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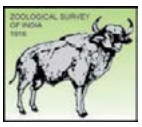

Flower Visiting Flies (Insecta: Diptera) and Their Interaction with The Flowering Plants in A Tropical Island Ecosystem

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Abstract

Pollen transportation and pollination is an essential ecological function. Flies of order Diptera perform a significant role in transfer of pollen and pollination to some extent (Raguso, 2020). In tropical island ecosystems the flower visiting dipteran flies may function simultaneously with the bees to maintain a healthy ecosystem service. However, the study of flower visiting Dipteran flies in India has received less attention from the entomologists and even lesser in island ecosystems. In tropical areas the Hymenopterans can be outnumbered by the Dipterans in terms of biodiversity (Inouye, 2001). So, the main objective of this study is to identify and make an inventory of flower visiting Dipteran flies of a tropical island along with their visited plant species. The study was conducted across the Sagar Island, West Bengal. The collection of flies and observation of the plants visited by them was done through line transect method in 10 chosen study sites containing both the crop and non-crop flowering plants. Throughout the study, a total of 41 species of flies belonging to 34 genera under 13 families have been observed to visit flowers of 32 species in our studied landscape. *Paragus (Paragus) serratus* of family Syrphidae has been found to be the most interactive fly visiting 27 different flowering plant species and *Mangifera indica* appears to be the most visited plant with 17 dipteran species visiting its flowers. We have also observed the variation in seasonal occurrence of the flower visiting flies and prepared a simple bipartite network representing the links between the dipteran flower visitors and their visited flowering plants. The outcomes illustrate a clear scenario of flower visiting Dipteran flies occurring in a tropical island which interact with the plants. This can also lead to future studies about pollination by Diptera in an island ecosystem.

Keywords: Insect-plant interaction, bipartite network, island agro-ecosystem, flower-visiting Diptera, Syrphidae

Introduction

Biodiversity in islands especially in the tropical area is always a fascinating field of study. The insect biodiversity has reached its heights in the tropics. Among the insects, order Diptera comprises about 14% of the global insect fauna (Evenhuis and Pape, 2020). The association of flowers and Dipteran flies enables pollination of various plants to some extent such as in chocolate plants (Raguso, 2020). In fact they are considered to be the primitive pollinators as they possess suctorial or lapping mouthparts (Kevan and Baker, 1983). Although bees are capable of carrying pollen with higher load, diversity and viability as compared to the flies, dipterans (specifically species from family Stratiomyidae and Syrphidae) are efficient to carry pollen up to further distances than the bees (Rader *et al.*, 2011). From the tropical region, a total of 42 families of Diptera are reported to visit flowers of which 12 families belong to the suborder Nematocera and 30 families under the suborder Brachycera (Roubik,

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1995). Syrphidae, Bombyliidae, Tephritidae, Stratiomyidae, Calliphoridae, Muscidae, Tachinidae are some of the notable families in which flower visiting flies belong to.

Bipartite ecological networks are used to depict the interaction patterns existing between two groups of organisms (such as organisms from two trophic levels) in which the connections between these two groups in different sets are considered (Zhou *et al.*, 2007). Study of ecological networks is considered as a useful tool for species conservation perspectives. In some cases, study of plant–animal mutualistic interactions may reflect the co-evolutionary processes that function dynamically throughout the timescale (Jordano *et al.*, 2003; Leimberger *et al.*, 2022). Here, the direct interactions among the organisms of same trophic level are less important (Dormann *et al.*, 2008). In this communication we try to represent the bipartite network of flowering plants (crop and non-crop) and the flower visiting flies of a tropical island. This will further demonstrate the possible interactions and foraging preferences of the flies of the island.

The study of flower visiting Dipteran flies in India has received less attention from the entomologists and even lesser in island ecosystems. It is primarily because of the Hymenopterans (the bees) who are considered as the major insect pollinators. But, in tropical areas the Hymenopterans can be outnumbered by the Dipterans in terms of biodiversity (Inouye, 2001). Limited research works exist which contributes to our knowledge about the flower visiting Diptera of India. Dhara Jothi and Tandon (1993) studied pollinator activity on Ber (*Ziziphus mauritiana*). Priti (1998), Priti and Sihag (1998) evaluated the pollination efficiency of insect pollinators on Onion (*Allium cepa*), Carrot (*Daucus carota*) and Cauliflower (*Brassica oleracea*), but the dipteran flower visitors were not given ample importance in those studies. Mukherjee *et al.* (2002) described the flower visiting hoverflies (Diptera: Syrphidae) on *Solanum nigrum* flowers. Mitra and Parui (2002a) published an account of dipteran flower visitors in Jessore Sloth Bear Sanctuary and Balaram Ambaji Wildlife Sanctuary of Gujarat. Later, Mitra *et al.* (2002, 2003, 2004, 2005, 2008); Mitra and Roy (2006); Mitra and Banerjee (2007) and Mitra (2010) published several researches about dipteran pollinators from southern West Bengal. But, no work has been conducted earlier in Sagar Island, West Bengal related to the diversity of flower visiting flies. Some isolated studies have been done in Sundarbans (Chakraborti *et al.*, 2019) and Nayachar Island (Mitra and Parui, 2002b) which are close to the Sagar Island. Moreover, none of the above mentioned works portray the scenario of any ecological interaction between the flower visiting dipteran flies and the flowering plants. Being a separate island the importance of documentation of flower visiting dipteran flies in Sagar Island is necessary from the aspect of pollination to maintain ecological balance.

