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FLIES MATTER: A STUDY OF THE DIVERSITY OF DIPTERA FAMILIES (INSECTA: DIPTERA) OF MUMBAI METROPOLITAN REGION, MAHARASHTRA, INDIA, AND NOTES ON THEIR ECOLOGICAL ROLES

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Flies matter: a study of the diversity of Diptera families (Insecta: Diptera) of Mumbai Metropolitan Region, Maharashtra, India, and notes on their ecological roles

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Abstract: Diptera is one of the three largest insect orders, encompassing insects commonly known as 'true flies'. They are one of the most important in terms of their interactions with humans. Family-level diversity of Diptera was studied in the Mumbai Metropolitan Region (MMR)—50 families were recorded in four protected areas—Sanjay Gandhi National Park, Tungareshwar Wildlife Sanctuary, Karnala Bird Sanctuary, and Matheran Eco-Sensitive Zone, of which 24 were also found in urban areas of Mumbai and Thane City. The MMR's family-level dipteran diversity constitutes 78% of families documented in the Western Ghats and 57% of India's known families of Diptera. The recorded Diptera families were segregated into two groups based on their habits - beneficial and pestiferous. Of the 50 families, 66% comprised members which were beneficial in terms of flower visitations (28%), decomposition (24%), and predators and parasitoids of pest insects (14%), whereas 34% comprised members that were pestiferous in nature in terms of posing a threat to human health and causing nuisance (11%), causing crop and food damage (12%), posing a threat to animal health (8%), and as parasitoids of beneficial insects (3%). In terms of their feeding preferences, the majority of the adults were flower visitors (26%), 24% were saprophagous, followed by members that were frugivorous, fungivorous, coprophagous, and predatory in nature. Among larval feeding habits, 31% were detritivorous, 18% phytophagous, and 13% predatory in nature. In terms of their habitat preferences, 24 families were found in dense undergrowth, 12 in mountainous forests, and 11 in fruit gardens. This study establishes that Diptera is more diverse in natural areas than urban areas, and emphasizes the need for further exploration in terms of taxonomic and ecological studies, and economic benefits vis-à-vis the losses they incur in the region.

Keywords: Diptera, diversity, ecology, MMR, Mumbai Metropolitan Region, true flies.

Abbreviations: KBS - Karnala Bird Sanctuary; MESZ - Matheran Eco-Sensitive Zone; MMR - Mumbai Metropolitan Region; SGNP - Sanjay Gandhi National Park; TWS - Tungareshwar Wildlife Sanctuary; UA - Urban area; WG - Western Ghats.

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INTRODUCTION

Diptera is an order of insects commonly referred to as true flies. Diptera stands for two-winged insects (*di* = two; *ptera* = wings), because the first pair of wings is primarily used for flying and the second pair is modified to form a small, club-shaped structure called halteres which aids in flight. Diptera is one of the three largest and diverse insect orders in terms of species richness, habitat exploitation, and life habits (Skevington & Dang 2002; Ssymank et al. 2008; Courtney et al. 2009), representing about 10% of world's biodiversity (Brown 2005). It is one of the most important in terms of its interaction with humans - especially in terms of spreading diseases and causing agricultural losses (Courtney et al. 2009; Pape 2009; Marshall 2012). The benefits that Diptera provide to the ecosystem are significant although less understood. Flies contribute to pollination of plants, biological control of pest insects, help in degradation of dung, carrion, and other organic matter (Skevington & Dang 2002; Marshall 2012). They are also of crucial importance in forensic sciences (Singh & Bharti 2000). Several authors (Pape 2009; Ghorpade 2011; Marshall 2012) have emphasised on the study of this diverse group of insects, not only for their impact on humans, but also for their role in ecosystem function. "The ecology of Diptera is shamefully side-lined" mentioned Ghorpade (2011).

India is home to a vast diversity of dipterans, with over 87 families (Alfred et al. 1998) of the estimated 188 families (Brake 2017) recorded so far. New species are continuously being discovered and described in the country, although the rate of number of dipteran species being described globally is about one percent per year (Marshall 2012). The first pioneering work on the study of Diptera in India was undertaken by Brunetti (1912, 1920, 1923) and White et al. (1940). Contributions from the Zoological Survey of India (ZSI) and other institutions have led to a better understanding of the diversity of this order across the country (Ghorpade 2011). Saha et al. (2012) and Sharma (2012a,b) have created a checklist of Diptera of the state of Maharashtra as a part of the State Fauna Series. The diversity of Diptera, however, largely remains unknown in India's financial capital and one of the largest metropolises of India, the Mumbai Metropolitan Region (MMR).

With an estimated population of over 22 million and a density of 5,361 persons km^{-2} (MMRDA 2016), MMR is one of the most populous areas of India. It lies between the biodiversity hotspot, the northern Western Ghats (WG), to its east, and the Arabian Sea to the west, in the region called North Konkan. The rivers Tansa and Patalganga flow to the north and south of the region, respectively (MMRDA 2016). The region boasts of several types of geographic features, including hills such as the Panvel-Mumbra ridge, Tungar Hills and Kanheri Hills, and mountains such as the Matheran ridge; rivers, the major among which are Ulhas, Tansa, Vaitarna, Mithi, Patalganga, and Panvel; and a coastline of 270km (MMRDA 2016). These geographic features have given rise to a variety of ecosystems; such as sandy and rocky shorelines, mudflats and mangrove forests, dry and mixed deciduous forests, as well as patches of evergreen forests, harbouring a diverse array of flora and fauna. Several studies have been undertaken to understand the biodiversity of MMR, including that of big cats such as Leopards *Panthera pardus*, insects such as butterflies and beetles, arachnids such as spiders and scorpions, as well the floral species; there are, however, lacunas in our understanding of some major groups of animals and plants—terrestrial as well as aquatic. In case of taxonomic studies of Diptera, about 87 families have been documented in India (Alfred et al. 1998), of which 64 are recorded in the WG (Ghorpade 2011). There are very limited records and collections from Mumbai, earliest of which were made by Brunetti (1923). Only two species of Stratiomyidae (Wachkoo et al. 2017) and four species of Syrphidae (Ghorpade 2015) were collected from the MMR. Studies focusing on Diptera as vectors, particularly *Aedes aegypti* and *A. albopictus* (Culicidae) (Kumar et al. 2014) and on an important pest of fruits, *Bactrocera zonata* (Tephritidae) (Choudhary et al. 2017), highlight their presence in the region. On the other hand, studies pertaining to ecology of Diptera vis-à-vis their diversity and role in ecological function, remains virtually unknown. This study aimed at identifying family-level diversity of Diptera in the MMR and at forming a baseline for further studies on this important group of insects.

