Exploratory studies on diversity of bees with special emphasis on non-*Apis* pollinators in some natural and agricultural plants of Jammu division, India

Pollination refers to the actual mechanism of transferring pollen from one flower to another[1]. It is a basic force for gene recombination in flowering plants and plays a key role in plant breeding programmes[2]. Among various pollinating agents, insects occupy the most important place (entomophily) when compared to other invertebrates and vertebrates[3]. No other group of insects is of more benefit to humans than bees. More than one-third of the world's crops requires pollination to set seeds and fruits, and most meat and dairy industries rely on bees for pollination of clover and lucerne[4]. In the changing world with climate change and other significant pollination stresses like drought, fire, habitat fragmentation, etc. there is a decline in the pollinator population in the past few decades generating great threats to the production of crops, thus leading to a food crisis. In this context, conservation of pollinators has emerged as a major issue. In order to formulate effective conservation strategies there is an urgent need to generate information regarding the particular species concerned, including all its aspects. Biosystematics holds great importance in this context supplying all such necessary data regarding a particular species to fulfil the need of conservation planning. In India, the northernmost state of Jammu and Kashmir is bestowed with magnificent diversity of flora and fauna, especially insects in which non-*Apis* bees are of importance in the aspect of pollination service of crops. Landscape diversity of the state is also a point of scientific interest which includes plains, foothills and high-altitude mountains. Insect–plant relationship, especially pollination which is directly related to crop production and economy of the state, attains utmost significance in view of the diversity of habitats, climate and expected diversity of pollinators. Keeping this fact in mind, the present study was initiated with two broad objectives: (i) documentation of non-*Apis* bee diversity across the altitudinal gradients in the plains and hilly regions of Jammu and (ii) association of non-*Apis* bees with various seasonal crops grown there.

Jammu and Kashmir is geographically divided into three divisions, viz. Jammu, Kashmir and Ladakh. The present study was undertaken in the Jammu division covering the districts of Kathua, Samba, Jammu, Udhampur, Ramban and Doda. Based on landscape elevation, the districts were classified into two groups – plains including Kathua, Samba and Jammu, and the hilly region covering Udhampur,

Table 1. Non-*Apis* bees documented from the study sites along with landscape of occurrence

Insect morpho species	Family	Area of occurrence	
		Plains	Hilly area
Andrena sp.	Andrenidae	+	+
Amegilla sp1.	Apidae	+	+
Amegilla sp2.	Apidae	+	–
Amegilla sp3.	Apidae	+	–
Amegilla sp4.	Apidae	–	+
Bombus sp1.	Apidae	–	+
Bombus sp2.	Apidae	–	+
Bombus sp3.	Apidae	–	+
Ceratina (*Pithitis*) sp1.	Apidae	+	+
Ceratina (*Pithitis*) sp2.	Apidae	+	–
Ceratina (*Pithitis*) sp3.	Apidae	+	–
Ceratina (*Pithitis*) *heiroglyphica* Smith	Apidae	+	+
Xylocopa latipes Drury	Apidae	+	–
Xylocopa pubescence	Apidae	+	–
Xylocopa sp.	Apidae	+	–
Gen1. sp1.	Apidae	–	+
Gen2. sp2.	Apidae	+	–
Gen3. sp3.	Apidae	+	–
Hylaeus sp.	Colletidae	–	+
Halictus sp1.	Halictidae	+	+
Halictus sp2.	Halictidae	+	–
Megachile bicolor (Fabricius)	Megachilidae	+	–
Megachile hera Bingham	Megachilidae	+	–
Megachile lanata (Fabricius)	Megachilidae	+	–
Megachile sp1.	Megachilidae	+	–
Megachile sp2.	Megachilidae	+	–
Megachile sp3.	Megachilidae	+	–
Osmia sp1.	Megachilidae	+	–
Osmia sp2.	Megachilidae	+	–
Osmia sp3.	Megachilidae	+	–

+, indicates recording the presence of the species in the respective landscape. –, indicates recording the absence of the species in the respective landscape.

