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Foraging pattern of *Lasioglossum* (Hymenoptera: Halictidae) species on Himalayan indigo (Fabaceae) in Kashmir

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Abstract
The present experiment on "Visitation pattern of *Lasioglossum* species on Indigofera species" was carried out in various transit areas of Kashmir valley during 2016. The totals of eleven species were recorded and were found differing in their visitation pattern; time of departure, time of arrival, total foraging times and the mean time spend outside the nesting site. Visitation rates were quantified by counting how many flowers/inflorescences were probed per unit time for 201 plants, in 32 sub-locations of 10 experimental transits, by following individual insects when foraging. The various species differed in their total time spend, total visits, visitation rates and per cent visits, with species *Lasioglossum marginatum* exhibiting efficient forging behaviour on Himalayan Indigo species. The reasons behind the difference in foraging behaviour were not known; however the species *L. marginatum* were efficient visitor in all areas and depart early from the nest and arrive late. The species L.marginatum spends comparatively more time in the field. Overall the family Halictidae were most dominant on Himalayan indigo in all patchy planting areas. Till now no data is available on foraging characteristics of any pollinator on Indigofera, therefore this article we highlights the primilarnary information on the foraging behaviour of halictid species in the hilly landscapes areas of the Kashmir region.

Keywords: Insect, ecology, landscape, foraging, *Prunus*

Introduction
Advertising through visual and/or olfactory cues is important to attract pollinators to the floral rewards of either sex. Pollination biology has always been studied from either a botanical or a zoological perspective where the ecology of plants and insect is intimately linked. Several factors can affect pollination. The various interactions benefit plant pollination through synergistic effects as well as complementary effects. Since, insect pollination is a generally indirect effect of foraging behaviour, and the plants have also evolved adaptations like providing rewards and developing nectar guilds which influence pollinating insects' movement and significantly affecting pollination. Specifically, the insect foraging behaviour is an area in which knowledge has advanced rapidly in recent years, and the majority of flowering plants rely upon insects to mediate pollen transfer. It is the behaviour of insects which determines which flowers will set seed and which will not, and which governs the pattern of transfer of gametes between plants. Insect pollination is one of the most important mechanisms and many ecosystems, including agro ecosystems, depend on pollinator diversity and the strong effect of insect pollinator diversity on the degree of pollination may be a result of their foraging behaviour of various functional groups (Gilbert, 1985) [4]. Further, the insects themselves also have various features which affect their efficacy as pollinators. The natural selection has favoured the flowering fruit plants that are most attractive to pollinators which are by their co-evolution of millions of years, resulted in overwhelming biodiversity of both insects and flowering shrubs.

Matrial and Methods
Indigofera species
It is a species of plant from the bean family and has been naturalized to tropical and temperate Asia (*I. himalyanses*), as well as parts of Africa, but its native habitat is unknown since it has been in cultivation worldwide for many centuries. Today most dye is synthetic, but natural dye from *I. tinctoria* is still available, marketed as natural coloring where it is

known as tarum in Indonesia and nila in Malaysia. In Iran and areas of the former Soviet Union it is known as basma. The plant is also widely grown as a soil-improving groundcover. True indigo is a shrub one to two meters high. It may be an annual, biennial, or perennial, depending on the climate in which it is grown. It has light green pinnate leaves and sheafs of pink or violet flowers. The plant is a legume, so it is rotated into fields to improve the soil in the same way that other legume crops such as alfalfa and beans are. Dye is obtained from the processing of the plant's leaves.

They are soaked in water and fermented in order to convert the glycoside indican to blue dye indigotin. The rotenoids deguelin, dehydrodeguelin, rotenol, rotenone, tephrosin and sumatrol can be found in *I. tinctoria*. Marco Polo (13th century) was the first to report on the preparation of indigo in India. Since, the plant has attractive flowers and is visited by many species of bees for the pollen and nectar.

