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Variations in the abundance and diversity of insects in apple orchards of Kumaun, Western Himalaya, India

Bhawana Kapkoti*, Ravindra K. Joshi and Ranbeer S. Rawal

Biodiversity Conservation and Management,
G.B. Pant Institute of Himalayan Environment and Development,
Kosi-Katarmal, Almora 263 643, India

Availability of pollinators in a landscape plays a significant role in pollination success, which is essentially important for crops like apple with high dependence on animal-mediated pollination. Realizing this, to estimate the availability (diversity and density) of insect visitors, including pollinators, the present study included pan trap experiments and transect walks for assessment of foraging resources across eight apple orchards in Kumaun, Western Himalaya, India. It was observed that insects were attracted more towards yellow traps, and availability was highest in summer season. Apple mass flowering during summer, in spite of lower diversity of other foraging resource, helps in maintaining availability of insect groups.

Keywords: Apple orchards, insect diversity, landscape, pollinator abundance.

EFFECTIVE animal pollination is an extremely important ecosystem service (ES)[1,2], and is often considered endangered ES[1]. Besides being important for many crops[3,4], it also helps in conservation of global biodiversity[5,6]. However, rapid decline of pollinator populations has emerged as an important concern for conservation biologists[2,7]. In this context, changing land-use patterns, human disturbances (e.g. pesticide use, habitat destruction, and resource destruction), etc. are reported as major causative factors[8].

The availability (diversity and abundance) of pollinators in a landscape plays a significant role in pollination success[9,10], and landscape attributes that have an impact on the availability of pollinators become responsible for effectiveness of pollination. Lonsdorf *et al.*[11] have provided quantitative evidence of relationships of specific pollinator nesting resources, floral resources and foraging distances to estimate the relative abundance of pollinators and the pollination services, across agricultural landscapes. Reports suggest that close to and in natural habitats, the wild bee populations thrive well[12,13]. The abundance of choice flowers, where colour defines the intensity of attraction for bees, also influences availability of pollinators[14]. Therefore, abundance of choice flowers within unit area around the study field is often used for

*For correspondence. (e-mail: bhawanakapkoti@yahoo.com)

assessing levels of pollination services[10–15]. As the pollinators also serve as indicators of the biodiversity pool[16], documentation of their diversity and distribution facilitates conservation and monitoring of biodiversity on a larger scale. More importantly, understanding magnitude, patterns and mechanisms of pollination services is crucial for addressing the issues of food security[17]. This underlines the need for systematic surveys and monitoring of insect visitors, including pollinators in diverse areas and seasons.

Apple, essentially being an insect-pollinated tree crop, requires abundance of efficient pollinators to ensure viable pollination service flow to achieve optimum and quality yield[18]. Evidence-based understanding on apple pollination is available in the northwestern part of the Indian Himalayan region (IHR)[19], especially in Jammu and Kashmir, and Himachal Pradesh. However, for Uttarakhand, another apple-growing state in the IHR, such scientific evidences are largely missing. The present study, therefore, attempts to address this issue by way of estimating spatial and temporal patterns of pollinator availability across various landscape attributes (i.e. composition of foraging resources within a study area and site, their availability through seasons, and preference of insect groups towards different flower colours) in selected orchards of Kumaun, Western Himalaya (Uttarakhand).

Ramgarh, Nainital district of Kumaun, Western Himalaya formed the broad study area. Eight apple orchards, i.e. the study sites, distantly located were selected to record the seasonal and spatial distribution of insect pollinators/visitors and availability of foraging resources (Table 1). Sites were located within the altitude range 1770–2250 m amsl, and were separated by at least 2 km aerial distance from one another[20]. The geo-coordinates and altitude of the sites were recorded using hand-held GPS (Garmin 12).