MATERIALS AND METHODS

The study was mainly undertaken using visual encounter surveys between 01 June 2007 and 31 July 2009, and 01 June 2011 – 31 August 2017. The documentation was chiefly undertaken in four protected areas, Sanjay Gandhi National Park (SGNP), Tungareshwar Wildlife Sanctuary (TWLS), Karnala Bird Sanctuary (KBS), and Matheran Eco-Sensitive zone (MESZ). Two urban areas, namely Mumbai and Thane city (considered as one unit) were surveyed as urban areas (UA) (Fig 1). All

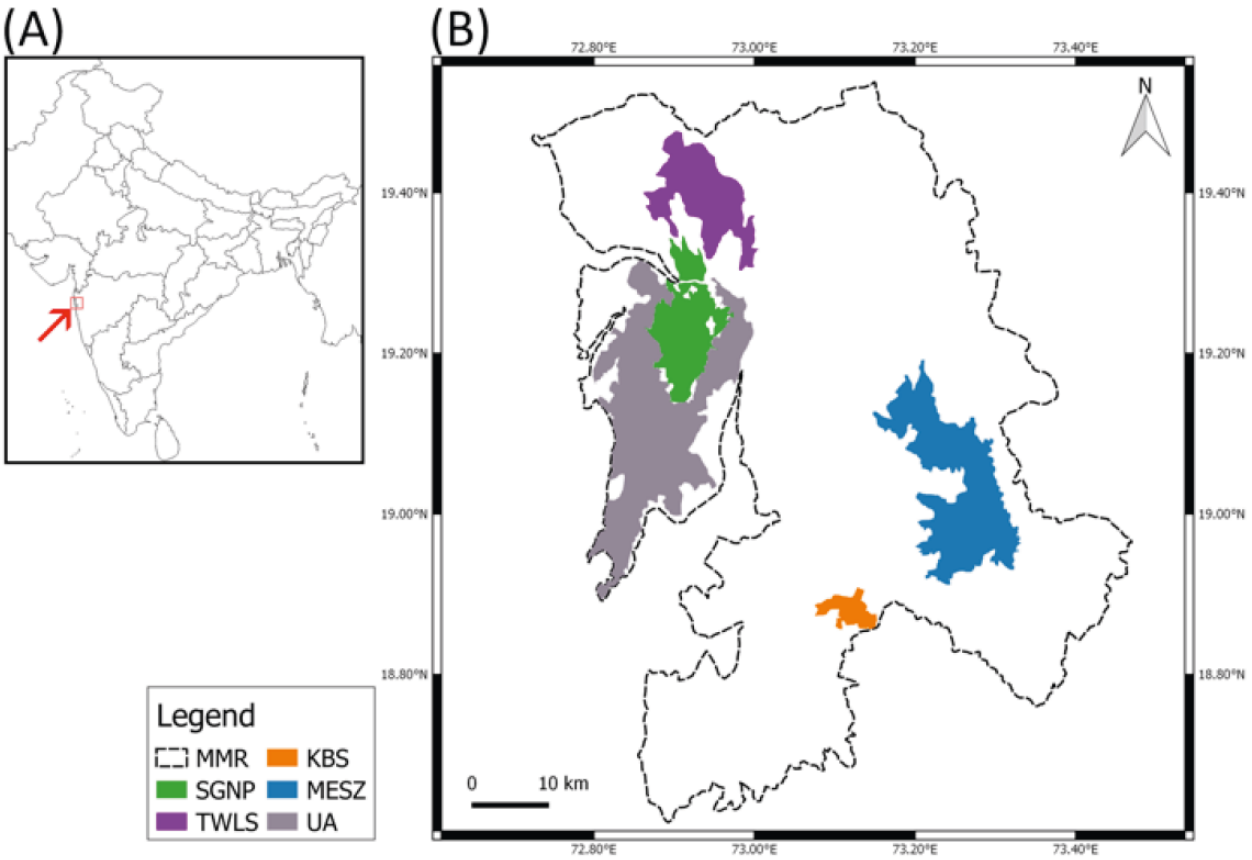

Figure 1. (A) Map showing location of the Mumbai Metropolitan Region (MMR) in India. (B) Map of the MMR showing documentation sites. Map created with QGIS 2.14.9-Essen and used for representation purposes only.
MMR = Mumbai Metropolitan Region, SGNP = Sanjay Gandhi National Park, TWS = Tungareshwar Wildlife Sanctuary, KBS = Karnala Bird Sanctuary, MESZ = Matheran Eco-Sensitive Zone, UA = Urban Area.

these sites fall under the administrative limits of the MMR.

Flies were photographed and notes were taken on their habits and the habitat they occupied through line transects on the existing forest trails measuring at least 1km, and at fixed sources of light during nights. All the four protected areas were visited at least twice every season every year except between August 2009 and May 2011. The habitats explored mainly included dry and mixed-deciduous forests, plateau grasslands, streams, riverbanks and lakes and semi-urban areas such as paddy fields and fruit gardens. In urban areas, flies were recorded opportunistically in gardens, residential areas, and garbage dump sites at particular locations in all seasons.

A. Study area

MMR lies along the Konkan coast, on the windward side of the WG, one of the 10 biogeographic regions of India. It extends over an area of 4,312km^2, interspersed with highly urbanized areas, agricultural areas, and natural spaces such as protected areas, with over 19% of the area under forest cover, 31% under agriculture, 21% under scrub/grassland/watershed, 7% under coastal wetlands, 4% under fresh water bodies, and 18% under urban built-up area (MMRDA 2016). The four natural areas in the present study cover about 9.6% of total area of the region. The study sites comprised:

1. Sanjay Gandhi National Park (SGNP): Spread over 103km^2; lies between 19.00244444 N & 72.01611111 E (Sanjay Gandhi National Park 2016; Forest Department 2016), habitat typically comprises dry and mixed deciduous forests, and basalt rock outcrops.