The main objective of this study is to identify and make an inventory of flower visiting Dipteran flies of Sagar Island along with their visited plant species. We have also observed the variation in seasonal occurrence of the flower visiting flies in the island. At last but not the least, our objective was to prepare a simple bipartite network representing the links between the dipteran flower visitors and their visited flowering plants.

Materials and Methods

Study Area: The present study was conducted in Sagar Island, West Bengal located between 21°37' N to 21°53' N latitude and 88°02' E to 88°10' E longitude with average elevation of 4 meters. For the sampling and observation of flies, 10 different sites were chosen (Figure I) and the whole study was carried out during the year 2021-2022. The study sites were selected in and around agricultural lands on the basis of two criteria: (i) the agricultural field is active i.e. cultivation of any crop is going at that time or it is not unused in current cultivation season and, (ii) there is considerable amount of non-crop flowering plants at the edge of the agricultural field (at least 3 plants per metre irrespective of the species, when walking through line transect). These criteria were considered in choosing the study sites to ensure that we observe all kinds of flowering plants present in the island i.e. both the crop and non-crop plants.

Collection of Specimen: Each site was surveyed 3 days in each of the three major seasons - summer, monsoon and winter. Thus, it accounts to 9 days of specimen sampling in each site per year. The flies were observed and collected from two types of vegetation around the study sites – from the agricultural field (seasonal crops or vegetables); and from field side herbs, and bushes (different non-crop flowering plants intermixed). For collection of the specimens, we observed line transect method in both the vegetation types, where one covered 100 metres distance in each collection episode and collected specimens from both side of the imaginary line. Transects were carried out once in an hour from 8:00 a.m. to 4.00 pm in both the crop and non-crop vegetation on the study day. Thus it accounts to 16 transects

per day in a study site, 8 in crop and 8 in non-crop patch. The data of the visited flowering plant was recorded by another person who was following the former. The fly specimens when observed on the flowers were collected using sweep nets. Then the captured specimens were put into killing-jar where they were exposed to benzene or high dose of chloroform. After that, flies are preserved in 70% ethyl alcohol until further analysis.

Identification: The preserved specimens were identified based on the classification system of McAlpine (1989) and using appropriate literatures and taxonomic keys. For this purpose, Leica EZ4 HD optical microscope was used. The plants were identified on the field whichever possible and rest in the laboratory by taking specimens.

Data Analyses: The preliminary analysis and sorting of the data were performed in Microsoft Excel 2019. To easily visualize the data of flower visiting flies and their visited plants, we constructed a bipartite network combining all seasons and study sites of the Sagar Island. The numbers of species in each family were pooled across all the study sites to evaluate family specific species richness. We also prepared a binary visitation matrix across all the study sites where "0" indicates no encounter and "1" indicates encounter of particular species of fly on particular flowering plant species during our observation period in our study sites. Using this matrix, a bipartite interaction network was constructed in "R" software (version 4.1.3) (R Core Team, 2013) using the 'Bipartite' (Dormann *et al.*, 2020) and 'Vegan' (Oksanen *et al.*, 2013) packages. The statistical analyses were done using 'lme4' (Bates *et al.*, 2015) and 'multcomp' (Hothorn *et al.*, 2008) packages in "R" software.

Results

During our study across the agricultural landscape of Sagar Island, we observed 41 species of Dipteran flies belonging to 34 genera under 13 families. The checklist of the flies along with their seasonal occurrence is represented in Table I. Species richness of Dipteran flower visitors significantly varied in the three seasons (Table. III). From the observation across all sites, in pre-monsoon (April-May) a total of 37 species of flies were recorded followed by 36 in post-monsoon (November-December) and 26 in monsoon (July-August) (Table III). The flies visited on flowers of 32 species of plants belonging to 17 families. The plants and their respective flower visiting flies as observed were listed in Table II. Among the 32 plant species recorded, maximum number of flower visiting flies were found to visit in *Mangifera indica* (17 species), followed by *Lagenaria siceraria*, *Cucurbita maxima, Tagetes erecta* (16 species); *Lantana camara (*14 species*); Tagetes patula (*12 species*); Alternanthera sessilis, Brassica nigra* (10 species), *Parthenium hysterophorus* (9 species), *Psidium guajava, Syzygium jambos* (8 species), *Heliotropium indicum, Lippia alba* (6 species), *Cyanthillium cinereum, Oxalis corniculata, Aegle marmelos* (5 species), *Ageratum conyzoides, Eclipta prostrata, Sonchus asper, Rorippa palustris, Mentha arvensis, Ocimum sanctum* (4 species), *Hygrophila spinosa, Catharanthus roseus, Tabernaemontana coronaria, Tridax procumbens, Ipomoea carnea, Leucas aspera, Mazus pumilus, Solanum nigrum* (3 species), *Trigonella foenum-graecum* (2 species) and *Mimosa pudica* (1 species) (Table II).

Figure II depicts the species richness of the 13 observed Dipteran families. However, the species richness varied in different seasons, we pooled the data of all seasons to represent an overall scenario. Among the 13 Dipteran families, the maximum number of fly species were found from family Syrphidae (13 species), followed by Calliphoridae (6 species), Stratiomyidae, Muscidae (5 species), Tephritidae (3 species) and Rhiniidae (2 species) (Figure II). Remaining observed families (Tabanidae, Bombyliidae, Micropezidae, Lauxaniidae, Sciomyzidae, Sarcophagidae and Tachindae) were found to contain one representative species.

A total of 214 interactions were observed throughout the 3 seasons between the 41 species of flies and 32 species of plants. The resulting bipartite network is represented in Figure III. The network depicts the complete scenario of flower visiting flies and their interaction with the flowering plants of the island.

