 DOI: 10.11598/btb.2017.24.1.480

POLLINATOR DIVERSITY AND FORAGING DYNAMICS ON MONSOON CROP OF CUCURBITS IN A TRADITIONAL LANDSCAPE OF SOUTH INDIAN WEST COAST

C. BALACHANDRAN, M.D. SUBASH CHANDRAN, S. VINAY, NAIK SHRIKANT and T.V. RAMACHANDRA*

Energy and Wetlands Research Group, Centre for Ecological Science, Indian Institute of Science, Bangalore, Karnataka 560012, India

Received 13 April 2015/Accepted 11 October 2016

ABSTRACT

Studies on insect pollinator ecology and dynamics are very rarely carried out in traditional Indian agriculture landscapes. Indiscriminate landscape changes in the rural areas and tendencies towards crop monocultures can have significant effects on pollinator habitats and effectiveness. This study was aimed at observing insect pollinators, their visitation frequencies and timings on monsoon cucurbit crops such as *Cucumis sativus* L., *C. pubescens* Willd., *Momordica charantia* L., *Trichonsanthes anguina* L. and *Luffa acutangula* L. (Roxb.), in a coastal Karnataka Village. This study was also aimed at covering the significance of the surrounding landscape elements in sustaining pollinator elements. Bees, such as *Apis dorsata*, *A. cerana* and *Trigona* sp., were major visitors on all cucurbits, except snake gourd which was pollinated mainly by lepidopterans. Insect species were found to partition floral resources of any given crops between them by minimal overlapping in their visitation timings. Natural elements of the landscape around, mainly a village forest and rocky savanna furnished habitats for bees and lepidopterans. Prolifically blooming monsoon herbs on lateritic plateaus, by providing nectar resources for pollinators, presumably play key role in making the case study village well known for monsoon vegetables.

Keywords: Agroecosystem, crop pollination, cucurbits, foraging behavior, landscape, laterite

INTRODUCTION

Zoophilous pollination by diverse animal pollinators is very important in flowering plants. About 87 of 115 important food crops of the world depend on animal pollination (Kevan 1999; Steffan-Dewenter & Westphal 2008). Insects pollinate an estimated 70% of flowering plants (Schoonhoven *et al.* 1998), of which the bee community (family Apidae) is the most important and efficient pollinators (Danforth *et al.* 2006). Increased flower visitation rate by insects causes more pollen deposits on the stigma, benefitting higher seed setting and better seed quality (Engel & Irwin 2003). Naturally, peak flowering seasons correspond with the highest densities of pollinator taxa (Wolfe & Barrett 1988).

Studies from an ecological perspective reveal landscape level habitat heterogeneity as having strong bearings on sustaining insect pollinators (Verhulst *et al.* 2004; Roschewitz *et al.* 2005; Fahrig *et al.* 2011). Linkages within pollination guilds can be disrupted in crop areas if habitat patches reduction causing increasing distances between nesting and foraging areas (Steffan-Dewenter *et al.* 2006; Pauw 2007). Most pollinators require a reliable supply of nectar within natural pollinator specific foraging distances to provide sufficient pollinator services including gene flow. Honeybees are known to forage in 1 - 3 km radius from the colony (within 1 km for *Apis florea* Fabricius, 1.5 km for *A. cerana* Fabricius and 3 km for *A. dorsata* Fabricius), although pollination efficiency is at the best between 183 – 275 m (Free 1993; Abrol 2012). Landscape maintenance focusing on better plant-pollinator interactions and on pesticide-free farming will have much significance in ensuring adequate food supplies for the world (Palma *et al.* 2015). The more we know about pollinators, plant pollination services

* Corresponding author: cestvr@ces.iisc.ernet.in

and the interactions between agro-ecosystems and pollination management, the more we can understand how to conserve them and manage them to maintain biodiversity, ensure ecosystem health and improve human livelihoods (FAO 2016).

Cucurbitaceae (118 genera, 825 species), members known as cucurbits, is an important family of food crops used as fruits (melons), salads (cucumber, gherkins, long melon), sweets (ash gourd, pointed gourd), pickles (gherkins), desserts (melons). Although widely distributed, cucurbit diversity is more concentrated in tropics and subtropics with hotspots in Southeast Asia, West Africa, Madagascar and Mexico (Schaefer & Renner 2011). India is rich in cucurbits and their wild relatives (31 genera, 94 species including 10 endemics). Cucurbits genus with the highest numbers of species are *Trichosanthes* (22 species), *Cucumis* (11 species), *Momordica* (8 species) and *Zehneria* (5 species) (Renner & Pandey 2013). Honeybees are considered the most efficient pollinator for cucurbit (Grewal & Sidhu 1979).

This study on cultivation of mixed crop of cucurbits in the monsoon period conducted in Utttara Kannada, district of South Indian west coast, is important because it relates to high production of pesticide free, good quality and wholesome gourds from a relatively small area by indigenous farmers. The undulating terrain borders the foothills of the Western Ghat mountain ranges. The cultivators are indigenous subsistence farmers of Halakkivokkal community who depends on traditional farming techniques, cattle manure and leaf manure. The rural landscape has rich biodiversity despite being in the vicinity of the densely populated municipal town and villages. Although cucurbits are grown year-round in India, studies on pollination during monsoon are needed in Southwest India when cucurbit cultivation is at the peak.

The study was aimed at documenting diversities of pollinator insects, their visitation timings and frequencies on cucurbits i.e. *Cucumis sativus* L. (cucumber), *Cucumis pubescens* Willd. (Mangalore gourd), *Momordica charantia* L. (bitter gourd), *Trichonsanthes anguina* L. (snake gourd) and *Luffa acutangula* L. (Roxb.) (ridge gourd). This study also presented the role of diverse elements of a traditional landscape in sustaining cucurbit pollinators and the synchronism of the pollinators with the varying flowering schedules of respective crops.