The pan trap method, which gives the highest sample coverage, collects the highest number of species, shows negligible collector bias and is considered the best indicator of overall bee species richness[21], was adopted to generate the multi-location datasets on insect visitor diversity[22]. Samples were collected across three seasons, i.e. summer (April), monsoon (August), and winter (December). Two readings per season were taken at 15 days interval. Each study site consisted of 30 pan traps (10 traps each of fluorescent blue, yellow and white UV reflective plastic bowls). These colours were used to: (i) represent a range of wavelengths found in the visual spectrum; (ii) exhibit similarity with flower colours, and (iii) follow proven evidences that these colours attract a variety of flower visiting species[21]. Each bowl was filled with one-third of water added with a few drops of detergent to reduce surface tension and prevent possible escape of trapped insects. Bowl traps were placed about 4–5 m apart in open space and in an alternate fashion. Traps were set out in the morning and collected the next morning with about 24 h exposure. Contents of traps were sieved for each colour to separate insects and properly washed with water to remove the attached dirt and pollen. Insects were then sorted and counted by broad insect groups (viz. bees, wasps, hoverflies, housefly, dragonflies, butterflies, moths and other insects). Thereafter, the insects were placed in small vials containing 70% alcohol. The collected specimens were air-dried, pinned and labelled for future identification.

The data on foraging resources/floral richness were obtained following transect walks and visual observations[23]. In each site, an observation plot extending to the adjacent 50 m area beyond the orchard was extensively surveyed. Data on foraging resources in bloom were recorded for each observation plot by walking along and across six 50 m long standardized transects within the area.

The density per 10 bowls of insects was observed on the basis of average value of two readings from different sites, season and colours. Pearson's correlation was performed to see the relationship of altitude and pollinator/visitor density. To find out the effect of the factors (i.e. season and colour), and their interaction, multifactor analysis of variance (ANOVA) was performed. Site effect was included as replication of the observational set-up. Using arcsine transformation, insect density data were analysed for all groups, except square root transformation for housefly and other group due to discrete data structure. The matrix of foraging resources was prepared on the basis of their presence (1) and absence (0) in different sites and seasons. The result of binary matrix was analysed with the help of hierarchical cluster analysis and dendrogram was fashioned based on the matrix using average linkage (between groups) using SPSS software (17.0 version).

Insect groups like bees, wasps, hoverflies and dragonflies did not exhibit significant variation in density across study sites (Table 1). The sites, however, showed significant ($P < 0.05$) difference in the case of houseflies (11.94–57.39), butterflies (0.44–3.61) and moths (0.06–0.50 individual/10 bowls). While analysing the insect groups for their pollination efficiency, the hymenopteran insects, considered to be the most efficient pollinators, were represented by bees (*Apis cerana*, *A. mellifera*, *Bombus haemorrhoidalis*, *Ceratina* sp., *Halictus* sp., *Andrena* sp.) and less recognized pollinators like paper wasps (*Polistes* sp.). Relatively less efficient but dominant insect pollinator group in these orchards was represented by houseflies (*Musca domestica*, *Musca* sp., *Calliphora vicina*) and hoverflies (*Episyrphus balteatus*, *Episyrphus* sp., *Scaeva* sp., *Syrphus* sp.). The spectrum of recorded insects also included lepidopterans (*Pieris canidia*, *P. brassicae*, *Gonepteryx rhamni*, *Colias electo fieldii*, *Aglais cashmirensis aesis*, *Cynthia cardui*, *Celestrina* sp. *Yptima* sp., *Ambylopodia* sp., Hawk moth), odonates

Table 1. Density of insects/pollinators in selected apple orchards

Site/orchard	Altitude (m asl)	Latitude (N)	Longitude (E)	Bee	Wasp	Hoverfly	Housefly	Dragonfly	Butterfly	Moth	Others
Satkhol	1873	29°30′05.6″	79°37′06.9″	3.11 a	1.11 a	7.06 a	19.72 ab	0.50 a	3.61 b	0.50 b	1.94 a
Sheetla	2002	29°29′23.0″	79°37′88.1″	5.06 a	1.33 a	3.06 a	18.33 ab	0.33a	0.72 a	0.11 ab	2.33 a
Orakhaan	1782	29°28′81.9″	79°37′66.2″	4.28 a	1.61 a	5.61 a	11.94 a	0.44a	0.89 a	0.33 ab	2.33 a
Darima	1772	29°27′60.0″	79°38′24.1″	4.61 a	1.67 a	7.56 a	31.33 abc	0.50 a	0.78 a	0.11 ab	1.89 a
Dukkhar	1899	29°27′15.5″	79°38′36.3″	4.11 a	2.50 a	5.11 a	12.39 a	0.44 a	0.44 a	0.06 a	2.11 a
Supi	2181	29°26′.6.0″	79°37′20.3″	4.50 a	1.39 a	5.78 a	44.67 abc	0.39 a	1.17 a	0.28 ab	2.61 a
Satbunga	2254	29°26′43.0″	79°36′68.2″	4.94 a	1.89 a	6.78 a	57.39 c	0.50 a	0.56 a	0.50 b	1.39 a
Dutkaanedhar	2198	29°26′28.1″	79°35′33.6″	6.17 a	1.39 a	8.28 a	51.78 bc	0.33 a	1.11 a	0.33 ab	14.33 a

Mean values followed by the same letter(s) in a column are not significantly different ($P < 0.05$) by Duncan’s multiple range tests.