Survey and sampling

All experimental sub-location were visited three times during the study period from May to October. Data were recorded between 900h to 1200h on each week by transect walk using plot samplings and the edge effect were removed by maintaining a fixed distance of 25m from forest edge. The three Indigofera plants/sub-plot were selected from a circular plot of 10m radius. The observations were made from onset of the blooming period with temperature ≥ 13-15 ºC, low rain, low wind and dry vegetation. The numbers of insects visiting the Indigofera species were reported. In 15 minute of the observation period in each plot, all flower-pollinator interactions were recorded. The open indigo flowers were monitored by moving slowly in the plot to avoid disturbance of pollinators visiting flowers, so as to determine the total number of observed individuals of pollinators interacting with the flowers. The indigo flowers are small and observations were taken very carefully when ≥ 50% of plants had started to bloom upto 99% of the anthesis. The rainy days with heavy winds were deliberately avoided. Prior to the data collection, the total flowers per meter square of the Indigofera plant were counted and the readinesses of flowers for insect visit were also confirmed. In each plot the mature flowers were sampled and observed to confirm that pollination has not been carried out. Observations in the national park were done with the assistance of the researcher Mr Gh. Mohammad and the observations were done for average of 27 days in flowering season.

Total visits =

Number of visits
Flower bout of one meter square length (m^2)

Visitation rate=

Total number of visits
Insects/m^2/10 minutes

Visitation per cent=

Total Number of visits	× 100
Bout of one meter square length (m^2)	

On each day we performed four observations, two in morning (9:30h-11:30h) and two in the afternoon (13:30:00-17:30h), and frequency of visitation of each insect were noted during 10 minutes period per hour. Insects were collected by telescopic net. For time calculation the stop watch was switched on when insect enters the plant and was kept off when it leaves the flower. The specimens collected were mounted and preserved. The samples were identified in the laboratory of RTCPPPM Srinagar, and then pinned, stretched and stored in the pollination laboratory of the SKUAST-K.

Results and Discussion

During the study period, a total of 213 individuals were recorded from the Himalayan Indigofera of the Dachigam area. Since the halictid species viz., *Sphecodes tentalus* and Sphecodes spp. were cleptoparasitic in nature and were excluded from the study. During the present study period, a total of 4 and 3 specimens of these two parasitic species (*Sphecodes tentalus* and Sphecodes spp.) were collected but excluded from analysis. A considerable variation existed in the foraging activity of 11 taxonomic categories that visited the plant. The most dominant and abundant species were L. marginatum (N=98) in all the study areas (Table 1), and exhibited maximum visits (2.14 No. of visits/ Flower m^2) and visitation rate [0.721 (Tot. no. visits/abundance (insects/m^2/10min)].

Table 1: Average time period spend (seconds), total visitation, visitation rate and per cent visitation rate by Halictid complex on *Himalayan Indigofera* flowers

S. No	Halictid species	Foraging characteristics					
		No. branches visited/plant ≥ 2m long	Time spent (in seconds)	Total Visits (No. of visits/ Flower m^2)	Visitation rate (Total No. visits/abundance (insects/m^2/10min)	% visitation (Total visits/(m^2)×100)	Abundance (No/m^2/10minuts)
1	*Lasioglossum sublaterale*	0.21	25±0.32	1.12	0.203	2.03	0.547
2	*L leucozonium*	0.54	30±0.16	1.00	0.427	4.27	0.339
3	*L. regolatum*	1.33	23±0.09	1.70	0.505	5.05	2.136
4	*L Himalayans*	1.04	17±0.82	2.10	0.312	3.12	2.014
5	*L.marginatum*	3.42	11±0.54	2.14	0.721	7.20	4.321
6	*L. polyctor*	0.33	24±0.65	0.21	0.119	1.19	0.090
7	*L nursei*	0.32	21±0.41	2.10	0.321	3.21	0.141
8	*Halictus constructus*	0.78	26±0.21	0.34	0.193	1.93	0.021
9	*Halictus ligatus*	0.91	19±0.62	0.26	0.051	0.51	0.035
10	*Sphecodes tantalus*	0.00	18±0.60	0.03	0.005	0.50	0.061
11	Sphecodes spp.	0.00	14±0.91	0.01	0.001	0.10	0.090
	N=11;Tot.specemens=213	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$