MATERIALS AND METHODS

Study Area

Tannirkuli Village (14.45876 ºN and 74.42694 ºE), in the Hegde Panchayat of Kumta Taluk of Uttara Kannada in the South Indian west coast was chosen for the study. Tannirkuli is dominated by Halakkivokkal community farmers who are skilled growers of vegetables using traditional agricultural techniques. During the intense coastal monsoon, the farmers mainly grow cucurbits in a 10 ha well-drained ground, while rice is cultivated in the flooded fields. Groundnut, vegetables and cucurbits constitute the second crop in the post-monsoon fields when the hill slopes are too dry for cultivation (Fig. 1).

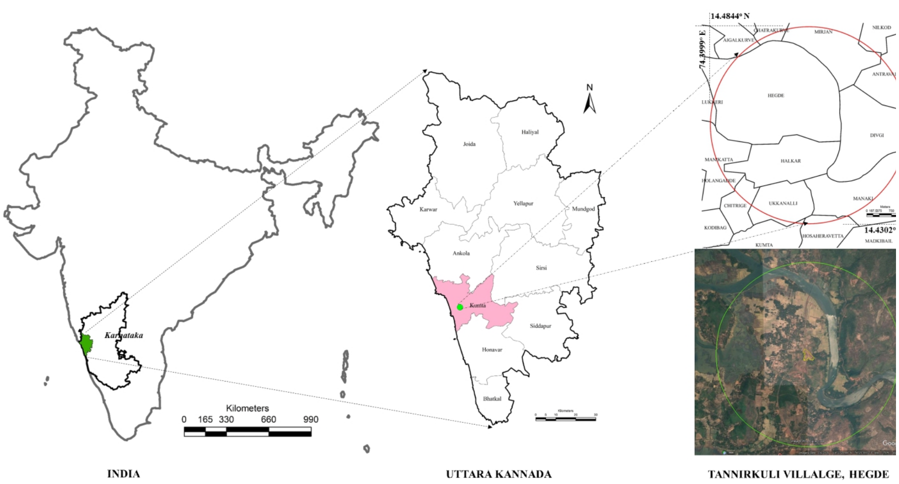

Figure 1 Map of study area: Tannirkuli Village, Uttara Kannada District, Karnataka State, India

Sampling Design

The preliminary studies were carried out from July to early August 2013. Observations on insect visitations on flowers were conducted from mid-August to the end of September. The crops studied were cucumber, bitter gourd, snake gourd, ridge gourd and Mangalore gourd (Fig. 2). The observations on pollination were started at 10% flowering and continued at weekly intervals until flowering nearly stopped (Belavadi & Ganeshaiah 2013). Numbers of visitor insects were counted species-wise. The frequency of visitation by a species was categorized as **very frequent** (>50% of the floral visits); **frequent** (>20% and <50%); and **rare** (<20%). Insect specimens were collected using a sweep-net and identified using

Figure 2 Flower and fruit of cucurbits plants

taxonomic keys (Michener 2007; Belavadi & Ganeshaiah 2013). The specimens were examined using stereo microscope for the presence of pollen and segregated as pollinators and non-pollinators. The pollen grains were matched with the host pollen separately collected before ascertaining the visitor insect as a pollinator of a specified crop, in accordance with Belavadi and Ganeshaiah (2013). The insect specimens were maintained in the Kumta field station of Centre for Ecological Sciences, Indian Institute of Science.

Foraging Dynamics

Insect foraging behavior was studied between 06:00 and 22:30 hours, at hourly intervals during species-specific blooming times. The observation protocols and frequency of visitors were measured using a hand tally counter and stopwatch following Free (1993). Sampling units of 1 m^2 (approximately covering 20 - 30 flowers) were selected and the visitor insects were documented. Each observation period for any crop selected was for 5 minutes, at 3 replications per hour. The foraging patterns were assessed based on the dominant groups of visitor insects and peak foraging times.

Landscape Analysis

Landscape elements of 3 km radius around the study area were deciphered using remote sensing data from Google Earth and Landsat-8 imageries of 2014. The time series spatial data acquired from Landsat Series Multispectral sensor and thematic mapper sensors were downloaded from http://glcf.umiacs.umd.edu/data. Land Use (LU) analysis involved Preprocessing, Classification and Accuracy Assessment. Land use classification was done using supervised pattern classifier-Gaussian maximum likelihood algorithm through open source GIS i.e. GRASS-Geographic Resource Analysis Support System downloaded from http://ces.iisc.ernet.in/grass (Fig. 3). The classifications were based on derived signatures (training polygons). Classifier performance was assessed considering reference pixels using kappa (ϰ) statistics (Ramachandra *et al.* 2013).