Discussion

Higher number of flower visiting flies especially Syrphid flies in agricultural landscape can increase the chance of better pollen transportation which leads to successful pollination and good crop yield (Toivonen *et al.*, 2022) thereby helps in stabilizing agro-ecosystems. Despite of having moderately high saline content in soil and water, our study revealed that Sagar Island is home to 32 species of flowering plants with 41 species of flower visiting Dipteran flies present for them to forage. According to the work of Mitra *et al.* (2008), there were 33 species of flower visiting Dipteran flies in Kolkata and its adjoining areas. The comparatively better scenario of Sagar Island suggests that this tropical island may be rich in terms of Dipteran biodiversity as compared to the nearby

mainland. However, more consolidated works are needed in the Kolkata and its surroundings for proper assessment of the current status of flower visiting flies.

The high species richness of family Syrphidae (13 species) compared to the other families (Calliphoridae is immediate next with 6 species) suggests that the flies of family Syrphidae may serve better in pollen transportation in this island agro-ecosystem. Dunn *et al.* (2020) have showed that hoverflies of genera *Eupeodes*, *Sphareophoria*, *Syrphus*, *Eristalis* and *Episyrphus* visit a wide variety of flowers, visiting atleast 40 species of plants. In our study we observed that each flowering plant species appears to have at least one species of Syrphid flower visitor (Table II). Our study revealed that *Paragus (Paragus) serratus* of family Syrphidae visited the highest number of plant species (27 species) (Figure IV). However, visiting a wide range of plant species does not establish the fly as a pollinator (Ne'eman *et. al*., 2010). Further evaluation of some key factors like the amount of pollen grains the fly can transport; how frequent the fly species deposit pollen on the stigma of the flower and the flower visitation rate of the species are required to determine the pollination ability of the fly (Herrera *et al.*, 1989; Rader *et al.*, 2009).

Among the 41 species of flies, 37 and 36 species were observed in the summer (pre-monsoon) and winter (post-monsoon) seasons respectively (Table I). Whereas in the monsoon, only 26 species of flower-visiting flies were recorded from the island. The significance of seasonal variation of the flies has been supported by the results of post-hoc Tukey test (Table III). The significant drop in the number of fly species in monsoon is primarily due to the inundation and flooding of majority of the agricultural lands, coupled with the unpleasant weather conditions. Out of the 41 species of flies, 25 species were observed in all the 3 seasons. The species richness of Syrphidae family varied in the seasons (Figure V) as in summer and winter 11 species of Syrphid flies were observed however it dropped in the monsoon to a count of 7 species. After the Syrphidae, the next major family according to species richness is Calliphoridae (Figure II) and interestingly the species richness of this family remained same throughout the year (Figure V) as all the 6 species of Calliphorid flies were encountered in 3 seasons. The flies of family Tabanidae, Bombyliidae and Tachinidae showed specific seasonal occurrence as the flies of those families were observed in monsoon, winter and summer seasons respectively.

The bipartite network (Figure III) clearly depicts that *Paragus (Paragus) serratus* (abbreviated as Pser) of family Syrphidae is the fly species with the highest number of possible interactions (visited 27 different flowering plants). On the other hand, *Mangifera indica* (abbreviated as Mind) is the plant species that received the highest number of fly species (17 species visited). The pollinator diversity of *Mangifera indica* is widely studied (Fajardo *et al.*, 2008; Chauhan *et al.*, 2018) but they do not provide any complete record of Dipteran visitors. In contrast to 7 Dipteran species reported by Chauhan *et al.* (2018), our study revealed 17 species of flies visiting the mango flowers.

Most of the flower visiting flies were unspecific in terms of preference of foraging i.e., they visited flowers of more than one species (Table II). Exceptions are there for some species e.g., *Hemipyrellia pulchra* (Hpul) of family Calliphoridae visiting only *Parthenium hysterophorus* (Phys); *Chrysomya rufifacies* (Cruf) of family Calliphoridae visiting only *Lantana camara* (Lcam) flowers; *Petrorossia ceylonica* (Pcey) of family Bombyliidae was found to visit only *Syzygium jambos* (Sjam); *Mesembrius (Mesembrius) quadrivittatus* (Mqua) *and Merodon (Merodon) equestris* (Mequ) of Syrphidae was only found on flowers of *Targetes erecta* (Tere); *Baccha (Allobaccha) amphithoe* (Bamp) of family Syrphidae visited flowers of *Aegle marmelos* (Amar) only; *Thelaira macropus* (Tmac) of Tachinidae family only visited *Heliotropium indicum* (Hind); *Hydrotaea chalcogaster* (Hcha) of family Muscidae visitied only *Alternanthera sessilis* (Ases) flowers and *Chrysops dispar* (Cdis) of Tabanidae family was found only in *Ipomoea carnea* (Icar) flowers.

Among the plants, *Mimosa pudica* (Mpud) is reported to have been visited by only one species of fly- *Episyrphus (Episyrphus) balteatus* (Table II). The rest of all plants interacted with more than one species of fly.

Our study provides pioneering information about the interactions among specific Dipterans and specific plants in an eastern Indian island ecosystem dominated by tropical agricultural landscape. As our results show, there are a number of fly species encountered in our study that are reported to be pollinators. This information may be useful for the sustainable agriculture where diverse floral species may be maintained that supports ecologically important fly species to augment ecosystem service (e.g., pollination) delivery across an island agro-ecosystem.

