Keystone food resources for honey bees in South Indian west coast during monsoon

C. Balachandran, M. D. Subash Chandran and T. V. Ramachandra*

Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012, India

The low level, denuded, laterite landscape of coastal Uttara Kannada has a rich diversity of monsoon herbs, including threatened and newly discovered ones. Our study reveals that honey bees congregate on the ephemeral herb community of *Utricularias*, *Eriocaulons* and *Impatiens* during their gregarious monsoon flowering period. *Apis dorsata* had highest visitations on *Utricularias*, *Impatiens* and *Flacourtia indica*, whereas *Trigona* preferred *Eriocaulons*. Laterite herb flora merits conservation efforts as a keystone food resource for the insect community, especially for honey bees.

Keywords: Flower visitation, food resource, honey bee, keystone, laterite.

ROCKY terrain is generally considered as an inhospitable and impoverished habitat due to the insufficiency of soil and poor water-holding capacity, even in heavy rainfall zones throughout the world. High levels of solar insolation, to which such terrain often get subjected to, cause immoderate rise and fall in diurnal temperature. Large stretches of low-level laterite hills and plateaus abutting the Western Ghats are characteristic of the western coastal tract of India, especially in the district of Uttara Kannada. Such landscape was considered infertile and of poor productivity. However, a spurt of interest in recent years has brought out the presence of many rare herbs growing on laterites of southwest India. These include new species such as *Rotala malabarica*, *Nymphoides krishnakesara*, *Justicia ekakusuma*, *Lepidagathis keralensis*, *Eriocaulon sivarajanii*, *E. kannurense, E. madayiparnese*, *Lindernia madayiparense*, etc. discovered first from the Malabar coastal hills[1–8]. Such findings are despite heavy human impacts like biomass harvests, cattle grazing, extraction of building stones and overall neglect such coastal habitats have been facing. Find of new species like *Eriocaulon belgaumensis* and *Dipcadi goaense* from the laterite hills of Karnataka and Goa respectively indicates that these habitats could be veritable hotspots for rare herbs[9,10]. The laterite-capped high-altitude hills of Maharashtra Western Ghats are no exception in yielding a good number of new and rare species[11–15]. Rao *et al.*[16] have provided a comprehensive account of the richness of monsoon herb flora of the laterite wetlands and meadows of Uttara Kannada implicating also the support such flora might provide to insect community prompting the present study.

Animal pollination is stated to benefit 87 out of the 124 leading food crops which humans cultivate worldwide[17]. Insects are the most important pollinators of an estimated 70% of flowering plants, honey bees leading among them[18–20]. Engel and Irwin[21] reported a positive relationship between honeybee visitation rates and pollen deposits on the stigma. The frequencies of bee visitations on flowers are indeed related to the amount of seed setting and seed quality[22]. Hence, honey bees are considered keystone species for reproductive success of many plant species, implying that their decline could spell disruption of plant–pollinator networks leading to possible extinction cascades[23,24].

The threats that honey bees face worldwide due to excessive use of pesticides, habitat shrinkages and food scarcity are a matter of concern. Nourishment of honey bees is mainly dependent on nectar and pollen. Smith[25] reported that the bees with higher levels of body protein lived longer than those with lower levels, thereby indicating the importance of bee nutrition in apiary. Pokhrel *et al.*[26] had reported death of forager bees in Nepal caused by intermittent rain-related nectar scarcity during April–May and washing away of pollen by heavier rains in July. Decline in bee flowers during rainy season was stated to be the reason for adverse impact on *Apis cerana* population in Chitwan, Nepal. Strength of bee colony weakening during mid-November to February at Kabre in Dolakha district of Nepal has been attributed to the dearth of forage plants[27,28].

Much less is known in India, one of the major honey-producing countries of the world, on the off-season, specially the monsoon period, nectar/forage resources of honey bees, a big lacuna with wider implications not just on honey production, but also on crop production[29]. In the Uttara Kannada district, despite a forest cover of about 70% of its land area exceeding 10,000 sq. km, and other forms of greenery elsewhere, the paucity of flowering in forests from June to September, a period of high-intensity monsoon rainfall, is a critical time for honey bees. In the district, well known for its forest honey, beekeepers in the Western Ghats terrain feed the domesticated bees with jaggery solution or its mixture with gram flour[30].

*For correspondence (e-mail: cestvr@ces.iisc.ernet.in)

During the monsoon of 2012, while inventorying the forage resources for honey bees in the district, we noticed congregations of bees and butterflies, in the coastal laterite hills and plateaus, flush with tiny herbs in bloom. This observation prompted us to undertake the present study aimed at the honey bee community meeting its off-season forage needs from the characteristic laterite flora, with special focus on the visitation rates of bees on two of the most prolific monsoon herbs, namely *Utricularia* spp. and *Eriocaulon* spp. and two others, viz. herbaceous *Impatiens* spp. and a thorny shrub *Flacourtia indica.*

Materials and methods

Study area

Honey bee visitations on the plant species were studied in the low-altitude (<100 m) coastal lateritic terrain of Uttara Kannada district (74°9′–75°10′E long. and 13°55′–15°31′N lat.), Karnataka. The terrain studied is closer to the shores of the Arabian Sea, flanked towards its immediate east by the wooded hills and valleys of the Western Ghats. Most of the district, located towards the central Western Ghats-west coast region, is characterized by high-intensity seasonal rainfall (300–400 cm/year) from the southwest monsoon. Sizeable portion of rainfall is received during June to September. July to mid-September period, coinciding with high-intensity rainfall, witnesses gregarious growth of ephemeral herbs with flowers of various hues, on these rocky expanses, a spectacle rarely referred to otherwise.