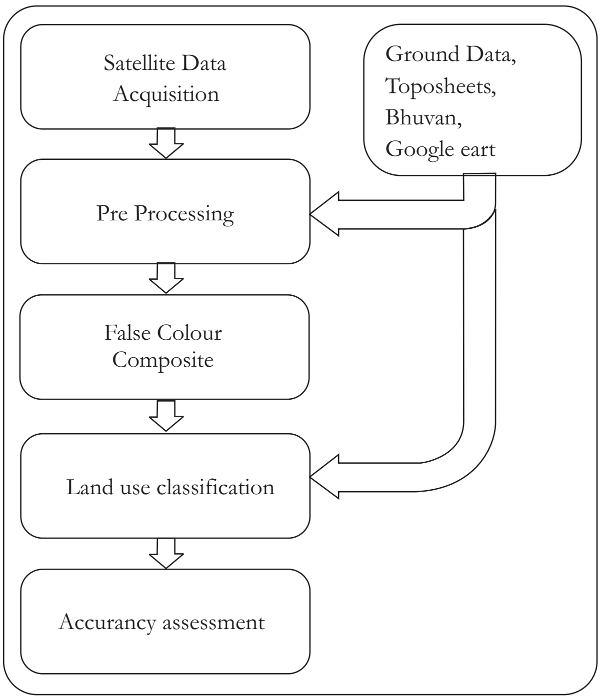

Figure 3 Method followed for land use assessment

RESULTS AND DISCUSSION

Diversity of Insect Visitors and Abundance on Cucurbits

Table 1 lists the spatial extent of landscape elements in the study area. About 25.1% of the area was used for agricultural fields (mainly paddy cultivation), 12.3% was used for horticulture (coconut, areca), 4.4% was used for forest area, 0.8% was used for built-up area and 0.5% was used for vegetable gardens. The overall accuracy of the classified data was 85.32% with kappa of 0.813 (Table 1).

Male flowers opened earlier than the female ones in all species. In bitter gourd, cucumber and Mangalore gourd anthesis commenced before sunrise, in ridge gourd towards sunset and in snake gourd after sunset (Table 2).

A total of 24 insect species (22 genera, 14 families, 4 orders), visited cucurbit flowers (Table 3).

Table 1 Elements of agricultural landscapes with beneficiary resource for pollinators

Land Use	Classification	Area (0-3 km radius) ha	%	F	N
Built-up	Residential Area, Industrial Area, mixed pixels with built-up area	23.7	0.8		
Open Area	Open lands, Quarries	212.1	7.5		
Open Wetland	Aquaculture and wetlands	96.4	3.4		
Water	River, Drainages	308.8	10.9		
Agriculture	Agriculture Fields Current Fallow and Sown (Paddy)	709.3	25.1		
Cashew	Cashew Plantations in scrub jungle	269.6	9.5	+	+
Forest	Evergreen forests, Deciduous and mixed Forests	123.7	4.4	+	+
Horticulture	Areca Gardens, Coconut plantations	349.2	12.3	+	
Laterite	Laterite Quarry, Laterite Open lands	318.5	11.3	+	
Laterite *Acacia*	*Acacia auriculiformis* plantation in laterite plateaus	193.8	6.9		
Acacia	*Acacia auriculiformis* plantation	210.8	7.5		
Vegetable Farm	Cucurbit varieties with inter crops like ladies finger	12.8	0.5	+	
Total area (ha)		2,828.7	100		
Overall accuracy of classification: **85.32%**; Kappa Statistics: **0.813**					

Notes: N = Nesting habitats; F = Foraging habitats; + = present

Table 2 Anthesis time observed in cucurbits studied (in the monsoon months)

Species	Common name	Male flower		Female flower	
		Starting time	Full bloom	Starting time	Full bloom
Momordica charantia	Bitter gourd	5:20 A.M	5:40 A.M	5:40 A.M	6:30 A.M
Cucumis sativus	Cucumber	6:10 A.M	6:40 A.M	6:10 A.M	7:10 A.M
Cucumis pubescens	Mangalore gourd	6:30 A.M	6:55 A.M	7:00 A.M	8:20 A.M
Luffa acutangula	Ridge gourd	5:20 P.M	6:10 P.M	5:25 P.M	6:30 P.M
Trichosanthes anguina	Snake gourd	8:20 P.M	8:50 P.M	8:30 P.M	9:25 P.M

Table 3 Insect species found on cucurbit flowers during the monsoon period

Family	Species	Common Name	*C. sativus* (cucumber)	*C. pubescens* (Mangalore gourd)	*M. charantia* (Bitter gourd)	*L. acutangula* (Ridge gourd)	*T. anguina* (Snake gourd)
Hymenoptera							
Apidae	*Apis dorsata* Fabricius	Giant honeybee	+	+	+	+	
	Apis cerana indica Fabricius	Indian honeybee	+	+	+	+	
	Trigona Jurine	Stingless bee	+	+	+	+	
	Ceratina Latreille	Small carpenter bee	+	+	+	+	
	Xylocopa Latreille	Carpenter bee				+	
Halictidae	*Halictus* Latreille	Sweat bee		+		+	
Vespidae	*Vespa cincta* DeGeer	Yellow banded wasp	+			+	
	Vespa L.	Common wasp				+	
	Polistes Latreille	Paper wasp		+			
Lepidoptera							
Nymphalidae	*Hypolimnas bolina* L.	Great eggfly					+
Papilionidae	*Papilio polytes* L.	Common mormon			+		+
	Graphium agamemnon L.	Tailed jay			+		+
Pieridae	*Catopsilia pomona* Fabricius	Common emigrant				+	+
	Eurema hecabe L.	Common grass yellow			+		
	Delias eucharis Drury	Common jezebel			+		+
Papilionidae	*Pachliopta hector* L.	Crimson rose					+
Hesperidae	*Borbo cinnara* Wallace	Rice swift	+		+	+	+
Sphingidae	*Cephonodes hylas* L.	Bee-hawk moth	+	+	+		+
Arctiidae	*Amata bicincta* Kollar	Handmaiden moth	+	+		+	
Geometridae	*Dysphania percota* Swinhoe	Blue Tiger moth			+		+
Coleoptera							
Chrysomelidae	*Aulacophora* Dejean	Leaf beetle	+	+		+	
Coccinellidae	*Henosepilachna* Li & Cook	Ladybird beetle			+	+	
Diptera							
Tabanidae	*Tabanus* L.	Horsefly		+			
Muscidae	*Musca domestica* L.	Housefly	+	+	+		

Note: + = present

With 8 species of butterflies and 3 species of moths from 7 families, the Lepidopterans had the highest numbers of pollinators. Hymenopterans followed with 6 species of bees and 3 species of wasps. Bees were the most frequent flower visitors. The Dipterans (flies) and Coleopterans (beetles), with 2 species each, were infrequent visitors and had no notable role in pollination as specimen examination revealed general absence of pollen. Hymenopterans were observed as having the highest visitations on ridge gourd, followed by Mangalore gourd, cucumber and bitter gourd, respectively. Lepidopterans were dominant on snake gourd and frequent on bitter gourd. Bitter gourd was also visited by bees. Coleopterans and Dipterans were infrequent on all cucurbits, except snake gourd.

