Project ID: 474

Competitive Research Grant

Sub-Project Completion Report

On

Status of insect biodiversity and ecosystem functions in tea estates of the Sylhet region

Project Duration
May 2017 to September 2018

Department of Entomology,
Sylhet Agricultural University

Submitted to:

The Director
Project Implementation Unit-BARC, NATP 2
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215

September 2018

CRG Sub-project Completion Report (PCR)

A. Sub-project Description

1. **Title of the CRG Sub-project**: Status of insect biodiversity and ecosystem functions in tea estates of the Sylhet region
2. **Implementation organization**: Sylhet Agricultural University, Sylhet-3100
3. **Name and full address with phone, cell and E-mail of PI/Co-PI (s): PI:** Dr. Md. Abdul Maleque, Associate Professor, Department of Entomology, Faculty of Agriculture, Sylhet Agricultural University, Sylhet-3100. Cell: 01758571672, 01838777634; E-mail: maleq68@gmail.com; **Co-PI:** Professor Dr. A.F.M. Saiful Islam, Department of Crop Botany and Tea Production Technology, Faculty of Agriculture, Sylhet Agricultural University, Sylhet-3100. Cell: 01711978392; E-mail: afmsislam@gmail.com
4. **Sub-project budget (Tk**): 2000000.00 (Twenty lac) only

   4.1 Total: 2000000.00 (Twenty lac) only

   4.2 Revised (if any): None
5. **Duration of the Sub-project**: From 07 May 2017 to 30 September 2018

   5.1 Start date (based on LoA signed): 07 May 2017

   5.2 End date: 30 September 2018
6. **Justification of undertaking the sub-project**:

   Biodiversity refers to the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Anonymous, 1992). Biodiversity and sustainable development is highly associated. It has been well-recognized that in the recent past decades biodiversity situation has been threatened many folds worldwide. Bangladesh is not an exception from various risks and uncertainties of biodiversity loss (Mukul, 2007). In response, Bangladesh has already signed five biodiversity-related international conventions namely CBD, CMS, Ramsar and WHC in order to get biodiversity-related benefits from various world conventions. The main reasons of biodiversity loss in Bangladesh are destruction and fragmentation of habitat at stand, landscape and regional levels, change of land-use pattern, over exploitation of natural resources, environmental pollution, urbanization, adverse impacts of climate change and others. As such, conservation and improvement of

biodiversity has been included in the 18(Ka) paragraph of the Constitution of Bangladesh (NBSAP, 2015). The 18(Ka) paragraph describes that the state will conserve and develop the environment and will ensure environmental conservation and safety measures for the natural resources, biodiversity, water-bodies, forest and wildlife. In this connection, Bangladesh Biological Diversity Act 2013 has also been passed in National Parliament of the People's Republic of Bangladesh (Anonymous, 2015).

Tea (*Camellia sinensis* L.) is a monoculture crop grown in tropical and subtropical climates. Tea is the most popular drink for two-thirds of the world's population (Dhekale *et al.,* 2014; Ye *et al.,* 2014). Tea was one of the major export-oriented industries in Bangladesh. The country exports tea to Pakistan, Saudi Arabia, United Arab Emirates and few countries. At present, there are 168 tea estates occupying 2 lakh 79 thousand 439 acres of land. Of all, 91 estates are located in Moulvibazar, 25 in Habiganj, 19 in Sylhet, 22 in Chattagram, 8 in Panchagarh, 2 in Rangamati and 1 in Thakurgaon (BTB, 2015; The Prothom Alo, 2019). Tea production has increased from 66 to 82 tons during 2014-2017 and upgraded from 10^{th} to 9^{th} position in 2018 in the world (BBS, 2018; The Prothom Alo, 2019). However, internal consumption reached to 98% with @3.23% increase, production increased to @2.0%, export declined @2.98% (BTRI, 2016). The country's population will reach up to 180 million by the end of 2021 which will need 76 million kg of made tea, but if current trend continues to the end of 2021, made tea production will increase up to 70 million kg (BTRI, 2016). In recent past it was assumed that the country will be a large tea importer, but if more new small growers and new plane lands come under tea cultivation, the production will considerably increase. The government has prepared "Road Map: Bangladesh Tea Industry" to produce 100 million kg of made tea by 2021 to meet domestic demand, restore and extend tea export by increasing quality tea production (BTRI, 2016).

Four types of naturally occurring microclimatic habitats viz., i) Large gap stand, ii) Small gap stand, iii) Gapless stand, and iv) Shade tree stand are often seen in tea estates (Fig. 1 & Fig 2). Naturally occurring microhabitats in tea estates are not well-planned for conservation of biocontrol agents, as those of the "line-thinning" in Japanese cedar plantations (Ishii *et al.*, 2008). It is obvious that microclimatic variations are present among the above mentioned microhabitats. It could be assumed that biodiversity status

representing various functional groups of insect species (e.g., harmful insects, predators, parasitoids, pollen feeders, pollinators, decomposers, scavengers, dung feeders, fungus feeders) significantly varies among the four microhabitats in tea stands. These variations could happen because arthropods including insect communities are very sensitive to environmental changes, habitat destruction and disturbances, and thus arthropods have been reported as good indicators of ecosystem functions and integrity especially in the forested landscapes (Maleque *et al.*, 2006). Several other authors have found that thinning and maintaining various types of gaps in forest stands (round gap, line gap, rectangular gap, canopy gaps) can significantly contribute to the conservation and improvement of biodiversity in forest ecosystems from landscape to regional levels (Aubry *et al.,* 2004; Ishii *et al.*, 2008; Maleque *et al.*, 2007ab). Considering the above facts, the status of insect biodiversity and ecosystem functions in tea estates of the Sylhet region needs to be explored in order to recommend biodiversity friendly tea pest management practice for the tea gardeners particularly for the Sylhet region and generally for other tea-growing regions of the country. The exploration of insect biodiversity in tea gardens could be useful to recommend environment friendly management techniques for the insect pests of tea.

7. **Sub-project goal**: Develop conservation strategies for the biocontrol agents in tea estates
8. **Sub-project objective** (s):
   - 8.1 Determine variations in insect biodiversity among four microhabitat types in tea estates;
   - 8.2 Determine relationships of various functional groups of insects with understory vegetation and microclimatic changes in tea estates; and
   - 8.3 Recommend biodiversity conservation and management strategy for the tea estates.
9. **Implementation location:** Lakkatura Tea Estate, National Tea Company Ltd., Sylhet sadar, Sylhet (Fig. 1).

Fig. 1. Sub-project site in Google Earth Map (left) and on-spot site (right)

10. Methodology in brief:

Selection of microclimatic habitats: Four naturally occurring microclimatic habitats viz., Large gap tea-stand (T1), Small gap tea-stand (T2), Gapless tea-stand (T3), and Shade tree tea-stand (T4) were selected from Lakkatura Tea Estate under the National Tea Company Limited, Sylhet. The selected four microclimatic habitats were located about 10-20m apart and size of each microclimatic habitat was about 40m × 50m. Presence of more than 2.5m dia gap inside microclimatic habitats was considered large gap stand and 1.5m to 2.5m dia was considered small gap stand. Traditional silk shade trees, *Albizia* spp. (Fabaceae) are present in the study site. Numbers of tea bush/16 m^2 area surrounding Malaise traps were recorded. Study site hosted a mixture of ten tea clonal varieties viz., BT1, BT2, BT7, BT9, BT12, BT13, BT17, TB12, TB23 and TB30.

Preparation and placement of Malaise traps: Townes-type Malaise trap is often used to capture most flight and crawling insects due to its handy design and light weight (Sheikh *et al.,* 2016). Malaise traps were prepared from white mosquito net. The size of Malaise trap was 120cm, 100cm and 150cm [height × width × length]. Plastic bottles (500ml) were attached to Malaise trap to capture arthropod samples. Diluted propylene glycol (50%) was used in the bottles for 15 days at field level sample preservation. One third of the bottle was filled with propylene glycol. Twenty Malaise traps were set up in four microclimatic habitats in November 2017 and sampling continued up to March 2018. Five traps were placed in each microclimatic habitat. Sampling with one Malaise trap was considered one replication. Each microclimatic habitat was considered one treatment

Large gap tea-stand (T1)

Small gap tea-stand (T2)

Gapless tea-stand (T3)

Shade tree tea-stand (T4)

Fig. 2. Malaise traps set up in four microclimatic habitats, Lakkatura Tea Estate, Sylhet.

Collection and preservation of arthropod samples: Arthropod samples were collected at 15-day intervals and brought to the Laboratory of Entomology, Faculty of Agriculture of Sylhet Agricultural University with plastic bottle (250ml) of one fourth 70% ethanol for laboratory preservation. Field samples were collected eight times on 06 December 2017, 22 December 2017, 05 January 2018, 20 January 2018, 04 February 2018, 19 February 2018, 06 March 2018 and 21 March 2018.

Recording weather data: Daily maximum and minimum fluctuation data of temperature (^{o}C), relative humidity (%) and rainfall (cm) were collected from the Meteorological Station at Shahi Eidgah, Sylhet and from those data monthly means were calculated and shown in Appendices 9-11.

Identification of arthropod samples: Preserved samples were transferred to Petri dishes and identified with common name, genus (where possible), family and order using photographs and keys described by Hamasaki *et al.* (2008), Goulet and Huber (1993), Shaw and Huddleston (1991), Chapman (2013), Kurosawa *et al.* (1998), Lawrence *et al.* (1999), Hayashi *et al.* (2002) and internet sources. Number of arthropods, scientific, family and order names including major functional groups viz., beneficial, harmful and neutral are shown in Appendices 1-8. Besides, identified samples were also classified into several more specific functional groups viz., blood sucker, edible insect, food feeder, fruit eater, leaf feeder, omnivore, parasite, parasitoid, plant feeder, pollinator, predator, rice milk sucker, sap sucker, saprophagous, scavenger, seed feeder, vector and wood eater. These functional groups were again classified into agriculturally important functional groups viz., biocontrol, detritivore, herbivore and others. Biocontrol agents included were the predators and parasitoids, detritivores included were the scavenger and saprophagous, herbivores included were the leaf feeder, plant feeder, rice milk sucker, sap sucker, seed feeder and wood eater, and other groups included were the blood sucker, edible insect, food feeder, omnivore, pollinator and vector. It is noted that the sampling was done during winter season (November 2017 to March 2018) in Bangladesh and thus trapped samples of the orders Hymenoptera and Coleoptera were not large enough. As such, individuals trapped under all other arthropod families were considered as experimental materials to achieve the objectives and goal of the sub-project.

Recording of understory vegetation: A quadrat of 4m × 4m size was placed keeping each Malaise trap inside to record tea bush as understory vegetation. A total of 20 quadrats were sampled surrounding all 20 Malaise traps. In order to determine the relationships of arthropod (insect, spiders and mites were not found any where in the study) abundance with understory vegetation in four microhabitats, number of tea bush in each trap location was recorded (Appendix 12).

Fig. 3. Arthropod samples preserved in the Entomology Laboratory, Faculty of Agriculture, Sylhet Agricultural University, Sylhet.

Data collection on light intensity (lux): Light intensity (Lux) of four microclimatic habitats was recorded at 9.00am, 12.00pm and 3.00pm in March 2018 using digital light meter (Model: LX-1102). Means of light intensity were calculated (Appendix 13).

Data collection on temperature, relative humidity and dew point: Using automatic Humidity/Temperature Datalogger (outdoor), temperature (°C), relative humidity (%) and dew point (°C) data from four microclimatic habitats were recorded during 05 to 26 March 2018 at 1-hour interval. A total of 500 sample points were selected to record the above environmental parameters. In case of temperature, low alarm was 0 (°C) and high alarm was 50 (°C). In case of relative humidity, low alarm was 20% and high alarm was 98%. Means of temperature, relative humidity and dew points were calculated (Appendices 14-16).

Analysis of data: Total numbers of beneficial, harmful and neutral insect arthropods were calculated by adding the individuals in respect of four microhabitats. The abundance of functionally beneficial, harmful and neutral insect arthropods was calculated by using the following formula:

$$\text{Abundance} = \frac{\text{Total no. of individuals in each species}}{\text{Total no. of replication}}$$

The relative abundance of beneficial, harmful and neutral functioning insect arthropods was calculated by using the following formula:

$$\text{Relative abundance (\%)} = \frac{\text{Total no. of individuals of each species}}{\text{Total no. of individuals of all species}} \times 100$$

Shannon-Weaver Diversity Index (H'): Shannon-Weaver Diversity Index (H') was used to measure the diversity of beneficial, harmful and neutral arthropods (Shannon and Weaver, 1963). The H' is the direct method of determining the diversity of different pest, beneficial and neutral arthropods among four treatments (micro-climatic habitat). The H' ranges from 0 to 1, where 1 indicates the maximum diversity. Jamago (2000) classified the diversity of mungbean based on morphological characters as high (H'= >0.750), moderate (H'= 0.50-0.75) and low (H' = <0.50). The same classification of diversity was also used by other researchers (Emannuel, 2000; Kete, 2001; Thuy, 2002; Uddin *et al.,* 2006). The higher the diversity index, the more is the diverse the population. Shannon-Weaver Diversity Index is defined by the formula (Yu Li *et al.,* 1996).

$$H' = -\sum_{i=1}^{n} Pi * \log_2(Pi)/\log_2(n)$$

Where, Pi is the proportion of the total number of entries belonging to the ith species and n is the number of natural enemies. The relative frequencies for the different species were used to calculate the diversity index. The H' for each of the species was calculated by using Microsoft Excel.

Species richness: To provide a cohesive overview of species richness, Margalef's Index was also calculated along with S (actual number of species collected). Margalef's index (Margalef, 1958; Khan, 2013) assumes a theoretical relationship between the number of individuals (N) and the number of species (S) in a sample and is expressed as follows:

$$\text{M.I.} = \frac{S-1}{\ln N}$$

The index logarithmically scales the value of S, and hence provides a means of comparison among four treatments with different ratios of S and N.