Table 2. Insect/pollinator density in different seasons

Season	Bee	Wasp	Hoverfly	Housefly	Dragonfly	Butterfly	Moth	Others
April	9.21 c	1.83 b	18.04 b	36.71ab	0.92 c	2.08 b	0.40 b	3.67 a
August	3.08 b	2.88 c	0.21 a	50.94 b	0.38 b	0.75 a	0.44 b	6.96 a
December	1.50 a	0.13 a	0.21 a	5.19 a	0.00 a	0.65 a	0.00 a	0.23 a

Mean values followed by the same letter(s) in a column are not significantly different ($P < 0.05$) by Duncan’s multiple range tests.

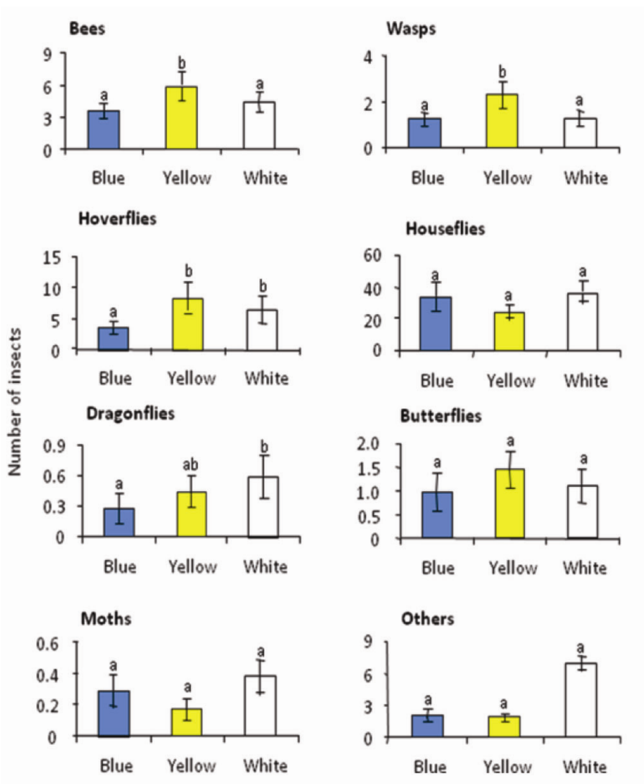

Figure 1. Insect/pollinator density in different coloured bowls.

(dragon flies) and others insects which are mostly not recognized as pollinators.

Across seasons, insect density was highest in summer (April) and lowest in winter (December). During summer density of all insect groups, except houseflies and wasps, was significantly higher ($P < 0.05$). Whereas, during rainy season significantly high density of wasps (2.88), houseflies (0.94) and moths (0.44 insects/10 bowl) was observed (Table 2).

All insect groups did not follow similar trends. Bees, wasps and hoverflies showed significantly greater density in the yellow bowl traps [hoverflies (8.56), bees (5.90) and wasps (2.31 insects/10 bowl)]. Houseflies, butterflies and moths, however, remained unaffected by bowl colour (Figure 1).

The multifactor ANOVA revealed that interaction of colour and season exhibits a significant variation for hoverflies, dragonflies ($P < 0.01$ for both) and other insects ($P < 0.05$), when sites were taken as replicates (Table 3). However, other groups of insects such as bees, wasps, houseflies, dragonflies, butterflies and moths were not impacted by similar interaction. Among the group of insects showing significant difference with factorial analysis, hoverflies were trapped maximum in yellow colour bowls during summer season (25.0 insects/10 bowls), while dragonflies were trapped maximum (1.50 insects/10 bowls) in white colour bowls during the same season. Other insects were attracted maximum (15.9 insects/10 bowls) for white colour bowl during rainy season.