Crop-wise abundance of insect visitors is summarized in Figure 4. *A. dorsata* had the highest abundance of visits on ridge gourd (70.1%) followed by cucumber (66%), Mangalore gourd (56%) and bitter gourd (38%). *A. dorsata* was negligible on snake gourd. *A. cerana* was most abundant on Mangalore gourd (39.6%) and cucumber (31.6%). Ridge gourd and bitter gourd also had good dependence on *A. cerana*. *Trigona* sp. more frequently visited bitter gourd than others. Butterflies and moths were predominant

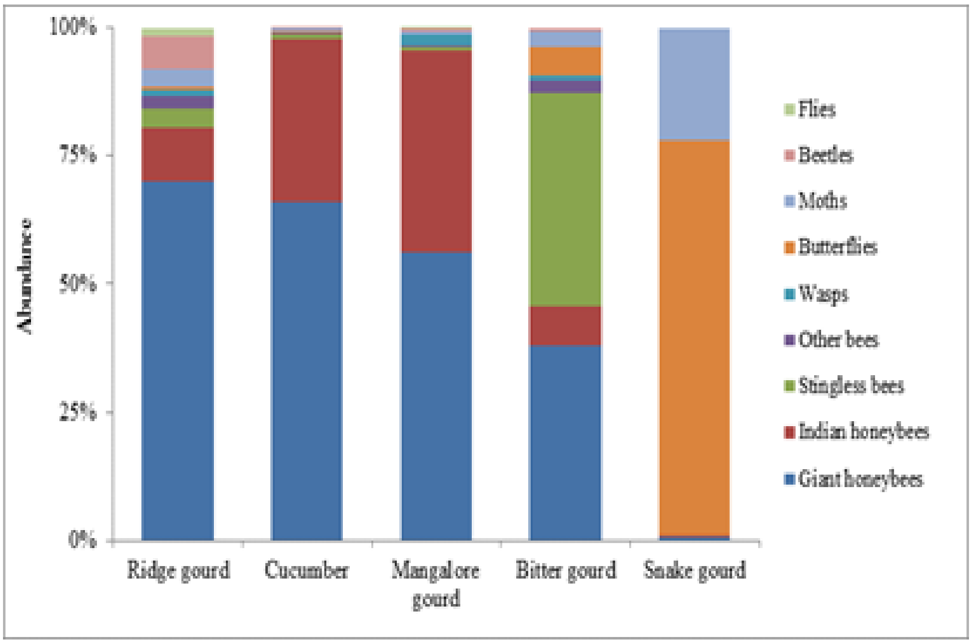

Figure 4 Bar diagram of insect abundance on different cucurbit plants

on snake gourd. Beetles and flies were the least important pollinators on all crops and did not visit snake gourd.

In regards of pollinators visitation on *Cucumis* spp., 11 insect species visited *C. pubescens* and 10 species visited *C. sativus* (Table 3). *A. dorsata* was observed dominant visitor on *Cucumis* spp., 66% on Mangalore gourd and 56% on cucumber. *A. cerana* had 39.6% visitation on Mangalore gourd and 31.6% on cucumber. In Dharwad, neighboring district of Uttara Kannada, Prakash (2002) recorded 27 species of insects pollinated cucumber during post-monsoon season, where honeybees (*A. dorsata, A. cerana* and *A. florea*) as well as *Trigona iridipennis* Smith were the dominating visitors, validating our findings on honeybees as prime pollinators of *Cucumis* spp.

Bitter gourd was visited by 13 species in which *A. dorsata* and *Trigona* sp. constituted 80.2%. Nidagundi and Sattagi (2005) recorded 10 insect visitors on bitter gourd in Dharwad i.e. 8 Hymenopterans and 2 Lepidopterans. Hymenopterans *T. iridipennis, Halictus gutturosus* Vachal and *A. florea* were important pollinators of bitter gourd (Subhakar *et al.* 2011). In Bangalore, 78.09% of pollinators on ridge gourd were bees, mainly *A. cerana, A. florea* and *Tetragonula iridipennis* (Kuberappa *et al.* 2008). In our study, the wild bee *A. dorsata* had the prime role as pollinator (70.1%). The rest of pollinators consisted of other bees, butterflies, flies, beetles and hawk moths.

Foraging Dynamics

Insect forage is a collective process of individuals, as well as of the group (Traniello 1989). Crop-wise foraging times in our study (*Trichosanthes* excluded) by different insects are presented in Figures 5 to 8. *A. dorsata* and *A. cerana,* visited cucumbers from 06:30 to 16:30 hours, until the flowers wilted (Fig. 5).

