Diversity, seasonal variation and diel pattern of nocturnal moths of IISER Mohali

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Certificate of Examination

This is to certify that the dissertation titled "Diversity, seasonal variation and diel pattern of moths of IISER Mohali" submitted by Mr. Tarunkishwor Yumnam (Reg. No. MS12063) for the partial fulfilment of BS-MS dual degree program of the Institute, has been examined by the thesis committee duly appointed by the Institute. The committee finds the work done by the candidate satisfactory and recommends that the report be accepted.

Dr. N.G. Prasad	Dr. Rajesh Ramachandran	Dr. Manjari Jain (Thesis Supervisor)

Date: November 24, 2017

Declaration

The work presented in this dissertation has been carried out by me under the guidance of Dr. Manjari Jain at the Institute of Science Education and Research Mohali.

This work has not been submitted in part or in full for a degree, a diploma, or a fellowship to any other university or institute. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due acknowledgement of collaborative research and discussions. This thesis is a bonafide record of original work done by me and all sources listed within have been detailed in the bibliography.

Tarunkishwor Yumnam

Dated: November 24, 2017

In my capacity as the supervisor of the candidate's project work, I certify that the above statements by the candidate are true to the best of my knowledge.

Dr. Manjari Jain

(Thesis Supervisor)

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Acronyms

LED: Light emitting diode

MVL: Mercury Vapour Lamp

CRA: Crambidae

ERE: Erebidae

GEO: Geometridae

NOC: Noctuidae

PLU: Plutellidae

PYR: Pyralidae

Contents

Abstract

There has been almost a century-long gap in the diversity study of moths of India after the extensive work of Hampson in 1890s, albeit certain works by Bell & Scott (1937). Fortunately, within the last few decades, there have been many regional studies on moth diversity of India. These studies, although, have been restricted mostly to the biological hotspots of Western Ghats, Himalayan region of Uttarakhand and the Indo-Burma region. Moreover, studies on seasonal variation and diel pattern of moths in Indian landscape have been very scarce. The condition is poorer in the case of Punjab, where very few literature is available reporting the moth diversity to 198 species. This study, by choosing Mohali as the site, has been conducted to contribute more towards this lack of one of the most foundational study. From over 100 sampling sessions, a total of 151 morphospecies have been recorded and 89 have been identified upto genus level, of which 81 have been identified upto species level. 33 of the identified species are new addition to the current checklist of moths of Punjab. Furthermore, this study also reports the significant variation in moth abundance and diversity in the post-monsoon season.

Chapter 1: Introduction

1.1 What are moths?

Kingdom **Animalia**

Class **Insecta**

Phylum **Arthropoda**

Subphylum **Hexapoda**

Order **Lepidoptera**

Heterocera (unranked)

Moths along with butterflies form the order Lepidoptera, which along with Coleoptera (beetles), Diptera (flies) and Hymenoptera (wasps), forms the four insect super radiations (Grimaldi & Engels, 2005). The presence of scales on their wings and bodies set them apart from other insect orders. The structural arrangements of these scales and the way they interact with incident light gives them an array of colours. The presence of haustellum or coiled proboscis and absence of ocelli is another defining characteristic of this widely recognisable insect order. But distinguishing between moths and butterflies can be hard sometimes.

Majority of butterflies are diurnal and majority of moths are nocturnal, albeit crepuscular and diurnal moths are also diverse. One of the easily identifiable feature is the presence of clubbed antennae in most of the butterflies. Moths, on the other hand, have many forms of antennae, from filamentous to feathery. This feature has led to a traditional division of Lepidotera order into butterflies as Rhopalocera (meaning clubbed horn or antennae) and moths as Heterocera (variable antennae). But the presence of a structure, which helps in wing coupling mechanism in moths, called frenulum in moths serves as a more rigid taxonomical distinguishing characteristic between moths and butterflies.

1.2 Reasons to study moths

Moths are known for their huge role as a pollinators. Many are generalist pollinators of a wide range of plants including mango, custard apple and oilseed rape (MacGregor et al. 2014; Rader, 2015). Although some of them act as obligate pollinators, for instance, the yucca moths *Parategeticula* sp. and *Tegeticula* sp. which pollinates and feeds only on yucca plants in North America.

Furthermore, understanding the diversity and ecology of moths is crucial in many aspects, from food chain and agricultural economics to cultural associations of many community where they are considered as delicacies. They act as the prey base for a number of predators including bats, birds and even grizzly bears (White et al. 1998, Razgour et al. 2011). The moth caterpillars, being an avid herbivorous consumer, can be used as biocontrol agents against weed infestations. One successful example is the use of plume moths *Platyptilia isodactyla* imported from Europe to control ragworts (*Jacobea vulgaris)* in Australia and New Zealand (Landcare research, 2011).

Their importance is furthered in understanding environmental changes. Many factors make them a suitable candidate for a sensitive ecological indicator: many groups can be sample using standard unattended traps, their huge diversity makes it easy to perform site to site comparison and the availability of abundant data (compared to other diverse insect groups like beetles) on their taxonomy and ecosystem offers the potential to study general patterns (Kitching et al. 2001; Rákosy & Schmitt, 2011)

Many of the moth larvae weave cocoons during their development, and some of them provide economic importance. The silk industry is founded on four moth species of the Bombycidae family. More than 99% of the entire silk production is from the cocoon woven by larva of silkmoth *Bombyx mori.*

Despite, their many ecological and economic importance, the need to study them more is equally born out of the many harmful effects it can leave. Being a diverse herbivore, many of them can be agricultural pests. The caterpillars of leaf-miners, for instance, can destroy a wide range of crops including mustard, cabbage and lettuce. Some moths are invasive species and can cause major damage by invading forests - Asian gypsy moth is an example (Gray, 2017). Many of these harmful effects can be control through a detailed understanding of their diversity and ecology.

1.3 Diversity of moths

There are 174,250 described lepidopterans among which only 17,500 belong to the butterfly superfamily Papilionoidea; the rest being moths belonging to 43 superfamilies (Lepidoptera Taxome Project). But the total estimate of the Lepidopteran diversity is believed to be as high as 300,000-500,000 (Chapman, 2009).

In India, no updated comprehensive list of moth diversity is available. The extensive work of Hampson (1892-1896) listed around 7000 species. Chandra (2007) estimated more than 12,000 species belonging to 41 families, but it is believed to be around 20,000. After a century-long gap of extensive study, moth diversity attracted the interests of many ecologists which were translated into regional studies, in parts of Andaman (Sivaperuman & Shah, 2012), Arunachal Pradesh (Chandra& Sambath, 2013), Maharashtra (Bharamal, 2015; Gadhikar, 2015; Gurule & Nikam, 2013), Uttarakhand (Sanyal et al. 2011; Smetacek, 2008; Sondhi & Sondhi, 2016), West Bengal (Biswas et al. 2016). Aggregation of such regional studies has made possible to the publication of certain family level preliminary checklists. Kirti & Singh (2015) have described a total of 535 Arctiinae moths; Mathew (2016) has listed 1646 species of Pyralid moths and Sivasankaran (2012) compiled 1374 moths of Noctuidae family. These rising studies in the last two decades have provided a renewed interest to the study a long-neglected insect order in the country, although a huge amount of efforts has to be put forth to arrive at a comprehensive checklist of moth diversity of India.

1.4 Rationale

Being a bio-diverse country with four global hotspots, many studies, as seen above, are focused in the hotspot region, and a large portion of the country has been neglected. The state of Punjab comes under the latter region. During the preliminary investigation for this study, only a few literatures were found which have listed a total of 198 moth species (Kaleka & Rose, 2001; Rose, 2001). The studies from which the aforementioned partial checklist has been concluded, were restricted to Bathinda, Patiala and the Sivalik belt. Hence, to study the diversity of moths in other parts of Punjab became the primary goal of this study, in the hope of adding more to the existing checklist.

Furthermore, there is a big absence of study on seasonal variation of moths in the country; Sanyal et al. (2011) being one of the few examples. This has prompted me to study the seasonal variation and also the diel pattern of adult moths (from hereon, moths), choosing IISER Mohali as the study site.

Figure 1.1 Map of the study site.

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Rest of the bibliography has been listed in section 2.6

Chapter 2: Diversity of moths of IISER Mohali

2.1 Background

The available literature on moth diversity of Punjab is very scarce. Using Rose (2001) and Kaleka and Rose (2001) as the main sources, the India Biodiversity Portal (1) has listed a total of 198 species belonging to 12 families in Punjab, which have been summarised family-wise in Table 2.1. Among these 198 species, 35 have been identified upto genus level only, and the higher-level classifications need to be revised according to the widely accepted new system provided by van Nieukerken et al. (2011). According to the new system, six of the reported families have been merged under two families – Arctiidae, Syntomidae (now under subfamily Arctiinae), Hypsidae (now under subfamily Aganainae) and Lymantriidae (now as subfamily Lymantrrinae) into Erebidae, and Boarmiinae (now a subfamily) and Scopulidae (under subfamily Sterrhinae) into Geometridae. Only two of the families from the 12 belong to micromoths. This may be due to want of focus in micromoth study as they pose more taxing challenges when it comes to the identification and many of them are not attracted to the traditional Mercury Vapour light trap. Similar issues have been faced in this study, and many micromoths and moths with wingspan <1cm have not been addressed, albeit some exceptional cases have been made and mentioned in section 2.5.