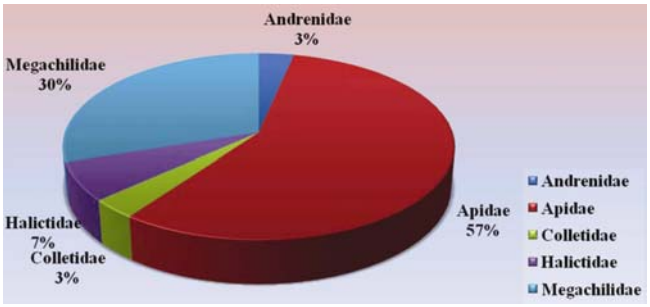

Figure 1. Composition of different families of various non-*Apis* bees based on the number of morpho species recorded.

Table 2. Host range of different non-*Apis* bees documented from different landscapes in Jammu

Non-*Apis* bees	Host range							
	Agricultural crops				Horticulture flowers/crops	Forest species		
	Cole crops	Oilseed crops	Leguminosae	Vegetables		Natural	Urban	Shrubs/ grassland
Andrena sp.	+	+	+	+	+	–	–	–
Amegilla sp1.	–	–	–	–	+	–	–	–
Amegilla sp2.	–	–	–	+	+	–	–	–
Amegilla sp3.	–	–	–	+	–	–	–	–
Amegilla sp4.	–	–	–	–	+	–	–	–
Bombus sp1.	–	–	–	–	+	+	–	+
Bombus sp2.	–	–	–	–	+	+	–	–
Bombus sp3.	–	–	–	–	+	–	–	–
Ceratina (*Pithitis*) sp1.	+	+	+	+	+	+	+	–
Ceratina (*Pithitis*) sp2.	+	–	–	+	–	–	+	–
Ceratina (*Pithitis*) sp3.	+	+	+	–	–	–	–	+
Ceratina (*Pithitis*) *heiroglyphica* Smith	+	+	+	+	+	+	+	–
Xylocopa latipes Drury	–	–	+	+	–	+	+	–
Xylocopa pubescence (Fabricius)	–	+	+	+	+	+	+	–
Xylocopa sp.	–	–	–	+	+	–	–	–
Gen1. sp1.	–	–	–	+	–	–	–	+
Gen2. sp2.	–	–	–	+	–	–	–	–
Gen3. sp3.	–	–	–	+	–	–	–	–
Hylaeus sp.		+	–	–	–	–	–	–
Halictus sp1.	+	+	–	–	+	+	–	–
Halictus sp2.	–	+	–	–	+	–	–	+
Megachile bicolor (Fabricius)	–	–	+	–	–	–	–	+
Megachile hera Bingham	–	–	+	–	–	–	–	+
Megachile lanata (Fabricius)	–	–	+	–	–	–	–	+
Megachile sp1.	–	–	+	–	–	–	–	+
Megachile sp2.	–	–	+	–	–	–	–	+
Megachile sp3.	–	–	+	–	–	–	–	+
Osmia sp1.	–	–	+	–	–	–	–	–
Osmia sp2.	–	–	+	–	–	–	–	–
Osmia sp3.	–	–	+	–	–	–	–	–

+, indicates recording foraging of the bee species on the respective host; –, indicates recording the absence foraging of the bee species on the respective host.

Ramban and Doda. Agri-horticulture crop fields were visited at peak flowering time during the respective cropping seasons mostly in October–November 2010 and March–June 2011. Collection of bees was mainly based on 'direct search method' using a hand-picking and net-sweeping methods. Bees captured from flowers were killed using a killing bottle containing cotton soaked with 98% solution of ethyl acetate. All the bees were transferred to separate individual containers. Individual specimens were preserved in 70% ethyl alcohol and card-mounted (wherever necessary) assigning a unique code. Based on morphological differences, recognizable taxonomic units (RTUs) were separated[5]. Identification of bees up to genus/species (wherever possible) was done in the laboratory and the same was authenticated by various national institutions. Host range and other parameters like climatic condition were recorded in field at the time of collection of the specimens and the same was used to derive the host spectrum of individuals/group of bees.

The studies revealed a rich diversity of pollinating bees. A total of 30 morpho species belonging to five major families of order Hymenoptera, viz. Apidae, Megachilidae, Andrenidae, Colletidae and Halictidae were documented during the course of study from various agri-horticulture plants in the study sites. Table 1 shows the diversity of non-*Apis* bees recorded during the study period with their respective areas of occurrence.