Peak visit of *A. dorsata* was during 10:30 hours (18.87 visits/m^2/5 minutes) and 11:30 hours (20 visits/m^2/5 minutes). The visits were lesser earlier and later (0.2, 0.4 and 1.2 visits/m^2/ 5 minutes at 07:30, 08:30 and 16:30 hours, respectively). Peak foraging by *A. dorsata* in a Dharwad study was between 11:00 to 12:00 hours (Pateel & Sattagi 2007). Conner-Michigan (1969) reported that 10:00 to 15:00 hours as the most effective time for cucumber pollination in Ohio, in which a flower required at least 8 to 10 visits by bees for satisfactory fruit set. The maximum foraging activity of *A. cerana* in our study nearly overlapped with that of *A. dorsata*. Although the flowers bloomed at sunrise, the highest visitation frequency of *A. cerana* was at 9:30 hours (8.8 visits/m^2/5 minuntes) and 10:30 hours (9.73 visits/m^2/5 minutes). Visitations declined from 11:30 hours (7.71 visits/m^2/5 minutes), reached minimum at 15:30 hours (0.13 visit/m^2/ 5 minutes). *Trigona* sp. was only a minor forager of cucumber. Other infrequent visitors like butterflies, moths and beetles foraged mainly

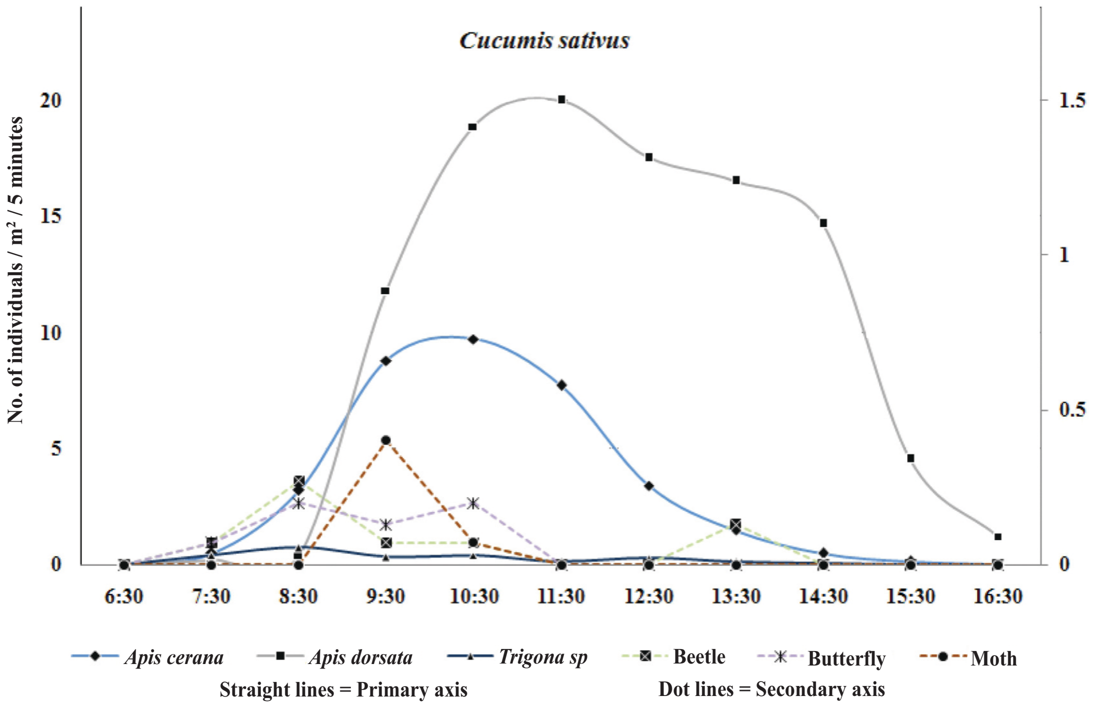

Figure 5 Foraging pattern of diverse insect visitors on *Cucumis sativus*

between 07:30 to 10:30 hours. Insect foragers on Mangalore gourd were observed from 06:30 to 17:30 hours (Fig. 6). The highest foraging frequency of 13.6 visits/m^2/5 minutes was observed at 12:30 hours by *Apis dorsata* and the least was observed at 07:30 hours. *Apis cerana* had peak visitations at 13:30 hours (11.2 visits/m^2/5 minutes), the lowest was at 08:30 and 17:30 hours (0.21visits/m^2/5 minutes). *Trigona* sp. foraged maximum at 11:30 hours with 2.1 visits/m^2/5 minutes and was not to be found from 15:30 hours.

