# Prey consumption by insectivorous bats in agro ecosystem, a study using insect capture and bat faecal pellet analysis

Velpandi, S[1]., Muthuselvam, S[2]., Parvathiraj, P[2]., Paramanantha Swami Doss, D[3] and Sudhakaran, M. R[4*]

[1]Research Scholar, Manonmaniam Sundaranar University, Tirunelveli, Tamilnadu, India

[2]Department of Zoology, Sri Ram Nallamani Yadava College, Tenkasi, Tamilnadu, India.

[3]Department of Zoology, St. John's College, Palayamkottai, Tirunelveli, Tamilnadu, India.

[4]Department of Zoology, Sri Paramakalyani College, Alwarkurichi, Tamilnadu, India.

*Corresponding author: Sudhakaran, M. R[4]

**Abstract**

A study was done in agro ecosystem to find out the abundance of insect population and the role of insectivorous bats in controlling them. The agroecosystem selected for the study were paddy, sugarcane, plantain and cotton. These agricultural crops were observed at varying growth stages and insects were captured using light traps. Insects captured predominantly belonged to eight orders namely Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Odonata, and Isoptera. A total of 65 pests were captured repeatedly, and of the total 65 pests, 27 pests were trapped in the paddy field, 14 pests were in the sugarcane field, 11 pests in the plantain field, and 13 pests in the cotton field. The consumption rate of insects by bats was evaluated by calculating percentage volume for each order of insects consumed by bats using faecal pellets analysis. All bats were observed to prey upon the insect items which they sought at their foraging perches and showed a varied in their prey preference. On the volume of feeding on prey items and insect pests, bats are an IPM agent in pest control.

**Key Words:** agro ecosystem, faecal pellet analysis, insect capture, insectivores

## Introduction

Insectivorous bats consume a wide range of arthropods, some of which are considered major agricultural pests worldwide (Kunz *et al*., 2011; Maine and Boyles 2015; McCracken *et al*., 2012; and Williams Guillen *et al*., 2008) and their potential to significantly increase agricultural productivity by suppressing insect pest is high. This pest control service has been estimated to be worth billions of dollars to agriculture globally by decreasing insect crop damage and increasing yield (Cleveland *et al*., 2006). However, a few studies have explicitly investigated the composition and abundance of dietary prey items or assessed the ratio of pest insects consumed by bats (Marco and Lanza, 2018; Holly, 2020 and Kerwin, 2020).

A piece of important knowledge about the diet of any organism can provide fundamental insights into the ecology and behaviour of that particular organism in its environment (Malmstrom, 2010). Such dietary information is essential for the proper management of any species. The hours of twilight followed by darkness is the best feeding time for the bat species (Rydell *et al.,* 1996). The night is alive with such a nocturnal elegant and fascinating creature, the bats. Bats play a tremendous role in bringing a sustainable balanced ecosystem and agriculture in upholding the economy of any country. Insectivorous

bats generally select from the available food but become more opportunistic when there is a demand for prey items (Whitaker 1995).

Bat - insect interaction and bat prey selection were observed through faecal pellet analysis. It has been stated that only a very small fraction of stomach content escapes reduction to unidentifiable soup (Gould 1955) while it is true that most bats thoroughly chew their food and so it is usually possible to identify most of the prey remain to reasonable level i.e., atleast to the Order level (Whitaker 1978).

This study was done to find species level dietary exploration of insectivorous bat community in different agricultural landscape. Within the current study, we investigated the insectivorous bat species activity and insect species composition within the four dominating crop types namely, paddy, plantain, sugarcane, and cotton. Along with this, we analysed the faecal pellets of bats in the study area to observe the dietary preference of these bats and their role in insect pest control in the agro ecosystem.

## Materials and Methods

Insect population in the various agro ecosystems of the study area like paddy, plantain, sugarcane, and cotton was analysed using insect light trap. Identification of insects was done up to orders. Dietary habit analysis of bats species in the study area was done by faecal pellet analysis.

## Selection of Sampling Site

To study the dietary preference of bats, faecal pellets were collected in and around the study area at various bat roosts in different localities like village limits, foothills, isolated, farmland, and small hillock. The bat roosts were selected as such they were around an agro ecosystem or its foraging area is in nearby agricultural fields. The first colony is in a village limit, located in an isolated place (Elevation- 245ft MSL, Location - N: 8° 43.635' E: 077° 31.202'), Ambasamudram (Bat colony: *H. speoris*). The second colony is in an unused chamber of Sri Paramakalyani College (Elevation- 249ft MSL, Location - N : 8° 42.67' E : 075° 198'), Alwarkurichi (Bat colony: *P. mimus*), and third colony is a small hillock of kallidaikurichi (Bat colony: *H. ater*), (Elevation - 192ft MSL, Location - N : 08° 42.701' E : 077° 43.776'). The fourth and fifth colonies are located in the middle of an agroecosystem. The fourth colony is in a farmland at Cheranmahadevi (Bat colony: *M. lyra*), (Elevation - 319ft MSL, Location - N : 8° 42.665' E : 077° 34.202') and the fifth colony is in Kadayam (Bat colony: *P. dormeri*), (Elevation - 124ft MSL, Location - N : 8° 44.083 E : 077° 41.854') and the sixth colony is a cave (Elevation - 260ft MSL, Location - N : 10° 40.565' E: 056° 30.103') at Anavankudiyiruppu (Bat colony: *R. hardwickii*), and the seventh colony is a farmland at Kovilkulam (Elevation - 120ft MSL, Location - N : 9° 41.625' E : 073° 29.204') (Bat colony: *T. melanopogon*).