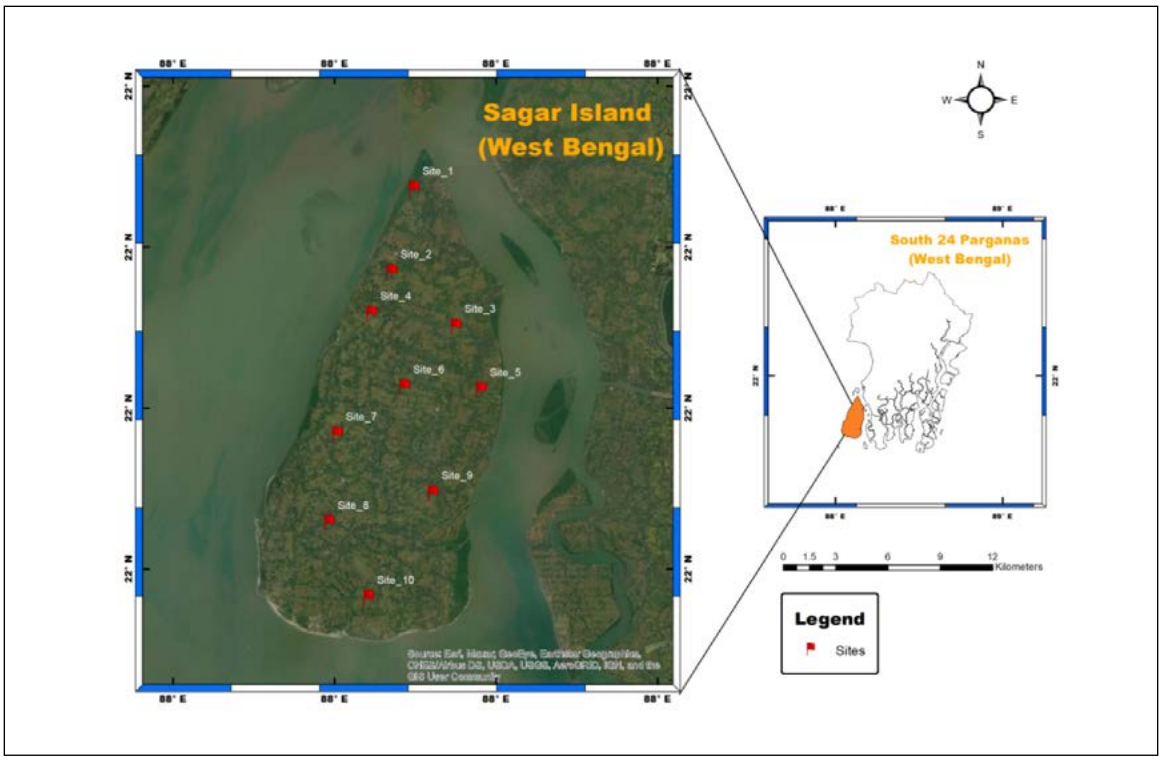

Figure I. Map showing the study sites in Sagar Island.

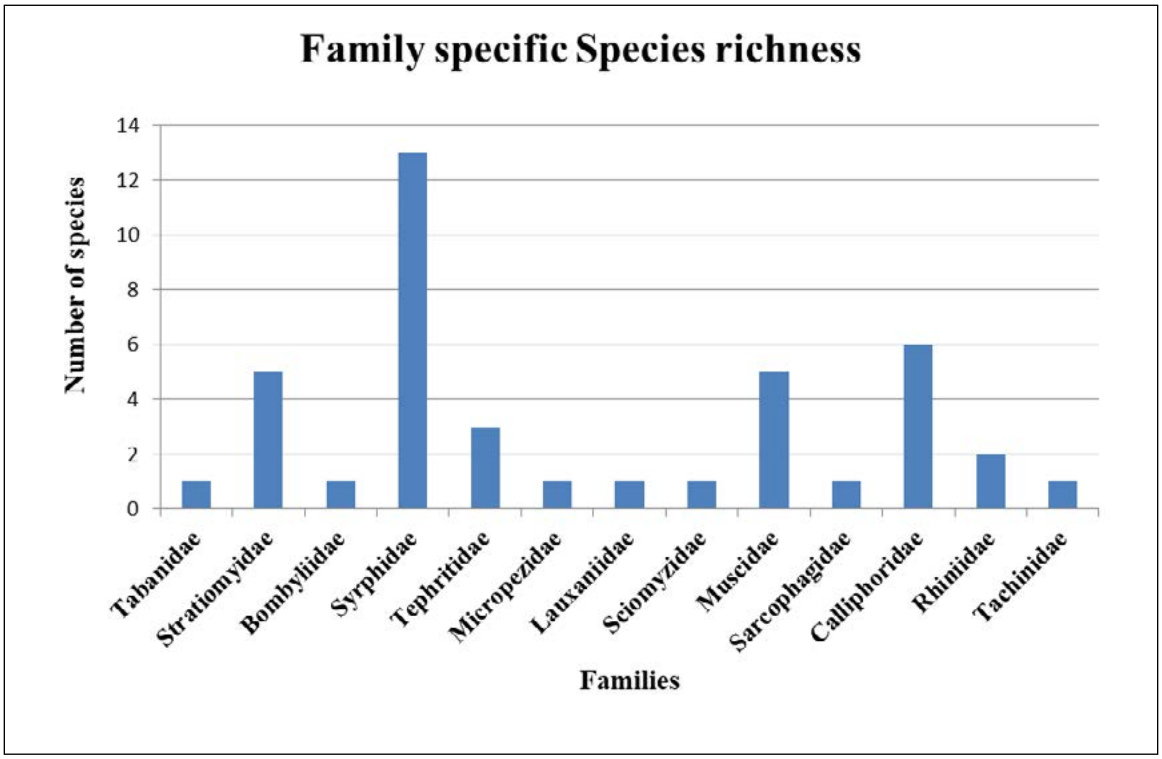

Figure II. Family specific Species Richness of different dipteran families associated with flower visiting in Sagar Island, West Bengal.