Overall, the species *L. marginatum* spend statistically less time period on the flowers compared to other species. Generally, the species *L. marginatum* showed preference towards longer branches and visited nearly 3.42 branches which were more than 2 meter in length (Table 1). The species *Sphecodes tantalus* and Sphecodes spp. generally move all along the ground surface and therefore don't visit the longer branches. We found a strong variation in the activity pattern of flower visitors on the Indigofera, with maximum of the activity recorded at the noon time and minimum in the morning. Generally the visitation activity diminished in afternoon. The pollinator abundance of the halictid species exhibited a clear proportionality with the visitation rates, time spend, per cent visits and the total number of visits. The variation in the abundance is a common trend in natural insect communities. The behavioural patterns of the species were compared between the morning and afternoon hours, and the significance was estimated by Tukeys Kremer Multiple comparison test. The family Halictidae constituted of 213 individuals, which showed a uni-modal activity. The Multiple Regression Analysis with intercept halictid population vs the foraging characteristics was performed and the results were found statistically significant. The maximum of the time period on the flowers were spend by *L. leucozonium*, partially supported by Oronje *et al*. (2012) [3] that *Lasioglossum* spp. spent 80s spend on single pistillate flowers. Since, the *Lasioglossum* spp. has a short tongue, therefore spends more time and showed two types of foraging behaviours (pollen and nectar). The minimum time period spend by *L. marginatum* were supported by Sung *et al.* (2006) [1] who observed that time spend by *Lasioglossum* species is 7.9 seconds only.

The visitation rate and total visits are inversely correlated with time spend on flower and therefore the species *L. marginatum* showed higher efficiency in their foraging behaviour during the study period, this was in accordance with Meerabai (2015) [2]. Further, in present study the number of visits and visitation rate by pollinator were in correspondence with number of open flowers and inversely related with time spend per flower. Since the Dachigam area is located at higher elevation and the various abiotic factors have their significant effect on foraging behaviour of the flower visitors.

Table 2: Mean times consumed for foraging by various species in the field

S. No	Halictid species	Foraging characteristics					
		Nest departure time (mint.)	Nest arrival time (mint.)	Time consumed (mint.)	Start foraging (mint.)	End time for foraging (mint.)	Average time spend on foraging (mint.)
1	*Lasioglossum sublaterale*	12:20	3:45	3:05 (±4.15)	12:30	3:42	3:12 (±5.33)
2	*L leucozonium*	11:10	3:50	4:40 (±5.55)	11:15	3:48	4:33 (±3.42)
3	*L. regolatum*	12:00	3:55	3:55 (±7.25)	12:10	3:52	3:42 (±4.05)
4	*L Himalayans*	10:20	3:45	5:25 (±2.41)	10:30	3:42	5:12 (±6.95)
5	*L.marginatum*	10:15	4:05	5:50 (±6.40)	10.25	4:01	5:36 (±15.95)
6	*L. polyctor*	12:00	3:05	3:05 (±5.03)	12:05	3:02	2:57 (±10.05)
7	*L nursei*	11:10	3:35	4:25 (±4.41)	11:25	3:30	3:55 (±9.65)
8	*Halictus constructus*	12:45	2:45	2:00 (±5.12)	12:55	2:56	1:59 (±7.85)
9	*Halictus ligatus*	12:35	2:45	2:10 (±3.49)	12:45	2:39	1:54 (±8.45)
10	*Sphecodes tantalus*	-	-	-	-	-	-
11	Sphecodes spp.	-	-	-	-	-	-
	N=11;Tot.specemens=213	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$	$p \leq 0.05$

The mean temperature during the study period ranged from 8.25 to 19 °C. And at this temperature range, the abundance of *L.marginatum* flower visitors were found positively correlated. However, the relative humidity recorded ranged from 39.7% to 65.8%. The abundance of the all the species showed decrease in foraging activity with the increased humidity. The halictid species showed a little stability with respect to environmental changes, since the population showed a decreasing trend, which is in contradiction with the results of previous findings that pollinators exhibit a constant stability with respect to environmental changes. Since, the pollinator species have wide thermal niches and are also more complementary in their thermal optima.

Fig 1: *Himalayan Indigofera* at flowering stage (July-September) in higher altitudes of district Budgam Jawalla pora Jammu and Kashmir, 2016.

The current study showed a certain level of "response diversity" between species and environmental conditions, and all species showed a relation with the ambient temperature (positive) and relative humidity (negative) so explained their cause of variation in abundance and foraging activity. The rough data were subjected to the predictive analysis and the high significance level were achieved for the time spend and the visitation rate.

Study showed that there is a clear relationship between annual halictid population abundance, flower visiting and environmental factors. Thus, we should expect a higher abundance and activity of Halictidae with higher heat accumulation. The pollinator community composition of *H. Indigofera* depends positively on the floral abundance and the average temperature during the blooming period. The maximum of the species showed a positive correlation with the open flowers in the experimental location, therefore higher flower density is important for the pollinator abundance. The studies also suggest a competition among the species for flower availability and that honey bees when present, did negatively affect the presence of other foraging insects for diet breadth, and hence are detrimental to their foraging activities on indigo flowers.

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