## Insect sample collection using a light trap

Insect light traps were set in the centre of different agricultural habitats such as paddy, banana, cotton, and sugarcane. Custom-made light traps are specially designed for insect capture. A fibreglass cone smooth on the inside was placed inside a 20-L plastic bin, with a

strip of 12-V LED light taped to a cover resting over the bin to attract flying invertebrates. The LEDs were connected to a 12-V battery to give an uninterrupted power supply. Insect light trap was set in an agricultural field from 06.00 pm to 06.00 am.

**Sample collection – Bat Faecal pellets**

Fresh faecal pellets were collected from the day roost by spreading polythene sheets at regular intervals (every week), ca. 50 pellets were randomly selected and their dried weight was taken using a digital balance (ROY -INDIA). The pellets were stored in 80% alcohol and observed for the presence of insect remnants using a fine slide under a microscope. Each slide was systematically searched for identifiable insect parts under a binocular microscope (Olympus CH20i. India). Identifications were made with the help of authenticated literature (Mani, 1990 and Borror *et al*., 1992) available on Indian insects.

**Result**

**Insect population survey using a light trap**

The insect population in the study area was surveyed using light traps for a period of one year from January 2020 - December 2021. The insects captured predominantly belonged to eight orders namely Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Odonata, and Isoptera (Table 1).

**Table: 1. Insects collected in the study area**

| Insect order | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coleoptera | 17± 8.52 | 12± 5.81 | 16± 7.91 | 15± 7.68 | 10± 4.67 | 20± 9.37 | 15± 7.54 | 17± 8.47 | 22± 10.94 | 27± 12.96 | 18± 8.94 | 14± 6.49 |
| Diptera | 15± 7.11 | 10± 4.95 | 15± 7.26 | 18± 9.02 | 14± 6.92 | 18± 8.64 | 16± 7.89 | 21± 10.28 | 18± 8.48 | 19± 9.47 | 20± 9.57 | 19± 9.36 |
| Hemiptera | 20± 9.52 | 15± 7.24 | 17± 8.35 | 10± 4.52 | 21± 10.35 | 17± 8.96 | 14± 6.18 | 23± 11.65 | 16± 7.61 | 21± 10.26 | 19± 9.37 | 25± 12.51 |
| Hymenoptera | 14± 6.90 | 8± 3.65 | 11± 5.41 | 7± 3.78 | 11± 5.32 | 15± 7.43 | 12± 5.81 | 14± 6.74 | 20± 9.15 | 13± 6.27 | 14± 6.87 | 18± 8.63 |
| Lepidoptera | 17± 8.52 | 13± 6.34 | 15± 7.26 | 19± 9.54 | 20± 10.02 | 19± 9.02 | 16± 7.89 | 18± 8.63 | 19± 9.31 | 17± 8.37 | 16± 7.89 | 22± 10.74 |
| Orthoptera | 16± 7.82 | 10± 4.95 | 9± 4.10 | 10± 4.52 | 10± 4.67 | 12± 5.47 | 14± 6.18 | 14± 6.74 | 16± 7.61 | 19± 8.97 | 11± 5.32 | 13± 6.26 |
| Odonata | 16± 7.82 | 9± 4.27 | 17± 8.35 | 15± 7.68 | 15± 7.36 | 20± 9.37 | 12± 5.81 | 10± 4.87 | 15± 7.24 | 15± 7.40 | 13± 6.48 | 11± 5.18 |
| Isoptera | 20± 9.52 | 8± 3.65 | 11± 5.41 | 9± 4.12 | 12± 5.46 | 11± 5.67 | 10± 4.73 | 15± 7.24 | 12± 5.38 | 13± 6.27 | 10± 4.62 | 9± 4.37 |

**Insect population in various Agroecosystem**

Insect capture was made in the different agroecosystems to study their abundance and diversity.

**Insects captured in Paddy field**

Insects were collected in paddy fields during two different cultivable seasons in an year. A light trap was set in the paddy field and insects were captured and classified up to

order. In paddy field, major insects captured falls into different groups that consists of Diptera (13.40%), Odonata (13.40%), Hemiptera (13.18%), Lepidoptera (12.96%), Coleoptera (12.74%), Isoptera (11.86%), Orthoptera (11.42%), and Hymenoptera (10.98%). During the early stage, insects belong to Hemiptera, Diptera and Odonata, were observed to be more, and in the milky stage of growth Coleoptera, Lepidoptera and Odonata were found to be in maximum. In the harvesting / fully grown period, Diptera, Lepidoptera, Orthoptera, and Isoptera were observed to be more (Table 2).

