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Insect Flower Visitors and their Role in Mangrove Pollination: A Study from East Coast of India

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Abstract

Insects play a critical role in bringing successful pollination in angiosperms. Mangrove pollination is a poorly studied aspect from scientific community. This particular work investigated the insect visitors and other prospective of mangrove flowers. Twenty two species (i.e., 17 true and 5 mangrove associates) from Bhitarkanika Wildlife Sanctuary and Devi estuary of Odisha state (East coast of India) were selected; plants were pre-marked and visiting insects were recorded starting from 07.00 am to 13.00 pm during the flowering period of each species. Fifty three species of insects which belongs to seven orders, twenty five families and forty four genera were recorded. The highest, i.e., 14 *sp.* of insects had been recorded from *Aegiceras corniculatum* which is a small tree and riverine mangrove. Among insects, bees were found as the most common flower visitors (in 82% mangroves) and particularly "honey bee", i.e., *Apis dorsata* visited to sixteen mangrove species (i.e., 73% mangroves). Bees, particularly Honeybee (*A. dorsata)*, sweet bee (*Lasioglossum sp.*) and carpenter bee (*Xylocopa pubescens*) were actively engaged in pollen dispersal. Resident time and visitation rate supported that bees with highest visitation rate and low resident time were powerful candidates in bringing mangrove pollination. Wasps, beetles and butterflies act more to be foraging species. Facilitation of bee management and particularly supporting apiculture will help to increase pollination successes of rare and threatened mangroves at regional and global level.

Keywords: Mangrove, flower, pollination, bees, forest conservation

1. Introduction

Mangrove ecosystems are well known in terms of productivity, role of coastal protection, a habitat for diverse flora and fauna and most importantly as a large carbon pool both in living tissues and in the form of sediments. Mangal loss is over alarming and thus had been legalised in many countries. Long term conservation only possible through maintaining a stable population structure and flora diversity in the ecosystem. This depends on successive reproduction and subsequent regeneration of mangrove species. Pollinators are one such group whose effective management can maximise reproductive success of rare and endemic mangroves. Pollinators depend less on the plants than the plants on them (Tomlinson, 2016). Pollination benefits society by increasing food security, improving livelihoods and act as a key driver in the maintenance of biodiversity and ecosystem function (Pratap, 2011).

Generally, pollination is done almost completely by canopy dwellers such as bats, birds, moths, butterflies, bees and other insects (Alongi, 2009). Identification of effective pollinator in forest with large

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canopy like mangrove is difficult. Tomlinson (2016) described pollination in terms of flower visitors that is presumed pollinators. Wild pollinators (mostly bees and flies) can be quite important for plants requiring insect pollination (Capinera, 2010). Not all bees gather nectar and produce honey but all of them gather and store up pollen grains and do cross pollination in flowering plants (Mani, 1995). The plants at most risk of loss which are dioecious and self-incompatible, and those that propagate only by seeds (Kearns and Inouye, 1997).

The floral and pollination biology of mangrove plants has been moderately studied (Raju, 1990, Raju et al., 1994, Mitra et al., 2013). Mangroves have both self-pollinating and cross-pollinating mechanisms that vary with species (Kathiresan and Bingham, 2001, Tomlinson, 2016). These pollinators are a group of animals which includes birds, bats and insects like butterflies, bees, beetles, flies and wasps etc. (Azuma et al., 2002; Ghosh et al., 2008; Ghosh and Chakrabarti, 2012; Hogarth, 2015; Tomlinson, 2016). The flowers of family Rhizophoraceae display three different pollination mechanisms i.e., *Rhizophora* spp.:wind pollinated, *Ceriops decandra*: insect pollinated and explosive pollen release in *Ceriops tagal* and *Bruguiera* spp. (Ghosh et al., 2008; Hogarth, 2015; Tomlinson, 2016). Ghosh and Chakrabarti (2012) reported bee, wasp, moth and flies are capable of pollinating in *C. decandra*. Large flowered species of Bruguiera are pollinated by birds and small flowered species of Acanthus, Aegiceras, Avicennia, Excoecaria, and Xylocarpus are probably by butterflies and various types of bees (Noske, 1993; Hogarth, 2015). Some wasps and flies are highly dependent on mangroves for nesting and are particularly important pollinators of *C. decandra*, *Kandelia candel* and *Lumnitzera racemosa* (Tomlinson, 2016). In *Avicennia marina*, the most common visitor was the honeybee, *Apis mellifera*, which is apparently attracted to the nectar-like secretion found toward the base of the corolla tube (Clarke and Myerscough, 1991).

The present study is undertaken to investigate the diversity of insect visitors and their role in pollination of twenty two mangroves (i.e., 17 true and 5 associate species) from Bhitarkanika Wildlife Sanctuary and Devi estuary (Odisha), along East Coast of India.

2. Methodology

2.1 The study area

Two mangrove ecosystems, Bhitarkanika Wildlife Sanctuary (BWS) and Devi estuary (DE) of Odisha state, along the East Coast of India were selected for present study. BWS comes under legal protection and a part of it having the mangrove forest is declared also as a National Park (86° 45′ to 87° 03′ E Longitude and 20° 30′ to 20° 48′ N Latitude) in the view of better protection of mangrove species, with special reference to residing salt water crocodiles (i.e., *Crocodylus porosus*), Olive ridley sea turtle (i.e., *Lepidochelis olivacea*) and many other threatened fauna and flora residing inside and in connection to the ecosystem. It is a deltaic ecosystem established in the evolutionary process from deposition of the Brahmani and Baitarani rivers in Rajnagar coastal block of Kendrapara District. Mangrove of DE (86° 18′ to 86° 20′ E and 19° 57′ to 19° 58′N) is thought to be of recent formation that got established along the river bank of Devi (a distributaries of river Mahanadi). The climate of these sites is almost tropical and subtropical type. Max. rainfall in July-August (200-450 mm) and Min. in December-January (0-10 mm); Max. temperature in April-May (~38° C) and Min. in January (~15° C) and Relative humidity ranges from 60-88 as received data from Indian Meteorological Department (IMD, Bhubaneswar) for the specified time period.

2.2 Data collection

Twenty two mangal species i.e., 17 true and 5 associates (Table 1; Supp. Table 1 and 2) were selected and study conducted during calendar year of 2016-2017. Five flowering twig of each species were pre-marked during flower bud stage. One day visual study was conducted from morning 07.00 am to 13.00 pm during flowering time of each mangrove species. Not a single insect was captured or harmed by any means; photographs were taken using the camera, Sony Alfa SLT 58Y, DSLR (Plate 1). Insects were identified through experts' knowledge and using literatures (Mani, 1995; Chinery, 2007; Resh and Carde, 2009; Singh, 2011; Smetacek, 2017).