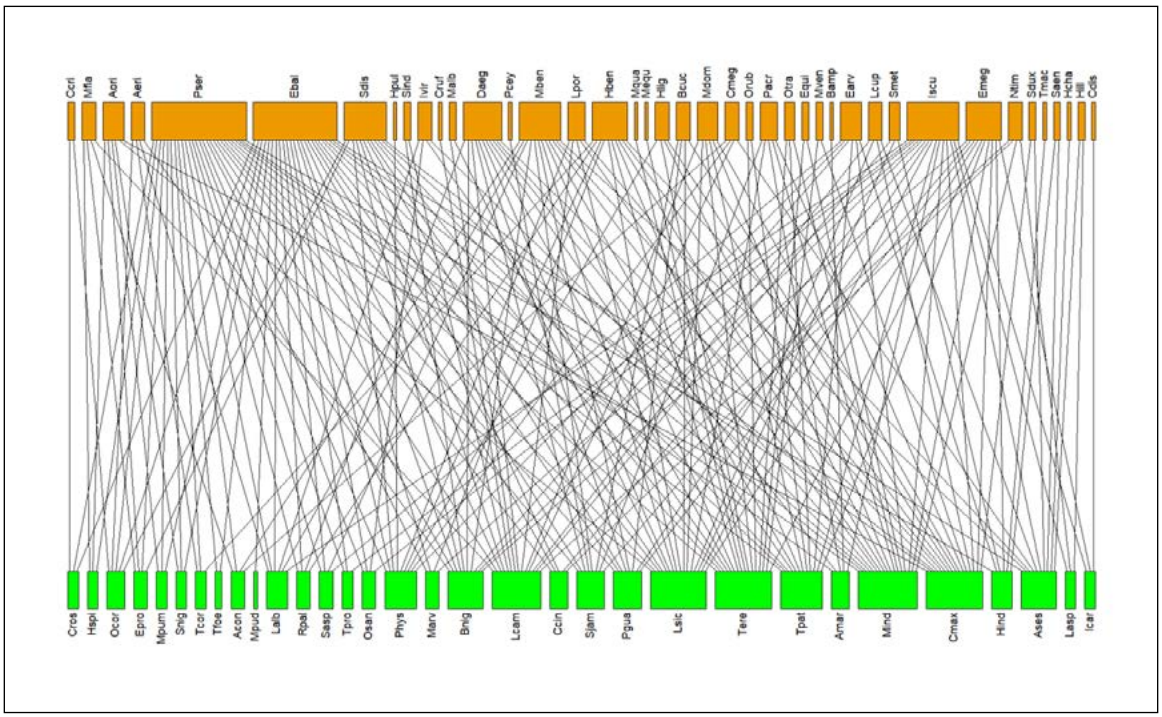

Figure III. Bipartite Network showing the possible interactions between the two trophic levels: the flower visiting dipteran flies (upper orange boxes or nodes) and flowering plants (lower green boxes or nodes) as produced from the observations in Sagar Island, West Bengal. For the abbreviations and respective species names, refer to Table I and Table II.

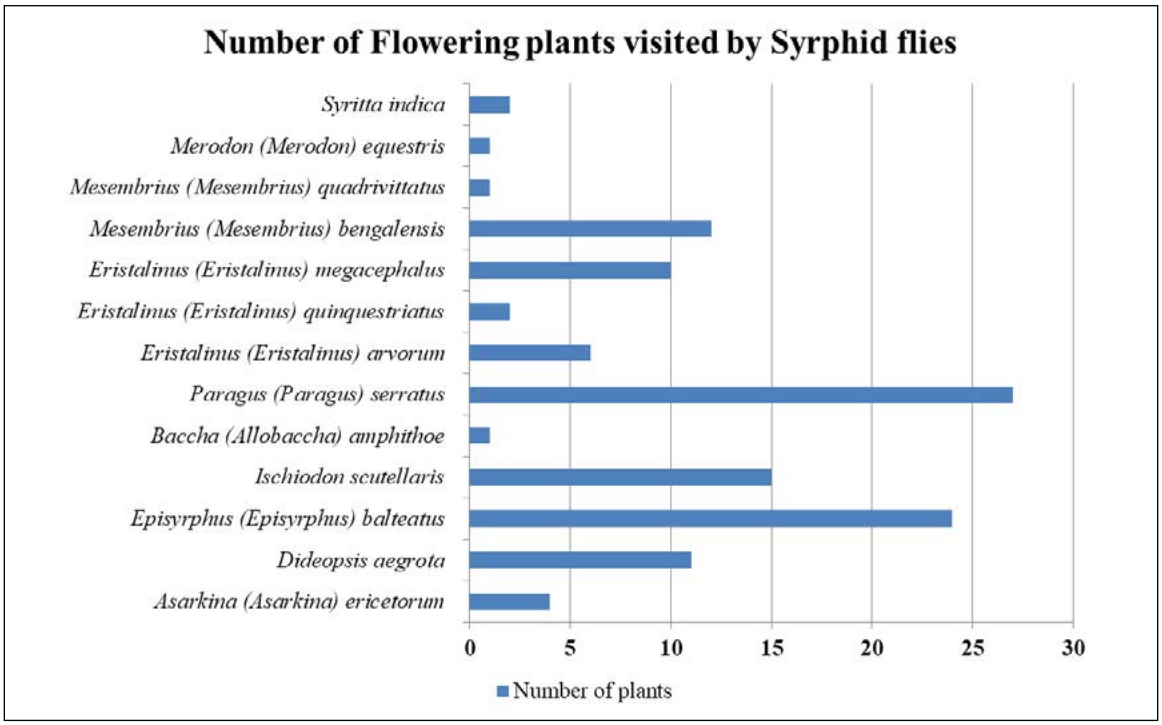

Figure IV. Number of flowering plants visited by different Syrphid species (pooled data of 3 seasons).