Species composition amongst different families of non-*Apis* bees showed (Figure 1) that Apidae constitutes 17 different morpho species followed by Megachilidae (nine morpho species) and Halictidae (two morpho species). Other families of hymenopterans documented under the study, viz. Andrenidae and Colletidae were shown to be represented by one morpho species each.

While comparing the different families in terms of the number of species of bees between two landscapes of Jammu (Figure 2), a striking spatial distribution pattern was prominently observed. Out of 30 species documented, 6 were found to be exclusive to the hilly areas, whereas 19 species were documented only from the plains. Five species of bees were documented from both landscapes. In the plains, Megachilidae and Apidae were found to be distributed equally being represented by nine morpho species, which were found only in this type of landscape. In the elevated landscape the species spectrum was represented by a single species of the family Colletidae along with five morpho species of Apidae. *Bombus* spp. (bumble bees) were found dominant in this particular landscape. On the other hand, *Halictus* sp1.

(Halictidae); *Andrena* sp. (Andrenidae) and three morpho species of Apidae (*Amegilla* sp1., *Ceratina* sp. and *Ceratina* (*Pithitis*) *heiroglyphica* Smith) were recorded from both the landscapes, besides the exclusive species. This shows the complete array of spatial distribution of non-*Apis* bees in different landscapes of Jammu division.

Host-range documentation also supports the distribution pattern of bees according to the agricultural practice and crop specificity in two different landscapes. Table 2 provides a clear-cut host-range differentiation of the bees documented: Foraging pattern and reward preference for the non-*Apis* bees collected in this study showed a diverse array of host plants both in the hilly areas and the plains. The host range included flowers of various seasonal agricultural crops, viz. cole crops (cauliflower, broccoli), oilseeds (mustard, linseed), different types of leguminous crops and vegetables. They were found to forage on a broad spectrum of horticulture plants, including various ornamental flowers, gardening flowers and fruit ecosystems. Some of the bees were documented foraging on flowers of various natural forestry and urban forestry tree species and in the grasslands. Individual and group-specific foraging patterns, when observed keenly, revealed many striking features amongst the members of the same family in the context of host preference. In both landscape types, Apidae and Halictidae were found to visit the flowers from almost all types of foraging habitats, although some members showed habitat-specific foraging preference. On the other hand, Andrenidae and Colletidae were found to visit agri-horticulture crops in plain habitat only. Members of Megachilidae were found to be specific in foraging only on the flowers of Leguminosae crops, whereas a few species were recorded foraging on some natural forestry tree species too.

Bee fauna of Jammu and Kashmir has drawn the attention of the scientific community since long. With extreme diversity in landscape and habitats across different altitudinal gradients, the state harbours considerable amount of resources which in turn support a large number of entomofauna, especially bees. Pollination entomology of Jammu and Kashmir includes a large number of bees, among which non-*Apis* bees play a major role in

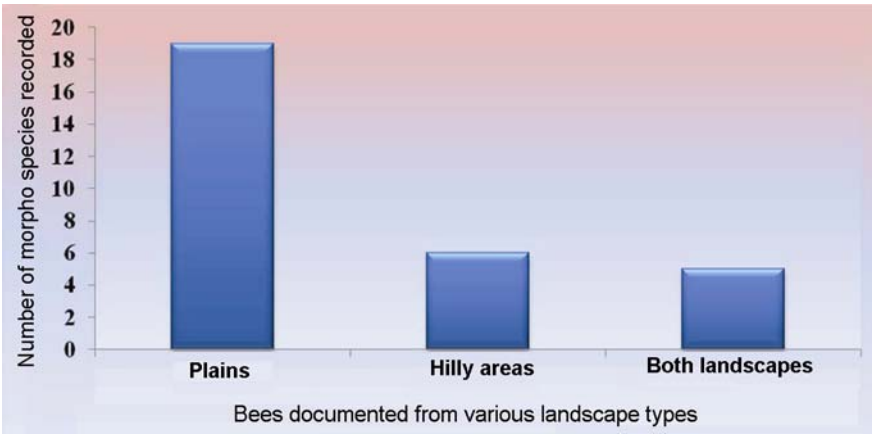

Figure 2. Distribution of various morpho species of bees in different landscape types in Jammu division.