Most of the rocky terrain during this time turns into a mosaic of seasonal wetlands, with its microhabitats like puddles, pools, streamlets, marshes and meadows teeming with plant life and insect community. Even the most denuded portions of inundated laterite get covered with gelatinous coating of blue-green algae. Shallow depressions, tubules and porosities in the rocks tend to have insectivorous herbs like *Droseras* and *Utricularias* along with *Eriocaulons* clinging on them. Seasonal pools and puddles are characterized by various hydrophytic herbs. Isolated amidst these in pockets of soil, occur leguminous herbs and stunted woody plants such as *Sapium insigne*, *Memecylon umbellatum*, *F. indica*, *Ixora coccinea* and some grasses. The tapering of rainfall from late September to almost its complete stoppage by end of November, marks the cessation of herbal flora. The herbs and grasses dry up giving a brownish hue to the hills and plateaus.

Study organisms

Honey bees were mainly found visiting the flowers of the herbs *Utricularia* spp., *Eriocaulon* spp., *Impatiens* spp., and of a shrub *F. indica* and hence the study was restricted to these plants. *Utricularias*, or bladderworts, named so due to tiny bladders fitted with trap doors, are nectar-producing insectivorous herbs. The laterite plateau bladderworts (Figure 1 *a*), notably *U. lazulina*, *U. reticulata* and *U. striatula* are delicate, leafless plants with brilliantly coloured flowers. The Western Ghats and west coast have many species of balsams (*Impatiens* spp.), which produce attractive flowers with saccate or spurred corolla (Figure 1 *c*). *Impatiens raziana* and *I. rosea* are characteristic rainy season balsams of laterite plateaus. They are also notable producers of nectar for the bees[31]. *Eriocaulons* grow on wet rocks, in marshes and meadows and freshwater pools and puddles. About 40 species of this pantropical herb occur in Karnataka and at least eight species occur in the study areas. They are identified easily by their minute flowers aggregated into white, button-like inflorescences (Figure 1 *d*). Their tiny petals are equipped with nectar-producing glands. *F. indica* is a thorny shrub with small, unisexual, greenish-yellow flowers in short axillaries or terminal sprays (Figure 1 *b*).

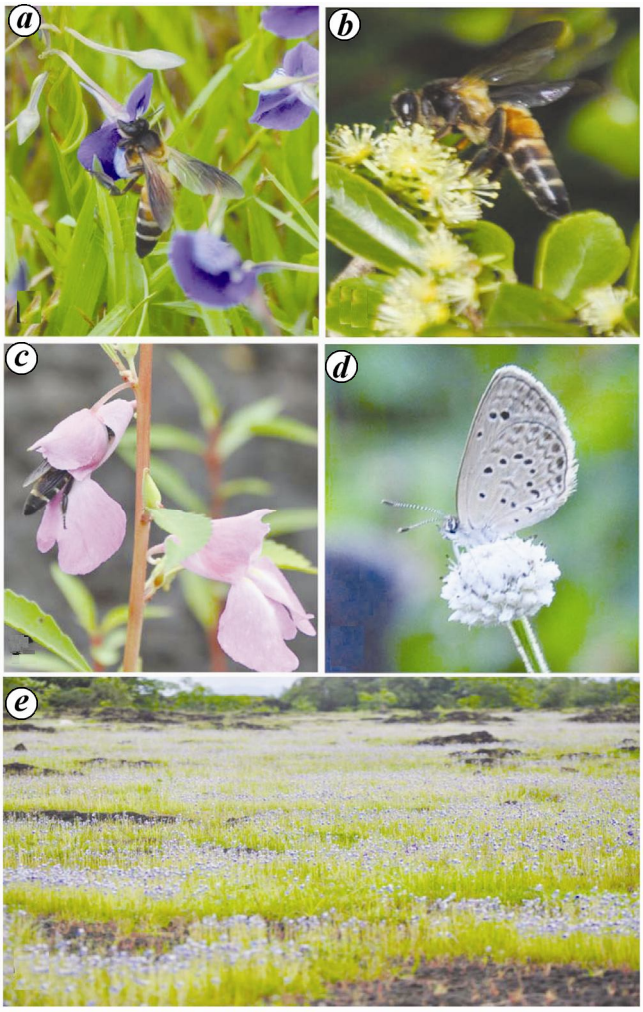

Figure 1 *a–c*. *Apis dorsata* on flower of (***a***) *Utricularias*; (***b***) *Flacourtia indica* and (***c***) *Impatiens rosea*. ***d***, *Chilades laius* on flower of *Eriocaulon*. ***e***, Mass flowering *Utricularia* spp. in Bhatkal laterite plateau.

Sampling methods

The present study was carried out in 12 sampling stations from August to mid-September 2012, during the peak flowering period for the herbs (Table 1). One of the sampling localities, a typical laterite plateau at Mugali (300 ha), in Honavar taluk, was chosen for one-time estimation of flower production, for the most prolifically occurring seasonal bee plants *Utricularia* spp. and *Eriocaulon* spp. A total of 65 quadrats (1 × 1 m each) were used along transect lines, leaving 20 m length intervals between quadrats, for counting the number of flowers of the two above-mentioned targeted genera, which contribute to the bulk of bee flower resources. After count of the total number of flowers (open ones and buds for *Utricularia* spp., and button-like flower heads bearing minute flowers in case of *Eriocaulon* spp.) from 65 quadrats, average number of flowers/m^2 was arrived at. These values were converted into standing floral wealth/ha of these two dominant ephemeral herbs of the laterite terrain.

For insect diversity and flower visitation rates, at each sampling station three replicate plots of 1 m^2 were laid down and all the insects visiting the flowers in these plots were recorded. An insect visit was recorded only when the insect landed on the flowers. Flower-visiting insects were identified using standard field keys from taxonomic literature[32–35]. The insect visitation rates of four selected plants were measured in the quadrats. In each quadrat, three freshly opened flowers were observed for visitation counts of four species of honey bees (*A. dorsata*, *Apis cerana*, *Apis florae* and *Trigona* sp.) for 5 min duration per flower. The more widespread *Utricularia* spp. and *Eriocaulon* spp. were examined altogether in 33 quadrats from 12 stations, whereas the relatively lesser *Impatiens* spp. and *F. indica* were observed in 9 quadrats each, in 3 sampling stations only. In addition, just to unravel the pollinator richness of laterite plateaus, the butterfly diversity also was recorded by walking along a 20 × 500 m belt transect, three transects per station. The observations were carried out during daytime only.