**Table - 2. Insects collected in Paddy field agroecosystem***

| Order | 1st month | 2nd month | 3rd month |
|---|---|---|---|
| Coleoptera | 17± 4.64 | 22± 2.8 | 19± 6.18 |
| Diptera | 21± 6.5 | 18± 2.82 | 22± 6.60 |
| Hemiptera | 23± 4.04 | 21± 3.86 | 16± 4.78 |
| Hymenoptera | 14± 3.16 | 24± 5.47 | 12± 5.31 |
| Lepidoptera | 18± 6.18 | 19± 5.90 | 22± 5.31 |
| Orthoptera | 14± 6.94 | 16± 3.30 | 22± 4.83 |
| Odonata | 20± 1.14 | 22± 8.77 | 19± 6.48 |
| Isoptera | 18± 2.36 | 15± 4.76 | 21± 7.13 |

*Three collections per month

**Insects captured in Plantain field**

Plantain was cultivated at a greater rate in the study area next to paddy, and insects were captured in plantain farms for 7 months. Plantain was grown and harvested after seven months. Insects were captured in the plantain fields in an interval of three times every month throughout the entire cultivable period. Insect captures data was given in the month.

In the plantain farm, insects collected include Odonata (14.31%), Hemiptera (14.21%), Lepidoptera (14.11%), Coleoptera (12.84%), Diptera (12.54%), Orthoptera (11.86%), Isoptera (10.29%), and Hymenoptera (9.80). In the first month, Coleoptera, Diptera, and Hemiptera were observed to be in maximum. In the second month, Coleoptera, Odonata, and Diptera were observed to be in maximum, and in the third month, Lepidoptera and Diptera were observed to be more. In the fourth month, Lepidoptera and Diptera were observed to be more. In the fifth month, Hemiptera and Diptera were in maximum. In the sixth month, Hemiptera was observed to be in maximum, and in the seventh month, Odonata was trapped in maximum (Table 3).

**Table- 3. Insects captured in plantain field***

| Order | 1st month | 2nd month | 3rd month | 4th month | 5th month | 6th month | 7th month |
|---|---|---|---|---|---|---|---|
| Coleoptera | 19±3.36 | 23±7.16 | 20±2.62 | 12±8.45 | 17±11.72 | 19±13.19 | 21±14.58 |
| Diptera | 18±3.16 | 20±3.86 | 18±4.69 | 21±14.78 | 21±14.48 | 16±11.11 | 14±9.72 |
| Hemiptera | 18±3.14 | 21±6.65 | 17±7 | 16±11.26 | 23±15.86 | 28±19.44 | 22±15.27 |
| Hymenoptera | 11±4.65 | 16±2.62 | 17±3.5 | 19±13.38 | 14±9.65 | 12±8.33 | 11±7.63 |
| Lepidoptera | 21±2.16 | 22±6.23 | 19±8.22 | 26±18.30 | 18±12.41 | 21±14.58 | 17±11.80 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Orthoptera | 16±3.76 | 18±3.59 | 17±6.24 | 16±11.26 | 14±12.41 | 20±13.88 | 20±13.88 |
| Odonata | 22±6.55 | 23±7.27 | 23±4.42 | 18±12.67 | 20±13.79 | 16±11.11 | 24±16.66 |
| Isoptera | 16±4.20 | 19±2.98 | 11±3.87 | 14±9.85 | 18±12.41 | 12±8.33 | 15±10.41 |

*Three collections per month

**Insects captured in sugarcane field**

Sugar cane was cultivated at a moderate rate in the study area next to paddy and plantain. Insects were captured on a sugar cane farm for 7 months. Sugar cane was grown and harvested after seven months. Insects were captured in the sugar cane fields three times every month for the entire cultivable period.

In the plantain farm, insects collected includes, Lepidoptera (14.52%), Hemiptera (13.54%), Diptera (13.5%), Coleoptera (12.95%), Odonata (12.16%), Isoptera (12.07%), Hymenoptera (11.57%), and Orthoptera (10.10%). In the first month, Hemiptera and Isoptera were observed to be in maximum. In the second month, Lepidoptera, Coleoptera, and Isoptera were observed to be in maximum, and in the third month, Lepidoptera and Odonata were observed to be more. In the fourth month, Diptera and Hymenoptera were observed to be more. In the fifth month, Coleoptera, Hemiptera, and Odonata were in maximum. In the sixth month, Diptera and Hemiptera were observed to be in maximum, and in the seventh month, Hemiptera and Lepidoptera were in maximum (Table 4).

**Table-4. Insects captured in Sugarcane field***

| **Order** | **1st month** | **2nd month** | **3rd month** | **4th month** | **5th month** | **6th month** | **7th month** |
|---|---|---|---|---|---|---|---|
| Coleoptera | 17±12.59 | 21±14.09 | 20±13.33 | 17±11.56 | 27±18 | 18±13.23 | 12±7.89 |
| Diptera | 15±11.11 | 18±12.08 | 15±10 | 25±17 | 19±12.66 | 22±16.17 | 19±12.5 |
| Hemiptera | 20±14.81 | 16±10.73 | 20±13.33 | 17±11.56 | 21±14 | 19±13.97 | 25±16.44 |
| Hymenoptera | 14±10.37 | 18±12.08 | 16±10.66 | 20±13.60 | 13±8.66 | 19±13.97 | 18±11.84 |
| Lepidoptera | 17±12.59 | 25±16.77 | 30±20 | 21±14.28 | 17±11.33 | 16±11.76 | 22±14.47 |
| Orthoptera | 16±11.85 | 13±8.72 | 14±9.33 | 14±9.52 | 19±12.66 | 11±8.08 | 16±10.52 |
| Odonata | 16±11.85 | 17±11.40 | 21±14 | 16±10.88 | 21±14 | 13±9.55 | 20±13.15 |
| Isoptera | 20±14.81 | 21±14.09 | 14±9.33 | 17±11.56 | 13±8.66 | 18±13.23 | 20±13.15 |

*Three collections per month

**Insects captured in Cotton field**

Cotton was cultivated in the study area next to paddy, plantain, and sugarcane, and it was grown and cultivated in two months. Insects were captured in the cotton fields three times every month for the entire cultivable period.