Family	**No. of Species**	**Family**	**No. of Species**
Arctiidae	19	Noctuidae	68
Boarmiinae	3	Pyralidae	40
Geometridae	35	Scopulinae	3
Hypsidae	2	Sphingidae	13
Lasiocampidae	1	Syntomidae	8
Lymantriidae	4	Tortricidae	2

Table 2.1 Family-wise total number of moth species recorded previously from Punjab (India Biodiveristy Portal).

2.2 Study site

IISER Mohali is spread over 125 acres of previously agricultural land in the Knowledge City, Mohali at Sector 81. Over the course of 7 years since its establishment, the surrounding area has seen a rapid change in infrastructural developments. The development of National Highway 5 and the Chandigarh International Airport have poured in a precipitous amount of anthropogenic activities in this area. Many real estates have sprung up nearby the campus. It is adjoined by Indian School of Business in the North, and CIAB and NABI in the North-West; only the agricultural area in the western side remains relatively unchanged. These developments have turned the area into a light polluted region. These artificial night lights may have many negative effects on moth population – e.g. increased flight-to-light behaviour (Hsiao, 1973) around streetlights, reduced foraging and reproduction activities, increased predation etc. (Langevelde & Donners 2011). The increased flight-to-light behaviour may also reflect in reduced catches in light traps for diversity assessment studies.

With the concern of artificial night lights in mind, the primary study site (30°39'55"N, 76°43'24"E) was fixed after a survey of three sites for 18 sampling nights. The site is located on a ~30 square meters of grass-covered open area enclosed by guava orchards; thus restricting the effects of artificial night lights. Furthermore, the site has a greater plant diversity, compared to the rest of area inside the campus. The diversity includes *Morus* sp.(Mulberry), *Ficus religiosa* (Sacred fig), *Ficus racemosa*, *Musa paradisiaca* (Banana), *Polyalthia longifolia* (Ashoka Mast tree), *Eucalyptus* sp., *Psidium guajava* (Guava), *Mimusops elengi*, *Melia azedarach* (Neem) and *Chukrasia tabularis* (Indian Mahogany); two creepers namely *Coccinia grandis* (Indian Ivy) and *Passiflora* sp. (Passion vine) were found spread over some of the trees present in the study site. It has been reported that greater plant diversity enhances moth diversity (Root et al. 2017). So the site serves as a better option, both in terms of the absence of artificial light and greater floral diversity.

2.3 Methodology

The partial checklist provided below is based on systematic surveys inside IISER Mohali campus. A total of 102 sampling nights have been conducted during January to October (with the exception of June) using the traditional white cloth sheet method. A 5 x 4.5 ft. white cloth sheet was hoisted on poles with some part of it extended over the ground. The light source was lighted directing towards one side of the sheet from 3 ft. away. 59 out of the 102 sampling nights, from January 20 to May 12, have been conducted using LED light source (18W powered by12V, 7Ah battery). The rest of the sampling sessions have been conducted using Philips HQL 125W Mercury Vapour lamp (MVL) powered by 220V AC source (White et al. 2016). During the LED light source period, sampling sessions were conducted from 1900 hours to 2300 hours. It was then extended from 1800 hours to 2400 hours after shifting to MVL. In addition to this, some sampling sessions were conducted from 2400 hours to 0600 hours for diel pattern study (ref. Chapter 3).

Figure 2.1 Photo of the MVL Light trap under operation.

2.4 Diversity indices

Diversity indices were calculated from the abundance data from May to October, during which MVL light trap was only used throughout. This selective treatment of the abundance data has been done so as not to introduce any inconsistency in the conclusion as a result of the changing methods.

1. Shannon index,

$$H' = -\sum p_i \ln p_i$$ where p_i = total individual of *i*th species/ total number of all individuals

$$= 3.588$$

2. Pielou's evenness index,

$$J' = H'/H'_{max}$$ where $H'_{max} = \ln(S)$; where $S = 132$

$$= 0.740$$

3. Simpson's diversity index,

$$D = \sum p_i^2$$

$$= 0.059$$

The indices suggest a very high diversity in the study site with high heterogeneity. For a detailed comparison of seasonal diversity indices, refer chapter 4.

2.5 Results

Over the 92 sampling nights, 2330 individuals have been recorded and grouped into 151 morphospecies. Of the 151 morphospecies, 81 have been identified up to species level and 8 more till genus level. Moth identification was done using available literatures through photographs, which included Hampson (1892-1896); Bell and Scott (1937); Holloway (1983-2011); Inoue et al. (1996); Kendrick (2002); Gurule & Nikam (2013); Solovyev (2014); Sondhi & Sondhi (2016) and Jatishwor et al. (2016). Further examination of genitalia of many moths was needed for species confirmation; hence species identities of which photographs were not enough to confirm, have been provisionally identified upto genus level.

On comparison to the only available checklist of moths of Punjab (India Biodiversity Portal[1]), 33 of the identified species are found to be new inclusion to the checklist of moths of Punjab (details in Table 2.2). It has to be mentioned here that these new inclusions have been recorded in other states.

The 89 identified species occupy12 families belonging to seven superfamilies below, following van Nieukerken et al. (2011):

Superfamily **Pyraloidea** Latreille, 1809

Family **Crambidae** Latreille, 1810 (15 genera, 16 species)

Family **Pyralidae** Latreille, 1809 (2 genera, 2 species)

Superfamily **Yponomeutoidea** Stephens, 1829

Family **Plutellidae** Guenée, 1845 (1 genus, 1 species)

Superfamily **Zygaenoidea** Latreille, 1809

Family **Limacodidae** Duponchel, 1845 (1 genus 1 species)

Clade **Macroheterocera** Chapman, 1893

Superfamily **Bombycoidea** Latreille, 1802

Family **Bombycidae** Latreille, 1802 (1 genus, 1 species)

Family **Eupterotidae** Swinhoe, 1892 (1 genus, 1 species)

Family **Sphingidae** Latreille, 1802 (6 genera, 8 species)

Superfamily **Geometroidea** Leach, 1825

Family **Geometridae** Leach, 1815 (11 genera, 12 species)

Superfamily **Lasiocampoidea** Harris, 1841

Family **Lasiocampidae** Harris, 1841 (1genus, 1 species)

Superfamily **Noctuoidea** Latreille, 1809

Family **Erebidae** Leach, 1815 (28 genera, 37 species)

Family **Noctuidae** Latreille, 1809 (8 genera, 8 species)

Family **Nolidae** Bruand, 1847 (1 genus, 1 species)

The higher-level classification of the genera belonging to Erebidae and Noctuidae was performed following Zahiri et al. (2010, 2011) which led to the placement certain older members of Noctuidae into Erebidae.

A total of 12 families, including four micromoth families have been recorded. The most diverse superfamily was Noctuoidea which is represented by three families: Erebidae (thirty-seven species), Noctuidae (eight species) and Nolidae (one species). Recent changes in the higher level classification have led to the treatment of (i) the previous families Arctiidae and Lymantriinae under the family Erebidae as Arctiinae and Lymantrrinae, and (ii) subfamily Calpinae (as a subfamily) and Catocalinae (under Erebinae subfamily) under Erebidae family(Zahiri et al. 2010, 2011). The most diverse families were Erebidae (37 species), Crambidae (16 species), Geometridae (12 species) and Noctuidae and Sphingidae (8 species each). This result is almost consistent with the results from studies conducted in the nearby state of Uttarakhand (Sanyal, 2013, Sondhi & Sondhi, 2016). Four families of micromoth have been included in the study; most members of Crambidae (16 species) and Pyralidae (2 species) of superfamily Pyraloidea have a wingspan greater than 1cm.

Only *Scopula* sp. of Geometridae family was recorded in January. *Plutellida xylostetella* of Plutellidae family and *Scoplua* sp. were the only species recorded in February. All the recorded eight species of family Sphingidae were recorded during July, August and September only. A total of twenty-two singleton species and 15 species were doubleton.

Table 2.2. Partial checklist of moths of IISER Mohali (*new inclusion to checklist of moths of Punjab).