Table 1. Sampling localities in different laterite plateaus of Uttara Kannada district

Sampling location	Latitude (°N)	Longitude (°E)	Altitude (m)
Bhatkal-I	14.01586	74.56985	95
Bhatkal-II	13.99985	74.55811	95
Hosapattana	14.23994	74.46896	56
Mugali	14.23678	74.45347	55
Ramangindi	14.36233	74.40858	68
Jalavalli	14.2657	74.53316	85
Kadale Cross	14.3458	74.4503	76
Ramthirtha	14.20662	74.45791	66
Chippikagalu	14.35763	74.43599	74
Belekeri	14.70337	74.28676	52
Moodangi	14.53949	74.34276	63
Nagoor-Brahmur	14.50173	74.42188	27

Similarities in butterfly taxonomic composition between sampling stations were measured by cluster analysis using Jaccard's similarity index. Visitation rates of honey bees are illustrated using box plot. For each species sample group, the 25–75% quartiles are represented using a box, the horizontal line within it indicating the median value. The minimum and maximum values are shown with short horizontal lines.

Results and discussion

Members of the insect orders Hymenoptera (bees and wasps), Diptera (flies), Coleoptera (beetles) and Lepidoptera (butterflies and moths) constituted the main floral foragers for *Utricularias*, *F. indica*, *Impatiens* and *Eriocaulons*. Altogether 58 taxa of insects visited the freshly opened study flowers in the 12 study areas (Table 2). The bees, especially honey bees (family Apidae) were abundant in all stations. In the lone work by Hobbhahn *et al.*[36] so far available on insect-related pollination of the Western Ghats laterite plateau herbs in Maharashtra and Goa, altogether about 50 species of insects have been listed as floral visitors. Some of the taxa which additionally figured in our study included the bee *A. florea*, wasps *Ropalidia* sp. and *Vespa cincta*, and butterflies *Troides minos* (Southern Birdwing), *Borbo cinnara* (Rice Swift), *Sarangesa purendra* (Spotted Small-flat), *Mycalesis patina* (Gladeye Bush-brown), *Spindasis vulcanus* (Silverline) and *Pachliopta hector* (Crimson Rose). The visiting insect communities on flowers of *F. indica*, *Utriculars*, *Impatiens* and *Eriocaulons* were recorded as about 24, 14, 14 and 9 insect species respectively. Among the insect species, honey bees (*A. dorsata*, *A. cerana*, *A. florea* and *Trigona* sp.) visited abundantly rather than other insect community (Figure 2).

The Lepidopteron foragers comprised of 39 butterfly species from 32 genera and 5 families (Table 2). Nymphalidae was the most specious (19 species) family followed by Pieridae (7 species), Lycaenidae (6 species), Papilionidae (5 species) and Hesperiidae (2 species). Two moth species (Bee-hawk moth and Hand-maiden moth) were also recorded, the former already known as an important pollinator. Based on Jaccard's cluster analysis, relying on butterfly species presence/absence data, the sampling stations were grouped into three basic clusters A, B, and C (Figure 3). Cluster B had the highest diversity of butterfly species, presumably due to more plant diversity. Cluster A was divided into two sub-clusters, A_1 and A_2. Sub-cluster A_1 consists of two lateritic areas (Ramthirtha and Nagoor-Brahmur), both sharing the taxa *Borbo cinnara*, *Sarangesa purendra*, *Talicada nyseus* and *Junonia iphita*. Sub-cluster A_2 consists of two sampling stations, namely Chippihakkalu and Moodangi, hosting about 9 and 10 taxa respectively. Cluster B has seven sampling stations, which are further divided into three

Table 2. Inventory of insects associated with plants of lateritic plateaus of coastal Uttara Kannada, South India