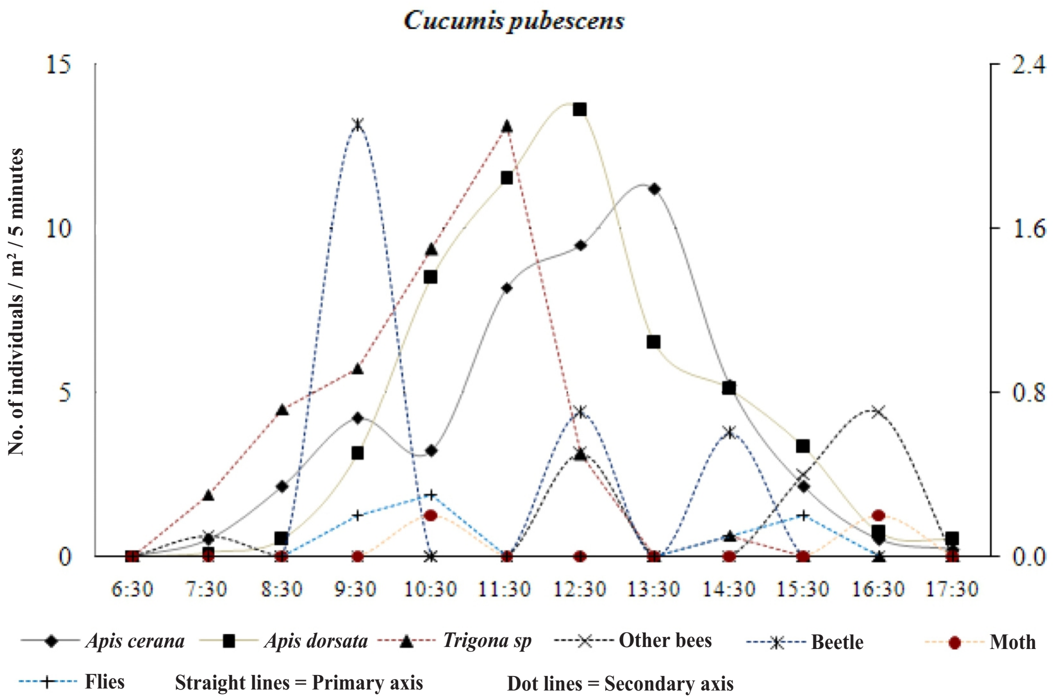

Figure 6 Foraging patterns of diverse insect visitors on *Cucumis pubescens*

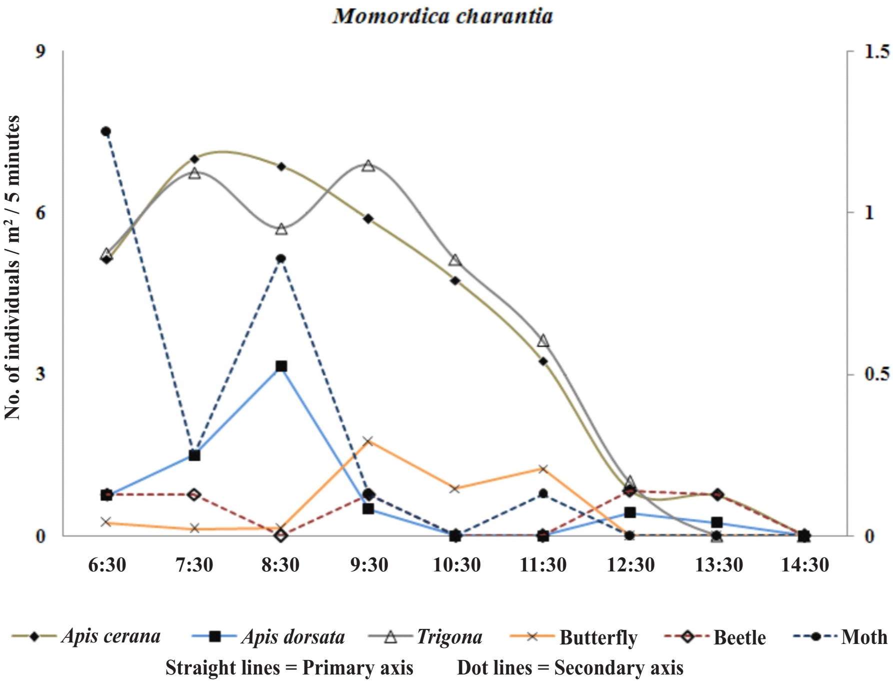

Figure 7 Foraging patterns of diverse insect visitors on *M. charantia*

Insects foraged on bitter gourd (*Momordica charantia*) from 06:30 to 14:30 hours (Fig. 7). The stingless bee *Trigona* sp. as the major pollinator had peak visitations at 09:30 hours (6.88 visits/m^2/5 minutes); lesser at 07:30 hours (6.75 visits/m^2/5 minutes). By midday, *Trigona* sp. shifted to other cucurbits, mainly to *Cucumis* spp. Visitations of *A. dorsata* nearly overlapped with that of *Trigona* sp. in the morning, peaking at 07:30 hours (7 visits/m^2/5 minutes) and 08:30 hours (6.88 visits/m^2/5 minutes). *A. cerana* succeeded reaching maximum at 08:30 hours (3.14 visits/m^2/5 minutes). The butterflies were infrequent on bitter gourd, the highest at 09:30 hours (1.75 visits/m^2/5 minutes). As bitter gourd flowers bloomed very early in the morning, few moths could be found at 07:30 hours. Study of Subhakar *et al.* (2011) in Tirupati also showed that *Trigona* (*iridipennis*) was the most abundant and frequent visitor on bitter gourd (10.83 visits/m^2/5 minutes).

Ridge gourd *Luffa acutangula* is an important vegetable in coastal Uttara Kannada. Foraging was observed from 17:30 to 22:30 hours (Fig. 8). Honeybees were major foragers. *A. dorsata* made 13.67 visits/m^2/5 minutes at 18:30 hours, while *A. cerana* had 4.67 visits/m^2/5 minutes at 17:30