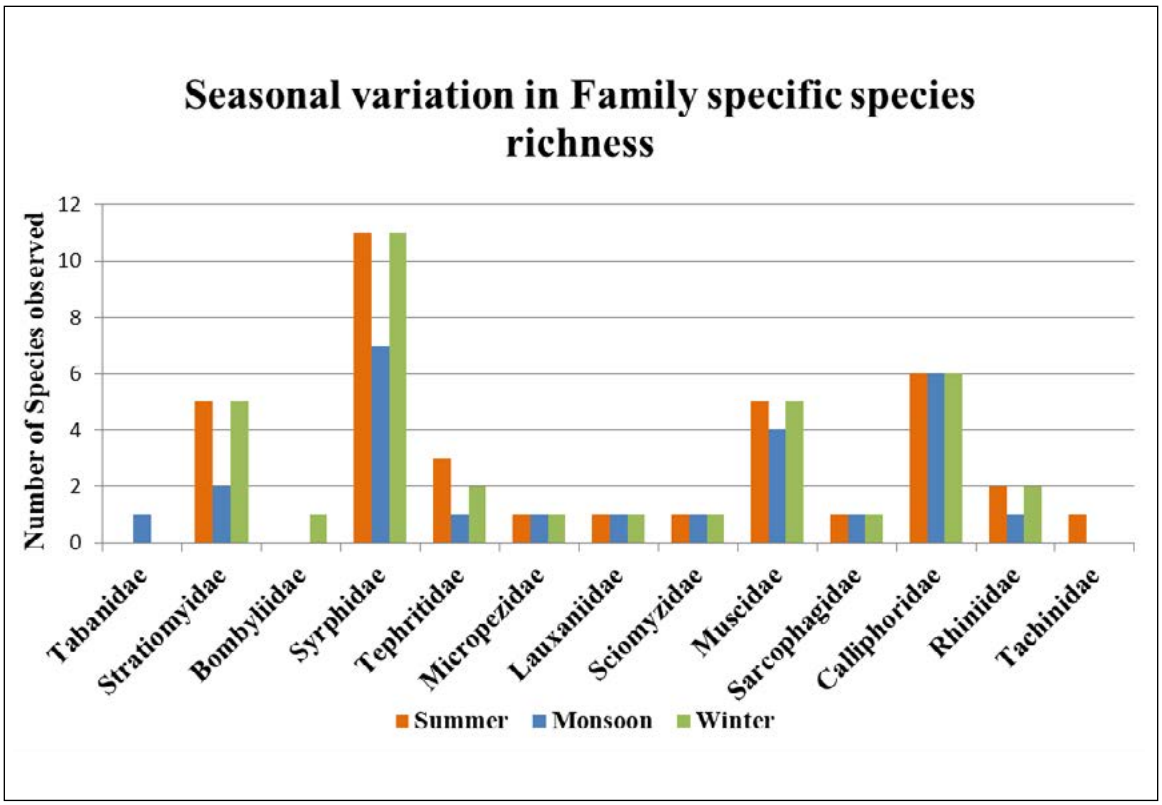

Figure V. Seasonal variation in species richness of different flower visiting fly families as observed in the Sagar Island.

Table I. List of dipteran species recorded during the study with their seasonal occurrence. (S = Summer, M = Monsoon and W = Winter, '+' denotes present, '-' denotes absence).

Sl. No.	Species name	Abbreviation used in the network	Occurrence in season		
			S	M	W
Family Tabanidae					
1	*Chrysops dispar* (Fabricius, 1798)	Cdis	-	+	-
Family Stratiomyidae					
2	*Microchrysa flaviventris* Wiedemann, 1824	Mfla	+	-	+
3	*Sargus metallinus* Fabricius, 1805	Smet	+	+	+
4	*Odontomyia transversa* Brunetti, 1920	Otra	+	-	+
5	*Oplodontha rubrithorax* (Macquart, 1838)	Orub	+	-	+
6	*Hermetia illucens* (Linnaeus, 1758)	Hill	+	+	+
Family Bombyliidae					
7	*Petrorossia ceylonica* (Brunetti, 1908)	Pcey	-	-	+
Family Syrphidae					