Table 1: Selected true mangrove and mangrove associates from two sites.

True mangroves	Mangrove associates
∗*Aegiceras corniculatum* (L.) Blanco, *Acanthus ilicifolius* L., *Aegialitis rotondifolia* Roxb, *Avicennia alba* Blume, *Avicennia marina* (Forsk.)Veierh, *Avicennia officinalis* L. *Bruuiera cylyndrica* (L.) Blume, *Bruguiera sexangula* (Lour.) Poir, *Bruguiera gymnorrhiza* (L) Lamk, *Excoecaria agallocha* L., *Heritiera fomes* Buch-Ham. ∗*Kandelia candel* (L) Druce, *Lumnitzera racemosa* Wild, *Rhizophora mucronata* Lamk. ∗*Sonneratia apetala* Buch. – Ham., *Xylocarpus granatum* Koenig,	*Caesalpinia crista* L., *Cerbera odollam* Gaertn, *Excoecaria indica* (Willd.) Mull. Arg., *Salvadora parsica* L. *Tamarix troupii* H.

∗ Species selected from DE

Pollinating efficacy was determined by comparing dynamic behavior of visitors, i.e., visitation rate (Landry, 2013) and resident time with consideration of morpho-structural characteristics of the visited insects. Other aspects like, host specificity, host range and pollination syndrome were also studied.

$$\text{Rate of visitation (20 min.)} = \frac{\text{number of particular species (insect)visits}}{\text{Number of flowers studied}} \quad (1)$$

Resident time = Time spend by visitor on a single visit to a particular flower (2)

A Jaccard index (C_j) was calculated to compare species similarity between the two study sites.

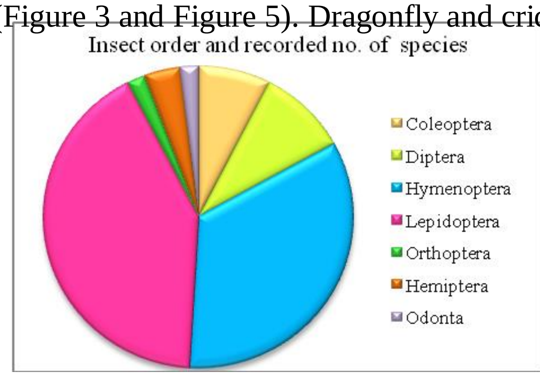
$$C_j = \frac{a}{a+b+c} \quad (3)$$

where:

a=The number of species common to both sites
b=The number of species in DE, but not in BWS
c=The number of species in site BWS, but not in DE

3. Results

A total of 53 species of insects were identified from flowers of studied mangrove species (Table 2; Supp. Table 1 and 2). The result excludes very small insects that were insignificant of carrying pollens. Identified insects belong to 7 orders, 24 families and from 44 genera. The representative orders were Coleoptera, Diptera, Hymenoptera, Lepidoptera, Orthoptera, Hemiptera and Odonta (Table 2 and Figure 1). Lepidoptera and Hymenoptera showed highest species diversity then others (22 spp. and 18 spp., respectively). Diptera and Coleoptera had only 5 and 4 species, respectively. Two species were from Hemiptera and one species each recorded from Orthoptera and Odonta. Out of the total, butterflies:19 spp., bees:8 spp., ants:6 spp., flies:5 spp., wasps and beetles:4 spp. each, moths:3 spp., bugs:2 spp. and one species each of crickets and dragonfly (Table 2 and Figure 2). The flowers of different mangrove species attract insects but variation exists between host range visited by a specific insect. *Apis dorsata* (Honeybee), *Micraspis discolor* (Ladybird beetle), *Crematogastor* spp. (Ant) and *Cochliomyia macellaria* (Flies) had wide host range then others (Figure 3). Maximum 15 insects were recorded from *A. corniculatum* and 12 recorded from *E. agallocha* (Figure 4). *C. crista*, a mangrove associate (climber) was found visited by 9 insects but most of them were moths and butterflies. The result showed flowers of four mangals, *A. rotondifolia*, *A. marina*, *K. candel* and *E. indica* were visited by eight insects each. Only, 3 insect species had been recorded from flowers of *H. fomes* and *B. gymnorhiza* (Figure 4). Among insects, bees were the most frequent visitors and they visited to 18 mangal species (82% of studied mangroves) and particularly “Honeybee”, i.e., *Apis dorsata* visited to sixteen mangrove species (i.e., 73% mangroves) (Figure 3 and Figure 5). Dragonfly and crickets were very rare flower visitors.



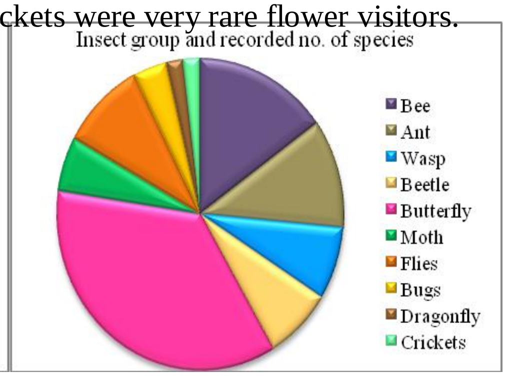


Figure 1. Insect order wise number of insect species. Figure 2. Insect group wise number of species.