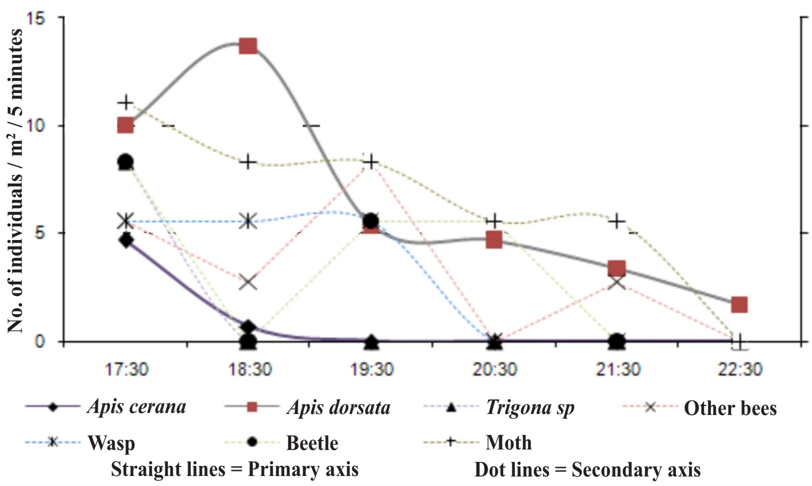

Figure 8 Foraging patterns of diverse insect visitors on *Luffa acutangula*

hours. Beetles, wasps and other bees were rare visitors. *A. cerana, A. florea* and *Tetragonula iridipennis* were reported as main pollinators of *Luffa* sp. in Bangalore (Kuberappa *et al.* 2008). Shrivastava (1991) reported sphingid moth as an important pollinator of *Luffa* sp., an evening bloomer. For snake gourd, a night bloomer with white flowers, moths were the main visitors during night, while butterflies frequented after daybreak. The bee-hawk moth had the highest visitations between 20:30 and 22:30 hours. The rainy nights of Southwest Monsoon hampered further observation in the midnight hours.

Elements of the Landscape

Insect pollinators are known to rely on diverse elements of landscapes (habitats) for resources like nectar, pollen, nesting materials and species-specific nesting sites. Landscape element analysis of the study area (with 3 km buffer) was done using remote-sensing data and field data (Fig. 9).

Forests provide nesting and foraging sites for insect pollinators, ensuring their permanence in the landscape. High proportions of natural or semi-natural habitats close to agricultural area are known to benefit bee diversity, mutualistic interactions and insect foraging movements (Hagen & Kraemer 2010). In the 3 km radius around the vegetable growing area, there were forest, cashew trees (in scrub jungle), horticulture, laterite plateaus and vegetable farm, which provided food for the insects. Only forest and cashew trees in scrub jungle were the main nesting areas for the insects. The presence of almost 100 ha forest patch, within the 3 km radius from the Halkar Village, was of high significance, especially in the vicinity of Kumta, a municipal town. The forest has been under careful protection by the village community for generations and is acclaimed as one of the best examples of community managed forests in India (Chandran 2001). The low laterite plateaus characteristic of Uttara Kannada is the key role in providing foraging resources for honeybees and lepidopterans (Balachandran *et al.* 2014). The forests and scrub on laterite hills provided habitats for *A. dorsata.* Changes in landscape structure are considered to be the primary cause of limitation in pollination services in agricultural systems (Viana *et al.* 2012).

In retrospect, plants can escape competition by utilizing different pollinator species or guilds, due to species-specific floral morphology and blooming times, favoring resource partitioning, conferring mutual benefits to both hosts and pollinators (Pleasants 1980; Schoonhoven *et al.* 2005). Bees are prominent among cucurbit pollinators. The foraging schedules on any given species showed minimal overlapping between different foragers. *A. dorsata,* took advantage of the early morning blooming of bitter gourd, congregated on it from 06:30 to 09:30 hours, and shifted to cucumber and Mangalore gourd as the day progresses, although it continued to forage in lesser frequencies until the flowers ceased by midday. After completing their visits on *Cucumis* spp. during the rest of the day, *A. dorsata* extended their foraging activity into the night on ridge gourd, although in lesser frequencies, up to 22:30 hours. The knowledge on foraging activity and local climate is important for carrying out multi-species cropping of gourds and cucumbers to obtain maximum crop production.

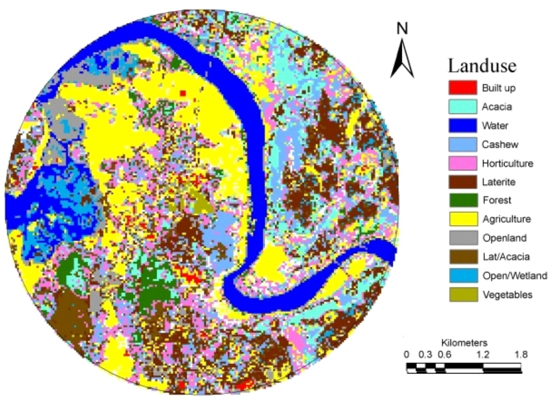

Figure 9 Land use elements in the landscape (with 3 km radius surrounding)

CONCLUSIONS

Insect pollinators can enhance production without additional inputs other than organic manure. Bees, mainly *A. dorsata, A. cerana* and *Trigona* sp. were the major pollinators on all cucurbits, except snake gourd. Traditional landscapes of coastal Uttara Kannada had all the necessary elements for sheltering and feeding of pollinator guilds which co-existed harmoniously with the cropping schedules of the local farmers. The rare survival of highly productive traditional farming system in the densely populated Indian west coast, the organic pesticides and the rich guilds of pollinators calls for also reexamining the suitability of traditional agricultural landscape management systems.

ACKNOWLEDGEMENTS

We are greatly indebted to the NRDMS Division, Ministry of Science and Technology, Government of India. We are grateful to the ENVIS Division, Ministry of Environment, Forests and Climate Change, Government of India as well as to Indian Institute of Science for the financial and infrastructure supports.

REFERENCES

Abrol DP. 2012. Pollination biology: biodiversity conservation and agricultural production. New York (US): Springer Dordrecht Heidelberg. 792 p.

Balachandran C, Chandran MDS, Ramachandra TV. 2014. Keystone food resources for honeybees in South India west coast during monsoon. Curr Sci 106(10):1379-86.

Belavadi VV, Ganeshaiah KN. 2013. Insect pollination manual. Bangalore (IN): University of Agriculture Sciences. 44 p.

Chandran MDS. 2001. Halkar Village, Uttara Kannada. In: Neema P, editor. Community conserved area in India-an overview. Pune (India): Kalpavriksh press. p. 316-21.