fruit set in many plant species. Despite their immense importance, these bees have received little attention from the point of view of documenting them with taxonomic detail, including behavioural aspect (mainly foraging behaviour). In the present study, 16 species of non-*Apis* bees were documented from different districts falling broadly under two landscape categories, viz. hilly areas and the plains. In terms of the number of species, Apidae was found to be the dominant group followed by Megachilidae, Colletidae, Halictidae and Andrenidae. The information on bee fauna of Jammu and Kashmir is either poorly known, fragmentary or some aspects are even unknown. Earlier, Abrol[6] had documented some of the insect pollinators of crops recorded in the present study. The present study provides a holistic approach towards the information gathered on non-*Apis* pollinators of this unique ecosystem.

Other than documenting diversity of non-*Apis* bees, one major focus of this study was to elucidate the occurrence of bees across different landscapes. The survey area was classified under two broad landscape areas, viz. plains and hilly areas. It has been observed that the occurrence of insects differed according to the variation in the landscape. Amongst 16 species documented from Jammu region, *Andrena* sp., *Bombus* sp. and *Hylaeus* sp. were reported from the hilly regions only. Previous studies have also shown the efficiency of *Andrena* sp. in the pollination of many agri-horticulture crops[7–10]. Bumble bees (*Bombus* sp.) are already well established in the field of crop pollination in high-altitude areas as reported from various parts of the country. Wide ranges of hilly crops were reported to be successfully pollinated by bumble bees[8,9]. In the present study, bumble bees were documented while visiting various horticulture crops in the hilly tracks of Jammu region. *Hylaeus* sp. is also an efficient pollinator of many important crops. In the present study this species was documented from crops of the hilly areas. In the plains, six species of Megachilidae and three species of *Xylocopa* were found to be the chief pollinators of a diverse array of crops. Megachilids were found to successfully pollinate Leguminosae. Species of *Megachile* were found to visit flowers of some vegetables and a few forest plants too. But species of *Osmia* were found to visit the flowers of only leguminous plants. Megachilid bees are reported to be well-known pollinators of many important plants in different parts of the world, mostly under captive conditions[11–14]. In this study, their preference for Leguminosae crops was noteworthy. Efficiency of *Xylocopa* sp. as an effective pollinator is well proved in several crops from different parts of the world and India. In this study, the host spectrum of *Xylocopa* sp. was found to be strikingly diverse ranging from various agricultural crops especially fruit crops and vegetable[7–10,15–21] to forest plant species[3]. *Halyctus* sp., *Amegilla* sp. and *Ceratina* sp. were recorded from both landscapes. These three insect groups were recorded to visit the flowers of almost all types of crops and plants in the study sites. *Amegilla* sp. was reported as a chief pollinator in the greenhouse for tomatoes[22]. In open fields also, they have already been established as well-known pollinators of

a wide range of crops of different sizes. It was interesting to find that *Ceratina* sp. with small body size can visit the flowers of many plant species and collect pollen and/or nectar whilst rendering pollination service to those plants. Sandhu *et al.*[23] have also reported the successful pollen transfer in alfalfa by this insect. Halictidae are also well-established pollinators of many important agri-horticulture species[9,17,18,24–28]. With considerable abundance of individuals and active foraging nature, they were found to visit the flowers of various crops and trees in both the plains and hilly regions of Jammu division. A perusal of the literature shows that some of the species recorded in the present study have not been recorded earlier from this area.

Considering the increasing global need of insect pollination and decline in the pollinator community, non-*Apis* bees along with honey bees hold immense importance. In order to formulate the conservation policy of any species, one needs considerable amount of available information regarding its habit and habitat. This study helps generate a baseline source of overall information regarding non-*Apis* bees providing ecosystem services as effective pollinators of various plant species. Documentation of diversity and occurrence of non-*Apis* bees across different landscapes may help understand the insect pollinator services in various ecosystems across the area. The diversity recorded on the host preference of 16 species of non-*Apis* bees in this study reveals the complete spectrum of crops which can be benefited by the vital ecosystem services rendered by various bees. Overall, the current study may help focus on various broader aspects of pollination leading to exploration of some unknown species of bees with their unique flower relationship.

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