Sl. No.	Scientific name	Author and Year of description	No. of nights sighted	Month(s) observed
1. Family: Bombycidae				
	Subfamily: Bombycinae			
1	*Trilocha varians*	Walker, 1855	11	VIII, IX,X
2. Family: Crambidae				
	Subfamily: Spilomelinae			

2	*Chabula acamasalis*	Walker,1859	1	X
3	*Cirrhochrista brizoalis*	Walker, 1859	1	IX
4	*Cnaphalocrocis medinalis*	Guenée, 1854	22	VII, VIII, IX, X
5	*Conogethes punctiferalis*	Guenée, 1854	10	VIII, IX, X
6	*Diaphania indica*	Saunders, 1851	6	VIII, IX
7	*Eoophyla sejunctalis*	Snellen, 1876	1	IX
8	*Hypsopygia mauritialis*	Boisduval, 1833	3	IX, X
9	*Hymenia perspectalis*	Hubner, 1790	2	IX, X
10	*Omiodes indicate*	Fabricius, 1775	6	VIII, IX, X
11	*Omiodes noctescens*	Moore, 1888	19	V, VII, VIII, IX, X
12	*Omphisa anastomosalis*	Guenée, 1854	1	IV
13	*Palpita asiaticalis*	Inoue, 1994	2	VIII, IX
14	*Parotis marginata*	Hampson, 1893	8	VIII, IX, X
15	*Pilocrocis barcalis*	Walker,1859	1	IX
16	*Pygospila tyres*	Cramer, 1780	2	VIII
17	*Sameodes cancellalis*	Zeller, 1852	2	VIII, X
3. Family: Erebidae				

	Subfamily: Aganainae			
18	*Asota caricae*	Fabricius, 1775	7	VIII, IX
19	*Asota ficus*	Fabricius, 1775	9	VIII, IX
20	*Asota product*	Butler, 1875	2	VIII, IX
21	*Digama hearseyana f. similis*	Moore, 1878	1	V
22	*Psimada quadripennis*	Walker, 1858	3	VIII, IX
	Subfamily: Arctiinae			
23	*Aloa lactinea*	Cramer, 1777	3	V, VIII
24	*Creatonotos gangis*	Linnaeus, 1763	19	IV, V, VIII, IX, X
25	*Creatonotos transiens*	Walker, 1855	8	VII, VIII, IX, X
26	*Eressa confinis**	Walker, 1854	20	III, IV, V, VIII, IX, X
27	*Spilosoma eldorado*	Rothschild, 1910	1	V
28	*Spilosoma* sp.		9	VII, VIII, IX, X
29	*Syntomoides imaon*	Cramer, 1780	22	III, V, VII, VIII, IX, X
	Subfamily: Calpinae			
30	*Calyptra parva**	Bänziger, 1979	3	VII, IX

31	*Eudocima materna**	Linnaeus, 1767	8	VIII, IX
32	*Oraesia emarginata*	Fabricius, 1795	11	VIII, IX
33	*Parallelia stuposa**	Fabricius, 1794	2	VIII
	Subfamily: Erebinae			
34	*Achaea janata*	Linnaeus, 1758	10	VIII, IX
35	*Aedia leucomelas*	Linnaeus, 1758	1	IX
36	*Attatha ino**	Drury, 1782	1	V
37	*Ericeia* sp.		1	VIII
38	*Grammodes geometrica*	Fabricius, 1775	3	VIII, X
39	*Mocis frugalis*	Fabricius, 1775	8	VIII, IX, X
40	*Ophiusa tirhaca*	Cramer, 1777	1	VIII
41	*Spirama retorta*	Clerck, 1764	6	VII, VIII
42	*Spirama heliciana**	Hübner, 1831	1	VIII
43	*Thyas honesta**	Hübner, 1806	4	VII, VIII, IX
44	*Thyas coronata**	Fabricius, 1775	2	VII, VIII
	Subfamily: Hypocalinae			
45	*Hypocala deflorata**	Fabricius, 1792	1	VIII
	Subfamily: Lithosiinae			

46	*Cyana puella**	Drury, 1773	3	VIII, IX
	Subfamily: Lymantriinae			
47	*Dasychira* sp.*		2	VIII, IX
48	*Euproctis lunata*	Walker, 1855	9	III, VII, VIII, IX, X
49	*Euproctis* sp01		8	VIII, IX, X
50	*Euproctis* sp02		1	X
51	*Orvasca subnotota**	Walker, 1865	2	VIII, IX
	Subfamily: Pangraptinae			
52	*Episparsis liturata*	Fabricius, 1787	1	VIII
	Subfamily: Scoliopteryginae			
53	*Anomis flava**	Fabricius, 1775	3	VIII, IX
54	*Anomis fulvida*	Guenée, 1852	4	VIII
4. Family: Eupterotidae				
	Subfamily: Eupterotinae			
55	*Eupterote fabia**	Cramer, 1779	5	VII, VIII
5. Family: Geometridae				
	Subfamily: Ennominae			

56	*Hypomecis* sp.		1	V
57	*Hyposidra talaca**	Walker, 1860	17	VIII, IX, X
58	*Petelia immaculata**	Hampson, 1893	2	IX
	Subfamily: Geometrinae			
59	*Agathia carissima**	Butler, 1878	1	VIII
60	*Comibaena mariae**	Lucas, 1888	1	X
61	*Comibaena cassidara*	Guenée, 1857	10	V, VIII, IX, X
62	*Hemithea constipuncta**	Moore, 1867	20	IV, V, VIII, IX, X
63	*Neohipparcus vallata*	Butler, 1878	1	VIII
64	*Thalassodes antiquadraria**	Inoue, 1976	7	V, VIII, IX, X
	Subfamily: Sterrhinae			
65	*Rhodometra sacraria*	Linnaeus, 1767	5	V
66	*Scopula* sp.		53	ALL
67	*Traminda mundissima*	Walker, 1861	9	VIII, IX
6. Family: Lasiocampidae				
	Subfamily: Lasiocampinae			
68	*Trabala vishnou*	Lefèbvre, 1827	2	VIII

7. Family: Limacodidae				
	Subfamily: Limacodinae			
69	*Parasa lepida**	Cramer, 1779	1	IX
8. Family: Noctuidae				
	Subfamily: Bagisarinae			
70	*Xanthodes intersepta**	Guenée, 1852	2	VIII
	Subfamily: Condicinae			
71	*Condica* sp.		13	VIII, IX
	Subfamily: Hadeninae			
72	*Acantholeucania loreyi**	Duponchel, 1827	1	IV
73	*Analetia unicorna**	Berio, 1973	1	V
	Subfamily: Heliothinae			
74	*Helicoverpa armigera*	Hübner, 1808	8	IV, V
	Subfamily: Noctuinae			
75	*Spodoptera litura**	Walker, 1857	8	VIII, IX
	Subfamily: Plusiinae			
76	*Chrysodexis eriosoma**	Doubleday, 1843	15	VII, VIII, IX
77	*Thysanoplusia orichalcea**	Fabricius, 1775	6	III, V, VIII

9. Family: Nolidae				
	Subfamily: Eariadinae			
78	*Earias cupreoviridis*	Walker, 1862	3	IV, VIII, IX
10. Family: Plutellidae				
79	*Plutella xylostella*	Linnaeus, 1758	15	II, III, IV
11. Family: Pyralidae				
	Subfamily: Pyralinae			
80	*Endotricha ruminalis**	Walker, 1859	2	IX, X
81	*Spoladea recurvalis*	Fabricius, 1775	28	V, VII, VIII, IX, X
12. Family: Sphingidae				
	Subfamily: Macroglossinae			
82	*Hippotion celerio*	Linnaeus, 1758	10	VIII, IX
83	*Hippotion rosetta**	Swinhoe, 1892	1	IX
84	*Macroglossum belis**	Linnaeus, 1758	3	VIII, IX
85	*Nephele hespera*	Fabricius, 1775	12	VII, VIII, IX
86	*Theratra oldenlandia**	Fabricius, 1775	7	VII, VIII, IX
87	*Theratra nessus**	Drury, 1773	1	VIII

	Subfamily: Smerinthinae			
88	*Cypa pallens**	Jordan, 1926	2	VII, VIII
	Subfamily: Sphinginae			
89	*Agrius convolvuli*	Linnaeus, 1758	2	VIII, IX
Total number of singleton species = 22				

Besides the systematic sampling, opportunistic samplings were also performed. Twelve species, belonging to four families, which have not been recorded in the systematic sampling are listed below. One micromoth family, namely Phaudidae, has not been recorded during any of the systematic samplings.

Table 2.3. Species recorded from opportunistic samplings

Sl. No.	**Family**	**Subfamily**	**Scientific name**	**Author and Year of discovery**	**Month recorded**
1	Erebidae	Arctiinae	*Utetheisa lotrix*	Cramer, 1777	IV
2	Erebidae	Erebinae	*Aedia acronyctoides*	Guenée, 1852	VIII
3	Erebidae	Erebinae	*Pericyma umbrina*	Guenée, 1852	III
4	Erebidae	Erebinae	*Grammodes stolida*	Fabricius, 1775	IV
5	Erebidae	Hypocalinae	*Hypocala subsatura*	Guenée, 1852	IV
6	Noctuidae	Noctuinae	*Agrotis ipsilon*	Hufnagel, 1766	IV
7	Noctuidae	Noctuinae	*Sesamia inferens*	Walker, 1856	III
8	Noctuidae	Noctuinae	*Xestia* sp.		IV

9	Noctuidae	Plusiinae	*Autographa crypta*	Dufay, 1973	IV
10	Noctuidae	Plusiinae	*Ctenoplusia limbirena*	Guenée, 1852	IV
11	Phaudidae	Phaudinae	*Phauda* sp.		X
12	Sphingidae	Sphinginae	*Acherontia lachesis*	Fabricius, 1798	IX

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Chapter 3: Diel pattern of moths of IISER Mohali

3.1 Background

Many moths are diurnal – presumably more diverse than diurnal butterflies – and some are crepuscular, for instance, many of the hawkmoths are crepuscular. But the majority of the 160,000 plus moths are nocturnal. Beyond studying the diversity of moths and their seasonal variations, diel pattern should also be studied with equal attention. Hence, many studies, using specific moth models, have been conducted on their diel pattern to understand their flight activity (Fullard & Napoleone, 2001; Sarvary et al. 2008; Broadhead et al. 2017), oviposition and mating cycles (Quiring, 1994) and moth visual (Xu et al. 2013). The present study was conducted as a preliminary investigation between diel pattern and overall abundance and diversity of moths.