Family	Species	Common name	Insects visited plants
Lepidoptera			
Hesperidae	*Borbo cinnara*	Rice Swift	*Andropogon* sp., *Cymbopogon* sp., *Eragrostis* sp., *Ischaemum* sp., *Utricularia* spp.
Hesperidae	*Sarangesa purendra*	Spotted Small Flat	*Crotalaria* spp., *Impatiens* sp
Lycaenidae	*Caleta caleta*	Angled Pierrot	*Ziziphus rugosa*, *Flacourtia indica*
Lycaenidae	*Castalius rosimon*	Common Pierrot	*Alternanthera sessilis*, *Justicia simplex*, *Tridax procumbens*, *Ziziphus rugosa*, *Ziziphus mauritiana*, *Sida* spp., *Flacourtia indica*, *Eriocaulon* sp.
Lycaenidae	*Spindasis vulcanus*	Common silverline	*Chromolaena odorata*, *Canthium coromandelicum*, *Ziziphus mauritiana*, *Ziziphus rugosa*, *Flacourtia indica*
Lycaenidae	*Jamides bochus*	Dark Cerulean	*Crotalaria* spp., *Utricularia* sp.
Lycaenidae	*Chilades laius*	Lime Blue	*Sida* spp., *Acacia* spp., *Eriocaulon* spp.
Lycaenidae	*Talicada nyseus*	Red Pierrot	Acanthaceous herbs, *Alternanthera sessilis*, *Eriocaulon* sp.
Nymphalidae	*Acraea violae*	Tawny Coster	*Tridax procumbens*, *Utricularia* spp. *Flacourtia indica*
Nymphalidae	*Cupha erymanthis*	Rustic	*Flacourtia indica*, *Utricularia* spp.
Nymphalidae	*Cynthia cardui*	Painted Lady	*Zornia diphylla*, *Utricularia* spp.
Nymphalidae	*Danaus chrysippus*	Plain Tiger	*Calotropis gigantea*, *Cryptolepis buchananii*
Nymphalidae	*Danaus genutia*	Striped Tiger	*Tylophora indica*, *Ceropegia* sp.
Nymphalidae	*Elymnias hypermenstra*	Common Palmfly	*Caryota urens*
Nymphalidae	*Euploea core*	Common Indian crow	*Ficus benghalensis*, *Ficus racemosa*, *Hemidesmus indicus*, *Ichnocarpus frutescens*, *Tylophora indica*, *Flacourtia indica*
Nymphalidae	*Hypolimnas bolina*	Great Eggfly	*Sida rhombifolia*
Nymphalidae	*Junonia atlites*	Grey Pansy	*Hygrophila auriculata*
Nymphalidae	*Junonia iphita*	Chocolate Pansy	*Hygrophila auriculata*, *Justicia simplex*
Nymphalidae	*Junonia lemonias*	Lemon Pansy	*Hygrophila auriculata*, *Sida rhombifolia*, *Corchorus capsularis*
Nymphalidae	*Junonia orithya*	Blue Pansy	*Justicia simplex*, *Tridax procumbens*, *Lepidagathis prostrata*
Nymphalidae	*Mycalesis patnia*	Gladeye Bush-brown	*Oryza* spp.
Nymphalidae	*Neptis hylas*	Common Sailer	*Corchorus* sp., *Grewia* sp.
Nymphalidae	*Phalanta phalantha*	Common Leopard	*Flacourtia indica*, *Alternanthera sessilis*, *Smilax* sp.
Nymphalidae	*Tanaecia lepidea*	Grey Count	*Careya arborea*, *Melastoma malabathricum*
Nymphalidae	*Tirumala limniace*	Blue Tiger	*Crotalaria* spp., *Heliotropium* sp., *Ageratum conyzoides*, *Calotropis gigantea*, *Tylophora indica*, *Wattakaka volubilis*, *Flacourtia indica*
Nymphalidae	*Ypthima asterope*	Common Three-ring	*Tridax procumbens*, *Grass* sp., *Eriocaulon* sp.
Nymphalidae	*Ypthima huebneri*	Common Four-ring	*Tridax procumbens*, *Clerodendrum serratum*, *Grass* sp., *Eriocaulon* sp.
Papilionidae	*Papilio polymnestor*	Blue Mormon	*Mussaenda frondosa*, *Ixora coccinia*, *Jasminum* spp., *Glycosmis arborea*, *Zanthoxylum rhetsa*, *Flacourtia indica*
Papilionidae	*Papilio polytes*	Common Mormon	*Mussaenda frondosa*, *Ixora coccinia*, *Jasminum* spp., *Glycosmis arborea*, *Zanthoxylum rhetsa* *Flacourtia indica*, *Utricularia*
Papilionidae	*Pachliopta hector*	Crimson Rose	*Aristolochia indica*, *Utricularia* spp.
Papilionidae	*Troides minos*	Southern Bird-wing	*Aristolochia indica*, *Ixora coccinia*, *Mussaenda frondosa*
Papilionidae	*Graphium agamemnon*	Tailed Jay	*Ixora coccinia*, *Mussaenda frondosa*, *Flacourtia indica*
Pieridae	*Catopsilia pomona*	Common Emigrant	*Tridax procumbens*, *Cassia tora*, *Flacourtia indica*
Pieridae	*Eurema hecabe*	Common Grass Yellow	*Tridax procumbens*, *Ageratum conyzoides*, *Acacia* spp., *Cassia tora*
Pieridae	*Pareronia ceylonica*	Dark Wanderer	*Capparis* sp., *Flacourtia indica*
Pieridae	*Pieris canidia*	Indian Cabbage White	Asteraceous plants, *Leucas aspera*, *Impatiens* spp.
Pieridae	*Catopsilia pyranthe*	Mottled Emigrant	*Cassia tora*
Pieridae	*Anaphaeis aurota*	Pioneer or Caper White	*Tridax procumbens*, *Capparis spinosa*
Pieridae	*Ixias marianne*	White Orange Tip	*Capparis* sp.
Sphingidae	*Cephonodes hylas*	Bee-hawk Moth	*Impatiens* spp.
Arctiidae	*Amata bicinota*	Handmaiden Moth	*Cassia mimosoides*, *Cassia tora*, *Eriocaulon* sp.
Coleoptera			
Meloidae	Unidentified sp. 1	Beetle	*Flacourtia indica*, *Utricularia* spp.
Meloidae	Unidentified sp. 2	Green Blister Beetle	*Cassia mimosoides*, *Cassia tora*, *Flacourtia indica*
Meloidae	*Mylabris* sp.	Blister Beetle	*Cassia mimosoides*, *Cassia tora*, *Flacourtia indica*, *Ixora coccinia*

(*Contd*)

Table 2. (*Contd*)