2. Tungareshwar Wildlife Sanctuary (TWS): Spread over 85.70km^2; lies between 19.00472222 N & and 72.00500000 E (Forest Department 2016). Habitat typically includes mixed deciduous forests.

3. Karnala Bird Sanctuary (KBS): Spread over 12.11km^2; lies between 18.85000000 N to 73.16666667 E longitude (Forest Department 2016). Habitat typically includes dry and mixed deciduous forests.

4. Matheran Eco-Sensitive Zone (MESZ): Spread over 214.73km^2; lies between 18.91666667 N &

73.85000000 E longitude (Mehta et al. 2014). Habitat typically includes dry and mixed deciduous, semi-evergreen forests, plateau grasslands, and basalt rock outcrops.

5. Urban Area (UA): The built-up area, comprising residential housing and urban gardens in two major cities of MMR were considered as urban habitats.

B. Methods

Flies were photographed through various angles to obtain morphological details such as wing venation, head and leg features, and their habitus. No specimens were sampled under this study, although dead specimens were considered as present in the area. The flies were identified up to family-level (Images 1–75) using identification keys provided by McAlpine et al. (1981, 1987), Scudder & Cannings (2006), and Marshall (2012). The families were classified as per Brake (2017). Wherever possible, individuals were identified up to subfamily/genus/species-level based on morphological observations. Feeding habits of adults were observed on field and, wherever not observed, were deduced from corresponding literature (Brooks 2002; Skevington 2002; Savage 2002; Scudder & Cannings 2006; Marshall 2012). Larval feeding habits were also based on published literature. The habitat preferences of adults were segregated into 16 microhabitats based on field observations. Based on their feeding habits, the flies were segregated into two groups, beneficial and pestiferous.

1. Beneficial: Flies that perform important ecosystem functions and/or are beneficial to humans were categorized as beneficial. It was further divided into four classes;

a. Flower visitors: Flies that feed on flowers, either on nectar or pollen, were considered as flower visitors. Since it was not certain whether they aid in pollination, they were considered as potential pollinators.

b. Decomposers: Flies (adult and/or larval) which feed on dead and decaying matter of animal or plant origin and help in the decomposition process.

c. Predators (pest control): Flies (adult and/or larval) which are predatory in nature, primarily preying upon insects considered harmful.

d. Parasitoids (pest control): Larval stages which are parasitoids of harmful insects.

2. Pestiferous: Flies that cause loss to humans in terms of spreading diseases or causing harm to humans and animals, damaging crops, and those which are parasitoids of beneficial insects. It was further divided into four classes;

a. Human-health and nuisance: Flies known to be vectors of diseases or in general caused nuisance were considered as one class. Nuisance flies included those which do not directly harm humans, but their presence, especially in large numbers, may be bothersome.

b. Animal health: Flies that infest and cause diseases in animals.

c. Crop and food damage: Flies that cause damage to standing crops and stored food including fruits, vegetables, dairy and meat products.

d. Paratitoids (of beneficial insects): Parasitic flies which target beneficial insects as hosts.

RESULTS

Diptera represents about 10% of the World's biodiversity (Brown 2005), with over 1,60,000 known species (Marshall 2012) in 188 families (Brake 2017). India is represented by 87 families containing well over 6,000 species (Alfred et al. 1998). The MMR is represented by 57% (n = 50) of family-level diversity of Diptera in India. The Zoological Survey of India has identified 37 families in the state of Maharashtra (Saha et al. 2012; Sharma 2012a,b). With the exception of four families, Chaoboridae, Acroceridae, Pipunculidae, and Oestridae, all the other families were identified in the MMR. The current study adds the following 18 families to the Diptera diversity of Maharashtra, viz., Anthomyiidae, Bibionidae, Celyphidae, Clusiidae, Hybotidae, Megamerinidae, Micropezidae, Milichiidae, Mycetophilidae, Neriidae, Platypezidae, Pyrgotidae, Rhagionidae, Scatopsidae, Sciomyzidae, Sciaridae, Therevidae, and Ulidiidae, taking the number of Diptera families of Maharashtra to 55.

Of the 64 families identified in Western Ghats (Ghorpade 2011), a considerable diversity (78%, n = 50) was recorded in the MMR. Two of the 11 families not recorded from the Western Ghats (Ghorpade 2011), Neriidae and Megamerinidae, were identified under this study, taking the diversity of Diptera of WG to 66 families. Brown (2005) identified 22 Diptera families with >2,000 species which constitute about 77% of World's described Diptera species; all the 22 families were recorded in the present study. Families with lower species diversity in the world (<200 species) found in the MMR were Megamerinidae (about 15 species worldwide), Neriidae (about 120 species worldwide), Celyphidae (about 120 species worldwide), and Diopsidae with under 200 species worldwide (Marshall 2012). Eighteen species

Table 1. A consolidated list of Diptera families of the MMR and their microhabitat preferences.