Equitability or Evenness: Equitability is considered a component of diversity, in that it provides an idea about the evenness of species distribution at a given site. Usually a positive correlation exists between diversity and equitability (Delong, 1975; Khan, 2013) i.e. a high equitability would indicate a high diversity and probably a healthy condition' of a fauna. Pielou's (1966) method of measuring equitability is most widely used. The computational formula is below:

$$J = \frac{H}{\log_e S}$$

Where, H = Shannon's index, S = Total species

11. Results and discussion

Results

11.1 Total number of insect individuals

A total of 3248 arthropod individuals were identified comprising 70 species in total (Table 1). Among all the identified samples, 566, 811, 1081 and 790 individual insects were found, respectively in large gap, small gap, gapless and shade tree stand. A total of 47, 49, 52 and 48 arthropod insect species were found in large gap, small gap, gapless and shade tree stand. Ant, bracon wasp, cabbage butterfly, crab spider, drosophila, house fly, hoverfly, ichneumonid wasp, ladybird beetle, leafhopper, mosquito, moth, rove beetle, short-horned grasshopper, short-tailed ichneumon wasp and tachinid fly were found as most abundant species with more than 40 individuals captured from all the four microclimatic habitats. These arthropods ranked as mosquito (590)> rove beetle (375)> moth (unidentified) (328)> short-tailed ichneumon wasp (256)> ant (256)> house fly (228)> crab spider (81)> short-horned grasshopper (77)> drosophila (75)> leafhopper (73)> hoverfly (62)> ichneumonid wasp (60)> bracon wasp (59)> tachinid fly (56)> cabbage butterfly (53)> ladybird beetle (44).

Table 1. Total number of arthropod individuals captured from Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Common Name	Number of arthropods in four microclimatic habitats				Total
		Large gap	Small gap	Gapless	Shade tree	
1	Amata (moth)	3	12	1	0	16
2	Ant	36	97	57	66	256
3	Aphid	0	0	1	0	1
4	Assassin bug	2	0	1	3	6
5	Black and yellow striped ichneumon wasp	0	3	9	10	22
6	Bracon wasp	14	20	17	8	59
7	Brown house moth	0	0	0	2	2
8	Brown plant hopper	0	0	1	0	1
9	Brush-footed butterfly	3	2	14	7	26
10	Cabbage butterfly	21	12	14	6	53
11	Cedar beetle	0	1	0	0	1
12	Chain-dotted geometer moth	0	0	1	0	1
13	Click beetle	13	13	7	8	41
14	Cockroach	5	6	8	5	24
15	Common earwig	0	0	1	0	1
16	Crab spider	9	18	28	26	81
17	Crane fly	0	2	7	2	11
18	Damselfly	1	3	1	12	17
19	Digger wasp	0	0	0	5	5
20	Dragonfly	1	3	27	12	43
21	Drosophila	8	12	55	0	75
22	Dung beetle	0	0	0	1	1
23	Eusocial wasp	2	3	4	2	11
24	Epilachna beetle	4	0	0	1	5
25	Field cricket	4	1	5	1	11
26	Firefly	0	0	0	2	2
27	Fruit fly	1	0	0	0	1
28	Gelechiid moth	2	3	2	0	7
29	Green bottle fly	2	7	6	5	20
30	Ground beetle	3	14	7	6	30
31	Hawk moth	0	1	2	0	3
32	Hawthorn slender moth	0	1	0	0	1
33	House cricket	6	4	2	3	15
34	House fly	44	38	106	40	228
35	Hoverfly	18	6	35	3	62
36	Ichneumon wasp	7	20	20	13	60
37	Japanese beetle	0	1	0	0	1
38	June beetle	0	2	1	3	6
39	Ladybird beetle	10	15	14	5	44
40	Leafhopper	14	23	20	16	73
41	Long-legged fly	0	0	4	0	4
42	May beetle	12	4	4	2	22
43	Minute brown scavenger	0	1	3	3	7
44	Mirid bug	3	0	0	0	3

Sl.	Common Name	Number of arthropods in four microclimatic habitats				Total
		Large gap	Small gap	Gapless	Shade tree	
45	Mole cricket	1	0	4	1	6
46	Mosquito	70	122	233	165	590
47	Moth (Unidentified)	71	60	121	76	328
48	Plant bug	0	0	0	1	1
49	Plant hopper	6	1	0	0	7
50	Preying mantid	3	0	1	1	5
51	Rice hispa	1	0	0	0	1
52	Rice bug	9	7	12	8	36
53	Rice green leafhopper	0	3	0	0	3
54	Robber fly	4	3	6	2	15
55	Rove beetle	44	111	74	146	375
56	Sawfly	0	3	2	0	5
57	Short-horned grasshopper	17	42	14	4	77
58	Short-tailed ichneumon wasp	38	77	69	72	256
59	Skipper butterfly	2	2	14	9	27
60	Stink bug	1	1	4	1	7
61	Sulphur butterfly	0	0	0	1	1
62	Tachinid fly	10	12	17	17	56
63	Tea mosquito bug	4	2	0	0	6
64	Tea shoot borer	0	0	3	0	3
65	Tea tortix	7	4	9	0	20
66	Termite	8	2	3	2	15
67	Tiger beetle	1	2	1	3	7
68	Treehopper	6	9	9	2	26
69	Trichogramma wasp	15	0	0	0	15
70	White-shouldered house moth	0	0	0	1	1
-	No. of individuals =	566	811	1081	790	3248
-	No. of species =	47	49	52	48	70

Note: No. of individuals, scientific, family and order names including functional groups are shown in Appendices 1-8.

Comment: Major damaging pest should have been identified like mites, bugs, hopper, etc.
Response: All arthropod sampling devices or techniques have some advantages and disadvantages. No single trap is enough to sample all types of arthrpods (harmful, beneficial & neutral) from any ecosystem. Malaise trap is not an exception. This trap is suitable for both trapping both crawling and flying arthropods and thus is most suitable for biodiversity study.
Comment: Is BPH a pest of tea?
Response: BPH is not a pest of tea, but a pest of rice plant. It should be mentioned that out of the trapped arthropod samples, there were both resident and visitor species. BPH is such a visitor species which was caught in Malaise trap, although it is not resident in tea ecosystem. Cockroah is not a pest of tea, rather it was a visitor in tea ecosystem.
Comment: What are the differences between Appexdix 1 & 5?
Response: Appexdix 1 shows major functional groups viz., harmful, beneficial and mixed functional groups, while appexdix 5 shows more specific functional groups viz., herbivore, leaf sucker, leaf feeder, blood sucker, parasitoid, predator, etc.
Comment: Other methods of collection should have been included. What are the major insect pests of Lakkatura?
Response: Due to time and resource limitations, other methods of arthropod collection were not included. The objective of the sub-project was not to identify major pest, rather to identify most suitable microclimatic habitat for beneficial fauna.

11.2 Total number of arthropods under different families

Total number of arthropods under different families is presented in Table 2. A total of 3248 arthropod individuals were identified belonging to 57 families. The number of arthropod families sampled was ranked as gapless stand (48)> large gap stand (42)> small gap stand (42)> shade tree stand (40).

Table 2. Total number of arthropod individuals under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Family	Total number of arthropods in four microclimatic habitats				Total
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand	
1	Acrididae	17	42	14	4	77
2	Aeshnidae	1	3	27	12	43
3	Alydidae	9	7	12	8	36
4	Aphididae	0	0	1	0	1
5	Asilidae	4	3	6	2	15
6	Blattidae	5	6	8	5	24
7	Braconidae	14	20	17	8	59
8	Calliphoridae	2	7	6	5	20
9	Carabidae	4	16	7	6	33
10	Cicadellidae	14	26	20	16	76
11	Cicindellidae	0	0	1	3	4
12	Coccinellidae	14	15	14	5	48
13	Coenagrionidae	1	3	1	12	17
14	Culicidae	70	122	233	165	590
15	Delphacidae	6	1	1	0	8
16	Dolichopodidae	0	0	4	0	4
17	Drosophillidae	8	12	55	0	75
18	Elateridae	13	13	7	8	41
19	Erebidae	3	12	1	0	16
20	Forficulidae	0	0	1	0	1
21	Formicidae	36	97	57	66	256
22	Gelechiidae	2	3	2	0	7
23	Geometridae	0	0	1	0	1
24	Gracillariidae	0	1	0	0	1
25	Gryllidae	6	5	7	4	22
26	Gryllotalpidae	4	0	4	1	9
27	Hesperidae	2	2	14	9	27
28	Hispidae	1	0	0	0	1
29	Ichneumonidae	45	100	99	95	339
30	Lampyridae	0	0	0	2	2
31	Latridiidae	0	1	3	3	7
32	Mantidae	3	0	1	1	5
33	Membracidae	6	9	9	2	26
34	Miridae	4	2	0	1	7
35	Muscidae	44	38	106	40	228
36	Noctuidae	79	60	121	76	336
37	Nymphalidae	8	2	14	7	31
38	Oecophoridae	0	0	0	3	3

Sl.	Family	Total number of arthropods in four microclimatic habitats				Total
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand	
39	Pentatomidae	1	1	4	1	7
40	Pieridae	24	12	14	7	57
41	Reduviidae	2	0	1	3	6
42	Rhipiceridae	0	1	0	0	1
43	Scarabeidae	12	7	5	6	30
44	Scolytidae	0	0	3	0	3
45	Sphecidae	0	0	0	5	5
46	Sphingidae	0	1	2	0	3
47	Staphylinidae	44	111	74	146	375
48	Syrphidae	8	6	35	3	52
49	Tachinidae	10	12	17	17	56
50	Tenthridinidae	0	3	2	0	5
51	Tephritidae	1	0	0	0	1
52	Termitidae	8	2	3	2	15
53	Thomicidae	7	18	28	26	79
54	Tipulidae	0	2	7	2	11
55	Tortricidae	7	4	9	0	20
56	Trichogrammatidae	15	0	0	0	15
57	Vespidae	2	3	4	2	11
No. of individuals =		566	811	1081	790	3248
No. of families =		42	42	48	40	57

11.3 Total number of beneficial arthropods under different families

Total number of beneficial arthropods under different families is presented in Table 3. A total of 1283 arthropods comprising 25 families were identified. The arthropod families was ranked as gapless stand (21)> shade tree (20)> small gap (17)>large gap (17). The number of individuals was ranked as gapless stand (408)> shade tree stand (358)> small gap stand (333)> large gap stand (184). Total number of arthropods under different families was ranked as Staphylinidae (375)> Ichneumonidae (348)> Thomicidae (79)> Drosophillidae (75)> Syrphidae (61)> Braconidae (59)> Tachinidae (56)> Coccinellidae (48)> Aeshnidae (43)> Carabidae (33)> Calliphoridae (20)> Coenagrionidae (17)> Asilidae (15) > Trichogrammatidae (15)> Tipulidae (11)> Vespidae (11)> Latridiidae (7)> Reduviidae (6)> Mantidae (5)> Sphecidae (5)> Cicindellidae (4)> Dolichopodidae (4) > Lampyridae (2)> Forficulidae (1)> Rhipiceridae (1).

Table 3. Total number of beneficial arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Family	Total number of arthropods in four microclimatic habitats				Total
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand	
1	Aeshnidae	1	3	27	12	43
2	Asilidae	4	3	6	2	15
3	Braconidae	14	20	17	8	59
4	Calliphoridae	2	7	6	5	20
5	Carabidae	4	16	7	6	33
6	Cicindellidae	0	0	1	3	4
7	Coccinellidae	14	15	14	5	48
8	Coenagrionidae	1	3	1	12	17
9	Dolichopodidae	0	0	4	0	4
10	Drosophillidae	8	12	55	0	75
11	Forficulidae	0	0	1	0	1
12	Ichneumonidae	45	100	99	95	339
13	Lampyridae	0	0	0	2	2
14	Latridiidae	0	1	3	3	7
15	Mantidae	3	0	1	1	5
16	Reduviidae	2	0	1	3	6
17	Rhipiceridae	0	1	0	0	1
18	Sphecidae	0	0	0	5	5
19	Staphylinidae	44	111	74	146	375
20	Syrphidae	8	6	35	3	52
21	Tachinidae	10	12	17	17	56
22	Thomicidae	7	18	28	26	79
23	Tipulidae	0	2	7	2	11
24	Trichogrammatidae	15	0	0	0	15
25	Vespidae	2	3	4	2	11
No. of individuals =		184	333	408	358	1283
No. of families =		17	17	21	20	25

11.4 Total number of harmful arthropods under different families

Total number of harmful arthropods under different families is presented in Table 4. A total of 929 harmful individuals were identified. Harmful arthropods were belonged to 23 families. The arthropod families was ranked as gapless stand (19)> small gap (18)> large gap (16)> shade tree stand (13). Number of harmful arthropods was ranked as gapless stand (279)> small gap stand (246)> large gap stand (206)> shade tree stand (198). Total number of harmful arthropod families was ranked as Noctuidae (336)>Formicidae (256)> Cicadellidae (76)> Elateridae (41)> Nymphalidae (31)> Scarabeidae (30)> Hesperidae (27)> Membracidae (26) > Tortricidae (20)> Termitidae (15).

Table 4. Total number of harmful arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Family	Total number of arthropods in four microclimatic habitats				Total
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand	
1	Aphididae	0	0	1	0	1
2	Cicadellidae	14	26	20	16	76
3	Delphacidae	6	1	1	0	8
4	Elateridae	13	13	7	8	41
5	Erebidae	3	12	1	0	16
6	Formicidae	36	97	57	66	256
7	Gelechiidae	2	3	2	0	7
8	Gracillariidae	0	1	0	0	1
9	Gryllotalpidae	4	0	4	1	9
10	Hesperidae	2	2	14	9	27
11	Hispidae	1	0	0	0	1
12	Membracidae	6	9	9	2	26
13	Miridae	4	2	0	1	7
14	Noctuidae	79	60	121	76	336
15	Nymphalidae	8	2	14	7	31
16	Oecophoridae	0	0	0	3	3
17	Pentatomidae	1	1	4	1	7
18	Scarabeidae	12	7	5	6	30
19	Scolytidae	0	0	3	0	3
20	Sphingidae	0	1	2	0	3
21	Tenthridinidae	0	3	2	0	5
22	Termitidae	8	2	3	2	15
23	Tortricidae	7	4	9	0	20
No. of individuals =		206	246	279	198	929
No. of families =		16	18	19	13	23

11.5 Total number of neutral arthropods under different families

Total number of neutral arthropods under different families is presented in Table 5. A total of 1036 arthropod individuals were identified. Harmful arthropods comprised 9 families. Numbers of arthropod families identified were 8, 7, 8 and 7, respectively in large gap stand, small gap stand, gapless stand and shade tree stand. Number of neutral arthropods was ranked as gapless stand (395)> shade tree stand (233)> small gap stand (232)> large gap stand (176). Total number of neutral arthropods was ranked as Culicidae (590)> Muscidae (228)> Acrididae (77)> Pieridae (57)> Alydidae (36)> Blattidae (24)> Geometridae (1)> Tephritidae (1).