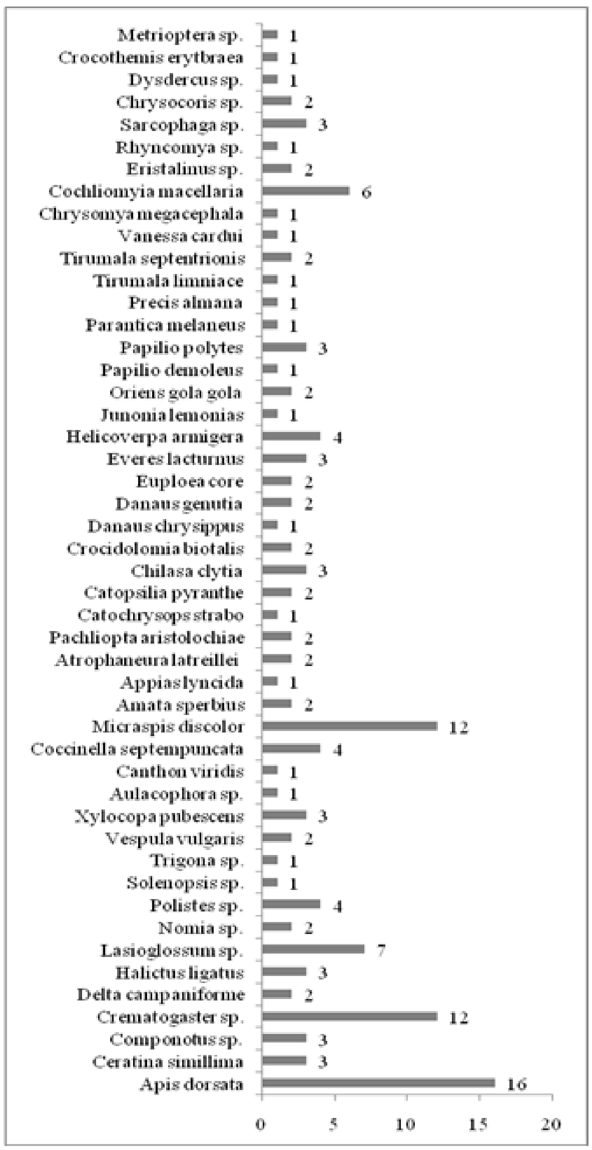


Figure 3. Showing host range of recorded insects (number of mangrove taxa visited by insects).

The comparison of resident time among insect groups showed a large variation. Bees and wasps were found more dynamic and frequent flower visitors. Similarly, study of visitation rate showed high rate for bees, wasps, flies and butterflies, respectively in comparison with other recorded insect groups (Table 3). Moths had more residing time on flowers than others. The increasing trend of resident time is as Bee<Butterfly<Wasp<Flies<Dragonfly<Beetle<Crickets<Bugs<Ants<Moth.

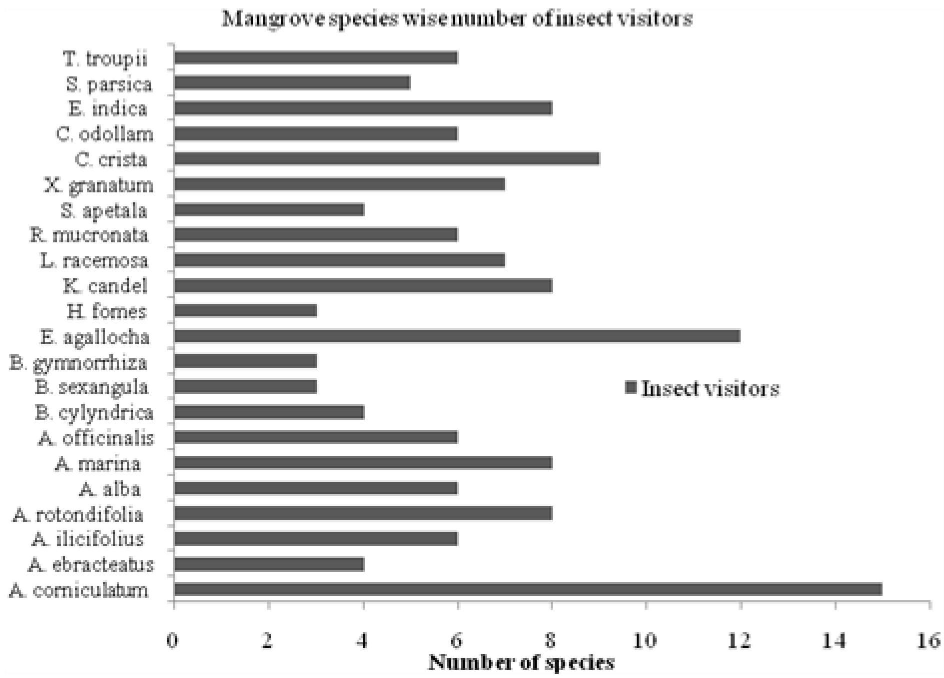


Figure 4. Mangrove species wise recorded number of visited insect species.

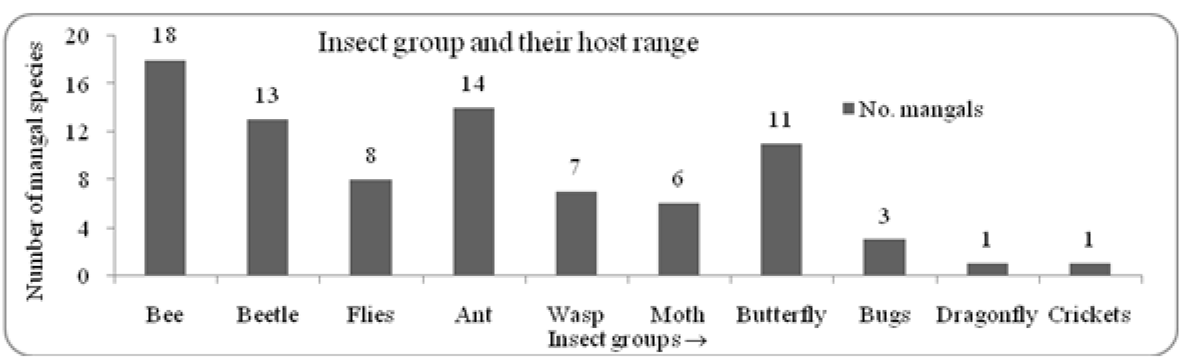


Figure 5: Insect group and their visited number of mangrove species.

Table 2: Recorded insects from mangrove flowers and their classification (spp=species).