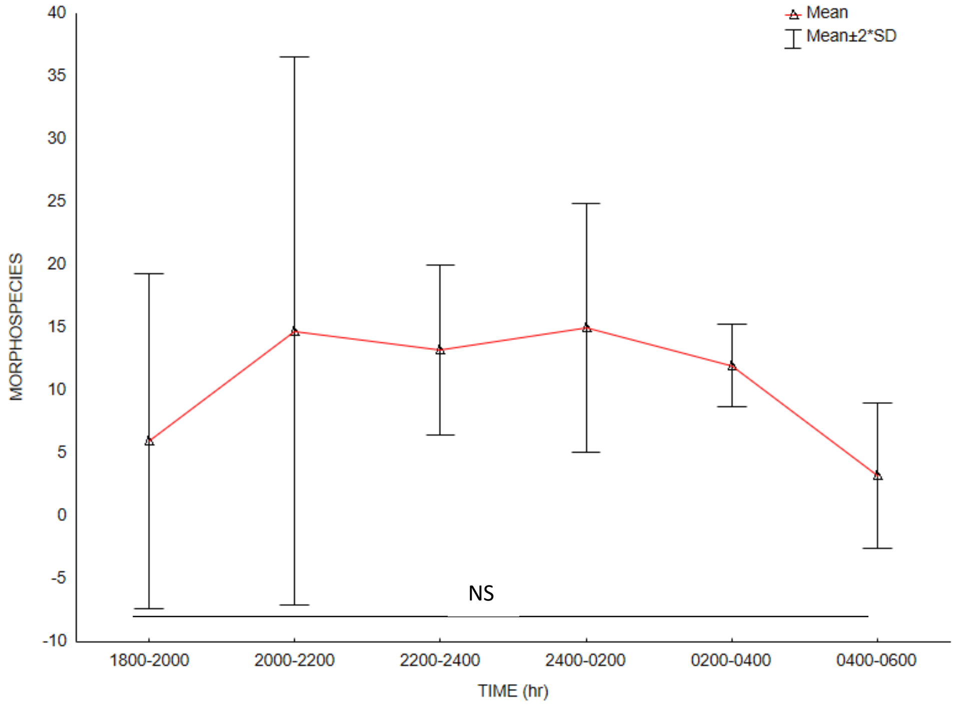
3.2 Methodology

The study was conducted using light trap method with MVL (ref Chapter 2 methods). Over the month of May, July, August and September, two sets of sampling sessions were performed: 1. Morning session from 00 00 hours to 06 00 hours and 2. Evening sessions from 18 00 hours to 24 00 hours. A total of 12 sampling session pairs have been successfully conducted. During each six hour sampling samplings, recordings were taken for every two hourly intervals. Unlike diversity study, in which moths with wingspan <1 cm were excluded, the diel variation was conducted based on all the moths that was attracted to the light trap.

3.3 Data Analysis

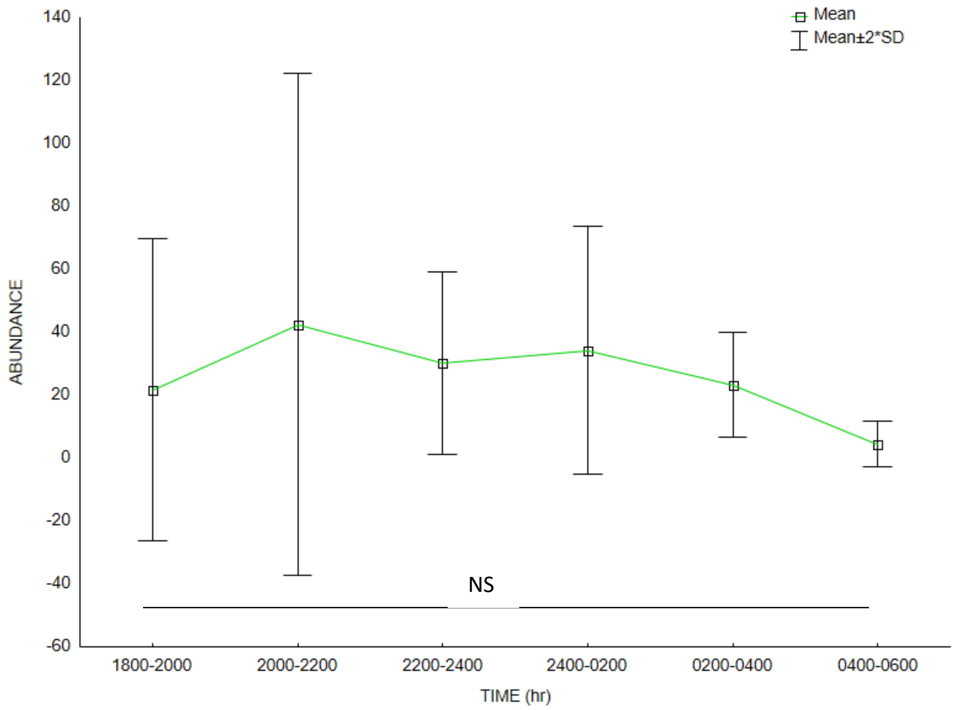
Due to the dissimilarities in photoperiod and weather conditions during the four months of this study, the data analysis has been conducted in two categories: 1. Pre-monsoon data covering May and July (4 sampling pairs) and 2. Post-Monsoon covering the moths of August and September (8 sampling pairs). A total of 1643 moth specimens were recorded – 626 in Pre-monsoon and 1017 in Post-monsoon. Nomality tests and the subsequent statistical analysis for each categories were performed in Statistica version 12.

3.4 Results



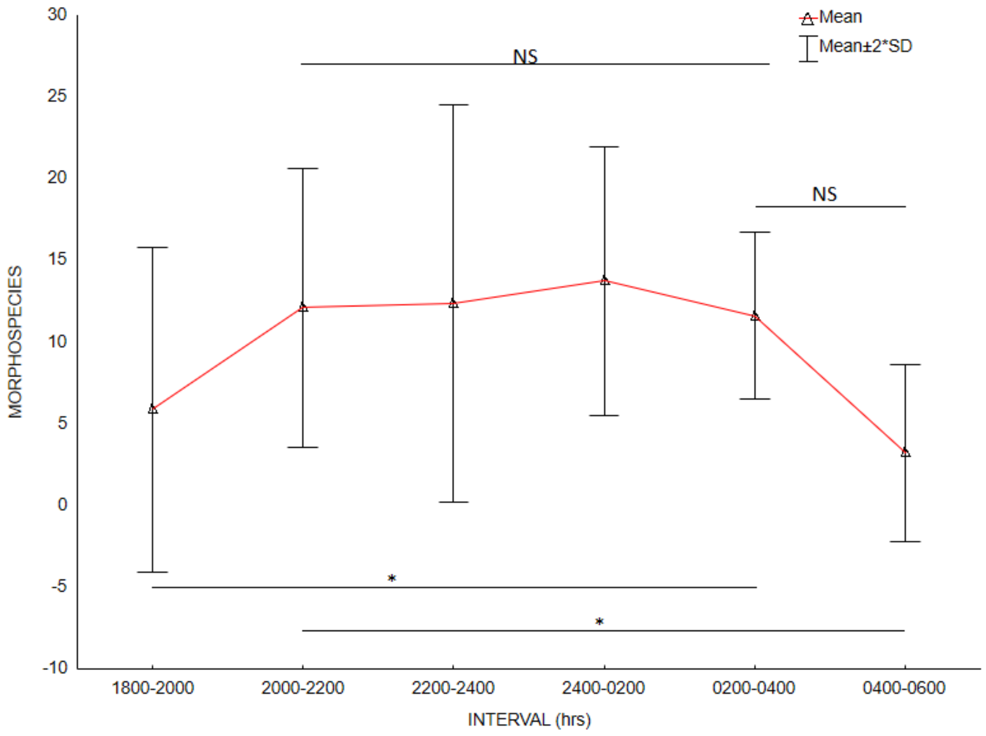
Mean
Mean±2*SD
MORPHOSPECIES
40
35
30
25
20
15
10
5
0
-5
-10
NS
1800-2000
2000-2200
2200-2400
2400-0200
0200-0400
0400-0600
TIME (hr)

(a)