Availability of forage plants varied across the sites (maximum Satkhol – 49 species; minimum Orakhan – 20 species). Following similarity matrix, Orakhan and Dutkaanedhar sites exhibited 80% similarity, whereas Supi and Satkhol sites showed only 50% similarity in foraging species (Figure 2 *a*). Among seasons, maximum forage plants were recorded in the rainy season (66 species) followed by summer (47 species) and winter (40 species). Considering the similarity matrix, 40% species

Table 3. Effect of site, season and colour on insect density

Source of variance	Site	Colour (C)	Season (S)	Interaction (C × S)	Error
Df	7	2	2	4	56
Bee					
MSS	15.86	51.97	854.82	24.41	15.52
F_{cal}	1.02	3.35*	55.08**	1.57	
Wasp					
MSS	9.91	42.22	435.10	5.08	9.84
F_{cal}	1.01	4.29*	44.22**	0.52	
Hoverfly					
MSS	15.88	124.03	4336.99	60.21	14.23
F_{cal}	1.120	8.71**	304.68**	4.23**	
Housefly$^+$					
MSS	1.64	0.82	25.47	1.10	0.56
F_{cal}	2.93*	1.46	45.3**	1.97	
Dragonfly					
MSS	0.55	12.32	111.72	23.39	5.87
F_{cal}	0.09	2.10	19.05**	3.99**	
Butterfly					
MSS	51.53	15.92	84.82	17.09	11.83
F_{cal}	4.36*	1.35	7.17**	1.44	
Moth					
MSS	10.07	8.63	64.78	3.09	3.13
F_{cal}	3.22*	2.76	20.71**	0.99	
Others$^+$					
MSS	0.35	0.57	11.05	1.03	0.37
F_{cal}	0.95	1.53	29.56**	2.77*	

Level of significance * $P < 0.05$; ** $P < 0.01$; df, degree of freedom; MSS, Mean sum of square; $^+$Square root transformation was performed.

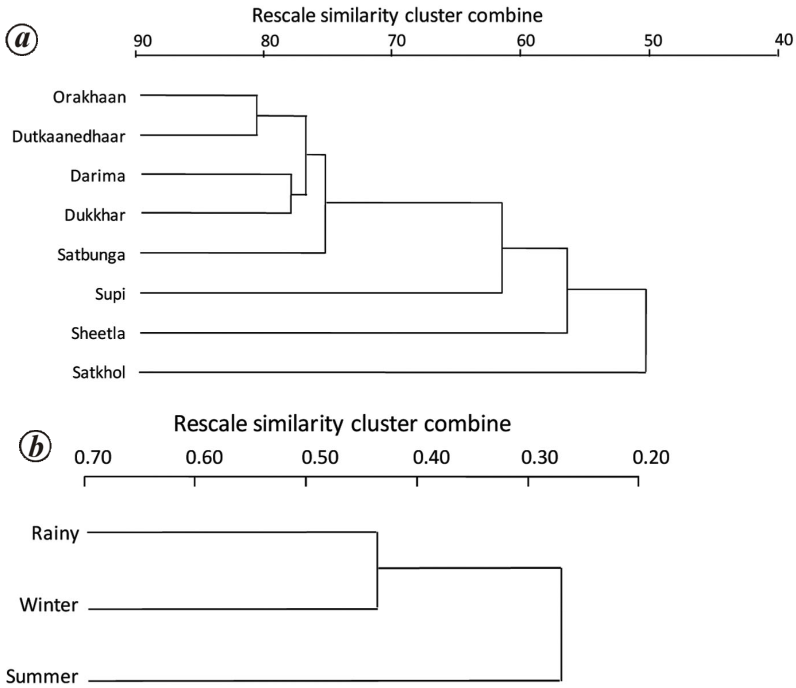

Figure 2. Similarity matrix (%) of foraging resources across different sites and seasons. ***a***, ***b***, Dendrograms prepared using (***a***) average linkages among the sites and (***b***) average linkages between seasons.

during winter (December) were similar with those during summer (April) and 45% with those during monsoon (August; Figure 2 *b*). Across seasons, for different life-forms, a total of 113 plant species were observed to be visited by diverse insect groups (i.e. trees – 2 species, shrubs – 17 and herbs – 94). Among forages, herb species like *Cirsium verutum*, *Coriandrum sativum*, *Geranium ocellatum*, *G. wallichianum*, *Heracleum candicans* and *Trifolium repens* appeared as the most important foraging species and they ensured prolonged provisioning of resources by way of flowering throughout the year.