Image	Family	Common name	SGNP	TWS	KBS	MESZ	UA	Microhabitat type*
1	Agromyzidae	Leaf-miner fly	+	+		+	+	DU, UG, FG
2	Anthomyiidae	Root maggot fly	+	+	+	+	+	DU, UG, FG
3–5	Asilidae	Robber fly	+	+	+	+		VN, GL
6–9	Bombyliidae	Bee fly	+	+	+	+		OF, GL, DU
10–11	Calliphoridae	Blow fly/ blue bottle fly	+	+	+	+	+	UQ
12	Celyphidae	Beetle-backed fly	+	+	+	+		DU, FG
13	Chloropidae	Frit fly/grass fly	+	+	+	+		DU, UG, FG, VN
14	Clusiidae	Druid fly			+			DW
15	Conopidae	Thick-headed fly			+			VN
16–17	Diopsidae	Stalk-eyed fly	+		+	+		DU, HS
18	Dolichopodidae	Long-legged fly	+	+	+	+	+	DU, FG, UG
19	Drosophilidae	Fruit fly	+	+	+	+	+	DU, FG, UG
20	Empididae	Empidid dance fly				+		MF, GL
21	Ephydridae	Shore fly	+				+	HS, LP
22	Hippoboscidae	Louse fly					+	AE
23	Hybotidae	Hybotid dance fly				+		MF, DU
24	Lauxaniidae	Lauxaniid fly	+		+	+		VN, DU
25	Megamerinidae	Megamerenid fly	+					DW
26	Micropezidae	Stilt-legged fly	+	+	+	+		DU, FG, MF
27	Milichiidae	Freeloader fly	+		+		+	DU, GD, OF
28–30	Muscidae	Muscid fly/ house fly	+	+	+	+	+	UQ
31	Neriidae	Banana stalk fly				+		DU, MF
32	Phoridae	Scuttle fly	+	+	+	+	+	UQ
33	Platypezidae	Flat-footed fly	+		+			VN
34	Platystomatidae	Signal fly	+		+			DU, MF, OF
35	Pyrgotidae	Scarab-killing fly	+					OL
36	Rhagionidae	Snipe fly				+		MF
37	Rhiniidae	Rhiniid fly	+		+			FG, MF, OF, UG
38–39	Sarcophagidae	Flesh fly	+	+	+	+	+	UQ
40	Sciomyzidae	Marsh fly/ Snail-killing fly	+			+		LP
41	Sepsidae	Ant-like scavenger fly	+	+	+	+		DU, GD, AS
42	Sphaeroceridae	Small dung fly	+	+				AS
43–45	Stratiomyidae	Soldier fly	+	+	+	+	+	DU, GD, MF, OF, UG
46–49	Syrphidae	Hover fly/ Flower fly	+	+	+	+	+	DU, FG, GL, SA, UG
50–52	Tabanidae	Horse fly	+	+	+	+		GL, VN
53–54	Tachinidae	Tachinid fly	+	+	+	+		VN
55	Tephritidae	True fruit fly	+		+		+	FG, GD, UG
56–57	Therevidae	Stiletto fly	+				+	DU, DW
58	Ulidiidae	Picture-winged fly	+	+	+	+	+	DU, FG, GD, HS, MF
59	Bibionidae	March fly	+			+		HS, MF, OF, GL
60	Cecidomyiidae	Gall midge	+	+	+	+	+	UQ
61	Ceratopogonidae	Biting midge				+		HS, DU, MF
62	Chironomidae	Non-biting midge	+	+	+	+	+	LP, UQ
63–68	Culcidae	Mosquito	+	+	+	+	+	LP, UQ

Image	Family	Common name	SGNP	TWS	KBS	MESZ	UA	Microhabitat type*
69	Mycetophilide	Fungus gnat	+	+	+	+	+	DW, DU, VN
70	Psychodidae	Moth fly	+	+	+	+	+	DU, GD, SA
71	Scatopsidae	Black scavenger fly					+	AS
72–73	Sciaridae	Dark-winged fungus gnat	+	+	+	+	+	DW, DU, VN
74	Simuliidae	Black fly			+			HS, DU, MF
75	Tipulidae	Crane fly	+	+	+	+	+	UQ
	Total		40	27	35	35	24	

* AE = Animal ectoparasite; AS = Animal scat; DU = Dense undergrowth; DW = Dead wood; FG = Fruit garden; GD = Garbage dump; GL = Grassland; HS = Hill stream; LP = Lakes and pools; MF = Mountainous forest; OF = Open forest; OL = Observed at lights; SA = Sewage area; UG = Urban garden; UQ = Ubiquitous; VN = Various forest types. Note: descriptions of microhabitat types are given in Appendix A.

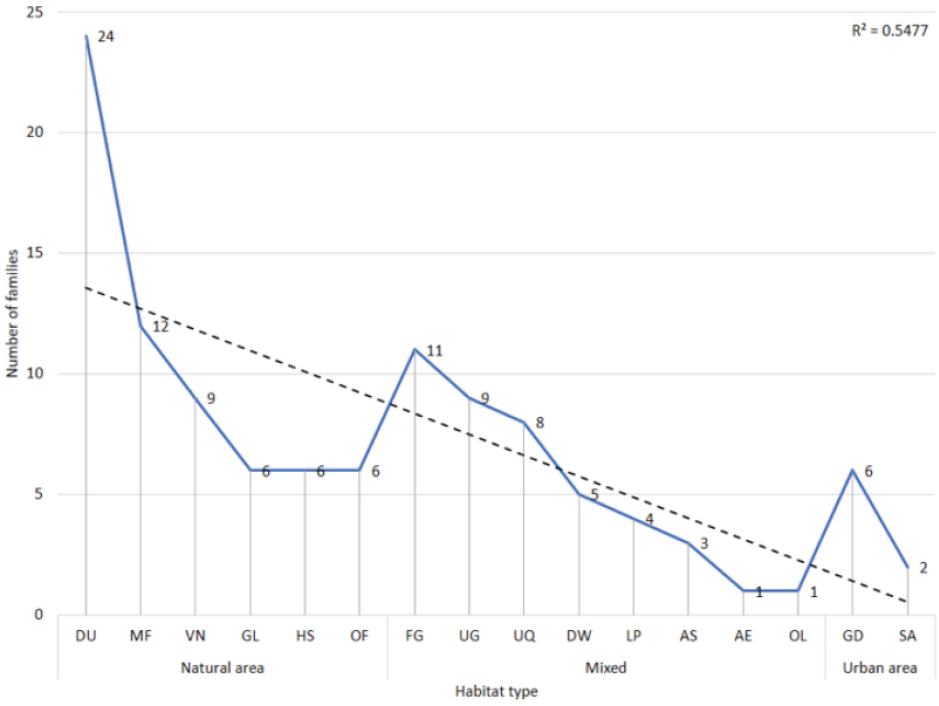

Figure 2. Distribution of Diptera families in various microhabitat types segregated into natural, mixed, and urban areas. Note: For description of the microhabitat types, see Appendix 1.

of Therevidae (>1,000 species worldwide) have been recorded in India (Mitra et al. 2016), of which only one species has been documented in Maharashtra. This family was also recorded in the MMR. Ghorpade (2011) identified 17 families in Western Ghats with only one recorded species, of which seven, namely, Micropezidae, Platypezidae, Pyrgotidae, Scatopsidae, Sphaeroceridae, Therevidae, and Ulidiidae (formerly Otitidae) were identified under this study. Photographic evidence under this study showed the presence of at least two species of Micropzeidae and Therevidae, and more than three species of Ulidiidae in the MMR.

Regionally, of the 50 families identified, 40 were recorded in SGNP, 27 in TWS, 35 in KBS and MESZ each, and 24 in UA (Table 1). On an average, 34 families were recorded in the four protected areas (comprising SGNP, TWS, KBS, and MESZ).