SI.No.	Name of insect	Order	Family	Insect class
1	*Apis dorsata*	Hymenoptera	Apidae	Bee
2	*Ceratina simillima*	Hymenoptera	Apidae	Bee
3	*Componotus* spp.1	Hymenoptera	Formicidae	Ant
4	*Componotus* spp.2	Hymenoptera	Formicidae	Ant
5	*Componotus* spp.3	Hymenoptera	Formicidae	Ant
6	*Crematogaster* spp.1	Hymenoptera	Formicidae	Ant
7	*Crematogaster* spp.2	Hymenoptera	Formicidae	Ant
8	*Delta campaniforme*	Hymenoptera	Vespidae	Wasp (Yellow potter)
9	*Halictus ligatus*	Hymenoptera	Halictidae	Bee
10	*Lasioglossum* spp.1	Hymenoptera	Halictidae	Bee
11	*Lasioglossum* spp.2	Hymenoptera	Halictidae	Bee
12	*Nomia* spp.	Hymenoptera	Halictidae	Bee (Sweet bee)
13	*Polistes olivaceus*	Hymenoptera	Vespidae	Wasp
14	*Polistes* spp. 2	Hymenoptera	Vespidae	Wasp
15	*Solenopsis* spp.	Hymenoptera	Formicidae	Ant
16	*Trigona* spp.	Hymenoptera	Apidae	Bee
17	*Vespula vulgaris*	Hymenoptera	Vespidae	Wasp
18	*Xylocopa pubescens*	Hymenoptera	Apidae	Bee
19	*Aulacophora* spp.	Coleoptera	Chrysomelidae	Beetle
20	*Canthon viridis*	Coleoptera	Scarabaeidae	Beetle
21	*Coccinella septempuncata*	Coleoptera	Coccinellidae	Beetle (Lady bird)
22	*Micraspis discolor*	Coleoptera	Coccinellidae	Beetle (Lady bird)
23	*Amata sperbius*	Lepidoptera	Arctiinae	Moth
24	*Appias lyncida*	Lepidoptera	Pieridae	Butterfly
25	*Atrophaneura latreillei*	Lepidoptera	Papilionidae	Butterfly
26	*Pachliopta aristolochiae*	Lepidoptera	Papilionidae	Butterfly
27	*Catochrysops strabo*	Lepidoptera	Lycaenidae	Butterfly
28	*Catopsilia pyranthe*	Lepidoptera	Pieridae	Butterfly
29	*Chilasa clytia*	Lepidoptera	Papilionidae	Butterfly
30	*Crocidolomia biotalis*	Lepidoptera	Crambidae	Moth
31	*Danaus chrysippus*	Lepidoptera	Nymphalidae	Butterfly
32	*Danaus genutia*	Lepidoptera	Nymphalidae	Butterfly
33	*Euploea core*	Lepidoptera	Nymphalidae	Butterfly
34	*Everes lacturnus*	Lepidoptera	Lycaenidae	Butterfly
35	*Helicoverpa armigera*	Lepidoptera	Noctuidae	Moth
36	*Junonia lemonias*	Lepidoptera	Nymphalidae	Butterfly
37	*Oriens gola gola*	Lepidoptera	Hesperiidae	Butterfly
38	*Papilio demoleus*	Lepidoptera	Papilionidae	Butterfly
39	*Papilio polytes*	Lepidoptera	Papilionidae	Butterfly
40	*Parantica melaneus*	Lepidoptera	Nymphalidae	Butterfly
41	*Precis almana*	Lepidoptera	Nymphalidae	Butterfly
42	*Tirumala limniace*	Lepidoptera	Nymphalidae	Butterfly
43	*Tirumala septentrionis*	Lepidoptera	Nymphalidae	Butterfly
44	*Vanessa cardui*	Lepidoptera	Nymphalidae	Butterfly
45	*Chrysomya megacephala*	Diptera	Calliphoridae	Flies
46	*Cochliomyia macellaria*	Diptera	Calliphoridae	Flies
47	*Eristalinus* spp.	Diptera	Syrphidae	Flies
48	*Rhyncomya* spp.	Diptera	Calliphoridae	Flies
49	*Sarcophaga* spp.	Diptera	Sarcophagidae	Flies
50	*Chrysocoris* spp.	Hemiptera	Scutelleridae	Bugs
51	*Dysdercus* spp.	Hemiptera	Pyrrhocoridae	Bugs
52	*Crocothemis erytbraea*	Odonata	Libellulidae	Dragonfly

53	*Metrioptera* spp.	Orthoptera	Tettigoniidae	Crickets

Table 3: Resident time and Visitation rate of each insect class.

Flower visitors	Resident time (S) (Mean±SE)	Visitation rate (m) (Mean±SE)
Bee	14.17±2.11	35.83±5.68
Beetle	34.67±3.28	4.17±1.23
Flies	23.08±3.42	5.33±1.25
Wasp	20.58±1.96	6.00±1.47
Butterflies	19.92±2.01	3.60±0.66
Ant	53.75±4.83	2.67±0.67
Moths	97.00±12.27	2.40±0.66
Bugs	50.17±4.04	3.00±0.82
Dragonflies	28.00±2.56	2.50±0.41
Crickets	45.67±2.31	1.67±0.33

4. Discussion

Mangrove flowers are not much eye-catching as like many terrestrial angiosperms. They also lack significant provisions in the form of pollinator rewards. In comparison to other forest or garden plants, few and specific insects do pollination in mangroves. Mangrove community contains species that are both generalists and specialists (Azuma et al., 2002). Our result showed similarity with many previous studies on aspects of pollinator diversity and role in mangrove species pollination (Clarke and Meyerscough, 1991; Pandit and Choudhury, 2001; Azmi et al., 2012; Raju et al., 2012; Raju et al., 2014, Hermansen et al., 2014; Tomlinson, 2016). The report towards visitation of ants, wasp, bugs, flies, bees, cantharid beetles and moths to flowers of *A. marina* by Clarke and Meyerscough (1991) showed similarity to this study. Hermansen et al. (2014) identified 38 species that visited to flowers of *A. marina* but only *A. mellifera* was a significant pollinator. We found *A. dorsata* as a potential pollinator of 16 mangrove species under our study. They had not reported butterfly visits which had been recorded during this particular investigation. In *L. racemosa*, three groups of flower visitors were found which include bees, wasps and butterflies (Raju et al., 2014). Our study had recorded beetle and ant visitation along with bees and butterflies from flowers of *L. racemosa*. *K. candel* is a riverine mangrove, occur along the river banks and influenced by freshwater input. The flowers of this plant produce a chemical (methyl anthranilate) that is known to repel species of birds and insects like bees and butterflies (Azuma et al., 2002). We recorded beetle, wasp and moth along with previously recorded bee and butterflies from flowers of *K. candel*. Pandit and Choudhury (2001) studied a 3 day (both day and night) flower visitors of mangrove species, *A. corniculatum* and *S. ceseolaris* at Bhitarkanika. They recorded 17 species of Lepidoptera, 7 species of Hymenoptera, 3 species of Diptera, 5 species of birds and 3 species of mammals from *S. ceseolaris* and 16 species of Lepidoptera, 9 species of Hymenoptera, 2 species of Diptera, 1 species of Coleoptera and 3 species of birds from *A. corniculatum.* The genus, *'Bruguiera'* show specialised pollination through birds. They have large flowers and peculiar tube shape which attracts birds. In *B. gymnorrhiza*, the calyx is red, a colour attractive to birds (Tomlinson, 2016). In this particular study we recorded wasp, bee and ant visitation to *B. sexangula*; bee and ant from *B. gymnorhiza* (Table 4). Bees because of their structural adaptations for the collection of pollen are considered to be the most efficient pollinators (Abrol, 2012). Bees as a flower visitor have been observed in many species of the genera like, *Acanthus*, *Aegiceras*, *Avicennia*, *Excoecaria*, *Rhizophora* and *Xylocarpus* (Tomlinson, 2016). *Xylocopa varipuncta* (carpenter bee) has been identified to carry pollens of exclusive mangroves like, *A. alba*, *L. racemosa*, *S. caseolaris*, *S. ovata* and *R. apiculata* in the mangrove community of Setiu Wetlands, Terengganu (Azmi et al., 2012). Bumble bee visited flowers show increased seed set than when plant excluded from it (Miller-Struttmann, 2017). Carpenter bees have long tongue which gathers mainly pollen, but not nectar. Carpenter bee is one among the most efficient agents for cross pollination in mangrove flowers (Mani, 1995). We found it's strong association with flowers of *E. agallocha* and *A. Corniculatum* (Plate 1). This bee is very dynamic and flies actively back and forth to flowers which help in pollen dispersal and deposition. The sweet bees (*Lasioglossum* spp.) are recorded from mangroves like, *A. corniculatum, A. rotondifolia, B. gymnorhiza, K. candel* and *R. mucronata* (Supp. Table 1). They were regular visitors in flowers of *A. corniculatum* (Plate 1). Their hind legs help and make them a good candidate for pollen dispersal. Comparison of host range showed bee, ant, beetles, butterfly, flies and wasps were more general flower visitors than moths, bugs, crickets and dragonfly which were rare and occasional visitors (Figure 5).