Table 5. Total number of neutral arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Family	Total number of arthropods in four microclimatic habitats				Total
		Large gap stand	Small gap stand	Gapless stand	Shade tree	
1	Acrididae	17	42	14	4	77
2	Alydidae	9	7	12	8	36
3	Blattidae	5	6	8	5	24
4	Culicidae	70	122	233	165	590
5	Geometridae	0	0	1	0	1
6	Gryllidae	6	5	7	4	22
7	Muscidae	44	38	106	40	228
8	Pieridae	24	12	14	7	57
9	Tephritidae	1	0	0	0	1
No. of individuals =		176	232	395	233	1036
No. of families =		8	7	8	7	9

11.6 Relative abundance of beneficial arthropods under different families

Relative abundances of beneficial arthropods under different families are presented in Table 6. In large gap stand, higher relative abundances were 24.46%, 23.91%, 7.61%, 7.61%, 8.15%, 5.43% and 3.80%, respectively in Ichneumonidae, Staphylinidae, Braconidae, Coccinellidae, Trichogrammatidae, Tachinidae, Thomicidae. In small gap stand, higher relative abundances were 31.05%, 31.62%, 5.70%, 4.27%, 5.13% and 3.42%, respectively in Ichneumonidae, Staphylinidae, Braconidae, Coccinellidae, Tachinidae and Thomicidae. In gapless stand, higher relative abundances were 24.26%, 18.14%, 4.17%, 3.43%, 4.17% and 6.86%, respectively in Ichneumonidae, Staphylinidae, Braconidae, Coccinellidae, Tachinidae and Thomicidae. In shade tree stand, higher relative abundances were 26.54%, 40.78%, 2.23%, 1.40%, 4.75% and 7.26%, respectively in Ichneumonidae, Staphylinidae, Braconidae, Coccinellidae, Tachinidae and Thomicidae. Irrespective of four micro-climatic habitats, important beneficial arthropod families were ranked as Staphylinidae (31.05%)> Ichneumonidae (31.05%)> Drosophillidae (13.48%)> Syrphidae (8.58%)> Braconidae & Coccinellidae (7.61%)> Thomicidae (7.26%)> Tachinidae (5.43%).

Table 6. Relative abundance of beneficial arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Beneficial families	Relative abundance (%)			
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand
1	Aeshnidae	0.54	0.85	6.62	3.35
2	Asilidae	2.17	0.85	1.47	0.56
3	Braconidae	7.61	5.70	4.17	2.23
4	Calliphoridae	1.09	1.99	1.47	1.40
5	Carabidae	2.17	4.56	1.72	1.68
6	Cicindellidae	0	0	0.25	0.84
7	Coccinellidae	7.61	4.27	3.43	1.40
8	Coenagrionidae	0.54	0.85	0.25	3.35
9	Dolichopodidae	0	0	0.98	0
10	Drosophillidae	4.35	3.42	13.48	0
11	Forficulidae	0	0	0.25	0
12	Ichneumonidae	24.46	31.05	24.26	26.54
13	Lampyridae	0	0	0	0.56
14	Latridiidae	0	0.28	0.74	0.84
15	Mantidae	1.63	0	0.25	0.28
16	Reduviidae	1.09	0	0.25	0.84
17	Sphecidae	0	0	0	1.40
18	Rhipiceridae	0	0.28	0	0
19	Staphylinidae	23.91	31.62	18.14	40.78
20	Syrphidae	4.35	4.27	8.58	0.84
21	Tachinidae	5.43	3.42	4.17	4.75
22	Thomicidae	3.80	5.13	6.86	7.26
23	Tipulidae	0	0.57	1.72	0.56
24	Trichogrammatidae	8.15	0	0	0
25	Vespidae	1.09	0.85	0.98	0.56
	Total =	100	100	100	100

11.7 Relative abundance of harmful arthropods under different families

Relative abundances of harmful arthropods under different families are presented in Table 7. In large gap stand, higher relative abundances were ranked as 38.35%> 17.48%> 6.80%> 5.83%> 3.40%, respectively Noctuidae> Formicidae> Cicadellidae> Scarabeidae> Tortricidae. In small gap stand, higher relative abundances were ranked 39.59%> 24.49%> 10.61%> 5.31%> 3.67%> 1.63%, respectively in Formicidae> Noctuidae> Cicadellidae> Elateridae> Membracidae> Tortricidae. In gapless stand, higher relative abundances were ranked as 43.37%> 20.43%> 7.17%> 3.23%> 1.43%> respectively in Noctuidae> Formicidae> Cicadellidae> Tortricidae> Pentatomidae. In shade tree stand, higher relative abundances were ranked 38.38%> 33.33%> 8.08%> 4.55%> 4.04%> 3.54% respectively in Noctuidae> Formicidae> Cicadellidae> Hesperidae> Elateridae> Nympahlidae> Scarebaeidae.

Table 7. Relative abundance of harmful arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Harmful families	Relative abundance (%)			
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand
1	Aphididae	0	0	0.36	0
2	Cicadellidae	6.80	10.61	7.17	8.08
3	Delphacidae	2.91	0.41	0.36	0
4	Elateridae	6.31	5.31	2.51	4.04
5	Erebidae	1.46	4.90	0.36	0
6	Formicidae	17.48	39.59	20.43	33.33
7	Gelechiidae	0.97	1.22	0.72	0
8	Gracillariidae	0	0.41	0	0
9	Gryllotalpidae	1.94	0	1.43	0.51
10	Hesperidae	0.97	0.82	5.02	4.55
11	Hispidae	0.49	0	0	0
12	Membracidae	2.91	3.67	3.23	1.01
13	Miridae	1.94	0.82	0	0.51
14	Noctuidae	38.35	24.49	43.37	38.38
15	Nymphalidae	3.88	0.82	5.02	3.54
16	Oecophoridae	0	0	0	1.52
17	Pentatomidae	0.49	0.41	1.43	0.51
18	Scarabeidae	5.83	2.45	1.79	3.03
19	Scolytidae	0	0	1.08	0
20	Sphingidae	0	0.41	0.72	0
21	Tenthridinidae	0	1.22	0.72	0
22	Termitidae	3.88	0.82	1.08	1.01
23	Tortricidae	3.40	1.63	3.23	0
	Total =	100	100	100	100

11.8 Relative abundance of neutral arthropods under different families

Relative abundances of neutral arthropods under different families are presented in Table 8. In large gap stand, higher relative abundances were ranked as 39.77%> 25.00%> 13.64%> 9.66%, respectively in Culicidae> Muscidae> Pieridae> Acrididae. In small gap stand, higher relative abundances were ranked as 52.59%> 18.10%> 16.38%> 5.17%> respectively in Culicidae> Acrididae>Muscidae> Pieridae. In gapless stand, higher relative abundances were ranked 58.99%> 26.84%> 3.54%> 3.54%> respectively in Culicidae> Muscidae> Pieridae> Acrididae. In shade tree stand, higher relative abundances were ranked as 70.82%> 17.17%> 3.00%> 1.72%, respectively in Culicidae> Muscidae> Pieridae> Acrididae.

Table 8. Relative abundance of neutral arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Neutral families	Relative abundance (%)			
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand
1	Acrididae	9.66	18.10	3.54	1.72
2	Alydidae	5.11	3.02	3.04	3.43
3	Blattidae	2.84	2.59	2.03	2.15
4	Culicidae	39.77	52.59	58.99	70.82
5	Geometridae	0	0	0.25	0
6	Gryllidae	3.41	2.16	1.77	1.72
7	Muscidae	25.00	16.38	26.84	17.17
8	Pieridae	13.64	5.17	3.54	3.00
9	Tephritidae	0.57	0	0	0
	Total =	100	100	100	100

11.9 Relative abundance of beneficial, harmful and neutral arthropods

Relative abundances of beneficial, harmful and neutral arthropods are presented in Fig. 4. The highest relative abundance of beneficial arthropods was found in shade tree stand (45%), with lowest in large gap stand (33%). Conversely, the highest relative abundance of harmful arthropods was found in large gap stand (36%), with lowest in shade tree stand (25%). The highest relative abundance of neutral arthropods was found in gapless stand (37%), with lowest in small gap stand (28%).

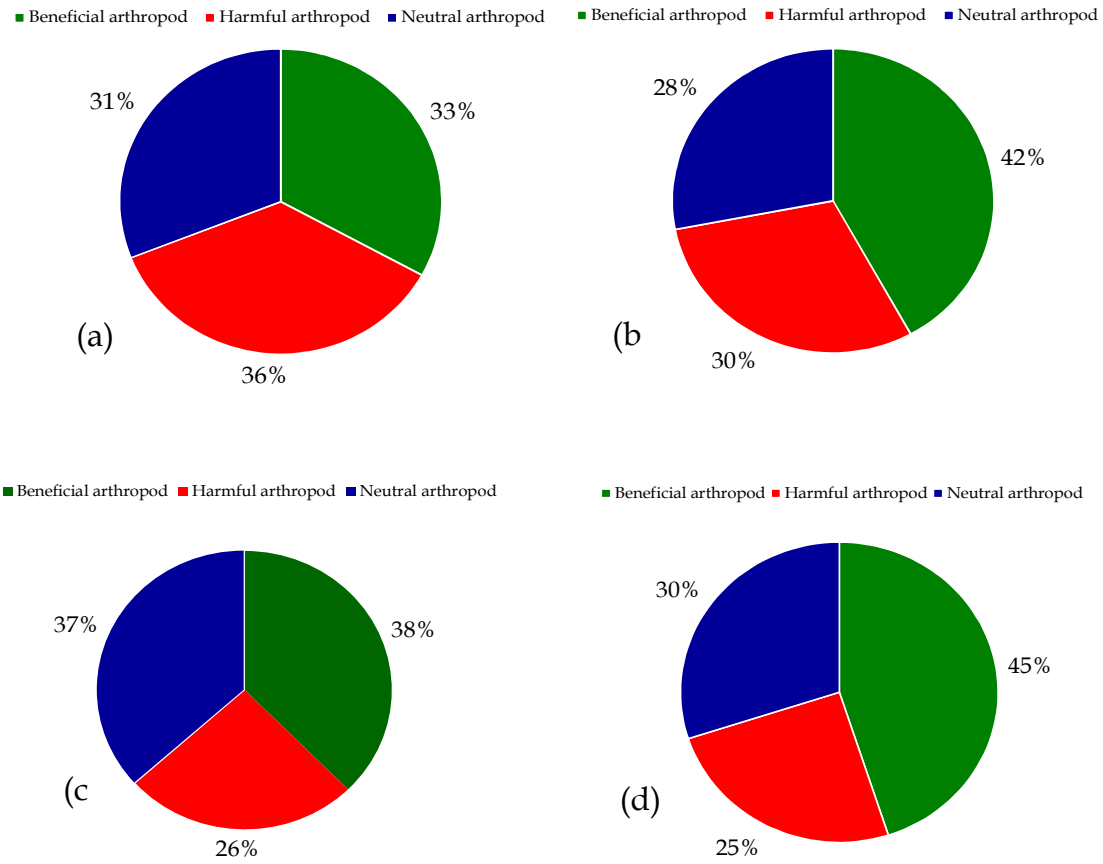

Fig. 4. Relative abundance of beneficial, harmful and neutral arthropod families in large gap stand (a), small gap stand (b), gapless stand (c) and shade tree stands (d) in Lakkatura Tea Estate, Sylhet during November 2017 to March 2018. Beneficial arthrpods indicate parasitoids, predators and pollinators. Harmful arthropods indicate herbivores, leaf suckers, leaf feeders, sap sucker, rice milk sucker, food feeder, vector, etc. Neutral arthrpods indicate edible insect, scavenger, etc.

Comment: The legends of beneficial, harmful and neutral arthropods should be clear enough to understand.
Response: Some more texts have been added with caption of Fig. 4 to make easy to understand.

11.10. Relative abundance of all arthropod functional groups

Relative abundances of all specific functional groups are presented in Table 9. Relative abundances in large gap stand having more than 5% were ranked as leaf feeder (21.9%)> predator (18.2%)> parasitoids (15.3%)> scavenger (12.8%)> blood sucker (8.3%)> vector (6.4%). In case of small gap, relative abundances were ranked as predator (23.4%)> parasitoid (19.6%)> scavenger (19.4%)> leaf feeder (12.7%)> blood sucker (9.6%)>. In case of gapless, relative abundances were ranked as predator (17.45%)> blood sucker (14.68)> leaf feeder (13.04%)> parasitoid (12.98%)> scavenger (12.79)> vector (10.27%)> food feeder (6.67%). In case of shade tree, relative abundances were ranked as predator (24.62%)> parasitoid (20.98%)> scavenger (18.05%)> blood sucker (13.06%)> leaf feeder (9.58%)>.

Table 9. Relative abundances of all arthropod functional groups, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Functional Groups	Relative abundance (%)			
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand
1	Blood sucker	8.38	9.60	14.68	13.06
2	Edible insect	1.20	0.47	0.315	0.079
3	Food feeder	5.27	2.36	6.679	0.396
4	Fruit eater	0.12	0.71	0	3.167
5	Leaf feeder	21.9	12.7	13.04	9.58
6	Omnivore	0.72	0.63	2.58	0.475
7	Parasite	0	0.08	0	0
8	Parasitoid	15.3	19.6	12.98	20.98
9	Plant feeder	0.6	0.08	0.567	0.079
10	Pollinator	2.28	1.26	4.033	2.771
11	Predator	18.2	23.4	17.45	24.62
12	Rice milk sucker	1.08	0.55	0.693	0.633
13	Sap sucker	2.51	2.91	2.205	1.504
14	Saprophagous	1.56	1.42	1.13	0.95
15	Scavenger	12.8	19.4	12.79	18.05
16	Seed feeder	0.60	0.08	0.38	0.079
17	Vector	6.47	4.56	10.27	3.405
18	Wood eater	0.96	0.16	0.189	0.158
	Total =	100.0	100.0	100.0	100.0

11.11 Total individuals of agriculturally important arthropod functional groups

Total individuals of agriculturally important functional groups are presented in Table 10. Total numbers of biocontrol were ranked as shade tree (576)> small gap (547)> gapless (483)> large gap (280). Total numbers of detritivore were ranked as small gap (264)> shade tree (240)> gapless (221)> Large gap (120). Total numbers of herbivore were ranked as gapless (271)> large gap (231)> small gap (210)> shade tree (152). Total numbers of other arthropods were ranked as gapless (612)>shade tree (294)> small gap (240)> large gap (203).