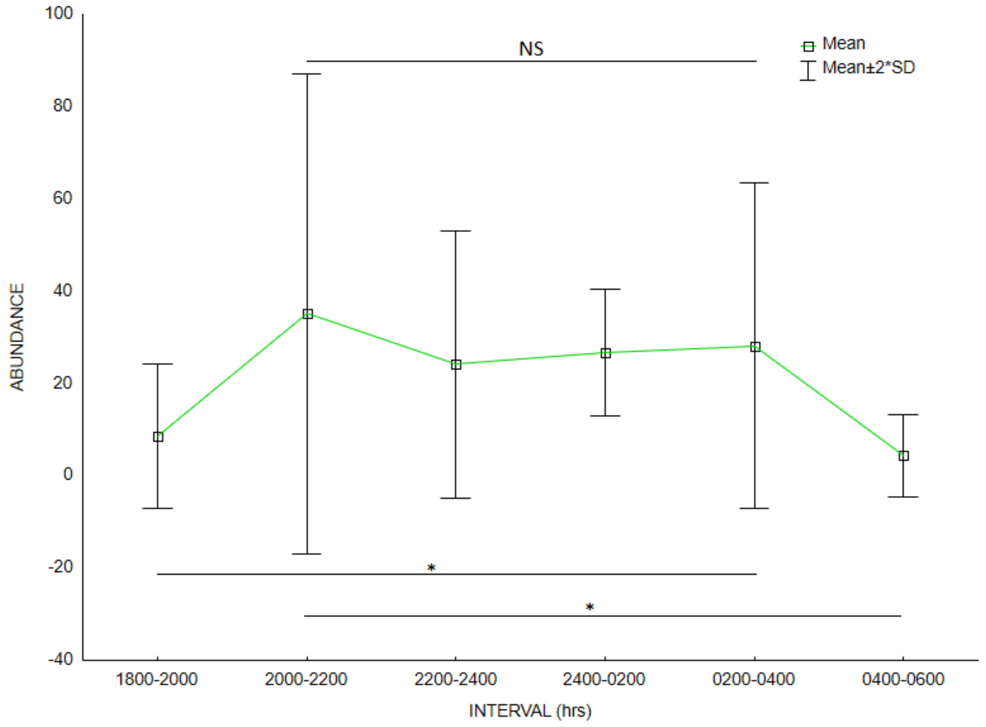


Mean
Mean±2*SD
ABUNDANCE
140
120
100
80
60
40
20
0
-20
-40
-60
NS
1800-2000
2000-2200
2200-2400
2400-0200
0200-0400
0400-0600
TIME (hr)

(b)



(c)

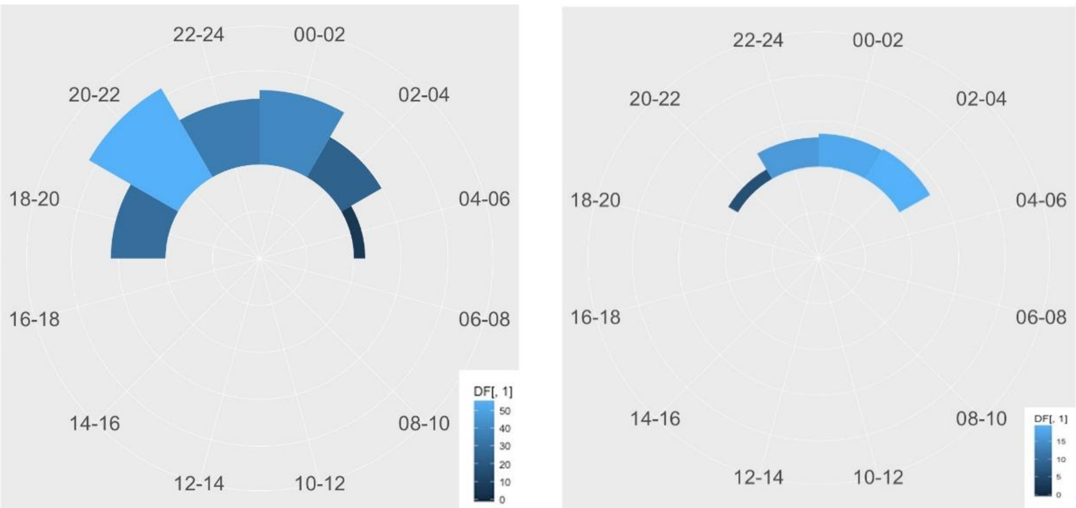


(d)

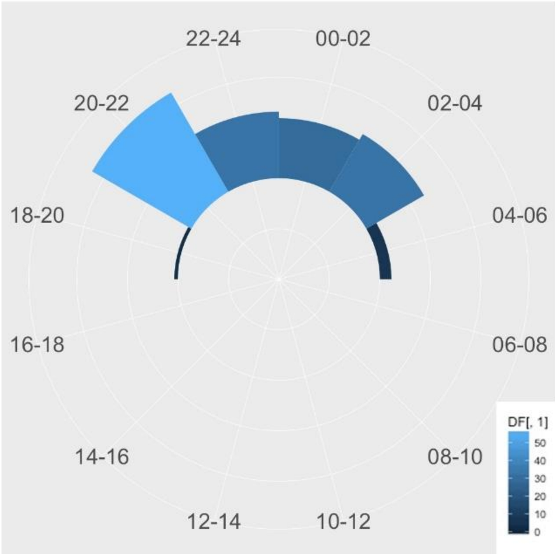
Figure 3.1 Average morphospecies per time interval (a, c) and average abundance per interval (b, d) of pre-monsoon (a, b) and post-monsoon categories (c, d). * marked are statistically significant ($p < 0.05$) pairs and NS, non-significant.

Pairwise t-tests for Morphospecies data			Mann-Whitney U tests for Abundance data		
Interval 1	**Interval 2**	**p value**	**Interval 1**	**Interval 2**	**p value**
1800-2000	2000-2200	0.017208	1800-2000	2000-2200	0.01813
1800-2000	2200-2400	0.034376	1800-2000	2200-2400	0.018130
1800-2000	2400-0200	0.003932	1800-2000	2400-0200	0.001629
1800-2000	0200-0400	0.011430	1800-2000	0200-0400	0.010082
2000-2200	0400-0600	0.000205	2000-2200	0400-0600	0.002762
2200-2400	0400-0600	0.001659	2200-2400	0400-0600	0.001948
2400-0200	0400-0600	0.000032	2400-0200	0400-0600	0.000939
			0200-0400	0400-0600	0.00136

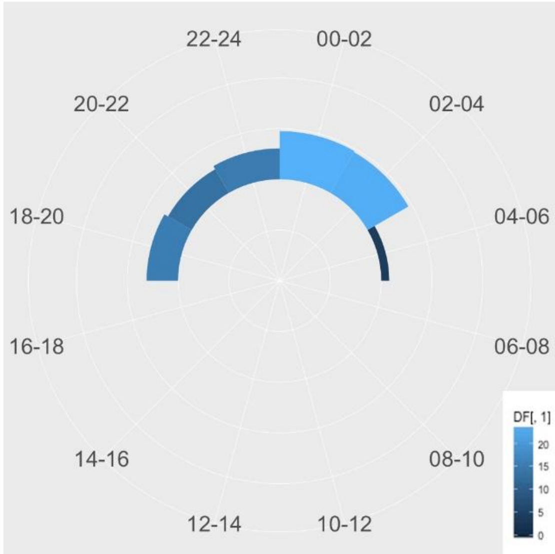
Table 3.1 Comparative analysis of the interval pairs for average morphospecies and abundance data for post-monsoon category (only the significantly different interval pairs are listed).



(a) **(b)**


22-24
00-02
20-22
02-04
18-20
04-06
16-18
06-08
14-16
08-10
12-14
10-12
DF[, 1]
50
40
30
20
10
0

(c)


22-24
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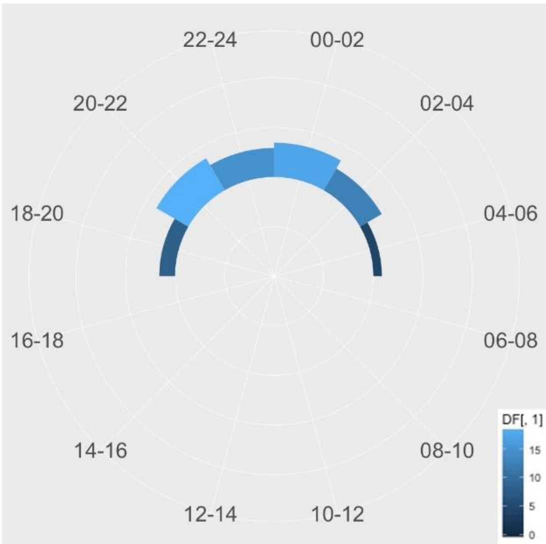
18-20
04-06
16-18
06-08
14-16
08-10
12-14
10-12
DF[, 1]
20
15
10
5
0

(d)


22-24
00-02
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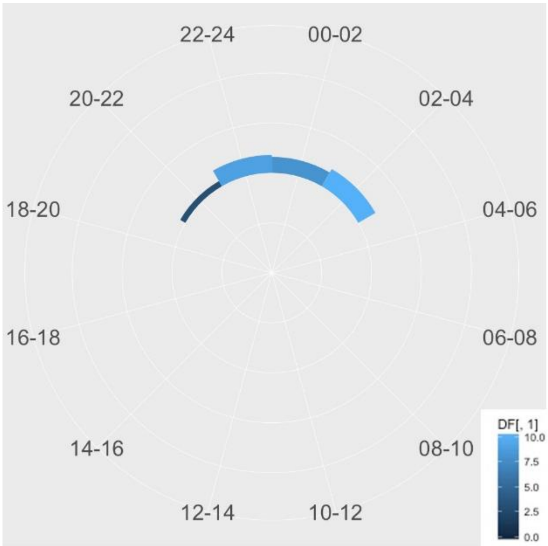
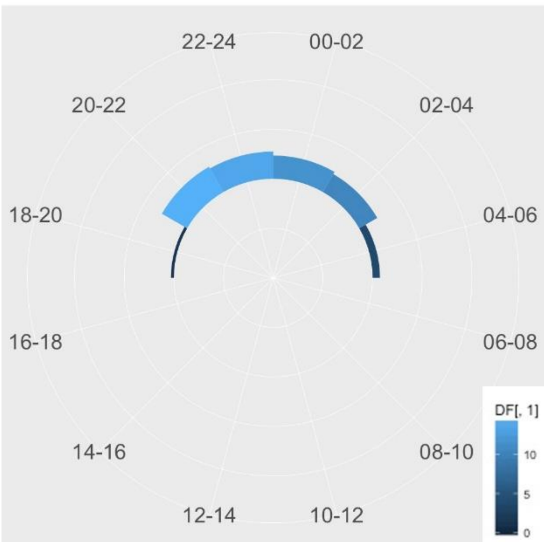
02-04
18-20
04-06
16-18
06-08
14-16
08-10
12-14
10-12
DF[, 1]
15
10
5
0