In cotton field, insects collected include Lepidoptera (16.19%), Coleoptera (14.78%) Diptera (13.38%), Hemiptera (13.38%), Odonata (11.26%), Isoptera (10.91%), Hymenoptera (10.56%), and Orthoptera (9.50%). In the first month, Diptera and Lepidoptera were observed

to be in maximum, and in the second month, Lepidoptera and Coleoptera were captured in maximum (Table 5).

**Table-5. Insects captured in Cotton field***

| Order | 1st month | 2nd month |
|---|---|---|
| Coleoptera | 19±13.57 | 23±15.97 |
| Diptera | 23±16.42 | 15±10.41 |
| Hemiptera | 21±15 | 17±11.80 |
| Hymenoptera | 12±8.57 | 18±12.5 |
| Lepidoptera | 20±14.28 | 26±18.05 |
| Orthoptera | 14±10 | 13±9.02 |
| Odonata | 15±10.71 | 17±11.80 |
| Isoptera | 16±11.42 | 15±10.41 |

*Three collections per month

**Insects captured in various agroecosystem during development stages of crops**

Based on insect population observed in paddy, plantain, sugarcane, and cotton fields, a varied proportion of insects belongs to different orders were captured.

Paddy field environments were observed at varying growth stages like nursery stage, vegetative stage, midseason or ripening stage, and mature stage. Insects captured during these periods come under the following orders at maximum numbers such as Diptera (13.40%), Odonata (13.40), and Hymenoptera (10.98%).

Plantain was cultivated and harvested after seven months and the development stages can be classified as grand daughter plant stage, daughter plant stage, and mother stage. A variety of insects was captured during its development stages and a maximum of insects captured belong to Odonata (14.31%), and Hymenoptera (9.80%) was captured in a lesser number.

Sugarcane was cultivated in the study area and it grows in seven months, it develops in four different stages like germination phase stage, tailoring phase stage, grand growth phase, and maturation stage. Insect captured falls into varied groups and a maximum number comes under the order Lepidoptera (14.52%) and the minimum number belongs to Orthoptera (10.10%).

Cotton was grown in the study area at a moderate level and its developmental stages consist of five stages namely germination and seeding stage, true leaves stage, cotton square stage, cotton blossom stage, and cotton boll stage. It is cultivated and harvested in sixty days. The insect captured in the cotton field comprises a maximum of Lepidoptera (16.19%) and Orthoptera (9.50%) was captured in a minimum number (Table 6).

**Table - 6. Insects captured in various agriculture fields**

| Order | Paddy field (%) | Plantain (%) | Sugarcane field (%) | Cotton field (%) |
|---|---|---|---|---|
| Coleoptera | 12.40 | 12.84 | 12.95 | 14.78 |

| | | | | |
|---|---|---|---|---|
| Diptera | 13.40 | 12.54 | 13.05 | 13.38 |
| Hemiptera | 13.18 | 14.21 | 13.54 | 13.38 |
| Hymenoptera | 10.98 | 9.80 | 11.57 | 10.56 |
| Lepidoptera | 12.96 | 14.11 | 14.52 | 16.19 |
| Orthoptera | 11.42 | 11.86 | 10.10 | 9.50 |
| Odonata | 13.40 | 14.31 | 12.16 | 11.26 |
| Isoptera | 11.86 | 10.29 | 12.07 | 10.91 |

**Insect Pests Collected**

Insect trap studies were made in the various agroecosystem, a total of 65 pests were captured repeatedly in the study area. Of the total 65 pests, 27 pests were trapped in the paddy field and 14 pests were in the sugarcane field, 11 pests in the plantain field, and 13 pests in the cotton field. They belong to eight different orders like Lepidoptera, Hemiptera, Hymenoptera, Odonata, Orthoptera, Coleoptera, Diptera, and Isoptera (Table 7).