Table 10. Total number of individuals of agriculturally important arthropod functional groups, in Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Functional groups	Number of individuals in four microclimatic habitats			
		Large gap stand	Small gap stand	Gapless	Shade tree
1	Biocontrol	280	547	483	576
2	Detritivore	120	264	221	240
3	Herbivore	231	210	271	152
4	Others	203	240	612	294
	Total =	834	1261	1587	1262

Note: Arthropods having plural functional groups were overlapped.

11.12 Mean number of agriculturally important functional groups

Mean numbers of agriculturally important functional groups per trap varied significantly in four microclimatic habitats (Fig. 5). The maximum number of biocontrol arthropods was found in shade tree stand and in small gap stand. In large gap stand, the number of biocontrol arthropods was lowest and the number of herbivore was highest. The minimum number of detritivore was found in large gap stand. The minimum number of herbivore was observed in shade tree stand. The maximum number of other functional arthropods was found in gapless stand.

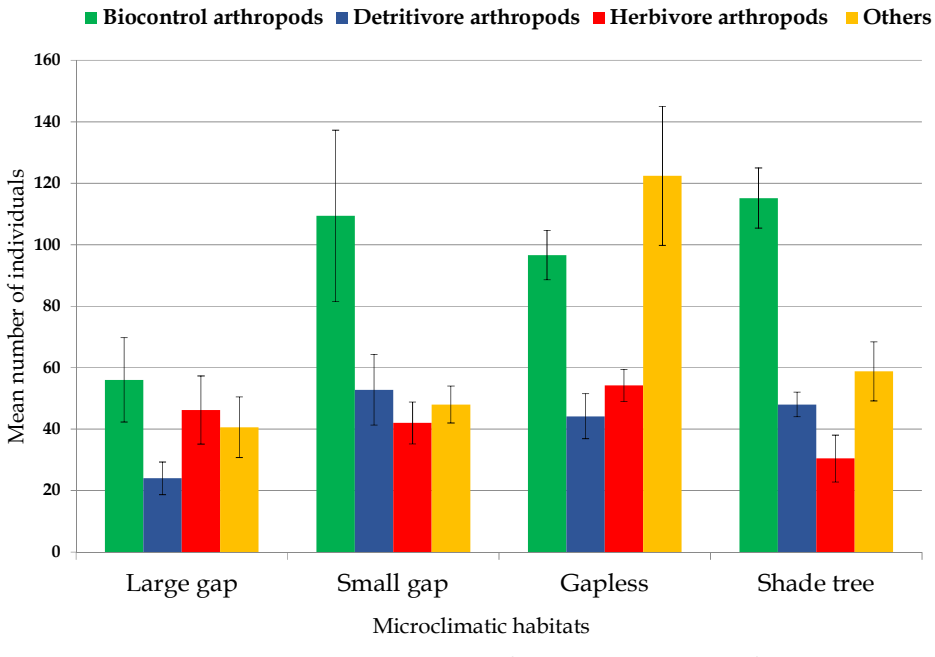

Fig. 5. Abundances (mean number of individuals per trap) of agriculturally important functional groups in four microclimatic habitats in Lakkatura Tea Estate, Sylhet during November 2017 to March 2018.

Comment: Mean number given in Y axis is different than those of mentioned in table 10.
Response: In table 10, total number of individuals trapped in five Malaise traps from each microclimatic habitat type is given. In Fig. 5, mean number of individuals sampled per trap is given. So, all values are five times lower that table 10.

11.13 Relative abundance of agriculturally important functional groups

Relative abundances of agriculturally important functional groups are presented in Table 11. The relative abundances of biocontrol arthropods were ranked as shade tree (45.64%)> small gap (43.38%)> large gap (33.57%)> gapless (30.43%). The relative abundances of detritivores were ranked as small gap (20.94%)> shade tree (19.02%)> large gap (14.39%)> gapless (13.93%). The relative abundances of herbivores were ranked as large gap (27.70%)> gapless (17.08%)> small gap (16.65%)> shade tree (12.04%). The relative abundances of other arthropod functional groups were ranked as gapless (38.56%)> large gap (24.34%)> shade tree (23.30%)> small gap (19.03%).

Table 11. Relative abundance of agriculturally important arthropod functional groups, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Functional groups	Relative abundance (%) in four microclimatic habitats			
		Large gap	Small gap	Gapless stand	Shade tree
1	Biocontrol	33.57	43.38	30.43	45.64
2	Detritivore	14.39	20.94	13.93	19.02
3	Herbivore	27.70	16.65	17.08	12.04
4	Others	24.34	19.03	38.56	23.30
	Total =	100.0	100.0	100.0	100.0

11.14 Total number of arthropods under different orders

T**o**tal number of arthropods under different orders is presented in Table 12. A total of 3248 arthropod individuals representing 13 orders were identified. In case of large gap, total number more than 50 were ranked as Diptera (143)> Lepidoptera (125)> Hymenoptera (112)> Coleoptera (88). In case of small gap, total number were ranked as Hymenoptera (232)> Diptera (208)> Coleoptera (163)> Lepidoptera (97). In case of gapless, total number were ranked as Diptera (463> Hymenoptera (179)> Lepidoptera (178)> Coleoptera (114). In case of shade tree, total number were ranked as Diptera (232)> Coleoptera (179)> Hymenoptera (176)> Lepidoptera (102). Irrespective of microclimatic habitats, total number more than 100 were ranked as Diptera (1046)> Hymenoptera (699)> Coleoptera (544)> Lepidoptera (502)> Hemiptera (147)> Orthoptera (108).

Table 12. Total number of arthropod individuals under different orders, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Sl.	Order	Total number of arthropods in four microclimatic habitats				Total
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand	
1	Araneae	7	18	28	26	79
2	Blattodea	5	6	8	5	24
3	Coenagrionidae	4	3	6	2	15
4	Coleoptera	88	163	114	179	544
5	Dermaptera	0	0	1	0	1
6	Dictyoptera	3	0	1	1	5
7	Diptera	143	208	463	232	1046
8	Hemiptera	42	46	48	31	167
9	Hymenoptera	112	232	179	176	699
10	Isoptera	8	2	3	2	15
11	Odonata	2	6	28	24	60
12	Orthoptera	27	47	25	9	108
13	Lepidoptera	125	97	178	102	502
No. of individuals =		566	811	1081	790	3248
No. of orders =		12	12	13	12	13

11.15 Diversity indices of arthropod families

The diversity indices of arthropod families are presented in Table 13. Diversity indices were ranked as large gap (083)> small gap (0.77)> gapless (0.75)> shade tree (0.72). The evenness values were ranked as large gap (0.51)> small gap (0.47)> gapless and shade tree (0.45). The richness values were ranked as gapless (6.73)> large gap (6.47)> small gap (6.10)> shade tree (5.85).

Table 13. Diversity indices of different arthropod families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Microclimatic habitats	Diversity index (H')	Evenness (J)	Richness (M.I.)
Large gap stand	0.83	0.51	6.47
Small gap stand	0.77	0.47	6.10
Gapless stand	0.75	0.45	6.73
Shade tree stand	0.72	0.45	5.85

11.16 Diversity indices of beneficial arthropod families

The diversity indices of beneficial arthropod families are shown in Table 14. Diversity indices were ranked as large gap (0.80)> gapless (0.77)> small gap (0.70)> shade tree (0.64). The evenness indices were ranked as large gap (0.65)> gapless (0.58)> small gap (0.57)> shade tree (0.49). The richness indices were ranked as gapless (3.33)> shade tree (3.23)> large gap (3.07)> small gap (2.73).

Table 14. Diversity indices of beneficial arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Microclimatic habitats	Diversity index (H')	Evenness (J)	Richness (M.I.)
Large gap stand	0.80	0.65	3.07
Small gap stand	0.70	0.57	2.73
Gapless stand	0.77	0.58	3.33
Shade tree stand	0.64	0.49	3.23

11.17 Diversity indices of harmful arthropod families

The diversity indices of harmful arthropod families are presented in Table 15. The diversity indices of arthropod families were ranked as large gap (0.77)> gapless (0.66)> small gap and shade tree (0.65). The evenness indices were ranked as large gap (0.64)> shade tree (0.58)> small gap and gapless (0.52). The richness indices were ranked as gapless (3.20)> small gap (3.09)> large gap (2.82)> shade tree (2.27).

Table 15. Diversity indices of harmful arthropods under different families, Sylhet during November 2017 to March 2018

Microclimatic habitats	Diversity index (H')	Evenness (J)	Richness (M.I.)
Large gap stand	0.77	0.64	2.82
Small gap stand	0.65	0.52	3.09
Gapless stand	0.66	0.52	3.20
Shade tree stand	0.65	0.58	2.27

11.18 Diversity indices of neutral arthropod families

The diversity indices of neutral arthropod families are presented in Table 16. The diversity indices were ranked as large gap (0.77)> small gap (0.63)> gapless (0.34)> shade tree (0.30). The evenness indices were ranked as large gap (0.86)> small gap (0.75)> gapless (0.38)> shade tree (0.36). The richness indices were ranked as large gap (1.35)> gapless (1.17)> small gap and shade tree (1.10).

Table 16. Diversity indices of neutral arthropods under different families, Lakkatura Tea Estate, Sylhet during November 2017 to March 2018

Microclimatic habitats	Diversity index (H')	Evenness (J)	Richness (M.I.)
Large gap stand	0.77	0.86	1.35
Small gap stand	0.63	0.75	1.10
Gapless stand	0.34	0.38	1.17
Shade tree stand	0.30	0.36	1.10

11.19 Relationships of tea bush with beneficial, harmful and neutral arthropods

There was no significant positive or negative linear relationship of number of tea bush with family abundance of beneficial, harmful and neutral arthropods (Fig. 6).

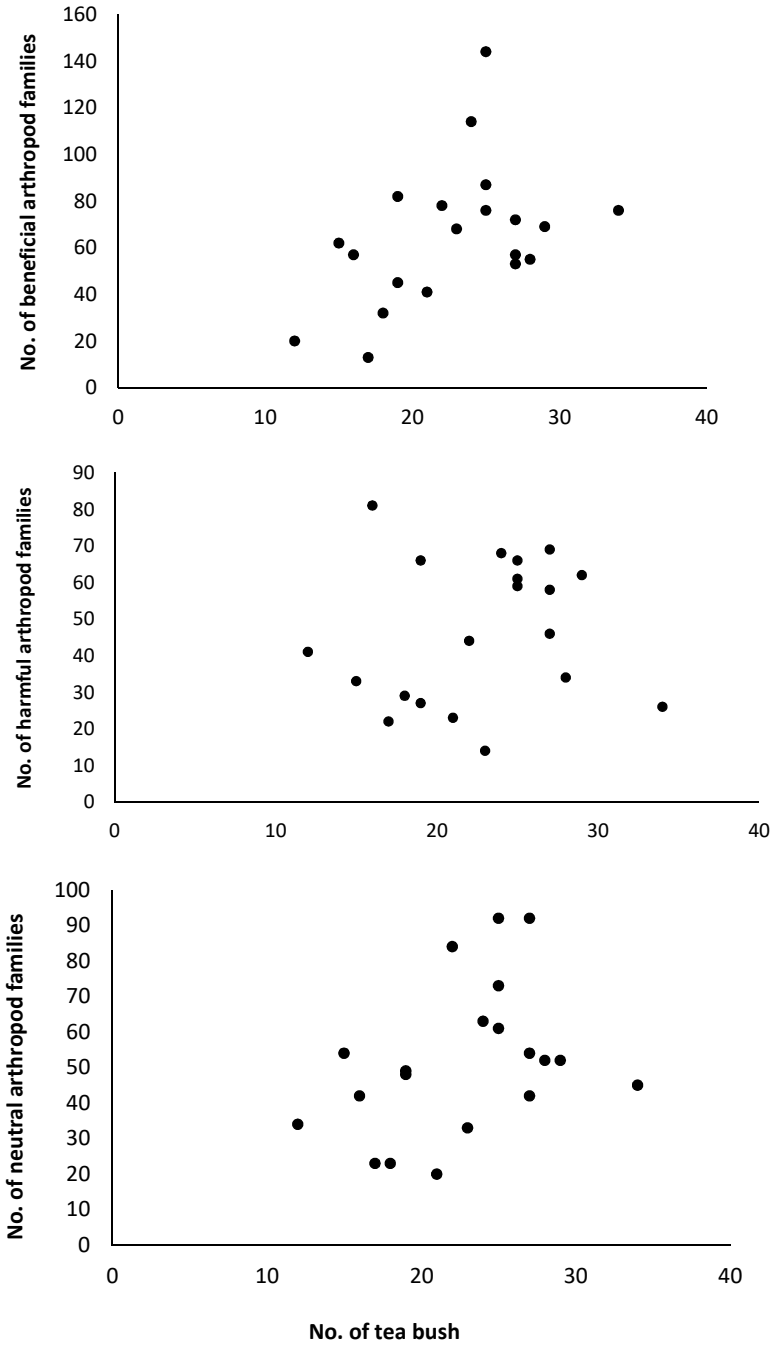

Fig. 6. Relationships of tea bush number with family abundance of beneficial (a), harmful (b) and neutral arthropods (c) in Lakkatura Tea Estate, Sylhet during November 2017 to March 2018.

11.20 Relationships of light intensity with beneficial, harmful and neutral arthropods

There was no significant positive or negative linear relationship of light intensity (Lux) with family abundance of beneficial, harmful and neutral arthropods (Fig. 7).