Non-significant impact of sites on the abundance of most insect visitor groups, including efficient pollinator insects (i.e. bees, bumble-bees), is indicative that availability of most insect visitors in apple orchards of the Western Himalaya remains unaffected by site variation. This can be attributed to prevalence of homogeneous climate and habitat conditions across target landscape. However, across sites, significant variation in density of lepidopteran insects (butterflies and moths) indicates their greater sensitivity to micro-habitat conditions. In general, the variation in habitat, and diversity and density of foraging resources has been reported to influence insect diversity[24]. Past studies have also indicated that insect density varies across sites, owing to habitat conditions, landscape heterogeneity, land use and elevation[21,25,26]. In the present study too, Satkhol site showed significantly higher number of butterflies, which is known to vary with the habitat type available within short distances[27]; they often have different habitat requirements for larva development[28,29]. On the other hand, sites located at a higher elevation (i.e. Satbunga – 2254 m amsl) possess higher density of houseflies, which is in support of previous studies indicating higher fly density in altitudinal range 2200–2500 m amsl (ref. 30).

Greater availability of insect visitors in summer (bees, hoverflies, butterflies and dragonflies) and monsoon (wasps, houseflies and moths) seasons can be explained on account of abundance of diverse forage and refuge needs. During this period most of the sites revealed diversity and abundance of foraging resources. Earlier reports suggest that rate of flower visitation is positively related to flower density[31]. In general, density of bees, flies and butterflies is reported higher during warm season[26,32]. Likewise, butterflies often spend the dry season as adults and begin with reproduction at the beginning of the rainy season[33].

The significantly higher density of most efficient pollinators (i.e. bees) during summer (April) is indicative of their synchrony with apple flowering. During summer, despite lower forage plant diversity compared to monsoon, apple flowers act as an important foraging resource. Some insects were even recorded as frequent visitors only in summer season (i.e. hoverflies), and are known to be the important insect pollinators[34]. Being a mass flowering and determinate crop apple does not provide resources to visiting insects for a long time. However, through mass flowering for a specific period apple not only helps social honey bees, but also many solitary and ground-nesting bees. During successive seasons, despite richness of forages insect abundance remained relatively low, partially due to the absence of densely available resources (as in the case of apple flowering in summer). Least number of insects in winter can be explained on account of insufficient food supply that may lead to decrease in pollinator diversity and abundance[35]. In summer apple flowers are the main foraging resources and the abundance of flowers is more important in determining insect species numbers than the diversity of forage[24,36]. The season has also been reported to have significant effect on density of butterflies[37].

Greater density of insects in yellow colour traps compared to white and blue traps reflects the flower colour preference of the visiting insects. As such, preference of bees for yellow colour compared to white is known[38]. Butterflies[14] and dipterans, including hoverflies also favour to yellow colour pans[39]. Laubertie *et al.*[40] attributed higher hoverflies catches in yellow traps to their ability to detect this colour at a great distance. Colour preference of insect visitors varies with seasons. Preference of bowl colour seems to be influenced by availability of flora having the particular flower colour in the corresponding season. For example, in summer, flowers of forage plants are mostly white and yellow coloured.

The higher density of insect visitors, including the efficient pollinators during summer, despite less diversity of forage explains how resource availability and dense forage patches (e.g. apple bloom) influence spatial and temporal variations of pollinators, and contribute to their abundance (diversity and density) in apple-dominated landscape. It further provide evidence that relatively less simplified systems (i.e. apple orchards) actually facilitate pollinator abundance and forage diversity in the surroundings during a specified period. Thereafter, this system with availability of wild forage diversity continues to provide a buffer when resources start shrinking following crop senescence. The case study suggests mass flowering crop, like apple along with the habitat matrix help ensure pollination service with improved pollinator abundance. Following the outcomes of this study, it is recommended that: (i) margins along apple orchards should be managed and enriched for promotion of diverse seasonal species that are preferred by visitors/pollinators for provisions of nectar, pollen and larval development to create a buffer against resource scarcity and avoid their switching to other distantly located resources; (ii) yellow colour flowering species may be given priority while restoring and maintaining field margins to attract viable pollinator populations within the orchard limits, and (iii) possible overlap in timing of flowering between target crop and surrounding flora needs to be considered to ensure optimized pollination of the target crop.

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