Family	Species	Common name	Insects visited plants
Diptera			
Syrphidae	*Syrphinids* sp.	Hoverfly	*Flacourtia indica*, *Justica simplex*, *Impatiens* spp.
Calliphoridae	*Lucilia* sp.	Blowfly	*Flacourtia indica*, *Justica simplex*, *Sida* sp.
Tabanidae	*Tabanus* sp.	Horsefly	*Flacourtia indica*, *Justica simplex*
Hymenoptera			
Apidae	*Apis dorsata dorsata*	Giant or Rock bee	*Utricularia* spp., *Impatiens* sp., *Flacourtia indica*, *Bacopa monnieri*, *Eriocaulon* spp.
Apidae	*Apis cerana indica*	Indian bee	*Utricularia* spp., *Impatiens* spp., *Flacourtia indica*, *Justicia simplex*, *Bacopa monnieri*, *Eriocaulon* spp.
Apidae	*Apis florea*	Little bee	*Utricularia* spp., *Impatiens* spp., *Flacourtia indica*, *Justicia simplex*
Apidae	*Xylocopa* sp. 1	Carpenter bee	*Impatiens* spp., *Flacourtia indica*
Apidae	*Xylocopa* sp. 2	Carpenter bee	*Impatiens* spp., *Capparis* sp.
Apidae	*Trigona* (*Tetragonala*) sp.	Stingless bee	*Eriocaulon* spp., *Weisneria triandra*, *Flacourtia indica*, *Impatiens spp.*, *Justica simplex*, *Mussaenda frondosa*, *Ixora coccinia*, *Jasminum* spp., *Glycosmis arborea*, *Zanthoxylum rhetsa*, *Lepidagathis prostrata*, *Utricularia* spp.
Halictidae	*Nomia* sp.	Sweat bee	*Utricularia* spp.
Vespidae	*Polistes* sp	Paper wasp	*Impatiens* spp., *Acacia* spp.
Vespidae	*Ropalidia* sp.	Paper wasp	*Impatiens* spp.
Vespidae	*Vespa cincta*	Yellow-banded wasp	*Impatiens* spp.
Vespidae	*Vespa* sp.	Yellow-banded wasp	*Impatiens* spp., *Utricularia* spp.

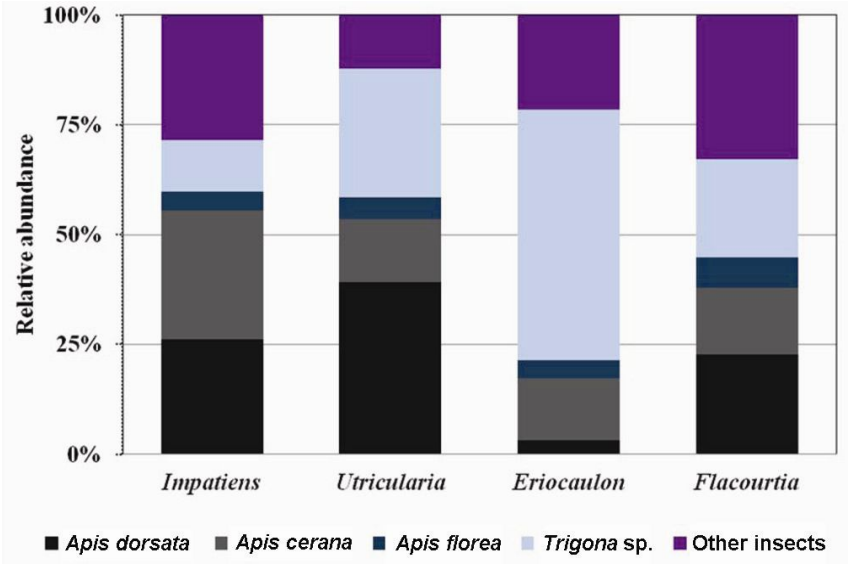

Figure 2. Percentage of insect population visited on the four study plants.

sub-clusters (B_1, B_2 and B_3). B_1 and B_2 sub-clusters have similarity to the tune of 55–60%. Sub-cluster B_3 shows nearly 40% similarity with B_1 and B_2. The B_3 site also harboured, the significantly important taxa, the Southern Bird-wing, restricted to southern India. The sampling stations of Mugali and Hosapattna of sub-cluster B_3 are important lateritic habitats considering their overall floral richness. Rao *et al.*[16] recorded 125 and 97 species of flowering plants respectively, from these two study areas.

A. dorsata had a higher visitation rate on *Utricularia* spp., followed by other honey bees *Trigona* sp., *A. cerana* and *A. florea* (Figure 4 *a*). The average visitation rate of *A. dorsata* was 4.4 ± 3.6 bees/flower for 5 min, *Trigona* sp. (3.2 ± 3.6), *A. cerana* (1.6 ± 1.6) and *A. florea* (0.6 ± 0.6). Hobbhahn *et al.*[36] in Maharashtra found that the *Utricularias* has small quantity of nectar per flower and good concentration of sugar, which attracts the insect visitor, and that the main pollinator of *U. albocaerulea* was *A. dorsata*. Our observations also support the role of *Utricularia* spp. in providing foraging support to honey bees, especially when most other plants are not flowering. Whereas the other bees were rarely found visiting the minute flowers of *Eriocaulon* sp. *Trigona*, the stingless, tiniest of the bees, had the highest visitation rate

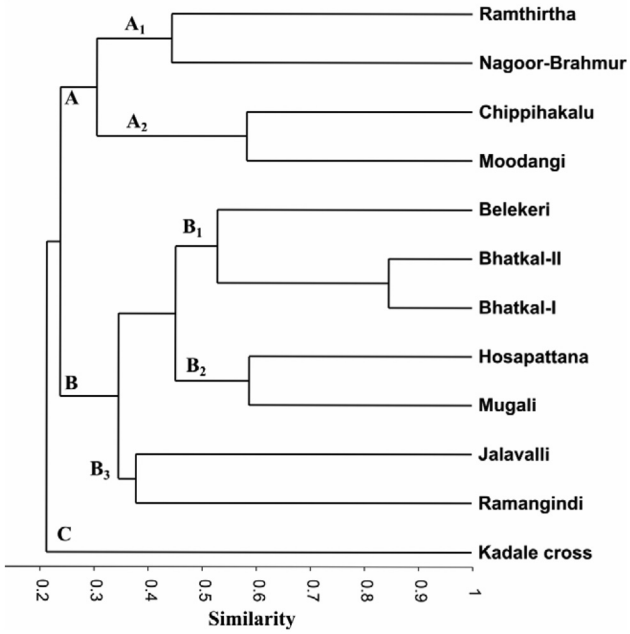

Figure 3. Jaccard similarity index for butterfly community in 12 lateritic areas of Uttara Kannada.