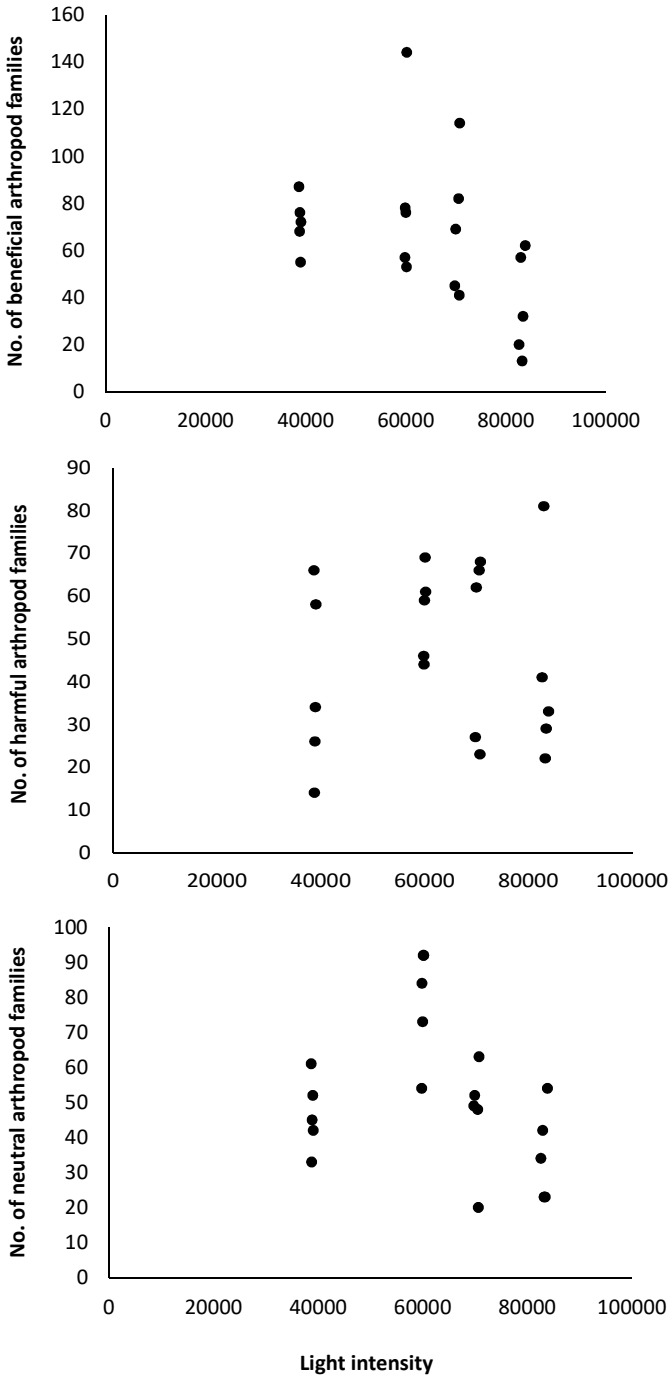

Fig. 7. Relationships of light intensity with families of beneficial (a), harmful (b) and neutral arthropods (c) in Lakkatura Tea Estate, Sylhet during November 2017 to March 2018.

11.21 Relationships of temperature with beneficial, harmful and neutral arthropods

There was no significant positive or negative linear relationship of temperature (ºC) with family abundance of beneficial, harmful and neutral arthropods (Fig. 8).

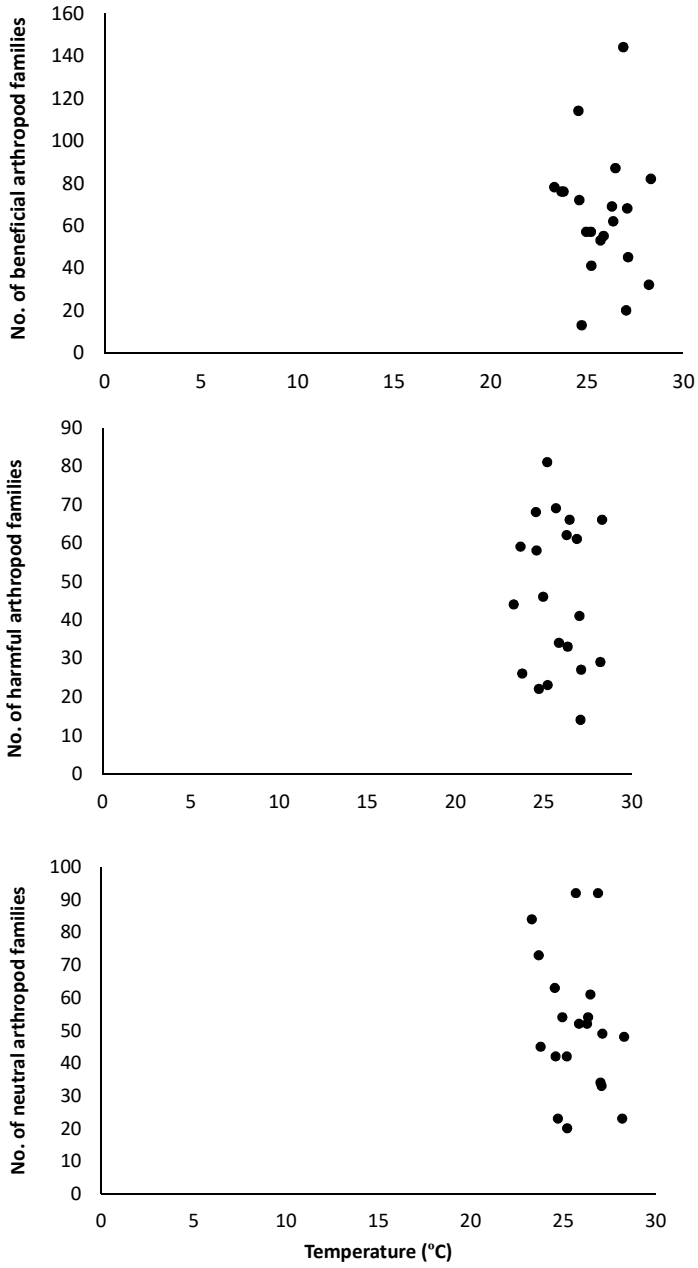

Fig. 8. Relationships of temperature with family abundance of beneficial (a), harmful (b) and neutral arthropods (c) in Lakkatura Tea Estate, Sylhet during November 2017 to March 2018.

11.22 Relationships of relative humidity with beneficial, harmful and neutral arthropods

There was no significant positive or negative linear relationship of relative humidity (%) with family abundance of beneficial, harmful and neutral arthropods (Fig. 9).

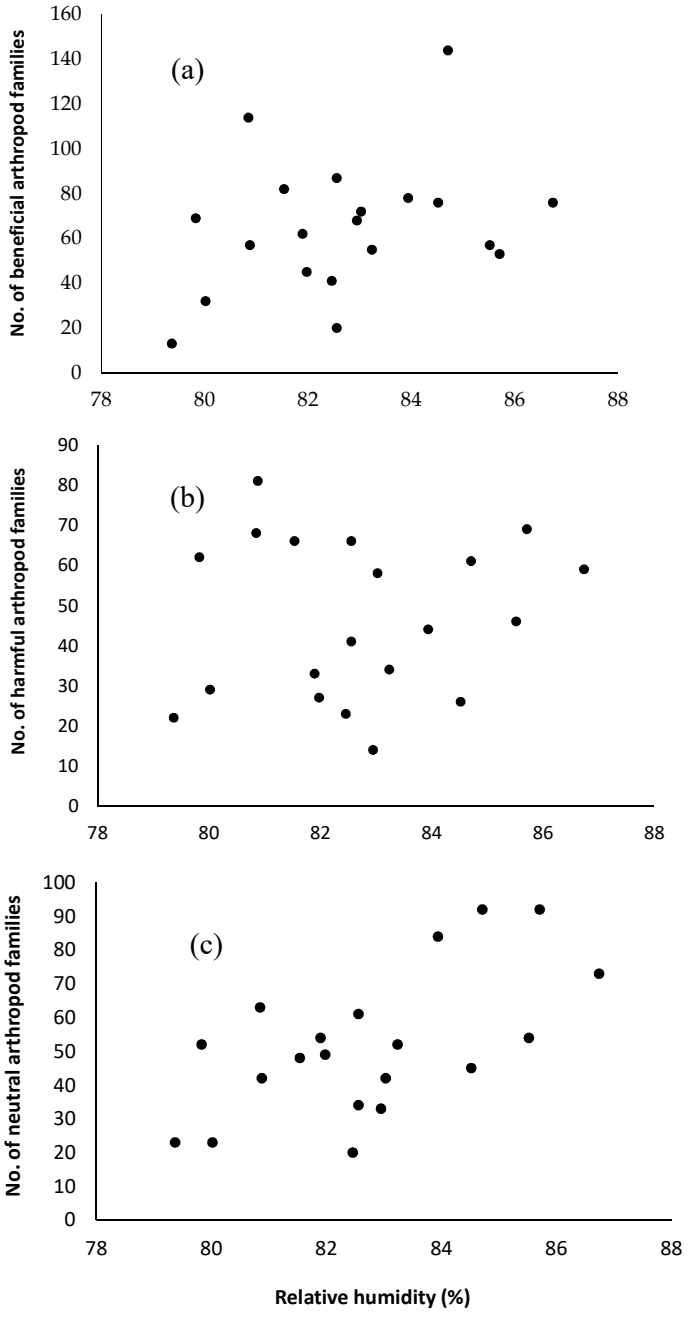

Fig. 9. Relationships of relative humidity with family abundance of beneficial (a), harmful (b) and neutral arthropods (c) in Lakkatura Tea Estate, Sylhet during November 2017 to March 2018.

Discussion

Tea infestation with insect and mite pests has been found as the biggest challenges for tea growers in Bangladesh. A large group of broad-spectrum synthetic pesticides are widely used for the management of tea pests. The use of synthetic pesticides causes many problems like development of pesticide resistance, destruction of beneficial arthropods like pollinators and residue in food items and environment. Thus, the study was undertaken to develop conservation strategies for the biocontrol agents in tea estates with a view to generating information for designing future research to develop environmentally friendly pest management strategies. The specific objectives were to know the most suitable microclimatic habitat for hosting biocontrol agents in tea estates. In response, tea stand with shade tree habitat has been found as most suitable for supporting biocontrol as well as other beneficial arthropods. In contrast, tea stand with large gap has been proved to be worst habitat to support beneficial arthropods. Although the tea stand with gapless habitat (no shade tree) had hosted most abundant and diverse arthropod communities, the relative abundance of beneficial arthropods was lower than those of shade tree habitat. In this study, no significant relationships of tea bush (as understory vegetation) with arthropod colonization were noticed. Similarly, microclimatic differences among the four naturally occurring habitats in tea estate studied were not considerable. It might have caused because of inadequate distance presence between the four habitats. Most trapped arthropods are mobile and have ability to travel sufficient distance and thus microclimatic conditions did they did not have pronounce impact on arthropod community assemblage among the habitats. In spite of so, shade tree habitat had contributed much to support relatively more abundant beneficial arthropod communities, suggesting that the presence of shade tree is essential if we expect to foster biocontrol arthropod communities in tea ecosystems. Several authors have shown that trees in agricultural and forested landscapes can conserve biodiversity and ecosystem services through modifying microclimate and giving habitat complexity (Maleque *et al.*, 2009; Barrios *et al.*, 2016). From the present study, it may be concluded that the Government body may promote the planting of shade trees and tea saplings in large gap areas of all the tea estates in Bangladesh to conserve biocontrol arthropods as well as to enhance tea productivity in the country, with minimum hazards to human health and environment.

12. Research highlight/findings (Bullet point – max 10 nos):

- Total 3,248 arthropod individuals were sampled, identified and classified into various functional groups;
- 566, 811, 1081 and 790 individuals were found in large gap, small gap, gapless and shade tree tea stands;
- 47, 49, 52 and 48 arthropod species were found in large gap, small gap, gapless and shade tree tea stands;
- 184, 333, 408 and 358 beneficial arthropods were found in large gap, small gap, gapless and shade tree tea stands;
- 206, 246, 279 and 198 harmful arthropods were found in large gap, small gap, gapless and shade tree tea stands;
- 176, 232, 395 and 233 neutral arthropods were found in large gap, small gap, gapless and shade tree tea stands;
- 280, 547, 483 and 576 biocontrol arthropods (i.e., predator, parasitoids) were found in large gap, small gap, gapless and shade tree tea stands;
- 231, 210, 271 and 152 herbivore arthropods (pest/harmful) were found in large gap, small gap, gapless and shade tree tea stands;
- 120, 264, 221 and 240 detritivore arthropods (beneficial) were found in large gap, small gap, gapless and shade tree tea stands; and
- Significantly the highest abundance of biocontrol arthropod individuals was found in shade tree stand of tea estate in the Sylhet region.