Previously, no beetle pollinated flowers had been recorded from mangroves, which are considered to be "primitive" pollinators and typically associated with large flowers or inflorescences of much generalised type (Tomlinson, 2016). This particular study had recorded lady bird beetle (*Micraspis discolor*) visitation from 12 mangroves (54%) and thought to have a major contribution and bringing pollination in species like *A. corniculatum*, *B. cylindrical*, *S. apetala*, *A. ilicifolius*, *C. decandra* and *K. candel* (Figure 3, Plate 1). *R. mucronata* primarily wind pollinated but insect visitation also reported which supports our work.

Table 4: Mangrove species and their flower visitor class identified in the present study.

	True mangroves	Visitor class		True mangroves	Visitor class
1	*A. corniculatum* (L.)	Bee, Flies, Wasp, Beetle,	13	*K. candel* (L) Druce	Bee, Beetle, Wasp,
2	*A. ebracteatus* Vahl.	Bee, Beetle, Wasp,	14	*L. racemosa* Willd.	Bee, Beetle, Ant, Butterfly,
3	*A. ilicifolius* L.	Bee, Beetle, Butterfly,	15	*R. mucronata* Lamk.	Bee, Beetle, Ant
4	*A. rotondifolia* Roxb.	Bee, Wasp, Ant	16	*S. apetala* Buch. - Ham.	Beetle, Moth, Bird
5	*A. alba* Blume	Bee, Beetle, Dragonfly,	17	*X. granatum* Koenig	Bee, Beetle, Moth, Bugs,
6	*A. marina* (Forsk.)Veierh	Bee, Beetle, Moth, Flies,		Mangrove associates	
7	*A. officinalis* L.	Bee, Beetle, Ant, Flies,	18	*C. crista* L.	Butterfly, Crickets, Moth,
8	*B. cylyndrica* (L.) Blume	Beetle, Ant, Flies	19	*C. odollam* Gaertn	Ant, Butterfly, Moth,
9	*B. sexangula* (Lour.)	Bee, Ant, Wasp, Bird	20	*E. indica* (Willd.) Mull.	Bee, Flies, Ants, Butterfly,
10	*B. gymnorrhiza* (L)	Bee, Ant, Bird	21	*S. parsica* L.	Bee, Beetle, Flies, Ant, Bird
11	*E. agallocha* L.	Bee, Wasp, Flies, Bugs,	22	*T. troupii* H.	Bee, Butterfly, Bird
12	*H. fomes* Buch-Ham.	Bee, Ant, Spider			

Ant and honey bee visitation to flowers of *H. fomes* showed their role in pollination of this south Asian endemic species. High resident time indicates it to be a forging species. An insect having high visitation rate and low resident time is a good pollinator (Landry, 2013). Our study showed, bees, butterflies, and wasps are efficient mangrove pollinators with low resident time and high visitation rate (Table 3). The species of former group with highest visitation rate, low resident time and with structural adaptation placed them a potential candidate in bringing mangrove pollination. Bugs, moths and ants were forging species and contribute little to the mangrove pollination as lack structural adaptation to carry pollens from flowers.

We reviewed literature of eighteen mangrove species that showed all species were more or less associated with biotic pollinators like insects more commonly from family Hymenoptera, Diaptera, Coleoptera and Lepidoptera (Marshall, 1983; Clarke and Meyerscough, 1991; Raju et al., 1994; Sun et al., 1998; Naskar and Mandal, 1999; Pandit and Choudhury, 2001; Raju et al., 2006; Ghosh et al., 2008; Nagarajan et al., 2010; Ghosh and Chakraborti, 2012; Raju et al., 2012; Pandey and Pandey, 2013; Hermansen et al., 2014; Raju and Raju, 2014; Raju et al., 2014; Tomlinson, 2016) (Table 5). The latter two groups spend enough time for nectar foraging. Mangrove flowers are not much attractive but still able fascinate few unique insects that bring successful pollination.

The work of Faegri and Pijl (1979) and Abrol (2012) on pollination syndrome (characters which attracts or favors for pollination) also supported our findings (Table 6). The yellow/brown coloured flower of *Avicennia sp.* and *B. sexangula*; Blue colour in *A. ilicifolius* are commonly visited by bees. White flowered species of *A. corniculatum* and *A. rotondifolia* with ample nectar were found to be frequently visited by bees, i.e., Honeybee and *Losioglossum* spp. (Supp. Table 1; Plate 1). Thus, attracting pollinators is a prerequisite for reproductive success in angiosperms (Moyroud and Glover, 2017). Past work showed the genus, *Sonneratia* have night blooming flowers which attract bats for foraging and pollination (Table 5). Beetle and moth visits to flowers of *Sonneratia* spp. had been recorded from this study (Table 4). Butterfly visitation to *T. troupii*; flies visitation to *E. agallocha* and *E. indica*; beetle visitation to *A. corniculatum*, *A. rotondifolia*, *K. candel* and *R. mucronata* etc., bird pollination in *B. sexangula* and *B. gymnorhiza*; moth visitation of mangrove associates like, *C. odollam* and *C. crista*; ant visits to *A. corniculatum* and *A. rotondifolia*, *X. granatum* and *H. fomes* were supported by previous studies on pollination syndrome (Faegri and Pijl, 1979; Abrol, 2012).