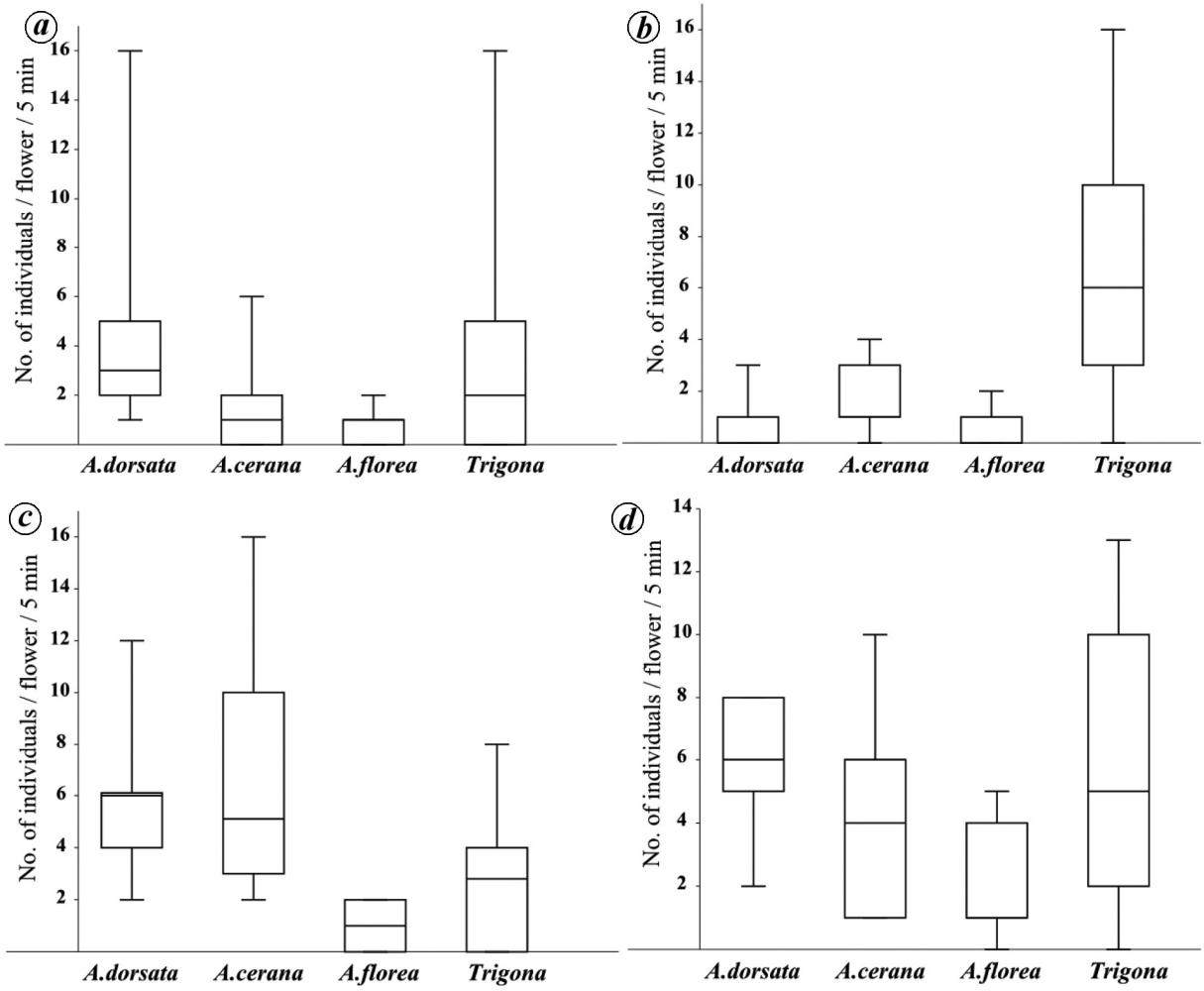

Figure 4. Honey bee visitation rate on (***a***) *Utricularias**, (***b***) *Eriocaulons**, (***c***) *Impatiens*** and (***d***) *F. indica***. **n* = 33; ***n* = 9.

on it. We could not ascertain whether the medium-sized bees like *A. cerana*, *A. florea* and the larger *A. dorsata* which perch on the *Eriocaulon* flower heads are able to gather nectar. The average visitation rate of *Trigona* sp. was 6.42 ± 4.34 individuals/flower for 5 min, followed by *A. cerana* (1.58 ± 1.3), *A. florea* (0.45 ± 0.56) and *A. dorsata* (0.36 ± 0.74; Figure 4 *b*). *A. dorsata* had the highest visitation rates on *F. indica* and *Impatiens*. The average visitation rate of *A. dorsata* on *Impatiens* was 6.8 ± 2.1 individuals/flower for 5 min, followed by *A. cerana* (6.7 ± 5.1), *Trigona* sp. (2.8 ± 2.7) and *A. florea* (1 ± 0.9; Figure 4 *c*). On *F. indica*, the average visitation rate of *A. dorsata* was 6.1 ± 1.96 individuals/flower for 5 min, followed by *Trigona* sp. (6 ± 4.24), *A. cerana* (4.11 ± 2.98) and *A. florea* (1.89 ± 1.62; Figure 4 *d*). *F. indica* was rated as a potential nectar resource for honey bees in Garhwal, Himalayas[37]. Study of honey samples from Andhra Pradesh by Lakshmi and Suryanarayana[38] detected the presence of high *F. indica* pollen in some honey samples. Our observations on *F. indica* also support the close association of *A. dorsata* and *A. cerana* with this plant, otherwise considered of little importance by the local village communities. The laterite formations are also the habitats for several recently discovered flowering herb species already referred to earlier[39].