B. **Implementation Position**

1. Procurement

Description of equipment and capital items	PP Target		Achievement		Remarks
	Phy (#)	Fin (Tk)	Phy (#)	Fin (Tk)	
(a) Office equipment					
	Digital SLR Camera = 01	1,50,000.00	Digital SLR Camera = 01	1,20,000.00	
	Desktop Computer = 01	1,10,000.00	Desktop Computer = 01	83,000.00	
	Laptop = 01	95,000.00	Laptop = 01	1,35,000.00	
	Laser Printer =01	20,000.00	Laser Printer =01	32,000.00	
	Scanner 01	10,000.00	Scanner 01	10,000.00	
	Total	**3,85,000.00**		**3,80,000.00**	
(b) Lab & field equipment					
	USB Temperature Data Logger (Outdoor)=4	80,000.00	USB Temperature Data Logger (Outdoor)=4	78,000.00	
	Global Positioning System =01	35,000.00	Global Positioning System =01	33,900.00	
	Simple Microscope =01	45,000.00	Simple Microscope =01	44,000.00	
	Malaise Traps =16	8,000.00	Malaise Traps =16	9,600.00	
	Petri Dish 4" = 50	7,500.00	Petri Dish 4" = 50	7,000.00	
	Plastic Water Bottle (500ml) =50	1,000.00	Plastic Water Bottle (500ml) =50	1,500.00	
	Plastic Boyam (250ml) = 160	4,800.00	Plastic Boyam (250ml) = 160	4000.00	
	Total	**181,300.00**		**1,78,000.00**	
(c) Other capital items					
	Furniture (Computer Table) =01	8500.00	Furniture (Computer Table) =01	8500.00	
	Total	**8500.00**		**8500.00**	

2. Establishment/renovation facilities: Not applicable

Description of facilities	Newly established		Upgraded/refurbished		Remarks
	PP Target	Achievement	PP Target	Achievement	

3. Training/study tour/seminar/workshop/conference organized

Description	Number of participant			Duration (Days/weeks/months)		Remarks
	Male	Female	Total			
(a) Training						
(b) Workshop	23	03	26	01 Day		

C. Financial and physical progress

Fig in Tk

Items of expenditure/ activities	Total approved budget	Fund received	Actual expenditure	Balance/ unspent	Physical progress (%)	Reasons for deviation
A. Contractual staff salary	455752	455752	455752	0	100%	
B. Field Research/lab expenses and supplies	609162	593807	593807	15355	100%	
C. Operating expenses	163918	162697	162697	1221	100%	
D. Vehicle hire and fuel, oil & maintenance	41700	41700	41700	0	100%	
E. Training/Workshop/ Seminar etc.	40000	37928	37928	2072	100%	
F. Publications and printing	95000	5120	5000	90000	50%	Fund was not received
G. Miscellaneous	27968	31569	31569	-3601	100%	
H. Capital expenses	566500	553183	553183	13317	100%	

D. Achievement of Sub-project by objectives: (Tangible form)

Specific objectives of the sub-project	Major technical activities performed in respect of the set objectives	Output (i.e. product obtained, visible, measurable)	Outcome (short term effect of the research)
▪ Determine variations in insect biodiversity among four microhabitat types in tea estates	▪ 20 Malaise traps set up done ▪ 15-day interval samples collected ▪ All samples identified	▪ Total 3248 arthropod individuals identified ▪ 566 from large gap ▪ 811 from small gap ▪ 1081 gapless ▪ 790 from shade tree stand	▪ Useful for educationists, researchers and other stakeholders ▪ Useful in future research
▪ Determine relationships of various functional groups of insects with understory vegetation and microclimatic changes in tea estates	▪ All identified samples classified to functional groups ▪ No. of tea bush per trap recorded and regression analysis done	▪ Total 1283 beneficial arthropods identified (184 in large gap, 333 in small gap, 408 in gapless, 358 in shade tree stand) Total 929 harmful arthropods identified (206 in large gap, 246 in small gap, 279 in gapless, 198 in shade tree stand) ▪ Total 1036 neutral arthropods identified (176 in large gap, 232 in small gap, 395 in gapless, 233 in shade tree stand)	▪ Useful for educationists, researchers and other stakeholders ▪ Useful in future research
▪ Recommend biodiversity conservation and management strategy for the tea estates	▪ Most suitable microclimatic habitat for hosting biocontrol agents identified	▪ Out of 358 individuals in shade tree stand, 45% beneficial ▪ Out of 184 individuals in large gap, 33% beneficial.	▪ Useful for policy makers and tea garden managers ▪ All stakeholders can think of filling large gaps in tea estates

E. Materials Development/Publication made under the Sub-project

Publication	Number of publication		Remarks (e.g. paper title, name of journal, conference name, etc.)
	Under preparation	Completed and published	
Technology bulletin/booklet/leaflet/flyer etc.	-	-	-
Journal publication	-	-	-
Information development	Two Masters Theses	-	Defense in June 2019
Other publications, if any	-	-	-

F. Technology/Knowledge generation/Policy Support (as applied)

i. Generation of technology (Commodity & Non-commodity)

Not applicable

ii. Generation of new knowledge that help in developing more technology in future

New knowledge on habitat preference of beneficial, harmful and neutral arthropod communities generated, which will be helpful to develop future pest management technologies through manipulating habitat attributes and augmenting natural biocontrol arthropod species through conserving beneficial species diversity in tea ecosystems.

iii. Technology transferred that help increase agricultural productivity and farmer's income

Not directly applicable, but could be useful to increase agricultural productivity in future.

iv. Policy Support

Presence of shade trees in tea estates have been proved to be the most suitable microclimatic habitat for hosting more abundant beneficial arthropod communities. Beneficial arthropods are mostly predators and parasitoids, which naturally regulate crop pest population. These beneficial arthropods need to be augmented to avoid excessive use of toxic pesticides for pest management in tea estates. So, policy makers can adopt strategies to promote the planting of shade trees as well as new tea saplings in large gap areas of the tea estates in the country. Planting of shade trees and tea saplings in large gaps will increase tea productivity and natural regulation of tea pests.

G. Information regarding Desk and Field Monitoring

i) Desk monitoring (description & output of consultation meeting, monitoring workshops/seminar etc.)

In the Inception Report presentation, several suggestions were made. Most important one was to write results in tangible form in project completion report.

ii) Field Monitoring (time & No. of visit, Team visit and output):

Monitoring team	Date(s) of visit	Total visit	Remarks
PIU-BARC, NATP-2	07 April 20 18	1	▪ Director, NATP and Research Management Specialist visited Laboratory of Entomology at Sylhet Agricultural University
Internal visitors	27 November 2017 19 January 2018	1 1	▪ Dean, Faculty of Agriculture and other teachers of Sylhet Agricultural University visited the research field. ▪ Vice-Chancellor and other teachers of Sylhet Agricultural University visited the research field.

H. Lesson Learned/Challenges (if any)

i) Data collection devices need to be procured at the very biginning of the project.
ii) Weather dependent experiments need to set up well ahead of time to avoid uncertainties.

I. Challenges (if any)

Allocated timeframe for the subproject was inadequate to complete the entire works.

30.09.18

Signature of the Principal Investigator

Date: 30.09.18

Seal

Dr. Md. Abdul Maleque
Associate Professor
Department of Entomology
Sylhet Agricultural University
Sylhet 3100, Bangladesh

Counter signature of the Head of the organization/authorized representative

Date: 30.9.18

Seal

Director (Research)
Sylhet Agricultural University
Sylhet-3100

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Appendices (1-16)

Appendix 1. Identification and grouping of arthropod samples collected from large gap tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Major category
Amata (moth)	3	*Amata* sp.	Erebidae	Lepidoptera	Pest
Ant	36	*Formica* sp.	Formicidae	Hymenoptera	Mixed
Assassin bug	2	*Pselliopus* sp.	Reduviidae	Hemiptera	Beneficial
Bracon wasp	14	*Atanycolus* sp.	Braconidae	Hymenoptera	Beneficial
Brush footed butterfly	3	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Pest
Cabbage butterfly	21	*Pieris* sp.	Pieridae	Lepidoptera	Pest
Click beetle	13	*Melanotus* sp.	Elateridae	Coleoptera	Mixed
Cockroach	5	*Periplaneta americana*	Blattidae	Blattodea	Mixed
Crab spider	9	*Ozyptila* sp.	Thomicidae	Araneae	Beneficial
Damselfly	1	*Ischnura* sp.	Coenagrionidae	Diptera	Beneficial
Dragonfly	1	*Anax* sp.	Aeshnidae	Odonata	Beneficial
Drosophila	8	*Drosophila* sp.	Drosophillidae	Diptera	Mixed
Epilachna beetle	4	*Epilachna dodecastigma*	Coccinellidae	Coleoptera	Pest
Eusocial wasp	2	*Vespula* sp.	Vespidae	Hymenoptera	Beneficial
Field cricket	4	*Gryllotalpa* sp.	Gryllotalpidae	Orthoptera	Mixed
Fruit fly	1	*Bactrocera* sp.	Tephritidae	Diptera	Pest
Gelechiid moth	2		Gelechiidae	Lepidoptera	Pest
Green bottle fly	2	*Lucilia* sp.	Calliphoridae	Diptera	Beneficial
Ground beetle	3	*Calleida decora* (Fabricius)	Carabidae	Coleoptera	Beneficial
House cricket	6	*Acheta domesticus*	Gryllidae	Orthoptera	Mixed
House fly	44	*Musca domestica*	Muscidae	Diptera	Pest
Hoverfly	18	*Eupeodes* sp.	Syrphidae	Diptera	Beneficial
Ichneumon wasp	7	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Beneficial
Ladybird beetle	10	*Coccinella* sp.	Coccinellidae	Coleoptera	Beneficial
Leafhopper	14	*Nirvana* sp.	Cicadellidae.	Hemiptera	Pest
May beetle	12	*Phyllophaga* sp.	Scarabeidae	Coleoptera	Mixed
Mirid bug	3	*Rhabdomiris striatellus*	Miridae	Hemiptera	Pest
Mole cricket	1	*Gryllotalpa* sp.	Gryllotalpidae	Orthoptera	Mixed
Mosquito	70	*Culex* sp.	Culicidae	Diptera	Pest
Moth (Unidentified)	71	Unidentified	Noctuidae	Lepidoptera	Pest
Plant hopper	6	*Nilaparvata* sp.	Delphacidae	Hemiptera	Pest
Preying mantid	3	*Mantis* sp.	Mantidae	Dictyoptera	Beneficial
Rice hispa	1	*Dicladispa armigera*	Hispidae	Coleoptera	Pest
Rice bug	9	*Leptocorisa* sp.	Alydidae	Hemiptera	Pest
Robber fly	4	*Promachus* sp.	Asilidae	Diptera	Beneficial
Rove beetle	44	*Aleochara* sp.	Staphylinidae	Coleoptera	Beneficial
Short-horned grasshopper	17	*Schistocerca* sp.	Acrididae	Orthoptera	Pest
Short-tailed ichneumon wasp	38	*Ophion* sp.	Ichneumonidae	Hymenoptera	Beneficial
Skipper butterfly	2	*Hesperia comma*	Hesperidae	Lepidoptera	Pest
Stink bug	1	*Chioroa* sp.	Pentatomidae	Hemiptera	Pest
Tachinid fly	10	*Hystricia* sp.	Tachinidae	Diptera	Beneficial
Tea mosquito bug	4	*Helopeltis sp.*	Miridae	Heteroptera	Pest
Tea tortix	7	*Homona* sp.	Tortricidae	Lepidoptera	Pest
Termite	8	*Nasutitermes* sp.	Termitidae	Isoptera	Mixed
Tiger beetle	1	*Cicindella sexpunctata*	Carabidae	Coleoptera	Beneficial
Treehopper	6	*Membracis* sp.	Membracidae	Hemiptera	Pest
Trichogramma wasp	15	*Tricogramma* sp.	Tricogrammatidae	Hymenoptera	Beneficial
Total =	566				

Appendix 2. Identification and grouping of arthropod samples collected from small gap tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Major category
Amata (moth)	12	*Amata* sp.	Erebidae	Lepidoptera	Pest
Ant	97	*Formica* sp.	Formicidae	Hymenoptera	Mixed
Black and yellow striped ichneumon wasp	3	*Gotra* sp.	Ichneumonidae	Hymenoptera	Beneficial
Bracon wasp	20	*Atanycolus* sp.	Braconidae	Hymenoptera	Beneficial
Brush-footed butterfly	2	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Pest
Cabbage butterfly	12	*Pieris* sp.	Pieridae	Lepidoptera	Pest
Cedar beetle	1	*Sandalus* sp.	Rhipiceridae	Coleoptera	Beneficial
Click beetle	13	*Melanotus* sp.	Elateridae	Coleoptera	Mixed
Cockroach	6	*Periplaneta americana*	Blattidae	Blattodea	Mixed
Crab spider	18	*Ozyptila* sp.	Thomicidae	Araneae	Beneficial
Crane fly	2	*Tipula* sp.	Tipulidae	Diptera	Beneficial
Damsel fly	3	*Ischnura* sp.	Coenagrionidae	odonata	Beneficial
Dragonfly	3	*Anax* sp.	Aeshnidae	Odonata	Beneficial
Drosophila	12	*Drosophila* sp.	Drosophillidae	Diptera	Mixed
Eusocial wasp	3	*Vespula* sp.	Vespidae	Hymenoptera	Beneficial
Field cricket	1	*Gryllus* sp.	Gryllidae	Orthoptera	Mixed
Gelechiid moth	3	Unidentified	Gelechiidae	Lepidoptera	Pest
Green bottle fly	7	*Lucilia* sp.	Calliphoridae	Diptera	Beneficial
Ground beetle	14	*Calleida decora*	Carabidae	Coleoptera	Beneficial
Hawk moth	1	*Macroglossum stellatarum*	Sphingidae	Lepidoptera	Pest
Hawthorn slender moth	1	*Parornix anglicella*	Gracillariidae	Lepidoptera	Pest
House cricket	4	*Acheta domesticus*	Gryllidae	Orthoptera	Mixed
House fly	38	*Musca domestica*	Muscidae	Diptera	Pest
Hoverfly	6	*Eupeodes* sp.	Syrphidae	Diptera	Beneficial
Ichneumon wasp	20	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Beneficial
Japanese beetle	1	*Popillia* sp.	Scarabaeidae	Coleoptera	Pest
June beetle	2	*Phyllophaga* sp.	Scarabaeidae	Coleoptera	Mixed
Ladybird beetle	15	*Coccinella* sp.	Coccinellidae	Coleoptera	Beneficial
Leafhopper	23	*Nirvana* sp.	Cicadellidae.	Hemiptera	Pest
May beetle	4	*Phyllophaga* sp.	Scarabaeidae	Coleoptera	Mixed
Minute brown scavenger	1	Unidentified	Latridiidae	Coleoptera	Beneficial
Mosquito	122	*Culex* sp.	Culicidae	Diptera	Pest
Moth (Unidentified)	60	Unidentified	Noctuidae	Lepidoptera	Pest
Plant hopper	1	*Nilaparvata sp.*	Delphacidae	Hemiptera	Pest
Rice bug	7	Leptocorisa sp.	Alydidae	Hemiptera	Pest
Rice green leafhopper	3	*Nephotettix* sp.	Cicadellidae.	Hemiptera	Pest
Robber fly	3	*Promachus* sp.	Asilidae	Diptera	Beneficial
Rove beetle	111	*Aleochara* sp	Staphylinidae	Coleoptera	Beneficial
Sawfly	3	*Tenthredo* sp.	Tenthridinidae	Hymenoptera	Pest
Short-horned grasshopper	42	*Schistocerca* sp.	Acrididae	Orthoptera	Pest
Short-tailed ichneumon wasp	77	*Ophion* sp.	Ichneumonidae	Hymenoptera	Beneficial
Skipper butterfly	2	*Hesperia comma*	Hesperidae	Lepidoptera	Pest
Sting bug	1	*Chlorochroa* sp.	Pentatomidae	Hemiptera	Pest
Tachinid fly	12	*Hystricia* sp.	Tachinidae	Diptera	Beneficial
Tea mosquito bug	2	Helopeltis *sp.*	Miridae	Heteroptera	Pest
Tea tortrix	4	*Homona* sp.	Tortricidae	Lepidoptera	Pest
Termite	2	*Nasutitermes* sp.	Termitidae	Isopteran	Mixed
Tiger beetle	2	*Cicindella sexpunctata*	Carabidae	Coleoptera	Beneficial
Treehopper	9	*Membracis* sp.	Membracidae	Hemiptera	Pest
Total =	811				