Table 5: Result of literature review showing studies on flower visitors and pollinators of different mangrove species.

Mangrove	Wind	Insect (H/D/C)	Butterfly (L)	Bird	Bats
A. corniculatum (L.) Blanco	-	3, 5, 6, 12*°	6, 12	6, 12	-
A. rotondifolia Roxb.	-	5	-	-	-
A. illicifolius L.	-	3*	-	3	-
A. alba Blume	-	11*	11	-	-
A. marina (Forsk.)Veierh	-	2*, 10*, 11, 13	2	-	-
A. officinalis L.	-	3,11*°	11	-	-
R. mucronata Lamk.	3,5,8,16	8*, 10*	-	-	-
B. cylindrical (L.) Blume	-	16	3, 5	-	-
B. gymnorhiza (L.) Lamk.	-	9*	-	3, 5, 16	-
B. sexangula (Lour.) Poir	-	9*	-	3, 5, 16	-
C. crista L.	-	5°,14*°	14	-	-
C. decandra (Griff.) Ding Hou	-	8, 7, 10*, 16	-	-	-
E. agallocha L.	-	5*	-	-	-
K. candel (L) Druce	-	3, 4*°, 5, 16	4, 5	-	-
L. racemosa Willd.	-	3, 15*, 16	15	-	-
Sonneratia sp.	-		-	-	1, 16
X. granatum Koenig	-	5*	-	-	-
H. fomes Buch.-Ham.	-	5*	-	-	-

Note: 1: Marshall, 1983; 2: Clarke and Meyerscough, 1991; **3:** Raju et al., 1994; 4: Sun et al., 1998; 5: Naskar and Mandal, 1999; 6: Pandit and Choudhury, 2001; 7: Raju et al., 2006; 8: Ghosh et al., 2008; 9: Nagarajan et al., 2010; 10=Ghosh and Chakraborti, 2012; 11: Raju et al., 2012; 12: Pandey and Pandey, 2013; 13: Hermansen et al., 2014; 14: Raju and Raju, 2014; 15: Raju et al., 2014; 16: Tomlinson, 2016

[H: Hymenoptera, D: Diaptera, C: Coleoptera, L: Lepidoptera and *=Honeybee, °= Bumble bee]

Among the four bee species i.e., honey bee, carpenter bee, sweet bee and bumble bee, we observed that honey bees were more common and visited inflorescence in group. A single inflorescence of *Salvadora parsica* was noted to host approximately about 10-15 honey bees at a particular time. Similar results were recorded from mangroves like, *A. corniculatum*, *A. marina* and *B. sexangula*. Carpenter bees were the second most sociable after honey bees and recorded in groups of approximately 3-4 from the flowers of *A. corniculatum* and *E. agallocha*. Bumble bee and sweet bee were rare and single individuals had been recorded from the visited flowers. During this particular work we noted anti-herbivory role of *Micraspis discolor* (Ladybird beetle) which prevents leaf herbivory and damage in many mangrove species. Leaf area loss by herbivores is a common phenomenon in mangroves like genera *Avicennia, Kandelia, Cerops* and *Rhizophora.* Presence of *Micraspis discolor* on mangrove leaves protect leaves from herbivory damages along with play a critical role in pollination (Plate 1). Honey bee not only brings successful pollination, it also supports the earnings of local livelihood through high quality honey production. About 200 tons of honey and 50 tons of beeswax are harvested annually from reserve forest of Sundarbans (Gani, 2001). This is 50 percentage of total honey production of Bangladesh. In Bhitarkanika, honey is collected by the local people largely to sell in the market as resource for their livelihood (Hussain and Badola 2010).

Table 6: Pollination syndromes: Traits of flowers pollinated by different pollinators, (Adapted after, Faegri and Pijl, 1979; Abrol, 2012).

Pollinator class	Floral morphology	Colour	Scent	Nectar tube	Primary attractants	Toughness	Floral opening
Insects (Entomophily)	Differs with type of pollinators	Yes	Yes	Yes		Not enough	Day and night
Bees (Melitophily)	Zygomorphic with great depth effect, mechanically strong adequate landing facility	Blue, yellow, purple (except red)	Sweet smell	Nose size or Long body width	Nectar hidden deep; sucrose rich; abundant pollen	Not enough, have a landing platform or lip	Day and night
Flies (Myophily)	Actinomorphic, regular, simple, funnel-like	Light or dull, whitish	Imperceptible	Open cups	Nectar	Not tough	Day and night
Butterflies (Psychophily)	Actinomorphic, flowers in group, erect radial, good landing facilities	Dull brown, white, blue and purple	Weak	Long narrow	Nectar in ample quantities, hidden at base of pollen tubes	Not tough, no landing platform	Day and night
Moths (Phalaenophily)	Actinomorphic or Zygomorphic, horizontal	Pale, purple, white	Strong sweet, nocturnal	Long narrow	Nectar in large but hidden in tubes	Not tough, no landing platform	Night
Ants (Myrmecophily)	Small, sessile, close to ground	∗White, purple, blue	∗Faint	∗Hidden deep	Nectar and Pollen	------------	∗Day and night
Beetles (Cantharophily)	Actinomorphic, large shallow, often bowl shaped blossoms	Dull white, purple or brown	Strong fruity	No	Mostly pollen, Sometimes nectar	Not enough	Day and night
Wasp (Sphecophily)		Dull brown			Nectar		Day and night
Birds (Ornithophily)	Large container like, tubular or funnel like strong supports for perch.	Red, yellow or orange	No (birds can't smell)	Long wider	Nectar, insects sitting flower, rarely pollen	Tough, leathery, plenty of nectar	Day and night
Wind (Anemophily)	Regular, small, Unisexual (either monoecious or dioecious species), highly reduced perianth, anthers and stigmas exerted	Yellow or brown, may be absent or reduced	No	No	-------	Not tough, big anthers, plenty of pollen. Stigmas feathery to catch the pollen	Day and night