**Table-7. Insect pests collected in the various agriculture fields**

| S. No | Pest | Scientific Name | Insects Order |
|---|---|---|---|
| **PADDY** | | | |
| 1 | Leaf folder | *Cnaphalocrocismedinalis* | Lepidoptera |
| 2 | Stem borer | *Scirpophagaincertulas* | Lepidoptera |
| 3 | Orthetrum | *Orthetrumsabina* | Odonata |
| 4 | Caseworm | *Nymphuladepunctalis* | Lepidoptera |
| 5 | Ear head bug | *Leptocorisaacuta* | Hemiptera |
| 6 | Black bug | *Scotinopharalurida* | Hemiptera |
| 7 | Mealy bug | *Brevenniarehi* | Hemiptera |
| 8 | Green leaf hopper | *Nephotettixvirescens* | Hemiptera |
| 9 | Butterfly | *Rhopalocera sp.* | Lepidoptera |
| 10 | Skipper | *Hesperiidea sp.* | Lepidoptera |
| 11 | Rice ear bug | *Leptocorisaacuta* | Hemiptera |
| 12 | Common evening brown | *Melanitisleda* | Lepidoptera |
| 13 | Yellow stem borer | *Scirpophagaincertulas* | Lepidoptera |
| 14 | Jewel blues | *Lycaenidae sp.* | Lepidoptera |
| 15 | Rice moth | *Corcyra cephalonica* | Lepidoptera |
| 16 | Acrididae | *Acrididaesp* | Orthoptera |
| 17 | Bed bug | *Cimicidae sp.* | Hemiptera |
| 18 | Army worm | *Spodopteraexempta* | Lepidoptera |
| 19 | Fruit fly | *Drosophila melanogaster* | Diptera |
| 20 | Butterfly | *Rhopalocera sp.* | Lepidoptera |
| 21 | Mosqito | *Culicidae sp.* | Diptera |
| 22 | House fly | *Muscadomestica* | Diptera |
| 23 | Carolina locust | *Dissosteiracarolina* | Orthoptera |
| 24 | Gomphidae | *Gomphidae sp.* | Odonata |
| 25 | Deer fly | *Chrysops sp.* | Diptera |
| 26 | Copera | *Coperamarginipes* | Odonata |
| 27 | Plains cupid | *Chiladespandava* | Lepidoptera |

| | | | |
|---|---|---|---|
| **SUGAR CANE** | | | |
| 28 | Grasshopper | *Caelifera sp.* | Orthoptera |
| 29 | Root grub | *Leucopholisirrorate* | Coleoptera |
| 30 | Plant hopper | *Dichopter sp.* | Hemiptera |
| 31 | Early shoot borer | *Chiloinfuscatellus* | Lepidoptera |
| 32 | Internode borer | *Chilosaccharifagusindicus* | Lepidoptera |
| 33 | Termites | *Odontotermesobesus* | Isoptera |
| 34 | Black beetle | *Euetheolohumilis* | Coleoptera |
| 35 | Fruit fly | *Drosophila melanogaster* | Diptera |
| 36 | Boll weevil | *Anthonomusgrandis* | Coleoptera |
| 37 | Crematogaster | *Crematogaster sp.* | Hymenoptera |
| 38 | Trithemis | *Trithemis aurora* | Odonata |
| 39 | Buffalo treehopper | *Stictocephalabisonia* | Hemiptera |
| 40 | House cricket | *Achetadomesticus* | Orthoptera |
| 41 | Black garden ant | *Lasiusniger* | Hymenoptera |
| **PLANTAIN** | | | |
| 42 | Sepsidae | *Sepsidae sp.* | Diptera |
| 43 | Weevil borer | *Cosmopolites sordidus* | Coleoptera |
| 44 | Leaf beetle | *Chrysomelidae sp.* | Coleoptera |
| 45 | Tree cricket | *Oecanthinae sp.* | Orthoptera |
| 46 | Ant | *Formicidae sp.* | Hymenoptera |
| 47 | Firefly | *Lampyridae sp.* | Coleoptera |
| 48 | Beetle | *Oryctes rhinoceros* | Coleoptera |
| 49 | Athous | *Athoushaemorrhoidalis* | Coleoptera |
| 50 | Termites | *Incistermes minor* | Isoptera |
| 51 | Christmas beetle | *Anoplognathus* | Coleoptera |
| 52 | Ground beetle | *Carabidae sp.* | Coleoptera |
| **COTTON** | | | |
| 53 | Agrotis | *Agrotis sp.* | Lepidoptera |
| 54 | White fly | *Bemisiatabaci* | Hemiptera |
| 55 | Brown bug | *Halyomorphahalys* | Hemiptera |
| 56 | Lesser wax moth | *Achroiagrisella* | Lepidoptera |
| 57 | Common bush hopper | *Ampittadioscorides* | Lepidoptera |
| 58 | Melamphaus | *Pyrrhocoridae* | Hemiptera |
| 59 | Army worm | *Spodopteralitura* | Lepidoptera |
| 60 | Beet army worm | *Spodopteraexigua* | Lepidoptera |
| 61 | Lady beetle | *Coccinellidae* | Coleoptera |
| 62 | True bug | *Boiseatrivittata* | Hemiptera |
| 63 | Large milk weed bug | *Oncopeltusfasciatus* | Hemiptera |
| 64 | Sap beetle | *Nitidulidae sp.* | Coleoptera |
| 65 | Katydid | *Microcentrumrhombifolium* | Orthoptera |

**Pests collected in various developmental stages of crops**

Insects were collected during different seasons of plant growth. In paddy fields, insect collection was made during their different stages of growth namely, nursery stage, vegetative stage, midseason stage or ripening stage, and mature stage. During the nursery stage, the

insect collection mainly consists of pests like *Spodoptera sp*, skipper, tree borer, and lilac root weevil, and during the vegetative stage, stem borer, leafhopper, brown plant hopper, stink bug, and thrips were observed to be in a maximum. During the mid-season stage, ear bug, grasshopper, leaf folder, plant hopper, maggot, and black bug army worms, and in the mature stage, mantis, crickets, rice moth, common brown stem maggot, aphids, rice swarming caterpillar were observed to be more (Table 8).

