoptera, diptera, and birds (Sayers *et al*., 2019). Studies have shown that the coleoptera are common and important visitors to flowers (Bernhardt, 2000; Wardhaugh *et al*., 2012).

CONCLUSION

We observed that documented pollinator diversity at DVNP has essentially contributed to maintain the natural plant communities that regulate this ecosystem. Variations in the insect pollinator diversity of the studied taxa indicate positive impact of floral resources in three sites, viz. Deva, Vatala, and Barmala.

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IRB approval

This study was approved by the Advanced Study and Research Board of the University of Gujrat.

Ethical statement

All efforts were taken to minimize pain and discomfort to the animal while conducting this research.

Statement of conflict of interest

The authors have declared no conflict of interest.

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