Appendix 3. Identification and grouping of arthropod samples collected from gapless tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Major category
Amata (moth)	1	*Amata* sp.	Erebidae	Lepidoptera	Pest
Ant	57	*Formica* sp.	Formicidae	Hymenoptera	Mixed
Aphid	1	Unidentified	Aphididae	Hemiptera	Pest
Assassin bug	1	*Pselliopus* sp.	Reduviidae	Hemiptera	Beneficial
Black and yellow striped ichneumon wasp	9	*Gotra* sp.	Ichneumonidae	Hymenoptera	Beneficial
Bracon wasp	17	*Atanycolus* sp.	Braconidae	Hymenoptera	Beneficial
Brown plant hopper	1	*Nilaparvata lugens*	Delphacidae	Homoptera	Pest
Brush-footed butterfly	14	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Pest
Cabbage butterfly	14	*Pieris* sp.	Pieridae	Lepidoptera	Pest
Chain-dotted geometer moth	1	*Cingilia catenaria*	Geometridae	Lepidoptera	Mixed
Click beetle	7	*Melanotus* sp.	Elateridae	Coleoptera	Mixed
Cockroach	8	*Periplaneta americana*	Blattidae	Blattodea	Mixed
Common earwig	1	*Forficula auricularia*	Forficulidae	Dermaptera	Beneficial
Crab spider	28	*Ozyptila* sp.	Thomicidae	Araneae	Beneficial
Crane fly	7	*Tipula* sp.	Tipulidae	Diptera	Beneficial
Damselfly	1	*Ischnura* sp.	Coenagrionidae	Diptera	Beneficial
Dragonfly	27	*Anax* sp.	Aeshnidae	Odonata	Beneficial
Drosophila	55	*Drosophila* sp.	Drosophillidae	Diptera	Mixed
Eusocial wasp	4	*Vespula* sp.	Vespidae	Hymenoptera	Beneficial
Field cricket	5	*Gryllus* sp.	Gryllidae	Orthoptera	Mixed
Gelechiid moth	2	Unidentified	Gelechiidae	Lepidoptera	Pest
Green bottle fly	6	*Lucilia* sp.	Calliphoridae	Diptera	Beneficial
Ground beetle	7	*Calleida decora* (Fab.)	Carabidae	Coleoptera	Beneficial
Hawk moth	2	*Macroglossum stellatarum*	Sphingidae	Lepidoptera	Pest
House cricket	2	*Acheta domesticus*	Gryllidae	Orthoptera	Mixed
House fly	106	*Musca domestica*	Muscidae	Diptera	Pest
Hoverfly	35	*Eupeodes* sp.	Syrphidae	Diptera	Beneficial
Ichneumon wasp	20	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Beneficial
June beetle	1	*Phyllophaga* sp.	Scarabaeidae	Coleoptera	Mixed
Ladybird beetle	14	*Coccinella* sp.	Coccinellidae	Coleoptera	Beneficial
Leafhopper	20	*Nirvana* sp.	Cicadellidae.	Hemiptera	Pest
Long-legged fly	4	*Condylostylus* sp.	Dolichopodidae	Diptera	Beneficial
May beetle	4	*Phyllophaga* sp.	Scarabaeidae	Coleoptera	Mixed
Minute brown scavenger	3	Unidentified	Lateridiidae	Coleoptera	Beneficial
Mole cricket	4	*Gryllotalpa* sp.	Gryllotalpidae	Orthoptera	Mixed
Mosquito	233	*Culex* sp	Culicidae	Diptera	Pest
Moth (Unidentified)	121	Unidentified	Noctuidae	Lepidoptera	Pest
Preying mantid	1	*Mantis* sp.	Mantidae	Dictyoptera	Beneficial
Rice bug	12	Leptocorisa sp.	Alydidae	Hemiptera	Pest
Robber fly	6	*Promachus* sp.	Asilidae	Diptera	Beneficial
Rove beetle	74	*Aleochara* sp	Staphylinidae	Coleoptera	Beneficial
Sawfly	2	*Tenthredo* sp.	Tenthridinidae	Hymenoptera	Pest
Short-horned grasshopper	14	*Schistocerca* sp.	Acrididae	Orthoptera	Pest
Short-tailed ichneumon wasp	69	*Ophion* sp.	Ichneumonidae	Hymenoptera	Beneficial
Skipper butterfly	14	*Hesperia comma*	Hesperidae	Lepidoptera	Pest
Sting bug	4	*Chlorochroa* sp.	Pentatomidae	Hemiptera	Pest
Tachinid fly	17	*Hystricia* sp.	Tachinidae	Diptera	Beneficial
Tea shoot borer	3	*Euwallacea* sp.	Scolytidae	Coleoptera	Pest

Common name	No. of individual	Scientific name	Family	Order	Major category
Tea tortix	9	*Homona* sp.	Tortricidae	Lepidoptera	Pest
Termite	3		*Termitidae*	Isoptera	Mixed
Tiger beetle	1	*Cicindella sexpunctata*	Cicindellidae	Coleoptera	Beneficial
Treehopper	9	*Membracis* sp.	Membracidae	Hemiptera	Pest
Total =	1081				

Appendix 4. Identification and grouping of arthropod samples collected from shade tree tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Major category
Ant	66	*Formica* sp.	Formicidae	Hymenoptera	Mixed
Assassin bug	3	*Pselliopus* sp.	Reduviidae	Hemiptera	Beneficial
Black and yellow striped ichneumon wasp	10	*Gotra* sp.	Ichneumonidae	Hymenoptera	Beneficial
Bracon wasp	8	*Atanycolus* sp.	Braconidae	Hymenoptera	Beneficial
Brown house moth	2	*Hofmannophila* sp.	Oecophoridae	Lepidoptera	Pest
Brush-footed butterfly	7	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Pest
Cabbage butterfly	6	*Pieris* sp.	Pieridae	Lepidoptera	Pest
Click beetle	8	*Melanotus* sp.	Elateridae	Coleoptera	Mixed
Cockroach	5	*Periplaneta americana*	Blattidae	Blattodea	Mixed
Crab spider	26	*Ozyptila* sp.	Thomicidae	Araneae	Beneficial
Crane fly	2	*Tipula* sp.	Tipulidae	Diptera	Beneficial
Damselfly	12	*Ischnura* sp.	Coenagrionidae	Diptera	Beneficial
Digger wasp	5	*Sphex* sp.	Sphecidae	Hymenoptera	Beneficial
Dragonfly	12	*Anax* sp.	Aeshnidae	Odonata	Beneficial
Dung beetle	1	*Scarabaeus* sp.	Scarabaidae	Coleoptera	Beneficial
Eusocial wasp	2	*Vespula* sp.	Vespidae	Hymenoptera	Beneficial
Epilachna beetle	1	*Epilachna dodecastigmata*	Coccinellidae	Coleoptera	Pest
Field cricket	1	*Gryllus* sp.	Gryllidae	Orthoptera	Mixed
Firefly	2	*Photinus* sp.	Lampyridae	Coleoptera	Beneficial
Green bottle fly	5	*Lucilia* sp.	Calliphoridae	Diptera	Beneficial
Ground beetle	6	*Calleida decora* (Fab.)	Carabidae	Coleoptera	Beneficial
House cricket	3	*Acheta domesticus*	Gryllidae	Orthoptera	Mixed
House fly	40	*Musca domestica*	Muscidae	Diptera	Pest
Hoverfly	3	*Eupeodes* sp.	Syrphidae	Diptera	Beneficial
Ichneumon wasp	13	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Beneficial
June beetle	3	*Phyllophaga sp.*	Scarabaeidae	Coleoptera	Mixed
Ladybird beetle	5	*Coccinella* sp.	Coccinellidae	Coleoptera	Beneficial
Leafhopper	16	*Nirvana* sp.	Cicadellidae.	Hemiptera	Pest
May beetle	2	*Phyllophaga* sp.	Scarabaeidae	Coleoptera	Mixed
Minute brown scavenger	3		Lateridiidae	Coleoptera	Beneficial
Mole cricket	1	*Gryllotalpa* sp.	Gryllotalpidae	Orthoptera	Mixed
Mosquito	165	*Culex* sp.	Culicidae	Diptera	Pest
Moth (Unidentified)	76	Unidentified	Noctuidae	Lepidoptera	Pest
Plant bug	1	Unidentified	Miridae	Hemiptera	Mixed
Preying mantid	1	*Mantis* sp.	Mantidae	Dictyoptera	Beneficial
Rice bug	8	*Leptocorisa* sp.	Alydidae	Hemiptera	Pest
Robber fly	2	*Promachus* sp.	Asilidae	Diptera	Beneficial
Rove beetle	146	*Aleochara* sp	Staphylinidae	Coleoptera	Beneficial
Short-horned	4	*Schistocerca* sp	Acrididae	Orthoptera	Pest

Common name	No. of individual	Scientific name	Family	Order	Major category
grasshopper					
Short-tailed ichneumon wasp	72	*Ophion* sp.	Ichneumonidae	Hymenoptera	Beneficial
Skipper butterfly	9	*Hesperia comma*	Hesperidae	Lepidoptera	Pest
Sting bug	1	*Chlorochroa* sp.	Pentatomidae	Hemiptera	Pest
Sulphur butterfly	1	*Colias* sp.	Pieridae	Lepidoptera	Pest
Tachinid fly	17	*Hystricia* sp.	Tachinidae	Diptera	Beneficial
Termite	2		*Termitidae*	Isopteran	Mixed
Tiger beetle	3	*Cicindella sexpunctata*	Cicindellidae	Coleoptera	Beneficial
Treehopper	2	*Membracis* sp.	Membracidae	Hemiptera	Pest
White-shouldered house moth	1	*Endrosis sarcitrella*	Oecophoridae	Lepidoptera	Pest
Total =	790				

Appendix 5. Trap wise grouping of arthropod samples collected from large gap tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Specific functional group
Short-horned grasshopper	17	*Schistocerca* sp	Acrididae	Orthoptera	Herbivore
Rice hispa	1	*Dicladispa armigera*	Hispidae	Coleoptera	Herbivore
Treehopper	6	*Membracis* sp.	Membracidae	Hemiptera	Herbivore
Leafhopper	14	*Nirvana* sp.	Cicadellidae.	Hemiptera	Herbivore
Mirid bug	3	*Rhabdomiris striatellus*	Miridae	Hemiptera	Herbivore
Epilachna beetle	4	*Epilachna dodecastigma*	Coccinellidae	Coleoptera	Herbivore
Gelechiid moth	2		Gelechiidae	Lepidoptera	Herbivore
Moth	71	Unidentified	Noctuidae	Lepidoptera	Herbivore
Cabbage butterfly	21	*Pieris* sp.	Pieridae	Lepidoptera	Herbivore
Mosquito	70	*Culex* sp	Culicidae	Diptera	Blood sucker
House fly	44	*Musca domestica*	Muscidae	Diptera	Food feeder, vector
Tea mosquito bug	4	*Helopeltis sp.*	Miridae	Heteroptera	Sap sucker
Rice bug	9	*Leptocorisa* sp.	Alydidae	Hemiptera	Rice milk sucker
Skipper butterfly	2	*Hesperia comma*	Hesperidae	Lepidoptera	Herbivore
Fruit fly	1	*Bactrocera sp.*	Tephritidae	Diptera	Fruit eater
Tea tortix	7	*Homona sp.*	Tortricidae	Lepidoptera	Leaf feeder
Amata (moth)	3	*Amata* sp.	Erebidae	Lepidoptera	Herbivore
Plant hopper	6	*Nilaparvata* sp.	Delphacidae	Hemiptera	Sap sucker
Brush footed butterfly	3	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Leaf feeder
Stink bug	1	*Chioroa sp.*	Pentatomidae	Hemiptera	Sap sucker
Short-tailed ichneumon wasp	38	*Ophion* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Ichneumon wasp	7	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Eusocial wasp	2	*Vespula* sp.	Vespidae	Hymenoptera	Predator
Rove beetle	44	*Aleochara* sp	Staphylinidae	Coleoptera	Predator, parasitoid, scavenger
Tiger beetle	1	*Cicindella sexpunctata*	Carabidae	Coleoptera	Predator
Hoverfly	18	*Eupeodes* sp.	Syrphidae	Diptera	Predator, pollinator
Ground beetle	3	*Calleida decora* (Fabricius)	Carabidae	Coleoptera	Predator
Crab spider	9	*Ozyptila* sp.	Thomicidae	Araneae	Predator
Ladybird beetle	10	*Coccinella* sp.	Coccinellidae	Coleoptera	Predator

Common name	No. of individual	Scientific name	Family	Order	Specific functional group
Assassin bug	2	*Pselliopus* sp.	Reduviidae	Hemiptera	Predator
Tachinid fly	10	*Hystricia* sp.	Tachinidae	Diptera	Parasitoid, pollinator
Preying mantid	3	*Mantis* sp.	Mantidae	Dictyoptera	Predator
Robber fly	4	*Promachus* sp.	Asilidae	Diptera	Predator
Trichogramma wasp	15	*Tricogramma sp.*	Tricogrammatidae	Hymenoptera	Parasitoid
Bracon wasp	14	*Atanycolus sp.*	Braconidae	Hymenoptera	Parasitoid
Green bottle fly	2	*Lucilia* sp.	Calliphoridae	Diptera	Scavenger, pollinator
Dragonfly	1	*Anax* sp.	Aeshnidae	Odonata	Predator
Damselfly	1	*Ischnura* sp.	Coenagrionidae	Diptera	Predator
Cockroach	5	*Periplaneta americana*	Blattidae	Blattodea	Omnivore, scavenger
Field cricket	4	*Gryllotalpa sp.*	Gryllotalpidae	Orthoptera	Plant feeder, seed feeder, predator
Termite	8	*Nasutitermes* sp	Termitidae	Isoptera	Wood eater, human food
Ant	36	*Formica* sp.	Formicidae	Hymenoptera	Predator, scavenger
Click beetle	13	*Melanotus* sp.	Elateridae	Coleoptera	Saprophagous, herbivore, predator
House cricket	6	*Acheta domesticus*	Gryllidae	Orthoptera	Vector, edible insect
May beetle	12	*Phyllophaga sp.*	Scarabeidae	Coleoptera	Scavenger, herbivore, predator
Mole cricket	1	*Gryllotalpa sp.*	Gryllotalpidae	Orthoptera	Omnivore
Drosophila	8	*Drosophila sp.*	Drosophillidae	Diptera	Vector, scavenger
	566				