**Table-8. Pests observed at various growth stages of paddy plant**

| **Developmental stages of Paddy** | **Pest name** |
|---|---|
| Nursery stage | *Spodoptera litura*, skipper, tree borer, lilac root weevil |
| Vegetative stage | Stem borer, leaf hopper, brown plant hopper, stink bug, thrips |
| Midseason stage (or) ripening | Ear bug, grasshopper, leaf folder, plant hopper, maggot, black bug, army worms (or) cut worms |
| Mature stage | Mantis, crickets, rice moth, common brown stem maggot, aphids, rice swarming caterpillar |

In sugar cane fields, insects were collected at different stages of growth and pest population was assessed. During the germination phase, the insect collection shows pests like stem borer, termites, aenictus, and bogong moth, and in the tillering stage, insect pests like early shoot borer, black garden ant, grass hopper, stem borer, and drosophila were observed. During the maturation phase, insect collection shows pests like top shoot borer, white fly, bobong moth, mantis, and ants (Table 9).

**Table- 9. Pests observed at various growth stages of sugar cane**

| **Development stage of Sugar cane** | **Pest name** |
|---|---|
| Germination phase | Stem borer, termites, aenictus, mantis, bogong moth |
| Tillering phase | Early shoot borer, black garden ant, grass hopper, stem borer, drosophila |
| Grand growth phase | Inter node borer, wooly aphid, root grub, leaf beetle, ground beetle |
| Maturation phase | Topshoot borer, white fly, bogong moth, mantis, ant |

In the plantain field, insect collection contains pests like weevil borer, thrips, termites, and sucker weevil. During the grand daughter plant stage, and in the daughter stage, pests like leaf beetle, pseudostem borer, aphid, flea beetle, sepsidae, skipper, and ground beetle were observed. Insect pests like jewel blues, root grub, crematogaster, mealy bug, ant, cricket, nematodes, and termites were abundant in mother plants (Table 10).

**Table-10. Pests observed at various growth stages of Plantain**

| Development stage of Plantain | Pest name |
|---|---|
| Granddaughter plant | Weevil borer, thrips, termites, suckers weevil |
| Daughter plant | Leaf beetle, pseudo stem borer, aphid, flea beetle, sepsidae, skipper, ground beetle |
| Mother plant | Jewel blues, root grub, crematogaster, mealy bug, ant, cricket, nematodes, termites |

In cotton fields, during the germination and seedling stage, leaf worm, flea hopper, and army worms were captured. During the true leaves stage, boll worm, plant bug, jewel bugs, and pod borers were captured, and in the cotton square stage, cabbage looper, cotton aphid, spiders, boll weevil and mantis were captured. During the cotton boll stage, pink boll worm, stink bugs, and boll weevil was captured (Table 11).

**Table-11. Pests observed at various growth stages of Cotton**

| Development stage of Cotton | Pest name |
|---|---|
| Germination and seedling | Leaf worm, flea hopper, army worm |
| True leaves | Boll worm, plant bug, jewel bugs, pod borers |
| Cotton square | Cabbage looper, cotton aphid, spiders, boll weevil, mantis |
| Cotton blossom | Grass hopper, white fly, true bug |
| Cotton boll | Pink boll worm, stink bugs, boll weevil |

**Analysis of bat faecal pellets to identify insect remnants:**

The consumption rate of insects by bats was evaluated by calculating percentage volume for each order of insects consumed by bats using faecal pellets analysis. The faecal pellets were collected from night roost and diurnal roosting sites and analysed for insect remnants (Table 12).

**Table-12. Insect remnants in bat faecal pellets**

| Insect order | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coleoptera | 14± 6.28 | 7± 3.40 | 14± 7.28 | 18± 9.18 | 17± 7.07 | 23± 11.07 | 21± 10.81 | 16± 7.39 | 14± 6.75 | 23± 11.40 | 14± 5.89 | 19± 9.67 |
| Diptera | 9± 4.52 | 11± 5.11 | 17± 8.85 | 12± 5.12 | 12± 5.19 | 13± 6.84 | 12± 5.72 | 14± 6.75 | 18± 7.03 | 17± 8.02 | 14± 6.45 | 14± 6.75 |
| Hemiptera | 16± 7.66 | 20± 9.37 | 12± 5.59 | 15± 7.15 | 9± 4.75 | 12± 6.30 | 16± 7.36 | 19± 9.67 | 11± 5.47 | 12± 5.76 | 17± 7.91 | 11± 5.47 |
| Hymenoptera | 11± 4.90 | 5± 2.40 | 8± 3.92 | 10± 4.60 | 14± 6.63 | 6± 2.85 | 12± 5.72 | 4± 1.91 | 14± 6.75 | 8± 3.51 | 8± 3.95 | 13± 6.11 |
| Lepidoptera | 21± 10.42 | 20± 9.37 | 14± 6.28 | 19± 7.69 | 17± 8.07 | 18± 8.46 | 18± 8.18 | 18± 9.01 | 13± 6.11 | 10± 4.63 | 11± 5.94 | 16± 7.39 |
| Orthoptera | 7± 3.14 | 7± 3.40 | 10± 4.71 | 3± 2.03 | 12± 5.52 | 4± 1.61 | 7± 3.27 | 11± 5.47 | 3± 1.57 | 8± 3.51 | 10± 4.84 | 8± 3.79 |
| Odonata | 14± 6.28 | 18± 8.51 | 16± 7.67 | 16± 7.66 | 7± 3.71 | 12± 5.30 | 9± 4.89 | 9± 4.83 | 16± 7.69 | 14± 6.89 | 8± 3.95 | 13± 6.11 |
| Isoptera | 4± 1.76 | 9± 4.25 | 5± 2.35 | 4± 1.54 | 9± 4.75 | 9± 4.23 | 2± 0.93 | 4± 1.91 | 8± 3.79 | 4± 1.75 | 5± 2.47 | 3± 1.27 |