(a*)


22-24
00-02
20-22
02-04
18-20
04-06
16-18
06-08
14-16
08-10
12-14
10-12
DF[, 1]
10.0
7.5
5.0
2.5
0.0

(b*)


22-24
00-02
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18-20
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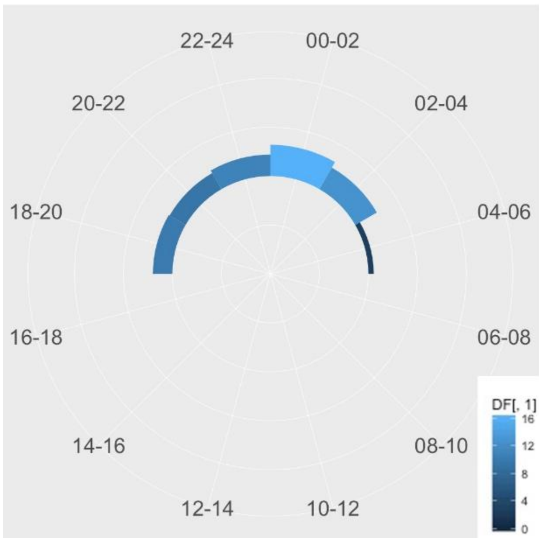
08-10
12-14
10-12
DF[, 1]
10
5
0

(c*)


22-24
00-02
20-22
02-04
18-20
04-06
16-18
06-08
14-16
08-10
12-14
10-12
DF[, 1]
16
12
8
4
0

(d*)

Figure 3.2 Polar plots of average abundance and average morphospecies respectively for May (a, a*), July (b, b*), August (c, c*) and September (d, d*).

3.5 Conclusion

For both categories, the morphospecies record and the abundance during dark hours between 2000 to 0400 hours were higher than the recordings during twilight hours i.e. 1800-2000 hours and 0400-0600 hours. But no statistically different results were observed during any of the interval pairs for both morphospecies and abundance data of pre-monsoon.

For post monsoon category, the timing within the night matters when it comes to moth activity. Moth diversity within 2000 to 0200 hours was significantly higher than diversity during 1800 to 2000 hours and 0200 to 0400 hours. Similar trend was found in moth abundance also; the dark period of the night from 2000 to 0400 hours shows significantly higher abundance than during the twilight hours from 1800 to 2000 hours and 0400 to 0600 hours. The significantly different time interval pairs have been summarised in Table 3.1.

From the polar plots in figure 3.2, it is obvious that the month of May and August has the highest activity of moths. The sharp drop in moth activity during July may be attributed to the disturbance in their flight activity due to monsoon rain. Another attribute can be the inability to reproduce their activity pattern correctly since the light trapping method was not suited for sampling during rain or drizzle.

3.6 Bibliography

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Chapter 4: Seasonal variation of moths of IISER Mohali

4.1 Methodology

The methodology mentioned in chapter 2 was followed for this study with a slight alteration in data accumulation (ref. 2.2 Methodology). The sampling sessions performed during 1800-2400 hours were only considered for this study. The morning sampling sessions between 2400-0600 hours were strictly excluded for drawing any result for this study.

4.2 Results

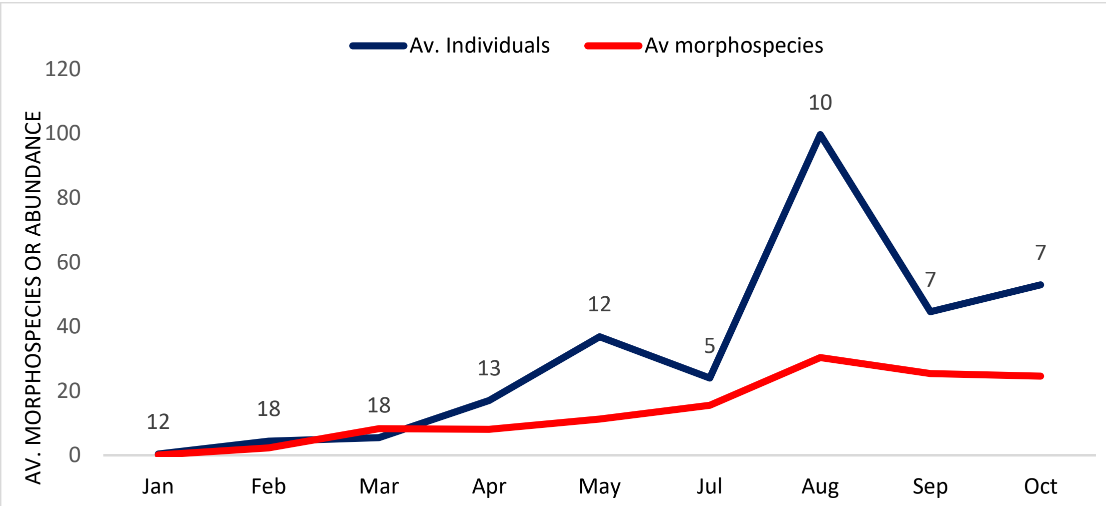

Figure 4.1 Variation in the average recorded individuals and morphospecies for each month. The numbers above data points indicate the number of sampling nights for the corresponding moth.

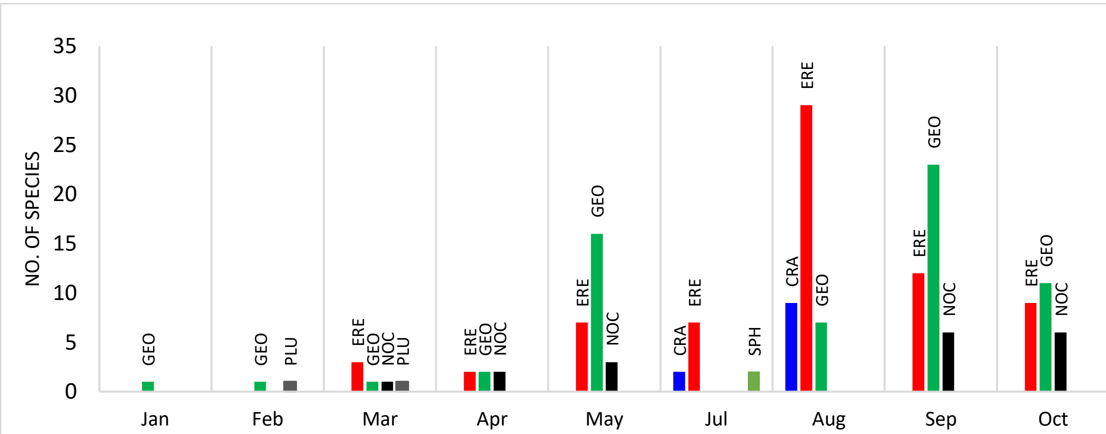

Figure 4.2 Monthly distribution of the top three most diverse families.

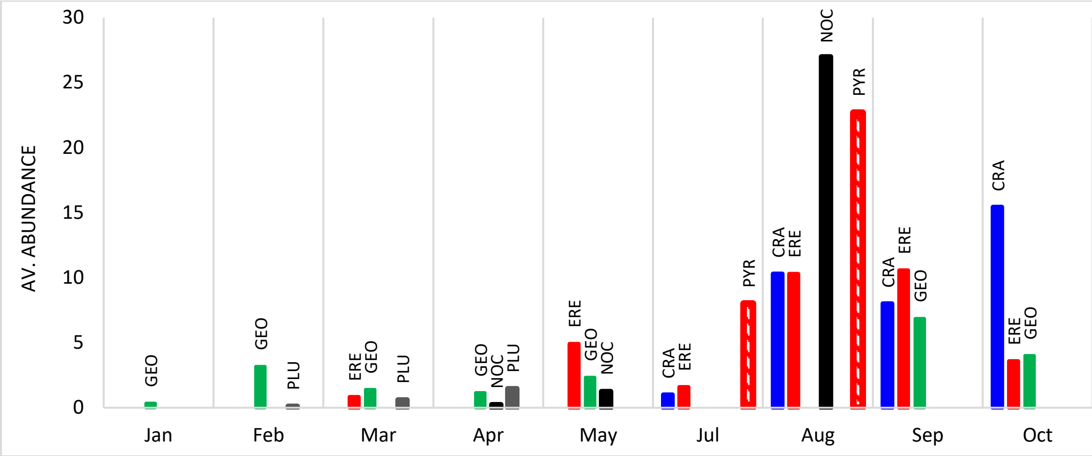

Figure 4.3 Monthly distribution of the top three most abundant families

4.3 Diversity indices

Following the same expressions given in Chapter 2 (ref. 2.4), diversity indices for pre-monsoon and post-monsoon were separately calculated. During pre-monsoon season, a total of 600 specimens belonging to 47 morphospecies were recorded, while a total of 1730 specimens belonging to 119 morphospecies were recorded during the post-monsoon season.