Power *et al.*[40] defined the keystone as 'a species whose impact on its community or ecosystem is large and disproportionately large relative to its abundance'. The keystone role has not been extended only to species (both flora and fauna), but also to critical limiting resources that 'occupy only a small area of the habitat, and yet are critical to many species in the community'[41]. Our estimate of the standing floral wealth/ha of *Utricularia* spp. was 1,019,538 flowers/ha and for *Eriocaulon* spp. it was 1,742,154 flower-heads/ha. The study shows the importance of *Utricularia* spp. for *A. dorsata*, *A. cerana* and *A. florea.* Also, *F. indica* and *Impatiens* spp. were found to be important forage species for these honey bees. *Eriocaulon* spp. were mainly foraged by *Trigona* sp., compared to other bees. This study reveals that the mass flowering lateritic flora provided food for honey bees and other insect communities during the dearth period for forage in this region. Some studies have shown that during dearth period for forage honey bees even visited certain weed species in cereal fields thus conferring keystone resource plants to such weeds[42,43]. Similarly, lateritic plateau having seasonal mass flowering of *Utricularias* and *Eriocaulons* is considered as a keystone resource for honey bee wealth.

Conclusion

In Uttara Kannada district, the peak monsoon season is considered as a challenging time for honey bees, due to the general absence of flowering in the vegetation, both wild and cultivated. The present study reveals that the largely denuded coastal laterite hills and plateaus, characteristic of Uttara Kannada district, seldom ever studied for their floristic diversity, play a crucial role in supporting the food-starved honey bee population during the peak monsoon season, when these habitats get carpeted with a wealth of ephemeral herbs flowering prolifically. Various species of monsoon herbs like *Utricularias*, *Eriocaulons* and *Impatiens*, and *F. indica*, a shrub, were the most notable monsoon-blooming species, which supported not only honey bees but also many other insects. These rocky habitats, subjected to heavy human pressures due to biomass removal, quarrying for building stones and, of late, due to *en masse* creation of *Acacia* plantations, should merit better conservation efforts not only for their off-season support to honey bee species or butterflies, but also for their unique community of herbs, with several rare and newly reported species.

1. Pradeep, A. K., Joseph, K. T. and Sivarajan, V. V., *Rotala malabarica*: a new species of Lythraceae from India. *Bot. Bull. Acad. Sin.*, 1990, **31**, 51–61.
2. Joseph, K. T. and Sivarajan, V. V., A new species of *Nymphoides* from India. *Nordic J. Bot*., 1990, **10**, 281–284.
3. Pradeep, A. K., Joseph, K. T. and Sivarajan, V. V., *Justicia ekakusuma* new species of Acanthaceae from peninsular India. *Rheedia*, 1991, **1**, 40–43.
4. Madhusoodanan, P. V. and Singh, N. P., A new species of *Lepidagathis* (Acanthaceae) from South India. *Kew Bull.*, 1992, **1**, 19–22.
5. Ansari, R. and Balakrishnan, N. P., *The Family Eriocaulaceae in India*, Bishen Singh Mahendra Pal Singh, Dehra Dun, 2009, revised edn.
6. Sunil, C. N., Narayanan, M. K. R., Nandakumar, M. K., Sujana, K. A., Jayesh, P., Joseph, J. P. and Kumar, A. N., *Eriocaulon kannurense* (Eriocaulaceae), a new species from Kerala, India. *Int. J. Plant. Anim. Environ. Sci*., 2013, **3**, 116–120.
7. Swapna, M. M., Rajesh, K. P., Manju, C. N. and Prakash Kumar, R., *Eriocaulon madayiparense* (Eriocaulaceae) – a new species from the foothills of the Western Ghats of India. *Phytokeys*, 2012, **10**, 19–23.
8. Narayanan, M. K. R., Sunil, C. N., Nandakumar, M. K., Sujana, K. A., Joseph, J. P. and Anil Kumar, N., *Lindernia madayiparense* (Linderniaceae) – a new species from Kerala, India. *Int. J. Plant. Anim. Environ. Sci.*, 2012, **2**, 59–62.
9. Shimpale, V. B. and Yadav, S. R., *Eriocaulon belgaumensis* – a new species of Eriocaulaceae from the Western Ghats of India. *Kew Bull.*, 2010, **65**, 337–339.
10. Prabhugaonkar, A., Usha, S., Yadav and Janarthanam, M. K., *Dipcadi goaense* (Hyacinthaceae) – a new species from the foothills of the Western Ghats, India. *Kew Bull*., 2009, **64**, 743–746.
11. Bachulkar, M. P., Endangered endemic taxa of Satara district, Maharashtra. *Rayat. Res. J*., 1983, **1**, 109–115.
12. Deshpande, S., Sharma, B. D. and Nayar, M. P., Flora of Mahabaleshwar and adjoining areas, Maharashtra. In *Flora of India*, BSI, Kolkata, Series 3, 1993, vol. II.
13. Yadav, S. R. and Sardesai, M. M., *Flora of Kolhapur District*, Shivaji University, Kolhapur, 2002.
14. Mishra, D. K. and Singh, N. P., Endemic and threatened flowering plants of Maharashtra. In *Flora of India*, BSI, Kolkata. Series 4, 2001.
15. Yadav, S. R., Potdar, G. G., Anil Kumar, Otaghvari, A. M. and Anand, S., *Eriocaulon epdunculatum* – a new species of Eriocaulaceae