The habitats occupied by adult Diptera were further divided into 16 microhabitats where it was most likely to find them (Table 1, Appendix 1). Most families (n = 24) preferred dense understory in any forest-type (DU), 12 were found almost exclusively in forests along the foothills and on top of mountains (MF), and 11 in kitchen gardens and fruit orchards (FG).

In Diptera, habitat-preferences are driven by the adult and larval feeding habits. Dividing the feeding habits into several food-specific diets (Table 2), it was found that a large number of adult flies composed of flower visitors (n = 22) and saprophages (n = 20), followed by frugivores, coprophages, predators, and

Table 2. Feeding habit preferences of adult and larval Diptera.

Feeding habit / Family	Adult feeding habit									Larval feeding habit									
	Plant matter			Animal matter						Plant matter			Animal matter						
	Flower-visitor	Frugivore	Saprophagous	Haematophagous	Coprophagous	Necrophagous	Predatory	Kleptoparasite	Fungivore	Phytophagous	Xylophagous	Detritivore	Coprophagous	Necrophagous	Parasitoid	Parasitic	Myiasitic	Predatory	Fungivore
Agromyzidae	+									+									
Anthomyiidae	+									+									
Asilidae							+											+	
Bombyliidae	+														+				
Calliphoridae	+	+			+	+		+						+			+		
Celyphidae			+						+	+		+							
Chloropidae	+		+					+		+		+							
Clusiidae			+								+								
Conopidae	+														+				
Diopsidae			+							+		+							
Dolichopodidae							+											+	
Drosophilidae		+	+						+	+		+							+
Empididae	+										+	+							
Ephydridae			+				+			+		+						+	
Hippoboscidae				+															
Hybotidae							+												
Lauxaniidae	+		+		+							+	+						
Megamerinidae			+								+							+	
Micropezidae		+	+							+	+		+						
Milichiidae			+					+				+				+			
Muscidae	+	+	+	+	+	+	+					+	+	+			+		+
Neriidae			+							+		+							
Phoridae		+	+			+		+	+			+			+	+			+
Platypezidae			+						+										+
Platystomatidae			+							+		+							
Pyrgotidae															+				
Rhagionidae							+					+						+	
Rhiniidae	+														+				
Sarcophagidae	+	+			+	+							+	+	+				
Sciomyzidae			+												+			+	
Sepsidae					+								+						
Sphaeroceridae			+		+							+	+						
Stratiomyidae	+										+	+						+	
Syrphidae	+											+						+	
Tabanidae	+			+														+	
Tachinidae	+														+				
Tephritidae		+	+							+									
Therevidae	+																	+	
Ulidiidae			+							+		+	+						

Feeding habit / Family	Adult feeding habit									Larval feeding habit									
	Plant matter			Animal matter						Plant matter			Animal matter						
	Flower-visitor	Frugivore	Saprophagous	Haematophagous	Coprophagous	Necrophagous	Predatory	Kleptoparasite	Fungivore	Phytophagous	Xylophagous	Detritivore	Coprophagous	Necrophagous	Parasitoid	Parasitic	Myiasitic	Predatory	Fungivore
Bibionidae	+											+							
Cecidomyiidae	+								+	+		+							
Ceratopogonidae	+			+								+							
Chironomidae	+									+		+							
Culcidae	+			+								+						+	
Mycetophilide									+			+							+
Psychodidae			+									+							
Scatopsidae					+							+	+						
Sciaridae									+			+							+
Simuliidae				+						+		+							
Tipulidae	+									+		+							
Total	22	7	20	6	7	4	6	4	7	16	5	28	8	3	8	2	2	11	6

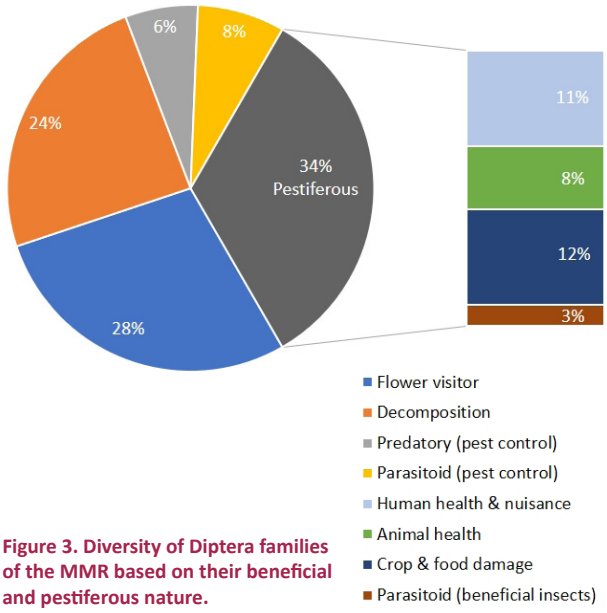

Figure 3. Diversity of Diptera families of the MMR based on their beneficial and pestiferous nature.

fungivores. In case of their larval feeding habits, most were detritivorous (n = 28), phytophagous (n = 16), predatory (n = 11), and parasitoids (n = 8). The feeding habits were considered to determine their interactions with humans. The families were classified into beneficial and pestiferous groups (Table 3). Since interfamilial diversity, in terms of habit, habitat, and larval food preferences within Diptera, is high, several families represented beneficial as well as pestiferous groups (e.g., Muscidae and Calliphoridae). In such instances, emphasis on their key role, driven either by their diversity or abundance, was notated by a '++' symbol as against a '+' symbol (Table 3). For instance, Muscidae is represented by pestiferous species which are vectors of diseases among humans and animals, and infest crops and spoil food, but some members are also beneficial as pollinators and as predators of other pest insects, however, their beneficial role is limited owing to low species diversity and abundance, or lack of knowledge. In such a case, the pestiferous nature of Muscidae was represented with '++' and the beneficial by '+'.

In the MMR, a majority of the Dipteran diversity was represented by beneficial flies (66%) than by pestiferous (34%). With respect to families represented by species which add a significant weight to their habits (notated by a ++ symbol), the families equally represented in beneficial (n = 12) and pestiferous (n = 11) groups. Among beneficial, 28% (n = 22) were flower visitors, 24% (n = 19) decomposers, and 14% (n = 11) predatory and parasitoids of other pests. Among pestiferous, 11% (n = 9) posed a direct threat to human health or were a nuisance and a same proportion were pests of standing crops and stored foods, whereas 8% (n = 6) were a concern for animal health and 3% (n = 2) were parasitoids of beneficial insects (Fig. 3).