Sl. No.	Species name	Abbreviation used in the network	Occurrence in season		
			S	M	W
8	*Asarkina (Asarkina) ericetorum* (Fabricius, 1781)	Aeri	+	+	+
9	*Dideopsis aegrota* (Fabricius, 1805)	Daeg	+	+	+
10	*Episyrphus (Episyrphus) balteatus* (De Geer, 1776)	Ebal	+	+	+
11	*Ischiodon scutellaris* (Fabricius, 1805)	Iscu	+	+	+
12	*Baccha (Allobaccha) amphithoe* Walker, 1849	Bamp	+	-	-
13	*Paragus (Paragus) serratus* (Fabricius, 1805)	Pser	+	+	+
14	*Eristalinus (Eristalinus) arvorum* (Fabricius, 1787)	Earv	+	-	+
15	*Eristalinus (Eristalinus) quinquestriatus* (Fabricius, 1794)	Equi	-	-	+
16	*Eristalinus (Eristalinus) megacephalus* (Rossi, 1794)	Emeg	+	+	+
17	*Mesembrius (Mesembrius) bengalensis* (Wiedemann, 1819)	Mben	+	+	+
18	*Mesembrius (Mesembrius) quadrivittatus* (Wiedemann, 1819)	Mqua	+	-	+
19	*Merodon (Merodon) equestris* (Fabricius, 1794)	Mequ	-	-	+
20	*Syritta indica* (Wiedemann, 1824)	Sind	+	-	-
Family Tephritidae					
21	*Bactrocera (Zeugodacus) cucurbitae* (Coquillett, 1899)	Bcuc	+	+	+
22	*Platensina acrostacta* (Wiedemann, 1824)	Pacr	+	-	+
23	*Campiglossa cribellata* Bezzi, 1913	Ccri	+	-	-
Family Micropezidae					
24	*Mimegralla albimana* (Doleschall, 1856)	Malb	+	+	+
Family Lauxaniidae					
25	*Homoneura (Neohomoneura) bengalensis* (Macquart,1843)	Hben	+	+	+
Family Sciomyzidae					
26	*Sepedon aenescens* Wiedemann, 1830	Saen	+	+	+
Family Muscidae					
27	*Musca (Byomya) ventrosa* Wiedemann, 1830	Mven	+	+	+
28	*Musca (Musca) domestica* Linnaeus, 1758	Mdom	+	+	+
29	*Neomyia timorensis* (Robineau-Desvoidy, 1830)	Ntim	+	-	+
30	*Hydrotaea chalcogaster* (Wiedemann, 1824)	Hcha	+	+	+
31	*Atherigona (Acritochaeta) orientalis* Schiner, 1868	Aori	+	+	+
Family Sarcophagidae					
32	*Sarcophaga (Liosarcophaga) dux* (Thomson, 1869)	Sdux	+	+	+

Sl. No.	Species name	Abbreviation used in the network	Occurrence in season		
			S	M	W
Family Calliphoridae					
33	*Lucilia porphyrina* (Walker, 1856)	Lpor	+	+	+
34	*Lucilia cuprina* (Wiedemann, 1830)	Lcup	+	+	+
35	*Hemipyrellia ligurriens* (Wiedemann, 1830)	Hlig	+	+	+
36	*Hemipyrellia pulchra* (Wiedemann, 1830)	Hpul	+	+	+
37	*Chrysomya megacephala* (Fabricius, 1794)	Cmeg	+	+	+
38	*Chrysomya rufifacies* (Macquart, 1843)	Cruf	+	+	+
39	*Isomyia viridaurea* (Wiedemann, 1819)	Ivir	+	-	+
Family Rhiniidae					
40	*Stomorhina discolor* (Fabricius, 1794)	Sdis	+	+	+
Family Tachinidae					
41	*Thelaira macropus* (Wiedemann, 1830)	Tmac	+	-	-

Table II. List of flowering plant species observed during the study in Sagar Island, along with the visiting fly species.

Sl. No.	Plant Species	Abbreviation used in the network	Observed Dipteran species
Family: Acanthaceae			
1	*Hygrophila spinosa*	Hspi	*Microchrysa flaviventris, Paragus (Paragus) serratus, Atherigona (Acritochaeta) orientalis*
Family: Amaranthaceae			
2	*Alternanthera sessilis*	Ases	*Hermetia illucens, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Mesembrius (Mesembrius) bengalensis, Homoneura (Neohomoneura) bengalensis, Sepedon aenescens, Hydrotaea chalcogaster, Sarcophaga (Liosarcophaga) dux, Lucilia cuprina, Chrysomya megacephala*
Family: Anacardiaceae			
3	*Mangifera indica*	Mind	*Odontomyia transversa, Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Eristalinus (Eristalinus) arvorum, Eristalinus (Eristalinus) quinquestriatus, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Platensina acrostacta, Homoneura (Neohomoneura) bengalensis, Musca (Musca) domestica, Neomyia timorensis, Lucilia porphyrina, Hemipyrellia ligurriens, Isomyia viridaurea, Stomorhina discolor*