Conner-Michigan. 1969. Honeybee pollination requirements of hybrid cucumbers *Cucumis sativus*. M. Sc. Thesis. East Lansing (US): Michigan State University. 150 p.

Danforth BN, Sipes S, Fang J, Brady SG. 2006. The history of early bee diversification based on five genes plus morphology. Proc Natl Acad Sci 103:15118-23.

Engel CE, Irwin RE. 2003. Linking pollinator visitation rate and pollen receipt. Am J Bot 90:1612-8.

Fahrig L, Baudry J, Brotons L, Burel FG, Crist TO, Fuller RJ, Sirami C, Siriwardena GM, Martin J. 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. Ecol Lett 14:101-12.

Food and Agricultural Organization. 2016. FAO's global action on pollination services for sustainable agriculture. www.fao.org/pollination/en

Free JB. 1993. Insect pollination of crops. Second edition. London (UK): Academic Press. 684 p.

Grewal GS, Sidhu AS. 1979. Insect pollination of some cucurbits in Punjab. Ind J Agricul Sci 48:78-83.

Hagen M, Kraemer M. 2010. Agricultural surroundings support flower visitor networks in an Afrotropical rain forest. Biol Conserv 143(7):1654-63.

Kevan PG. 1999. Pollinators as bioindicators of the state of the environment: species, activity and diversity. Agric Ecosyst Environ 74:373-93.

Kuberappa GC, Ramesh RG, Vishwas AB. 2008. Pollinator's fauna with special reference to the role of honeybees in ridge gourd, *Luffa acutangula* L. In: Bioresources conservation and management. New Delhi (IN): Today and Tomorrow Printers and Publishers. p. 163-74.

Michener CD. 2007. The bees of the world. Second edition. London (UK): Johns Hopkins University Press, 953 p.

Nidagundi BR, Sattagi HN. 2005. Pollinator fauna and foraging activity of bees in bitter gourd Karnataka. J Agric Sci 18(4):982-85.

Palma AD, Kuhlmann M, Roberts SPM, Potts SG. Borger L, Hudson LN, Lysenko I, Newbold T, Purvis A. 2015. Ecological traits affect the sensitivity of bees to landuse pressures in European agricultural landscapes. J Appl Ecol 52(6): 1567-77.

Pateel MC, Sattagi HN. 2007. Abundance of different insect pollinators visiting cucumber (*Cucumis sativus* L) in Rabi Season. Karnataka. J Agric Sci 20(4):853-54.

Pauw A. 2007. Collapse of a pollination web in small conservation areas. Ecology 88:1759-69.

Pleasants JM. 1980. Competition for bumble bee pollinators in Rocky Mountain plant communities. Ecology 61:1446–59.

Prakash KB. 2002. Pollination potentiality of Indian honeybee viz. *Apis cerana* on the production of cucumber (*Cucumis sativus*). M.Sc. Thesis. Bangalore (IN): University of Agricultural Sciences.

Ramachandra TV, Chandran MDS, Joshi NV, Setturu B. 2013. Land use land cover dynamics in Uttara Kannada District, Central Western Ghats. ENVIS Tech Report 56, CES, IISc, Bangalore.

Renner SS, Pandey AK. 2013. The Cucurbitaceae of India: accepted names, synonyms, geographic distribution, and information on images and DNA sequences. PhytoKeys 20:53-118.

Roschewitz I, Thies C, Tscharntke T. 2005. Are landscape complexity and farm specialisation related to land-use intensity of annual crop fields? Agr Ecosyst Environ 105:87-99.

Schaefer H, Renner SS. 2011. Phylogenetic relationships in the order Cucurbitales and a new classification of the gourd family (Cucurbitaceae). Taxon 60(1):122-38.

Schoonhoven LM, Jermy T, Van-Loon, JJA. 1998. Insect-plant biology: from physiology to evolution. London (UK): Chapman and Hall. 412 p.

Schoonhoven LM, Van-Loon JJA, Dicke M. 2005. Insect-plant biology. Second edition. New York (US): Oxford University Press. 421 p.

Shrivastava U. 1991. Insect pollination in some cucurbits In: proceedings of the 6th international symposium Palm. p. 445-51.

Steffan-Dewenter I, Klein AM, Alfert T, Gaebele V, Tscharntke, T. 2006. Bee diversity and plant–pollinator interactions in fragmented landscapes In: Waser NM, Ollerton J, editors. Specialization and generalization in plant–pollinator interactions. Chicago (US): Chicago Press. p. 387-408.

Steffan-Dewenter I, Westphal C. 2008. The interplay of pollinator diversity, pollination services and landscape change. J Appl Ecol 45:737-74.

Subhakar G, Sreedevi K, Manjula K, Reddy NPE. 2011. Pollinator diversity and abundance in bitter gourd, *Momordica charantia* Linn. Pest Manag Horticul Ecosyst 17(1):23-7.

Traniello J. 1989. Foraging strategies of ants. Ann Rev Entomol 34:191-210.

Verhulst J, Baldi A, Kleijn D. 2004. Relationship between land-use intensity and species richness and abundance of birds in Hungary. Agr Ecosyst Environ 104:465-73.

Viana BF, Boscolo D, Neto EM, Lopes LE, Lopes AV, Ferriera P, Pigozzo, CM, Primo LM. 2012. How well do we understand landscape effects on pollinators and pollination services? J Pollinat Ecol:31-41.

Wolfe LM, Barrett SCH. 1988. Temporal changes in the pollinator fauna of tristylous *Pontederia cordata*, an aquatic plant. Canadian J Zool 66(6):1421-24.