The hierarchy in the selection and consumption of insect orders and preference throughout the year consists mainly of insects belonging to eight orders namely Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Odonata, and Isoptera.

**Dietary preference by bats analysed through faecal analysis**

On analysing the insect remnants in faecal pellets of bats in the study area, they show a varied preference of its dietary item in different seasons. *H. ater*, *H. speoris* and *M. lyra* was observed to prefer and feed at coleopterans at a greater rate, their preference rate on coleopterans was 17.76%, 17.56%, and 17.39% respectively. Species such as *T. melanopogon*, *P. mimus*, *P. dormeri*, *H. speoris*, and *R. hardwickii* feeds on lepidopterans at a greater rate. All bats were observed to prey upon the insect items which they sought at their foraging perches and showed a varied in their prey preference (Table 13).

**Table-13. Dietary preference of bats from insect remnants (in%)**

| Insects Order | BATS | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***H. ater*** | ***H. speoris*** | ***M. lyra*** | ***T. melanopogon*** | ***P. dormeri*** | ***R. hardwickii*** | ***P. mimus*** |
| Coleoptera | 17.76 | 17.56 | 17.39 | 17.45 | 14.15 | 14.78 | 13.82 |
| Diptera | 13.33 | 13.06 | 15.41 | 13.67 | 15.04 | 13.91 | 14.28 |
| Hemiptera | 16.19 | 16.21 | 11.46 | 16.98 | 15.92 | 16.52 | 15.66 |
| Hymenoptera | 9.55 | 9.45 | 10.27 | 8.69 | 9.29 | 8.69 | 9.67 |
| Lepidoptera | 16.66 | 17.56 | 15.01 | 18.86 | 17.69 | 18.26 | 17.05 |
| Orthoptera | 10.47 | 6.30 | 6.32 | 4.71 | 8.84 | 7.39 | 8.29 |
| Odonata | 10 | 14.86 | 13.83 | 14.15 | 14.15 | 15.21 | 13.36 |
| Isoptera | 6.19 | 4.95 | 10.27 | 5.18 | 4.86 | 5.21 | 7.83 |

**Discussion**

Insect light traps were set in the agriculture fields to observe the availability of insect populations in the various agroecosystems. Bats were observed to forage on these insects at a greater rate.The dietary selection of microchiropteran bats mainly includes coleopteran, lepidopteran, dipteran, orthopteran, hymenopteran, isopteran, odonatan, and hemipteran group of insects. Many insectivorous bats are opportunistic predators (Heim *et al*., 2017) or selective opportunists choosing particular insect families from a variety of taxa available (McCracken *et al*., 2012; Murray and Kurta, 2002). Incidentally, they are the insect groups that include our predominant crop pest. However, few studies have explicitly investigated the composition and abundance of dietary prey items or assessed the ratio of pest and beneficial arthropods consumed (Maine and Boyles 2015; McCracken *et al*., 2012; and Williams Guillen *et al*., 2008, making it difficult to assess the quality of the pest control service provided by bats. In India, 20% of total agricultural production is lost by insect pests every year (Krishnan, 1993).

Among the dietary selection, coleopterans and lepidopterans rank high among the bats roosted in the agroecosystem. Bats actively search areas with abundant prey sources and in areas of insect abundance, such as pest outbreaks in agricultural systems (Charbonnier*et al*., 2014). It indicates that the insectivorous bats can adjust their predatory activity with prey

abundance (Heim *et al*., 2017; Lee and McCracken 2005). However, little is known about the breadth of arthropods consumed by bats in the agroecosystem, a critical step in understanding their "total" contribution to pest suppression. Indian bats like *M lyra* (Balasingh, 1990) *H. speoris* (Swamidoss and Sudhakaran 2012), *T. Brasiliensis* (Kunz *et al*., 1995), *H. lankadiva* (Phillips, 1980), and *H. commersoni* (Whitaker and Black,1976) prefers coleopteran insects as their major dietary items. Dietary niche and preference varied greatly among the taxa. Some are generalized while others are specialists (or) opportunistic in their dietary preference (Feldman *et al*., 2000). Among microchiropterans, hipposiderid bats generally prefer beetles and moths (Whitaker and Black, 1976). In addition (Kurta and Whitaker, 1996) coleopteran and lepidopteran insects appear to be the two most important insect orders in the diet of Indian bats. This dietary preference confirms their impact on pest management in the agroecosystem. In our study also micro bats feed on 65 pests of major crops in the study area. Lepidoptera, Coleoptera, Hemiptera, and Diptera, dominated the catches for both the years contributing about 18.86%, 17.76%, 16.98%, and 15.41% respectively. A total of 2,970 insects were collected during the study period.