Table 3. Categorization of Diptera families into Beneficial and Pestiferous groups.

Group / Family	Beneficial				Pestiferous			
	Flower visitor	Decomposition	Predatory (pest control)	Parasitoid (pest control)	Human-health & nuisance	Animal health	Crop & food damage	Parasititoid (beneficial insects)
Agromyzidae	+						++	
Anthomyiidae	+						++	
Asilidae			++					
Bombyliidae	++			++				
Calliphoridae	+	++			++	++		
Celyphidae							+	
Chloropidae	+						++	
Clusiidae		+						
Conopidae	+							+
Diopsidae		+						
Dolichopodidae			+					
Drosophilidae							++	
Empididae	++	+						
Ephydridae	+							
Hippoboscidae					+	++		
Hybotidae			+					
Lauxaniidae	++							
Megamerinidae		+						
Micropezidae		+						
Milichiidae	+							
Muscidae	+	+	+		++	++	++	
Neriidae		+						
Phoridae		++			+			+
Platypezidae		+						
Platystomatidae		+						
Pyrgotidae				+				
Rhagionidae			+					
Rhiniidae	++			++				
Sarcophagidae	+	+			+	+		
Sciomyzidae				++				
Sepsidae		++						
Sphaeroceridae		++						
Stratiomyidae	+	+						
Syrphidae	++			++				
Tabanidae					+	++		
Tachinidae	++			++				
Tephritidae							++	
Therevidae	+							
Ulidiidae		+					+	
Bibionidae	+							
Cecidomyiidae	+						++	
Ceratopogonidae	+							
Chironomidae	+							
Culcidae					++			
Mycetophilide		+						
Psychodidae					+			
Scatopsidae		+						
Sciaridae		+						
Simuliidae					+	+		
Tipulidae	+							
Total ++	6	4	1	5	3	5	7	0
Total +	16	15	4	1	6	1	2	2
Total	22	19	5	6	9	6	9	2

DISCUSSION AND CONCLUSIONS

The current study reveals the family-level diversity of Diptera of the MMR for the first time. All the 50 families were documented in the four sites (SGNP, TWS, KBL, and MESZ) which receive some degree of protection through the Maharashtra Forest Department. Less than half (48%, n = 24) were recorded in the UA. It is likely that, given the immensely diverse habits of certain families, they were also present in urban areas in a much larger proportion. For instance, a member of Therevidae, a family associated with natural areas, was identified from a dead specimen found in the UA. This was likely because of the presence of a small copse in the vicinity. Ghorpade (2011) and Mitra et al. (2016) mentioned presence of only one species in WG and Maharashtra, respectively. This study shows that there are at least two species of this family in the MMR and the family is either rare or difficult to capture. It also shows that it is habitat-

Images 1–15. 1 - Agromyzidae; 2 - Anthomyiidae; 3–5 Asilidae (3: Laphrinae; 4 - Leptogastrinae; 5 - Asilinae, *Promachus* sp.); 6–9 Bombyliidae (6, 7 - Anthericinae; 8 - Bombyliinae, *Euchariomyia dives*, Bigot; 9 - Toxophorinae, *Systropus* sp.); 10–11 - Calliphoridae (11 - Bengaliinae, *Bengalia* sp.); 12 - Celyphidae; 13 - Chloropidae, Chloropinae, *Rhodesiella* sp.; 14 Clusiidae; 15 - Conopidae. © Aniruddha Dhamorikar

Images 16–30. 16–17 Diopsidae (16: Diopsinae, *Teleopsis sykesii*, Westwood; 17: Sphyracephalinae, *Sphyracephala hearseiana*, Westwood); 18 Dolichopodidae; 19 Drosophilidae; 20 Empididae; 21 Ephydridae, Gymnomyzinae, *Ochthera* sp.; 22 Hippoboscidae; 23 Hybotidae; 24 Lauxaniidae; 25 Megamerinidae; 26 Micropezidae, Calycopteryginae, *Mimegralla* sp.; 27 Milichiidae; 28–30 Muscidae (28: Muscinae, *Musca* sp.; 29: Atherigoninae, *Atherigona* sp.; 30: Coenosiinae, *Lispe* sp.). © Aniruddha Dhamorikar

specific and hence may be found in any region where its larval habitat exists. On the other hand, families such as Neriidae, Hybotidae, Micropzeidae, Rhagionidae, and Bibionidae were almost exclusively found in natural areas with the least amount of disturbance, such as protected areas.

Insects are highly responsive to environmental changes, including those resulting from anthropogenic activities (Schowalter 2011). Natural areas offer various resources and provide diverse niches to occupy. On the other hand, urbanization leads to homogenous landscapes, increased environmental disturbance and pollution levels, and promote biotic homogenization by reducing the diversity of some species and increasing the abundance of species which are able to tolerate disturbance and recover quickly (Buczkowski & Richmond 2012). For instance, only a handful species of mosquitoes (Culicidae) breed in urban areas, such as *Aedes aegypti* and *Culex* sp., however, species such as *Aedes albopictus* which are also vectors of dengue, are more common in natural areas and seldom found in highly urban areas. Similarly, other members of Culicidae such as *Mansonia* sp., and *Toxorhynchites* sp., also recorded in the MMR, are almost exclusively found in natural areas where they breed in ponds with a good vegetative cover (*Mansonia* sp.) and in rainwater collected in tree hollows (*Toxorhynchites* sp.). This study suggests that flies are also affected by urbanization, and hence their family- and species-level diversity is more in natural areas.