Diversity index	Pre-monsoon (May & July)	Post-monsoon (Aug-Oct)	Overall (May-Sep)	Comparison*
Shannon Diversity Index, H'	2.487	3.507	3.588	3.433
Pielou's Evenness Index, J'	0.679	0.734	0.740	0.8153
Simpson's Diversity Index	0.168	0.065	0.059	NA

Table 4.1 Diversity indices for pre-monsoon and post-monsoon seasons. * The indices value used here for comparative analysis has been referred from Choudhury & Choudhury (2013).

4.4 Conclusion

The sharp decline in the month of July, in both morphospecies count and abundance can be attributed to the lack of sampling efforts due to logistical challenges. From fig. 4.1, it can be concluded that the month of august proved to be the most diverse and abundant period for moths.

As summarised in fig. 4.2, family Geometridae is present abundantly throughout the sampling months. Sphingidae were active during July, Augus and September only. From May onwards, members of Erebidae family were the most diverse and one of the most abundant.

The index values (Table 4.1) leaves little doubt that the moth diversity increases from pre-monsoon-season (May and July) to post-monsoon season (August to October). It should be mentioned here that the Simpson' diversity index, being employed here, gives an inverse relation to the heterogeneity. Following suggestions proposed by Berger & Perker (1970) and Greenberg (1956), it can be recalculated again using the formulation suggested by Gini (1912):

$$\text{Simpson's Diversity Index, } D' = 1 - \sum p_i^2$$

where p_i is the proportions of individuals of *i*th species. The Simpson's diversity index, D' for pre-monsoon and post-monsoon seasons are 0.855 and 0.935. This suggests an increase in the heterogeneity (1, being the highest value) of moth diversity during the post-monsoon season.

For a comparative analysis of the diversity indices from this present study, indices values of Geomteridae family – one of the most diverse and abundant family in India – from a study conducted in Cachar, Assam has been provided (Choudhury and Choudhury, 2013). The comparison shows the highly diverse distribution and heterogeneity of moths in the study area.

4.5 Bibliography

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Chapter 5: Species accumulation and rank abundance curves

5.1 Rank abundance curve

The curve has been plotted using only the data from the eighty-night identified species, and in doing so, around 29% of the total abundance, belonging to unidentified morphospecies groups, have been neglected.

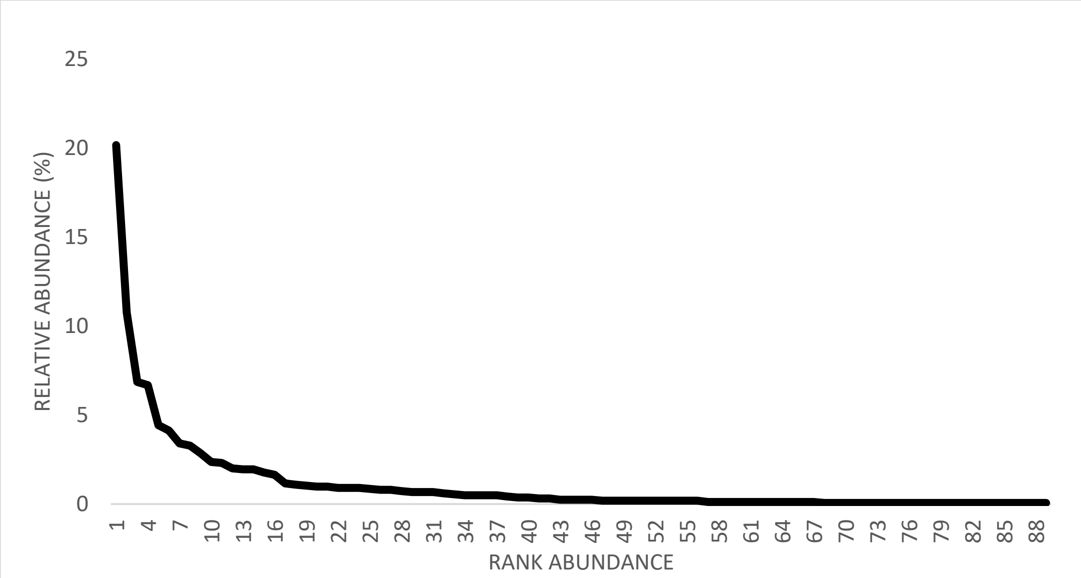


Figure 5.1 Rank abundance curve with rank abundance in x-axis (the most abundant species is given rank 1 and the least, rank 89).

5.2 Species accumulation curve

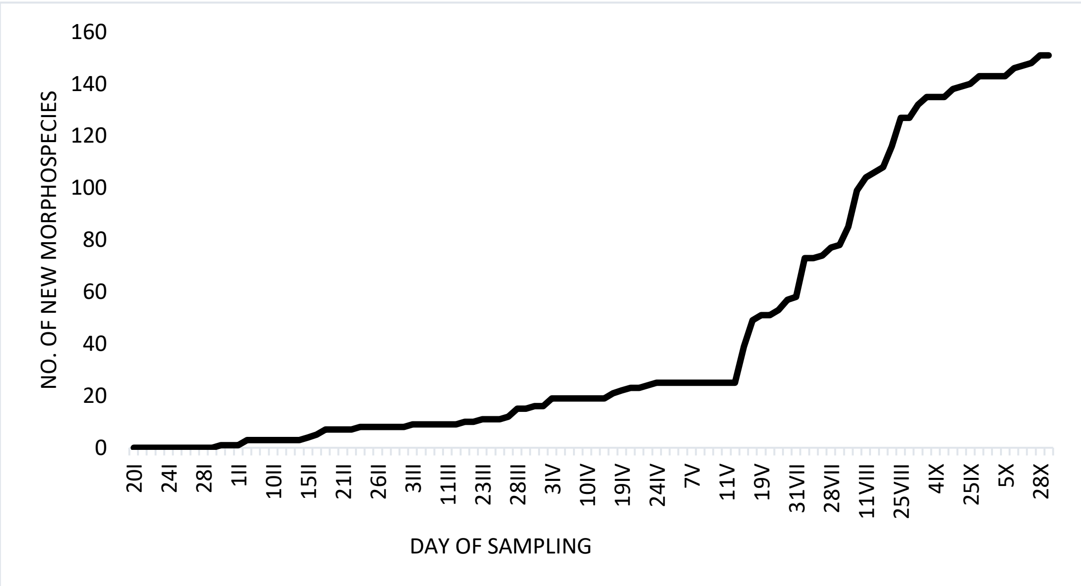
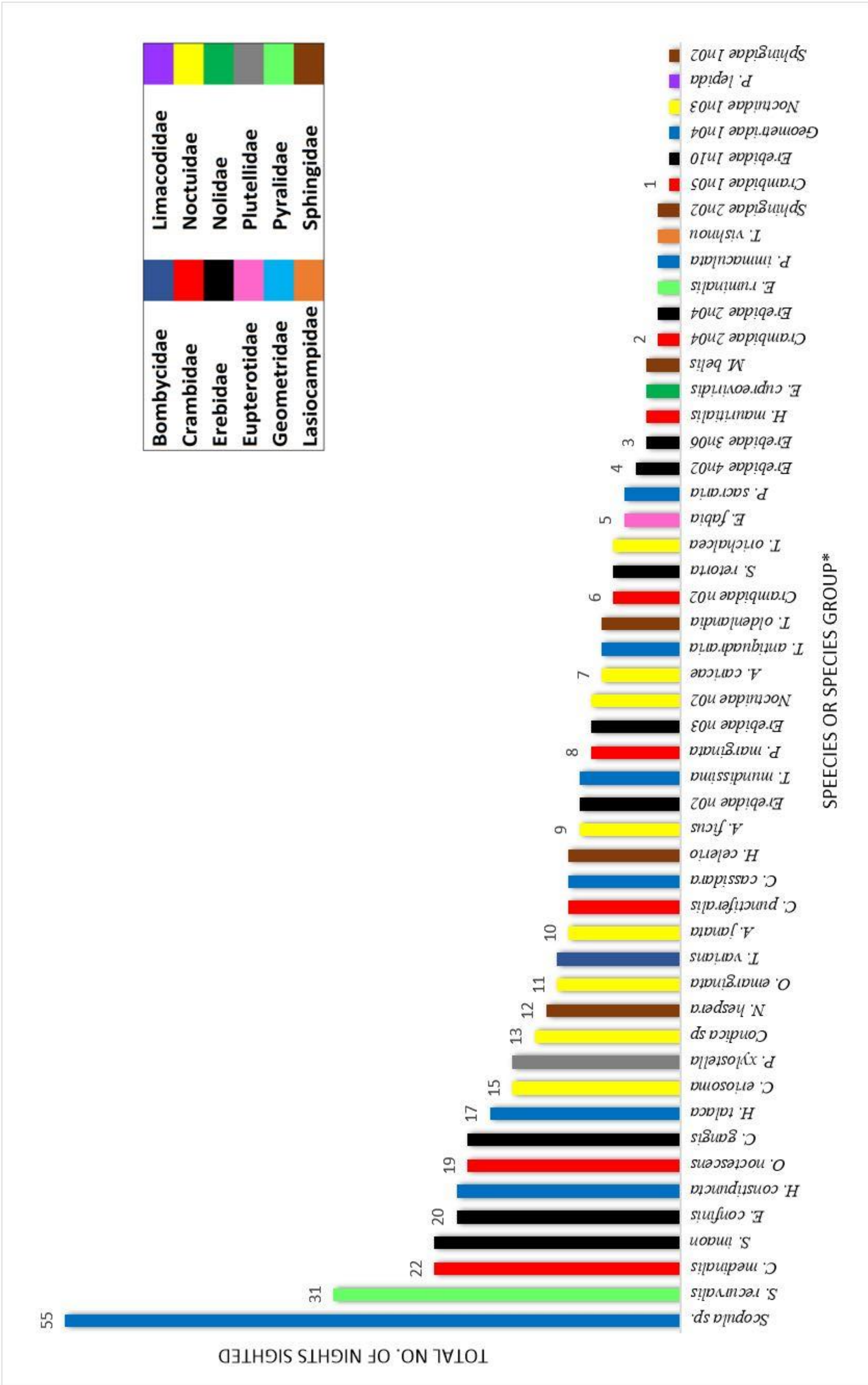


Figure 5.2 Species accumulation curve of the total 151 morphospecies.