from the Western Ghats, India. *Kew Bull.*, 2008, **63**, 503–505.
16. Rao, G. R., Krishnakumar, G., Chandran, M. D. S. and Ramachandra, T. V., Seasonal wetland flora of the laterite plateaus of coastal Uttara Kannada. In Proceedings of National Conference on Conservation and Management of Wetland Ecosystems, Mahatma Gandhi University, Kottayam, 2012.
17. Klein, A. M., Vaissiere, B. E., Cane, J. H., SteffanDewenter, I., Cunningham, S. A., Kremen, C. and Tscharntke, T., Importance of pollinators in changing landscape for world crops. *Proc. R. Soc. London Ser.*, 2007, **274**, 303–313.
18. Schoonhoven, L. M., Jermy, T. and Van Loon, J. J. A., *Insect–Plant Biology: From Physiology to Evolution*, Chapman and Hall, London, 1998.
19. Roubik, D. W., Pollination of cultivated crops in the tropics. *FAO Agric. Bull.*, 1995, **118**.
20. Danforth, B. N., Sipes, S., Fang, J. and Brady, S. G., The history of early bee diversification based on five genes plus morphology. *Proc. Natl. Acad. Sci. USA*, 2006, **103**, 15118–15123.
21. Engel, C. E. and Irwin, R. E., Linking pollinator visitation rate and pollen receipt. *Am. J. Bot.*, 2003, **90**, 1612–1618.
22. Vazquez, D. P., Morris, W. S. and Jordano, P., Interaction frequency as a surrogate for the total effect of animal mutualists on plants. *Ecol. Lett.*, 2005, **8**, 1088–1094.
23. Steffan-Dewenter, I. and Tscharntke, T., Effects of habitat isolation on pollinator communities and seed set. *Oecologia*, 1999, **121**, 432–440.
24. Waser, N. M. and Ollerton, J., *Plant–Pollinator Interaction: From Specialization to Generalization*, University of Chicago Press, Chicago, 2006.
25. Smith, W. E., Honey bee nutrition and supplementary feeding. Agnote, State of New South Wales, NSW Agriculture, 2000, 1–8.
26. Pokhrel, S., Thapa, R. B., Neupane, F. P. and Shrestha, S. M., Absconding behavior and management of *Apiscerana* f. honeybee in Chitwan, Nepal. *J. Inst. Agric. Anim. Sci.*, 2006, **27**, 77–86.
27. Bista, S. and Shivakoti, P. G., Honeybee flora at Kabre, Dolakha District, Nepal. *J. Nepal Agric. Res.*, 2001, (4–5), 16–25.
28. Ayalew, K., The loss of some natural plant species in Tigray and the concern to the living conditions of honeybee loss of natural plants. In Proceedings of the 5th Annual National Conference of Ethiopian Beekeepers Association, 2006, pp. 8–15.
29. Oldroyd, B. P. and Nanork, P., Conservation of *Apis* honeybees. *Apidologie*, 2009, **40**, 296–312.
30. Ramachandra, T. V., Chandran, M. D. S., Joshi, N. V. and Balachandran, C., Beekeeping: sustainable livelihood option in Uttara Kannada, central Western Ghats. Environmental Information System (ENVIS) Technical Report No. 49, ENVIS, CES, Indian Institute of Science, Bangalore, 2012, pp. 1–149.
31. Dube, D., Flight path of pollinators foraging on impatiens: decision rules and their implications for gene flow. M Sc thesis, Biology Department, McGill University, Canada, 1989.
32. Henri, G. and Huber, J. T., *Hymenoptera of the World: An Identification Guide to Families*, Canadian Cataloguing in Publication Data, Canada, 1993.
33. Michener, C. D., *The Bees of the World*, The Johns Hopkins University Press, Baltimore, 2007, 2nd edn, p. 953.
34. Wynter-Blyth, M. A., *Butterflies of the Indian Region*, Bombay Natural History Society, Bombay, 1957, p. 523.
35. Kunte, K., *Butterflies of Peninsular India*, Universities Press Limited, Hyderabad, 2000, p. 254.
36. Hobbhahn, N., Kuchmeister, H. and Porembski, S., Pollination biology of mass flowering terrestrial *Utricularia* species (Lentibulariaceae) in the Indian Western Ghats. *Plant Biol.*, 2006, **8**, 791–804.
37. Tiwari, P., Tiwari, J. K. and Ballabha, R., Studies on sources of bee-forage for rock bee (*Apis dorsata* F.) from Garhwal Himalaya, India: a melisso-palynologaical approach. *Nat. Sci.*, 2010, **8**, 5–15.
38. Lakshmi, K. and Suryanarayana, M. C., Microscopical analysis of rock bee honeys from Nallamalai forest of Andhra Pradesh, India. *J. Palynol*., 1997, **33**, 263–272.
39. Chandran, M. D. S., Ramachandra, T. V., Joshi, N. V., Rao, G. R., Mesta, P. N., Balachandran, C. and Dudani, S. N., Conservation reserve status to lateritic plateaus of coastal Uttara Kannada. Environmental Information System (ENVIS) Technical Report No. 51, ENVIS, CES, Indian Institute of Science, Bangalore, 2012, p. 32.
40. Power, M. E. *et al.*, Challenges in the quest for keystones. *BioScience*, 1996, **46**, 609–620.
41. Primack, R. B., *Essentials of Conservation Biology*, Sinauer Associates Inc, Sunderland, Massachusetts, USA, 1993.
42. Beekman, M. and Ratnieks, F. L. W., Long-range foraging by the honey-bee, *Apis mellifera* L. *Funct. Ecol.*, 2000, **14**, 490–496.
43. Odoux, J. F., Caro, G., Touillet, C., Peyra, E., Derelle, D., Aupinel, P. and Bretagnolle, V., Which landscape features influence population ecology of bee colonies in farmland intensive cereals systems?. In Proceedings Apimondia 41st Congress, Montpellier, France, 15–20 September 2009.

ACKNOWLEDGEMENTS. We thank the Ministry of Science and Technology, Government of India; Karnataka Biodiversity Board, Government of Karnataka and Indian Institute of Science for financial and infrastructure support. We also thank our colleagues G. R. Rao, Sumesh Dudani, Shrikanth Naik and D. M. Vishnu for assistance and valuable suggestions during field studies.

Received 21 March 2013; revised accepted 24 March 2014