There is, however, a largely misunderstood notion

Images 31–45. 31 Neriidae; 32 Phoridae, Metopininae, *Megaselia scalaris*, Loew; 33 Platypezidae; 34 Platystomatidae; 35 Pyrgotidae; 36 Rhagionidae; 37 Rhiniidae; 38–39 Sarcophagidae (39: Miltogramminae); 40 Sciomyzidae; 41 Sepsidae; 42 Sphaeroceridae; 43–45 Stratiomyidae (43: Hermetiinae, *Hermetia* sp.; 44: Sarginae, *Sargus* sp.; 45: Sarginae, *Ptecticus* sp.). © Aniruddha Dhamorikar

Images 46–60. 46–49 Syrphidae (46: Syrphinae, *Episyrphus* Sp.; 47: Eristalinae, *Eristalinus* sp.; 48: Syrphinae, *Paragus* sp.; 49: Eristalinae, *Phytomia crassa*, Fabricius); 50–52 Tabanidae (50: Tabaninae, *Haematopota* sp.; 51: Pangoniinae, *Philoliche trapobanes*, Walker; 52: Tabaninae, *Tabanus* sp.); 53–54 Tachinidae (53: Dexiinae, *Prosena* sp.; 54: Dexiinae, *Phyllomya* sp.);
55 Tephritidae, Dacinae, *Bactrocera cucurbitae*, Coquillett;
56–57 Therevidae; 58 Ulidiidae, Ulidiinae, *Physiphora* sp.;
59 Bibionidae; 60 Cecidomyiidae.
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that flies are more common in unhygienic places, especially around human-generated waste dumping sites. To understand this, the 16 microhabitat types were classified into habitats exclusively found in natural areas (six types), mixed habitats (eight types) found in urban as well as natural areas, and those exclusive to urban areas (two types). The study showed that the family-level diversity decreased from natural to urban areas (Fig. 2). While most families (48%, n = 24) were recorded in forested areas with a dense undergrowth (DU), only 16% (n = 8) were found in garbage dumps (GD) and sewage areas (SA), and eight other families were identified in the ubiquitous (UQ) category, represented by species that were found in all habitat types. A majority of these, namely Muscidae, Phoridae, Sarcophagidae, Cecidomyiidae, and Culicidae, fell in the pestiferous category.

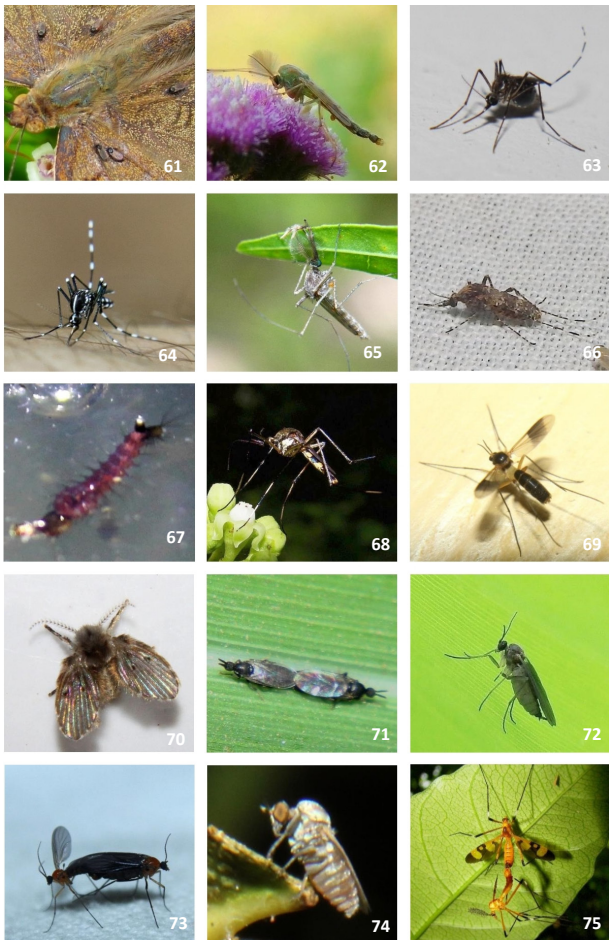
The adult and larval feeding habits influence the habitat of Diptera, which in turn determines their presence in natural, mixed, and urban areas. The pestiferous Diptera were also present in natural areas, however, the potency of their pestiferous nature was noteworthy in mixed and urban areas. For instance, members of family Agromyzidae, whose larva are phytophagous and cause loss to standing crops, were common in fruit gardens. Hendrickson & Day (1986) stated 7.7–11 % loss to Alfalfa (*Medicago sativa*) yield, an important fodder crop, by *Agromyza frontella* (Agromyzidae) in the USA. On the other hand, the adults are also flower visitors and contribute to the ecosystem

services of pollination. Ollerton et al. (2009) identified members of Agromyzidae, among members of other families generally considered as pestiferous such as Calliphoridae, Cecidomyiidae, Drosophilidae, Phoridae, and Tephritidae, as pollinators of *Ceropegia* sp. Similarly, members of Calliphoridae are largely necrophagous, and are particularly common in unhygienic environments, but several members are also pollinators (Marshall 2012).

Of the total diversity, 66% was represented by beneficial Diptera and 34% by pestiferous (Fig. 3). The benevolence of beneficial flies is reflected in their diverse functions which are of considerable importance in an ecosystem and human wellbeing. These functions include pollination, decomposition, and biological pest control through predation and parasitoidism. All these functions are crucial ecosystem services (Sarukhan & Whyte 2003) when related to a positive impact on human activities. Diptera is probably the only insect group which plays a certain role in all these activities. In the MMR, 42 families were identified to be of beneficial nature. Orford et al. (2015) mentioned that Diptera are unlikely to be the most important pollinators, however they could play a significant role in pollination en masse. They also play a significant role in agrobiodiversity (Ssymank et al. 2008). About 71 families contain flower visitors (Orford et al. 2015), of which 38 families are reported as flower visitors in India (Mitra & Banerjee 2007). Members of 22 families which are flower visitors were recorded in the MMR.

Detritivorous Diptera are an important component of the ecosystem. They are ubiquitous on dead and decaying organic matter in natural as well as urban areas, and are considered the fundamental participants in decomposition processes (Savage 2002). The larvae of Diptera play a crucial role in decomposition by boring through the organic matter and preparing the site for further decomposition by microorganisms (Savage 2002). Of the 58 families known as decomposers of animal and plant matter, 19 were recorded in the MMR. Some flies are bred for their efficiency in bio-composting, such as larvae of *Hermetia* sp. (Stratiomyidae), also recorded in the MMR, and are considered as an emerging inexpensive method of managing organic waste (Diener et al. 2011).