Sl. No.	Plant Species	Abbreviation used in the network	Observed Dipteran species
Family: Apocynaceae			
4	*Catharanthus roseus*	Cros	*Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Campiglossa cribellata*
5	*Tabernaemontana coronaria*	Tcor	*Asarkina (Asarkina) ericetorum, Paragus (Paragus) serratus, Homoneura (Neohomoneura) bengalensis*
Family: Asteraceae			
6	*Ageratum conyzoides*	Acon	*Microchrysa flaviventris, Paragus (Paragus) serratus, Mesembrius (Mesembrius) bengalensis, Chrysomya megacephala*
7	*Cyanthillium cinereum*	Ccin	*Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Neomyia timorensis, Stomorhina discolor*
8	*Eclipta prostrata*	Epro	*Microchrysa flaviventris, Paragus (Paragus) serratus, Atherigona (Acritochaeta) orientalis, Stomorhina discolor*
9	*Parthenium hysterophorus*	Phys	*Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Eristalinus (Eristalinus) arvorum, Homoneura (Neohomoneura) bengalensis, Lucilia porphyrina, Hemipyrellia ligurriens, Hemipyrellia pulchra, Chrysomya megacephala, Stomorhina discolor*
10	*Sonchus asper*	Sasp	*Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Eristalinus (Eristalinus) arvorum, Mesembrius (Mesembrius) bengalensis*
11	*Tagetes erecta*	Tere	*Odontomyia transversa, Oplodontha rubrithorax, Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Eristalinus (Eristalinus) quinquestriatus, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Mesembrius (Mesembrius) quadrivittatus, Merodon (Merodon) equestris, Homoneura (Neohomoneura) bengalensis, Musca (Byomya) ventrosa, Musca (Musca) domestica, Hemipyrellia ligurriens, Isomyia viridaurea, Stomorhina discolor*
12	*Tagetes patula*	Tpat	*Odontomyia transversa, Oplodontha rubrithorax, Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Eristalinus (Eristalinus) arvorum, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Homoneura (Neohomoneura) bengalensis, Musca (Musca) domestica, Stomorhina discolor*
13	*Tridax procumbens*	Tpro	*Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus*
Family: Boraginaceae			
14	*Heliotropium indicum*	Hind	*Sargus metallinus, Paragus (Paragus) serratus, Eristalinus (Eristalinus) arvorum, Eristalinus (Eristalinus) megacephalus, Sepedon aenescens, Thelaira macropus*
Family: Brassicaceae			

Sl. No.	Plant Species	Abbreviation used in the network	Observed Dipteran species
15	*Brassica nigra*	Bnig	*Asarkina (Asarkina) ericetorum, Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Eristalinus (Eristalinus) arvorum, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Syritta indica, Stomorhina discolor*
16	*Rorippa palustris*	Rpal	*Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Homoneura (Neohomoneura) bengalensis*
Family: Convolvulaceae			
17	*Ipomoea carnea*	Icar	*Chrysops dispar, Ischiodon scutellaris, Eristalinus (Eristalinus) megacephalus*
Family: Cucurbitaceae			
18	*Cucurbita maxima*	Cmax	*Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Bactrocera (Zeugodacus) cucurbitae, Platensina acrostacta, Homoneura (Neohomoneura) bengalensis, Musca (Byomya) ventrosa, Musca (Musca) domestica, Atherigona (Acritochaeta) orientalis, Sarcophaga (Liosarcophaga) dux, Lucilia porphyrina, Lucilia cuprina, Hemipyrellia ligurriens, Stomorhina discolor*
19	*Lagenaria siceraria*	Lsic	*Sargus metallinus, Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Bactrocera (Zeugodacus) cucurbitae, Platensina acrostacta, Mimegralla albimana, Homoneura (Neohomoneura) bengalensis, Musca (Musca) domestica, Atherigona (Acritochaeta) orientalis, Lucilia porphyrina, Lucilia cuprina, Stomorhina discolor*
Family: Fabaceae			
20	*Mimosa pudica*	Mpud	*Episyrphus (Episyrphus) balteatus*
21	*Trigonella foenum-graecum*	Tfoe	*Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus*
Family: Lamiaceae			
22	*Leucas aspera*	Lasp	*Hermetia illucens, Ischiodon scutellaris, Neomyia timorensis*
23	*Mentha arvensis*	Marv	*Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Homoneura (Neohomoneura) bengalensis*
24	*Ocimum sanctum*	Osan	*Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Isomyia viridaurea*
Family: Mazaceae			

Sl. No.	Plant Species	Abbreviation used in the network	Observed Dipteran species
25	*Mazus pumilus*	Mpum	*Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Atherigona (Acritochaeta) orientalis*
Family: Myrtaceae			
26	*Psidium guajava*	Pgua	*Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Bactrocera (Zeugodacus) cucurbitae, Stomorhina discolor*
27	*Syzygium jambos*	Sjam	*Petrorossia ceylonica, Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Eristalinus (Eristalinus) megacephalus, Mesembrius (Mesembrius) bengalensis, Bactrocera (Zeugodacus) cucurbitae, Platensina acrostacta*
Family: Oxalidaceae			
28	*Oxalis corniculata*	Ocor	*Asarkina (Asarkina) ericetorum, Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Campiglossa cribellata, Stomorhina discolor*
Family: Rutaceae			
29	*Aegle marmelos*	Amar	*Dideopsis aegrota, Ischiodon scutellaris, Baccha (Allobaccha) amphithoe, Paragus (Paragus) serratus, Platensina acrostacta*
Family: Solanaceae			
30	*Solanum nigrum*	Snig	*Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Atherigona (Acritochaeta) orientalis*
Family: Verbenaceae			
31	*Lippia alba*	Lalb	*Asarkina (Asarkina) ericetorum, Episyrphus (Episyrphus) balteatus, Ischiodon scutellaris, Paragus (Paragus) serratus, Mesembrius (Mesembrius) bengalensis, Isomyia viridaurea*
32	*Lantana camara*	Lcam	*Microchrysa flaviventris, Sargus metallinus, Dideopsis aegrota, Episyrphus (Episyrphus) balteatus, Paragus (Paragus) serratus, Syritta indica, Mimegralla albimana, Musca (Musca) domestica, Neomyia timorensis, Lucilia porphyrina, Lucilia cuprina, Chrysomya megacephala, Chrysomya rufifacies, Stomorhina discolor*

Table III. Tukey's post-hoc test to determine the differences in species richness of flower-visiting flies among three seasons across all study sites.

Seasons	Z - value	P - value
Pre-monsoon – Monsoon	- 6.336	< 0.001
Monsoon – Post-monsoon	- 9.630	< 0.001
Post-monsoon – Pre-monsoon	3.315	0.00256

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