∗ From present study

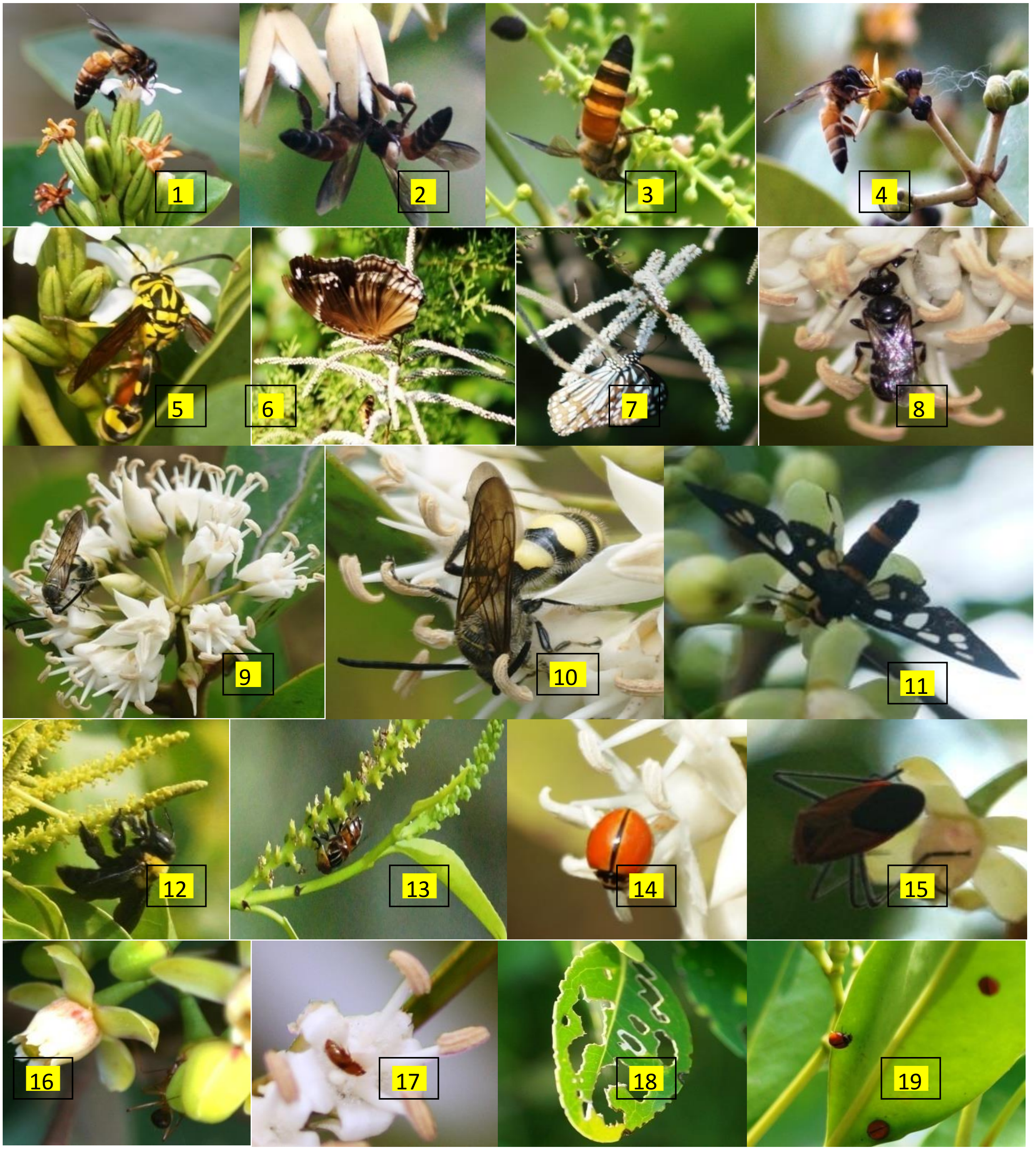


Plate 1: Flower visitors and presumed pollinators in different mangrove species of BWS and DE.

[Note: 1-4: *A. dorsata* (Giant honey bee) on flowers of *A. rotondifolia*, *R. mucronata*, *S. parcica* and *A. officinalis*, respectively; 5: *Vespula sp.* on flower of *A. rotondifolia;* 6-7: *Euploea core* and *Tirumala limniace* on flowers of *T. troupii*, respectively; 8: *Lasioglossum sp.*1 on flower of *A. corniculatum*; 9-10: *Lasioglossum sp.*2 on flower of *A. corniculatum*; 11: *Amata sperbius* feeding on flowers of *X. granatum*; 12: *Xylocopa pubescens* visiting flowers *E. agallocha;* 13: *Nomia sp.* on *E. indica;* 14: *Micraspis discolor* sitting on flower of *A. corniculatum*; 15 & 16: *Dysdercus sp.* (bug) & Ant visitation on flowers of *X. granatum*, respectivly*;* 17: A bug (*Aulacophora sp.*) sitting on *A. corniculatum;* 18: Herbivory of mangrove leaves; 19: Undamaged leaves in presence *of Micraspis discolor* on *K. Candel*]

5. Conclusion

Mangroves are exclusively seed propagated plants. Excluding *Rhizophora* spp. which bears predominantly wind pollinated mangroves, all other species more or less depend on biotic agents/pollinators for effective pollen transfer. Habitat degradation, conversion to aquaculture land, use of pesticides in agriculture, introduction of exotic plant species are strongly affecting the existence and action of natural pollinators. 'Bhitarkanika' being the second large single mangrove patch in India, presently experiencing loss of species diversity for which it was previously known throughout the globe. Impact of climate change on pollinator availability and specialist pollination in mangroves can further studied towards effective management of fragile ecosystem like mangrove.

Giving more emphasis on bee keeping can help to increase the reproductive success and seed output in many mangroves. Not only the honey bee but others like Carpenter bee (*Xylocopa* spp.), Sweet bee (*Lasioglosum* spp.) may need to be given priority for increase of their population. Conservation of associate mangrove species will give additional advantage to maintain true mangrove diversity as they provide alternative forage during non flowering period of true mangrove species. Making policies and law to prevent use of harmful chemicals in peripheral agriculture land will help to prevent further loss of these natural pollinators. The anti-herbivory role of the predatory ladybird beetle and effect of climate change on pollinator availability in this fragile coastal ecosystem may be further investigated and can be used towards long term management.

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References

Abrol, D.P., 2012. Pollination biology: biodiversity conservation and agricultural production. *Springer Science*, 792.

Alongi, D.M., 2009. The energetics of mangrove forests. *Springer Science*, 216.

Azmi, W.A., Ghazi, R. and Mahamed, N.Z., 2012. Importance of Carpenter Bee, Xylocopa varipuncta (Hymenoptera: Apidae) as Pollination Agent for Mangrove Community of Setiu Wetlands, Terengganu, Malaysia. Sains Malaysiana, 41:1057-1062.

Azuma, H., Toyota, M., Asakawa, Y., Takaso, T. and Tobe, H., 2002. Floral scent chemistry of mangrove plants. *Journal of Plant Research*, 115:47-53.

Capinera, J.L., 2010. Insects and wildlife: arthropods and their relationships with wild vertebrate animals. John Wiley and Sons Ltd., 487.

Chinery, M (2007). Insects of Britain and Western Europe. Domino Books Ltd., 320.