Predation is a common trait among flies—in adult as well as larval stage—and most predatory flies are obligate carnivores. Of the 42 families known as predators (Brooks 2002), six were recorded in the MMR. The major, and common, predatory families documented were Asilidae, Dolichopodidae, and Ephydridae.



Images 61–75. 61 Ceratopogonidae; 62 Chironomidae; 63–68 Culicidae (63: Culicinae, *Aedes aegypti*, Linnaeus; 64: *Aedes albopictus*, Skuse; 65: *Culex* sp.; 66: *Mansonia* sp.; 67–68: *Toxorhynchites* sp. larva and adult); 69 Mycetophilidae; 70 Psychodidae, Psychodinae, *Clogmia* Sp.; 71 Scatopsidae; 72–73 Sciaridae; 74 Simuliidae; 75 Tipulidae, Ctenophorinae, *Pselliophora laeta*, Fabricius. © Aniruddha Dhamorikar

Kleptoparasitic flies (which steal food captured by another animal) contributed to four families, the most noteworthy of which were Milichiidae, which are almost always present on bees captured by spiders, and *Bengalia* sp. (Calliphoridae), which can be commonly seen lying in wait close to a trail of ants to steal the food being carried by the ants. Among fungivores (which feed on sap and spores of fungi), seven families were recorded in the MMR, the most common being Drosophilidae, Celyphidae, and Cecidomyiidae.

Some flies are parasitoid (where the host gets killed by the developing parasite) of pest insects. About 31 families have some species which are parasitic in nature (Skevington 2002), of which six were recorded in the MMR. Some members of Bombyliidae are parasitoids of grasshopper eggs, acting as biological controllers

of grasshopper populations that damage crops; some members of Sciomyzidae are parasitoids or predators of snails, helping in controlling the populations of snails which spread a flatworm that causes liverfluke in livestock (Marshall 2012) - a common disease in livestock in the Indian countryside. Members of Pyrgotidae are parasitoids of scarab beetles, and that of Tachninidae attack a number of other insects including moths, bugs, beetles, and grasshoppers (Marshall 2012).

Pestiferous Diptera represented 34% of the total families. Nine families were recorded which pose a threat to human health or are a general nuisance. The most important were *Musca domestica* (Muscidae), a global vector of over 100 diseases (Scott et al. 2014), as well as vectors such as *Aedes aegypti* and *A. albopictus* (Culicidae) which cause dengue, and *Anopheles* sp. which causes malaria. The other haematophagous Diptera, such as horseflies (Tabanidae) and biting midges (Simuliidae), can cause persistent itching and secondary infections at the site of bite. Six families found in the MMR are known to affect animals, the most notable are Calliphoridae and Muscidae which cause myiasis, and Hippoboscidae which are ectoparasites of birds and mammals, and nine families are known to damage standing crops and stored food, the most important being Tehpritidae, with over 200 species identified in India (Verghese et al. 2002). Members of this family cause an estimated loss of US$ 242 million per year in Brazil (Oliveira et al. 2013). In terms of parasitoids infecting beneficial insects, two families were recorded, namely Conopidae which infect solitary wasps and Phoridae which infect ants and bees (Marshall 2012), however, their impact on the host population is insignificant although worthy of note for their role in ecosystem dynamics.

The current study intended to provide a glimpse of the family diversity of Diptera in the MMR. Much remains to be discovered in the region in terms of taxonomic studies. I recorded Mythicomyiidae on onion flowers in Madhya Pradesh, however they were not recorded in the MMR. Similarly, Ghorpade (2011) remains uncertain of the presence of Canacidae in the Western Ghats, a large family with a coastal distribution, which I recorded on a sandy beach of northern Karnataka. Families such as Nycteribiidae and Streblidae, both highly specialized ectoparasites of bats, were not studied under this study although recorded in Western Ghats (Ghorpade 2011) and are likely also present in the MMR.

The comparison between beneficial and pestiferous group was intentionally made to dissuade the general negativity towards flies because of a small group of species. Weighing the beneficial qualities of Diptera against their pestiferous is one way of understanding their importance in an ecosystem (Fig. 3). In face of rapid urbanization, increasing pollution, and habitat degradation, Diptera may be one of the significantly affected yet overlooked group of insects. In the case of the MMR, the urban built-up area has increased from 13–16 % (MMRDA 2013, 2016). It may have implications on the diversity of Diptera, such as a shift in the diversity from beneficial to pestiferous. Praja Foundation (2017) noted a 265% increase in the number of dengue, spread by *A. aegypti* (Culicidae), cases in the MMR between 2012–13 and 2016–17. As the highly resilient, pestiferous species proliferate, habitat degradation will reduce or eliminate populations of beneficial niche-specific mosquitoes such as *Toxorhynchites* sp. (Culicidae) which, in larval stage, feed on the larva of pestiferous mosquito species (Marshall 2012). Degradation of tropical forests has a negative impact on certain butterfly species (Malabika 2011), a similar effect could be expected on Diptera. In the view of serious declines in bee populations, Orford et al. (2015) recommended the importance of understanding the role of Diptera as pollinators.

Further studies will help us understand how these inconspicuous insects contribute to the ecosystem health, the management of natural and agricultural

Appendix 1. Descriptions of microhabitat types inhabited by Diptera families in the MMR.

Microhabitat type	Code	Description
Animal ectoparasite	AE	Completing entire lifecycle externally on an animal
Animal scat	AS	Scat of wild and domestic animals
Dense undergrowth	DU	Forests with a dense understorey
Dead wood	DW	Standing or fallen dead trees
Fruit garden	FG	Kitchen gardens, fruit orchards
Garbage dump	GD	Organic waste dumping sites
Grassland	GL	Natural areas of grasses on plateaus and meadows
Hill stream	HS	Seasonal streams emerging from mountains
Lakes and pools	LP	Natural and/or man-made lakes and seasonal pools
Mountainous forest	MF	Forests along foothills and on top of mountains
Open forest	OF	Scrub and secondary forest growth
Observed at lights	OL	Unclassified habitat; observations made at a light source
Sewage area	SA	Human-generated waste water areas
Urban garden	UG	Cultivated, non-agricultural green spaces
Ubiquitous	UQ	Wide-range of natural and man-made ecosystems
Various forest types	VN	Wide-range of forest types

areas, and provide a better understanding of the biodiversity of metropolises like the MMR.

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