Earlier studies have proved that the dietary selection of many microchiropteran bats mainly includes common agricultural pests (Advani, 1981; Whitaker *et al.,* 1991). This study revealed a statistically significant positive relationship between overall insect and insectivorous bat activity. Other studies have also documented the linkage between insect and bat abundance (Rautenbach *et al*., 1996; Pavey *et al*., 2001), as insects constitute the principal food component of insectivorous bats (Williams and Singh, 1951; Holyoak, 2001). Furthermore, food preference, availability, and accessibility of prey (Kusch *et al*., 2004; Almenar *et al*., 2012) could have resulted in differences in the agroecosystems' ability to support insectivorous bats. Our findings, which conform to studies elsewhere, reveal that different agroecosystems influence insect abundance variably (Perfecto *et al*., 1997; Bengtsson *et al*., 2005). Thus, we argue that in agroecosystem insectivorous bats could have led to the decline in numbers of insect pests.

Our observation support a growing body of global evidence illustrating the significant role played by bats in dipteran, hemipteran, coleopteran, lepidopteran, orthopteran, odonates, hymenopterans, and isopteran pest control. Thus, based on pest versus beneficial insect consumption alone, the benefits of bat-mediated insect suppression in crops outweigh any disservice. The most abundant hemiptera in the diet of insectivorous bats were pests of summer crops, suggesting that bats were sourcing arthropods from cotton and other summer-grown crops. Furthermore, insectivorous bats consumed few unique species and many species only once, supporting evidence that bats exploit preferred locally abundant taxa (such as large pest moth population influxes) in agriculture while simultaneously consuming a wide selection of available prey (Krauel *et al*., 2018).

Insect remnants on bat faecal pellet study shows that bats frequently consumed soft-bodied flies, but these do not contribute greatly to the overall diet in terms of volume, as found in various studies (Gonsalves *et al*., 2013; Rydell *et al*., 2002 and Wetzler and Boyles 2017).

The study consisted of assessing the effects of agroecosystems on dominant captures of insectivorous bat species (*Hipposideros speoris* and *H. ater*) and insect orders

(Lepidoptera and Coleoptera) shows an existence of predator-prey relationship. Dietary composition (average relative abundance and richness) was dominated by Lepidoptera and Coleoptera, and did not change significantly over the growing season, irrespective of fluctuations in moth abundance in the landscape. Importantly, bats continued to consume high proportions of Hemiptera, Lepidoptera, Coleoptera, and Odonata even though light trap data suggested an increase in Coleoptera. These results suggest that bats selectively predated lepidopteran and likely reflect an adjustment in the habitat where moths were sourced since lepidopteran abundance declined in the season.

Increased predator functional diversity improves natural pest control (Barbaro *et al*., 2017 and Greenop *et al*., 2018) and is important for the suppression of a range of pest insect species in crops. This is because bats exert different pressures on different insects, mediated by echolocation constraints, and thus the detection and capture of prey varies among bat species (Waters *et al*., 1995). The magnitude of bat insect pest suppression changes during the night, with bats' timing of roost emergence, coincides with access to preferred prey (Swift *et al*., 1985), but is dependent on predation risk, light intensity, and life stage. Farmers wishing to benefit from the insect pest control service provided by bats in the paddy, banana, sugarcane, and cotton growing landscape should not destruct or disturb the habitat and roosting sites of bats and should support different bat species to forage over crops.

Our results support a growing body of global evidence illustrating the significant role that insectivorous bats play in arthropod pest control. Our results also emphasize the service, rather than disservice, bats provide to agriculture, consuming a diet comprised of around 1% relative abundance and richness of beneficial insects (predators and pollinators). Thus, based on pest versus beneficial insect consumption alone, the benefits of bat-mediated insect suppression in crops outweigh any disservice. Importantly, 65 pest species, in eight arthropod orders were detected in the diet of bats. The most abundant arthropods in the diet of insectivorous bats were pests of major crops, suggesting that bats were sourcing arthropods from paddy and other crops. Furthermore, insectivorous bats consumed few unique species and many species only once, supporting evidence that bats exploit preferred locally abundant taxa (such as large pest moth population influxes) in agriculture while simultaneously consuming a wide selection of available prey (Krauel *et al*., 2018). Dietary composition (average relative abundance and richness) was dominated by Lepidoptera and did not change significantly over the growing season, irrespective of fluctuations in moth abundance in the landscape. Importantly, bats continued to consume high proportions of lepidopterans and light trap data also suggested an availability of lepidopterans and coleopterans in bats foraging perches.

**Conclusion**

These results suggest that bats selectively predated lepidopterans and likely reflect an adjustment in the habitat where moths were sourced since lepidopteran abundance declined late in the season. Farmers wishing to benefit from the insect pest control service provided by bats in the agriculture landscape can incorporate bat-mediated insect suppression into existing IPM strategies by managing a diversity of non-crop habitat and roosting sites to support different bat species foraging over crops.

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