Clarke, P.J. and Meyerscough, P.J., 1991. Floral biology and reproductive phenology of Avicennia marina in south eastern Australia. *Australian Journal of Botany*, 39:283-293.

Faegri, K. and Pijl, L., 1979. The principles of pollination ecology. Pergamon Press Ltd., 244.

Gani, M.O., 2001. The giant honey bee (Apis dorsata) and honey hunting in Sundarbans reserved forests of Bangladesh. In: Proceedings of 37th International Apiculture Congress, held in 28th Oct.-1st Nov., 2001, Durban, South Africa, 1-10.

Ghosh, A. and Chakraborti, P., 2012. Evaluation of some mangrove species on the nature of their reproduction along coastal belt of the Indian Sunderbans. *Journal of Threatened Taxa*, 4:2427-2435.

Ghosh, A., Gupta, S., Maity, S. and Das, S., 2008. Study of Floral Morphology of Some Indian Mangroves in Relation to Pollination. *Research Journal of Botany*, 3:9-16.

Hermansen, T.D., Britton, D.R., Ayre, D.J. and Minchinton T.E., 2014. Identifying the Real Pollinators? Exotic Honeybees Are the Dominant Flower Visitors and Only Effective Pollinators of Avicennia marina in Australian Temperate Mangroves. *Estuaries and Coasts*, 37:621-635.

Hogarth P.J., 2015. The biology of mangroves and Seagrasses. Oxford University Press, New York, 289.

Hussain, S.A. and Badola, R., 2010. Valuing mangrove benefits: contribution of mangrove forests to local livelihoods in Bhitarkanika Conservation Area, East Coast of India. *Wetlands Ecology and Management*, 18:321-331.

Jagtap, T.G., Chavan, V.S. and Untawale, A.G., 1993. Mangrove Ecosystems of India: A Need for Protection. *Ambio*, 4:252-254.

Kathiresan, K. and Bingham, B.L., 2001. Biology of Mangroves and Mangrove Ecosystems. *Advance In Marine Biology*, 40:81-251.

Kearns, C.A. and Inouye, D.W., 1997. Pollinators, Flowering Plants, and Conservation Biology: Much remains to be learned about pollinators and plants. *Bioscience*, 47:297-307.

Landry C.L., 2013. Pollinator-mediated competition between two co-flowering Neotropical mangrove species, Avicennia germinans (Avicenniaceae) and Laguncularia racemosa (Combretaceae). *Annals of Botany*, 111:207-214.

Mani M.S., 1995. Insects. National Book Trust, India, 162.

Marshall A.G., 1983. Bats, Flowers and Fruit: Evolutionary Relationships in the Old World. Biological *Journal of the Linnean Society*, 20, 125-135.

Miller-Struttmann, N.E., Heise, D., Schul, J., Geib, J.C. and Galen, C., 2017. Flight of the bumble bee: Buzzes predict pollination services. *PLoS ONE*, 12:1-14.

Mitra, B., Biswas, O., Roy, S. and Chakraborti, U., 2013. Pollinators of mangroves in the perspective of Indian Sundarbans. *ENVIS Newsletter*, 21:6-11.

Moyroud, E. and Glover, B.J., 2017. The physics of pollinator attraction. *New Phytologist*. 216: 350-354.

Nagarajan, M., Krishnamoorthy Padmini, S. and Daniel, A., 2010. Nectar robbery in bird pollinated mangroves! *Current Science*, 98:603-604.

Naskar, K. and Mandal, R., 1999. Ecology and Biodiversity of Indian Mangroves. Daya Publishing House, Delhi, Vol. I and II, 754.

Noske, R.A., 1993. Bruguiera hainesii: Another Bird-Pollinated Mangrove? *Biotropica*, 25:481-483.

Pandey, R. and Pandey, C.N., 2013. Spatial and Temporal variations in floral visitors of a mangrove species-Aegiceras corniculatum (L.) Blanco-In the Marine National Park, Gujarat, India. *International Journal of Botany and Research*, 3:35-42.

Pandit, S. and Choudhury, B., 2001. Factors affecting pollinator visitation and reproductive success in *Sonneratia caseolaris* and *Aegiceras corniculatum* in a mangrove forest in India. *Journal of Tropical Ecology*. 17:431-447.

Pratap, U., 2011. The Pollination Role of Honeybees. In: Honeybees of Asia, ed. H.R. Hepburn and S.E. Radloff, Berlin, *Springer Science*, 227-255.

Raju, A.J.S., 1990. Studies on Pollination Ecology in India: A review. Proceedings of Indian National Science Academy, B56, 4:375-388.

Raju, A.J.S., Jonathan, K.H. and Lakshmi, A.V., 2006. Pollination biology of *Ceriops decandra* (Griff.) Ding Hou (Rhizophoraceae), an important true viviparous mangrove tree species. Current Science. 91:1235-1238.

Raju, A.J.S., Kumar, R. and Rajesh B., 2014. Pollination ecology of Lumnitzera racemosa Willd. (Combretaceae), a non-viviparous mangrove tree. *Taprobanica*, 6:100-109.

Raju, A.J.S., Rao, P.V.S., Kumar, R. and Mohan, S.R., 2012. Pollination biology of the crypto-viviparous Avicennia species (Avicenniaceae). *Journal of Threatened Taxa*. 4:3377-3389.

Raju, A.J.S., Reddi, C.S. and Sujatha, B., 1994. Pollination in mangrove plants. *Journal of Natcon*, 6:89-96.

Raju, P.S. and Raju, A.J.S., 2014. Pollination ecology of the Gray Nicker *Caesalpinia crista* (Caesalpiniaceae) a mangrove associate at Coringa Mangrove Forest, Andhra Pradesh, India. *Journal of Threatened Taxa*, 6:6345-6354.

Resh, V.H. and Carde, R.T. (ed.), 2009. Encyclopedia of Insects. Elsevier, Inc., 1132.

Robertson, A.I., 1991. Plant-animal interactions and the structure and function of mangrove forest ecosystems. *Australian Journal of Ecology*. 16:433-443.

Singh, A.P., 2011. Butterflies of India. Om Books International, 183.

Smetacek, P., 2017. A naturalist's guide to the Butterflies of India. John Beaufoy Publishing Limited. 176.

Sun M., Wong K.C. and Lee J.S.Y., 1998. Reproductive biology and population genetic structure of Kandelia candel (Rhizophoraceae), A viviparous mangrove species. *American Journal of Botany*. 85:1631-1637.

Tomlinson, P.B., 2016. The Botany of Mangroves. Cambridge University Press, Cambridge, UK, 418.