TOTAL NO. OF NIGHTS SIGHTED
SPEECIES OR SPECIES GROUP*
Bombycidae
Crambidae
Erebidae
Eupterotidae
Geometridae
Lasiocampidae
Limacodidae
Noctuidae
Nolidae
Plutellidae
Pyralidae
Sphingidae
Scopula sp.
S. recurvalis
C. medinalis
S. imaon
E. confinis
H. constipuncta
O. noctescens
C. gangis
H. talaca
C. eriosoma
P. xylostella
Condica sp
N. hespera
O. emarginata
T. varians
A. janata
C. punctiferalis
C. cassidara
H. celerio
A. ficus
Erebidae n02
T. mundissima
P. marginata
Erebidae n03
Noctuidae n02
A. caricae
T. antiquadraria
T. oldenlandia
Crambidae n02
S. retorta
T. orichalcea
E. fabia
P. sacraria
Erebidae 4n02
Erebidae 3n06
H. mauritialis
E. cupreoviridis
M. belis
Crambidae 2n04
Erebidae 2n04
E. ruminalis
P. immaculata
T. vishnou
Sphingidae 2n02
Crambidae 1n05
Erebidae 1n10
Geometridae 1n04
Noctuidae 1n03
P. lepida
Sphingidae 1n02
55
31
22
20
19
17
15
13
12
11
10
9
8
7
6
5
4
3
2
1

Species group	Family	Species name	Species group	Family	Species name
Erebidae 9n02	Erebidae	*E. lunata*	Sphingidae 2n02	Sphingidae	*A. convolvuli*
		Spilosoma sp.			*C. pallens*
Erebidae 8n03	Erebidae	*C. transiens*	Crambidae 1n05	Crambidae	*A. ino*
		E. maternal			*C. acamasalis*
		Euproctis sp01			*C. brizoalis*
Noctuidae 8n02	Noctuidae	*H. armigera*			*E. sejunctalis*
		S. litura			*O. anastomosalis*
Crambidae 6n02	Crambidae	*D. indica*	Erebidae 1n10	Erebidae	*D. hearseyana f. similis*
		O. indicate			*Ericeia* sp.
Erebidae 4n02	Erebidae	*A. fulvida*			*E. liturata*
		T. honesta			*Euproctis* sp02
Erebidae 3n06	Erebidae	*A. flava*			*H. deflorata*
		A. lactinea			*M. frugalis*
		C. parva			*O. tirhaca*
		C. puella			*P. barcalis*
		G. geometrica			*S. Eldorado*
		P. quadripennis			*S. heliciana*
Crambidae 2n04	Crambidae	*H. perspectalis*	Geometridae 1n04	Geometridae	*A. carissima*
		P. asiaticalis			*C. mariae*
		P. tyres			*Hypomecis* sp.
		S. cancellalis			*N. vallata*
Erebidae 2n04	Erebidae	*P. stuposa*	Noctuidae 1n03	Noctuidae	*A. loreyi*
		T. coronata			*A. unicorna*
		Dasychira sp.			*A. leucomelas*
		O. subnotota	Sphingidae 1n02	Sphingidae	*H. rosetta*
Noctuidae 2n02	Noctuidae	*A. product*			*T. nessus*
		X. intersepta			

Figure 5.3 Number of days sighted per species/ species group – species group refers to a group of species belonging to the same family clustered on the basis number of days sighted. The table above gives the details of all species belonging to a species group.

5.3 Conclusion

The rank abundance curve has been inferred from the abundance data of only the 89 identified species. In doing so, around 29% of abundance has been neglected. Therefore the relative abundance values given in figure 5.1 is expected to drop when abundance data of the unidentified morphospecies is incorporated.

Figure 5.1 data concludes that the chances of observing the most abundant species *Spoladea recurvalis* is only 20.17%, which suggests that the chances of finding a moth other than *S. recurvalis* is ~80%. This result suggests the highly diverse nature of moth distribution in the study area.

Chapter 6: Discussions

The change in the light source from LED to MVL in mid-May has resulted in significant increase in the number of moth catches. The shift in the method was made in order to cover more diversity of the moths in the study area. This change has been kept in mind during drawing any inferences from the study.

During the initial phase of the study, some moths with similar phenotypes were grouped together into single morphospecies, resulting in abundance data of 132 morphospecies. But later inspection has revealed a total of 151 morphospecies. All the diversity indices have been calculated using the abundance data of 132 morphospecies. This mis-grouping of morphospecies will slightly affect the indices values, but can show up as only underrepresentation of the actual diversity. Hence, it can be concluded that the diversity of the study area is greater, to some extent, than is being represented by the diversity indices.

From the study of the species accumulation curve, which has quite yet not approached towards an asymptote, it can be concluded that the results from this study represents an incomplete diversity. Therefore, continued sampling effort, using the same method (MVL), is highly suggested. It is important here to mention that, even with the incomplete representation of the diversity, the diversity indices suggest a very highly diverse distribution of moths in the study area.

To draw more rigid conclusions from the study, further investigation of the unidentified specimens can be conducted through examination of their genitalia. The results from the study can provide more meaning if further studies, using consistent and comparable methods, can be conducted.

BOMBYCIDAE

Trilocha varians

CRAMBIDAE

Chabula acamasalis

Cirrhochrista brizoalis

Cnaphalocrocis medinalis

Conogethes punctiferalis

Diaphania indica

Eoophyla sejunctalis

Hymenia perspectalis

Hypsopygia mauritialis

Omiodes indicata

Omiodes noctescens

Omphisa anastomosalis

Palpita asiaticalis

Parotis marginata

Pilocrocis barcalis

Pygospila tyres

Sameodes cancellalis

EREBIDAE


Achaea janata


Aedia leucomelas


Aloa lactinea


Anomis flava


Asota caricae


Asota ficus


Attatha ino


Creatonotos gangis


Cyana puella


Digama hearseyana f. similis


Episparsis liturata


Eressa confinis


Ericeia sp.


Eudocima materna


Euproctis lunata


Grammodes geometrica


Hypocala deflorata


Mocis frugalis


Ophiusa tirhaca


Oraesia emarginata


Parallelia stuposa


Spilosoma eldorado


Spilosoma sp.


Creatonotos transiens

EREBIDAE


Spirama retorta


Spirama retorta


Syntomoides imaon


Thyas honesta


Anomis fulvida


Asota producta


Dasychira sp.


Euproctis sp.


Euproctis sp.


Orvasca subnotota


Psimada quadripennis


Thyas coronata

EUPTEROTIDAE

Eupterote fabia

GEOMETRIDAE

Agathia carissima

Comibaena cassidara

Comibaena mariae

Hemithea constipuncta

Hypomecis sp.

Hyposidra talaca

Petelia immaculata

Rhodometra sacraria

Scopula sp.

Scopula sp.

Thalassodes antiquadraria

Traminda mundissima

LASIOCAMPIDAE

Trabala vishnou

LIMACODIDAE

Parasa lepida

NOCTUIDAE

Acantholeucania loreyi

Analetia unicorna

Oraesia emarginata

Condica sp.

Helicoverpa armigera

Spodoptera litura

Thysanoplusia orichalcea

Xanthodes intersepta

NOLIDAE

Earias cupreoviridis

PLUTELLIDAE

Plutelida xylostella

PYRALIDAE

Endotricha ruminalis

Spoladea recurvalis

SPHINGIDAE

Agrius convolvulii

Cypa pallens

Hippotion celerio

Hippotion rosetta

Macroglossum belis

Nephele hespera

Theratra nessus

Theratra oldenlandia

OPPORTUNISTIC CATCHES

Aedia acronyctoides[1]

Grammodes stolida[1]

Hypocala subsatura[1]

Pericyma umbrina[1]

Utethesia lotrix[1]

Agrotis ipsilon[2]

Autographa crypta[2]

Ctenoplusia limbirena[2]

Sesamia inferens[2]

Xestia sp.[2]

Phauda sp.[3]*

Acherontia lachesis[4]*

1 EREBIDAE; 2 NOCTUIDAE; 3 PHAUDIDAE; 4 SPHINGIDAE *Photo by Aditya Kanwal


Theratra nessus
1 cm


Spirama retorta
1 cm


Thyas honesta
1 cm