Appendix 6. Trap wise grouping of arthropod samples collected from small gap tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Specific functional groups
Mosquito	122	*Culex* sp	Culicidae	Diptera	Blood sucker
Moth	60	Unidentified	Noctuidae	Lepidoptera	Herbivore
Leafhopper	23	*Nirvana* sp.	Cicadellidae.	Hemiptera	Sap sucker
Short-horned grasshopper	42	*Schistocerca* sp	Acrididae	Orthoptera	Herbivore
Sting bug	1	*Chlorochroa* sp.	Pentatomidae	Hemiptera	Sap sucker
Rice bug	7	Leptocorisa sp.	Alydidae	Hemiptera	Rice milk sucker
Skipper butterfly	2	*Hesperia comma*	Hesperidae	Lepidoptera	Herbivore
Hawk moth	1	*Macroglossum stellatarum*	Sphingidae	Lepidoptera	Leaf feeder
Treehopper	9	*Membracis* sp.	Membracidae	Hemiptera	Sap sucker
Plant hopper	1	*Nilaparvata sp.*	Delphacidae	Hemiptera	Sap sucker
House fly	38	*Musca domestica*	Muscidae	Diptera	Vector, food eater
Tea tortrix	4	*Homona* sp.	Tortricidae	Lepidoptera	Leaf feeder
Amata (moth)	12	*Amata* sp.	Erebidae	Lepidoptera	Herbivore
Brush-footed butterfly	2	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Leaf feeder
Rice green leafhopper	3	*Nephotettix* sp.	Cicadellidae.	Hemiptera	Sap sucker, vector
Tea mosquito bug	2	Helopeltis *sp.*	Miridae	Heteroptera	Sap sucker
Gelechiid moth	3	Unidentified	Gelechiidae	Lepidoptera	Herbivore
Cabbage butterfly	12	*Pieris* sp.	Pieridae	Lepidoptera	Herbivore

Common name	No. of individual	Scientific name	Family	Order	Specific functional groups
Japanese beetle	1	*Popillia* sp.	Scarabaeidae	Coleoptera	Leaf feeder
Hawthorn slender moth	1	*Parornix anglicella*	Gracillariidae	Lepidoptera	Herbivore
Sawfly	3	*Tenthredo* sp.	Tenthridinidae	Hymenoptera	Leaf feeder
Tachinid fly	12	*Hystricia* sp.	Tachinidae	Diptera	Parasitoid, pollinator
Hoverfly	6	*Eupeodes* sp.	Syrphidae	Diptera	Predator, pollinator
Green bottle fly	7	*Lucilia* sp.	Calliphoridae	Diptera	Scavenger, pollinator
Ground beetle	14	*Calleida decora* (Fab.)	Carabidae	Coleoptera	Predator
Dragonfly	3	*Anax* sp.	Aeshnidae	Odonata	Predator
Damsel fly	3	*Ischnura sp.*	Coenagrionidae	odonata	Predator
Short-tailed ichneumon wasp	77	*Ophion* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Ladybird beetle	15	*Coccinella* sp.	Coccinellidae	Coleoptera	Predator
Tiger beetle	2	*Cicindella sexpunctata* (Fab.)	Carabidae	Coleoptera	Predator
Rove beetle	111	*Aleochara* sp	Staphylinidae	Coleoptera	Predator, parasitoid, scavenger
Crab spider	18	*Ozyptila* sp.	Thomicidae	Araneae	Predator
Bracon wasp	20	*Atanycolus* sp.	Braconidae	Hymenoptera	Parasitoid
Minute brown scavenger	1	Unidentified	Latridiidae	Coleoptera	Scavenger
Black and yellow striped ichneumon wasp	3	*Gotra* sp.	Ichneumonidae	Hymenoptera	Pollinator
Cedar beetle	1	*Sandalus* sp.	Rhipiceridae	Coleoptera	Parasite
Ichneumon wasp	20	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Wasp	3	*Vespula* sp.	Vespidae	Hymenoptera	Predator
Robber fly	3	*Promachus* sp.	Asilidae	Diptera	Predator
Crane fly	2	*Tipula* sp.	Tipulidae	Diptera	Saprophagous
Field cricket	1	*Gryllus* sp.	Gryllidae	Orthoptera	Predator, seed feeder, plant feeder
House cricket	4	*Acheta domesticus*	Gryllidae	Orthoptera	Vector, human food
Cockroach	6	*Periplaneta americana*	Blattidae	Blattodea	Omnivore, scavenger
Click beetle	13	*Melanotus* sp.	Elateridae	Coleoptera	Saprophagous, herbivore, predator
May beetle	4	*Phyllophaga sp.*	Scarabaeidae	Coleoptera	Saprophagous, herbivore
Drosophila	12	*Drosophila sp.*	Drosophillidae	Diptera	Vector, scavenger
June beetle	2	*Phyllophaga sp.*	Scarabaeidae	Coleoptera	Saprophagous, herbivore
Termite	2		Termitidae	Isopteran	Wood eater, human food
Ant	97	*Formica* sp.	Formicidae	Hymenoptera	Predator, scavenger
	811				

Appendix 7. Trap wise grouping of arthropod samples collected from gapless tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Specific functional groups
Short-horned grasshopper	14	*Schistocerca* sp	Acrididae	Orthoptera	Herbivore
House fly	106	*Musca domestica*	Muscidae	Diptera	Vector, food eater
Moth	121	Unidentified	Noctuidae	Lepidoptera	Herbivore
Hawk moth	2	*Macroglossum stellatarum*	Sphingidae	Lepidoptera	Leaf feeder
Sawfly	2	*Tenthredo* sp,	Tenthridinidae	Hymenoptera	Leaf feeder
Aphid	1	Unidentified	Aphididae	Hemiptera	Sap sucker
Brush-footed butterfly	14	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Leaf feeder
Leafhopper	20	*Nirvana* sp.	Cicadellidae.	Hemiptera	Sap sucker
Tea tortix	9	*Homona* sp.	Tortricidae	Lepidoptera	Leaf feeder
Treehopper	9	*Membracis* sp.	Membracidae	Hemiptera	Sap sucker
Gelechiid moth	2	Unidentified	Gelechiidae	Lepidoptera	Herbivore
Cabbage butterfly	14	*Pieris* sp.	Pieridae	Lepidoptera	Herbivore
Mosquito	233	*Culex* sp	Culicidae	Diptera	Herbivore, Blood sucker
Rice bug	12	Leptocorisa sp.	Alydidae	Hemiptera	Rice milk sucker
Brown plant hopper	1	*Nilaparvata lugens*	Delphacidae	Homoptera	Sap sucker
Skipper butterfly	14	*Hesperia comma*	Hesperidae	Lepidoptera	Herbivore
Tea shoot borer	3	*Euwallacea* sp.	Scolytidae	Coleoptera	Plant feeder
Sting bug	4	*Chlorochroa* sp.	Pentatomidae	Hemiptera	Sap sucker
Amata (moth)	1	*Amata* sp.	Erebidae	Lepidoptera	Herbivore
Short-tailed ichneumon wasp	69	*Ophion* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Black and yellow striped ichneumon wasp	9	*Gotra* sp.	Ichneumonidae	Hymenoptera	Pollinator
Rove beetle	74	*Aleochara* sp	Staphylinidae	Coleoptera	Predator, parasitoid, scavenger
Dragonfly	27	*Anax* sp.	Aeshnidae	Odonata	Predator
Tachinid fly	17	*Hystricia* sp.	Tachinidae	Diptera	Parasitoid, pollinator
Hoverfly	35	*Eupeodes* sp.	Syrphidae	Diptera	Predator, pollinator
Crane fly	7	*Tipula* sp.	Tipulidae	Diptera	Saprophagous
Crab spider	28	*Ozyptila* sp.	Thomicidae	Araneae	Predator
Robber fly	6	*Promachus* sp.	Asilidae	Diptera	Predator
Assassin bug	1	*Pselliopus* sp.	Reduviidae	Hemiptera	Predator
Bracon wasp	17	*Atanycolus* sp.	Braconidae	Hymenoptera	Parasitoid
Ladybird beetle	14	*Coccinella* sp.	Coccinellidae	Coleoptera	Predator
Green bottle fly	6	*Lucilia* sp.	Calliphoridae	Diptera	Scavenger, pollinator
Ground beetle	7	*Calleida decora* (Fab.)	Carabidae	Coleoptera	Predator
Ichneumon wasp	20	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Eusocial wasp	4	*Vespula* sp.	Vespidae	Hymenoptera	Predator
Common earwig	1	*Forficula auricularia*	Forficulidae	Dermaptera	Predator
Tiger beetle	1	*Cicindella sexpunctata*	Cicindellidae	Coleoptera	Predator
Long-legged fly	4	*Condylostylus* sp.	Dolichopodidae	Diptera	Predator
Preying mantid	1	*Mantis* sp.	Mantidae	Dictyoptera	Predator
Damselfly	1	*Ischnura* sp.	Coenagrionidae	Diptera	Predator
Minute brown scavenger	3	Unidentified	Lateridiidae	Coleoptera	Scavenger
Cockroach	8	*Periplaneta americana*	Blattidae	Blattodea	Omnivore, scavenger

Common name	No. of individual	Scientific name	Family	Order	Specific functional groups
Mole cricket	4	*Gryllotalpa* sp	Gryllotalpidae	Orthoptera	omnivore,
House cricket	2	*Acheta domesticus*	Gryllidae	Orthoptera	Vector, human food
Ant	57	*Formica* sp.	Formicidae	Hymenoptera	Predator, scavenger
Drosophila	55	*Drosophila sp.*	Drosophillidae	Diptera	Vector, scavenger
Field cricket	5	*Gryllus* sp.	Gryllidae	Orthoptera	Predator, seed feeder, plant feeder
Click beetle	7	*Melanotus* sp.	Elateridae	Coleoptera	Saprophagous, herbivore, predator
Chain-dotted geometer moth	1	*Cingilia catenaria*	Geometridae	Lepidoptera	Herbivore, Omnivore
May beetle	4	*Phyllophaga sp.*	Scarabaeidae	Coleoptera	Saprophagous, herbivore
Termite	3		*Termitidae*	Isopteran	Wood eater, human food
June beetle	1	*Phyllophaga sp.*	Scarabaeidae	Coleoptera	Saprophagous, herbivore
	1081				

Appendix 8. Trap wise grouping of arthropod samples collected from shade tree tea stand, Lakkatura Tea Estate, Sylhet

Common name	No. of individual	Scientific name	Family	Order	Specific functional groups
House fly	40	*Musca domestica*	Muscidae	Diptera	Vector, food eater
Mosquito	165	*Culex* sp	Culicidae	Diptera	Blood sucker
Sulphur butterfly	1	*Colias* sp.	Pieridae	Lepidoptera	Leaf feeder
Moth	76	Unidentified	Noctuidae	Lepidoptera	Herbivore
Rice bug	8	*Leptocorisa* sp.	Alydidae	Hemiptera	Rice milk sucker
Treehopper	2	*Membracis* sp.	Membracidae	Hemiptera	Sap sucker
Leafhopper	16	*Nirvana* sp.	Cicadellidae.	Hemiptera	Sap sucker
Short-horned grasshopper	4	*Schistocerca* sp	Acrididae	Orthoptera	Herbivore
Brown house moth	2	*Hofmannophila* sp.	Oecophoridae	Lepidoptera	Herbivore
White-shouldered house moth	1	*Endrosis sarcitrella*	Oecophoridae	Lepidoptera	Herbivore
Cabbage butterfly	6	*Pieris* sp.	Pieridae	Lepidoptera	Herbivore
Brush-footed butterfly	7	*Basilarchia* sp.	Nymphalidae	Lepidoptera	Leaf feeder
Epilachna beetle	1	*Epilachna dodecastigmata*	Coccinellidae	Coleoptera	Leaf feeder
Skipper butterfly	9	*Hesperia comma*	Hesperidae	Lepidoptera	Herbivore
Sting bug	1	*Chlorochroa* sp.	Pentatomidae	Hemiptera	Sap sucker
Assassin bug	3	*Pselliopus* sp.	Reduviidae	Hemiptera	Predator
Tachinid fly	17	*Hystricia* sp.	Tachinidae	Diptera	Parasitoid, pollinator
Damselfly	12	*Ischnura* sp.	Coenagrionidae	Diptera	Predator
Crab spider	26	*Ozyptila* sp.	Thomicidae	Araneae	Predator
Short-tailed ichneumon wasp	72	*Ophion* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Rove beetle	146	*Aleochara* sp	Staphylinidae	Coleoptera	Predator, parasitoid, scavenger
Tiger beetle	3	*Cicindella sexpunctata*	Cicindellidae	Coleoptera	Predator
Green bottle fly	5	*Lucilia* sp.	Calliphoridae	Diptera	Scavenger, pollinator
Ground beetle	6	*Calleida decora* (Fab.)	Carabidae	Coleoptera	Predator
Dragonfly	12	*Anax* sp.	Aeshnidae	Odonata	Predator

Common name	No. of individual	Scientific name	Family	Order	Specific functional groups
Ladybird beetle	5	*Coccinella* sp.	Coccinellidae	Coleoptera	Predator
Preying mantid	1	*Mantis* sp.	Mantidae	Dictyoptera	Predator
Firefly	2	*Photinus* sp.	Lampyridae	Coleoptera	Predator
Hoverfly	3	*Eupeodes* sp.	Syrphidae	Diptera	Predator, pollinator
Bracon wasp	8	*Atanycolus* sp.	Braconidae	Hymenoptera	Parasitoid
Crane fly	2	*Tipula* sp.	Tipulidae	Diptera	Saprophagous
Minute brown scavenger	3		Lateridiidae	Coleoptera	Scavenger
Black and yellow striped ichneumon wasp	10	*Gotra* sp.	Ichneumonidae	Hymenoptera	Pollinator
Dung beetle	1	*Scarabaeus sp.*	Scarabaidae	Coleoptera	Dung feeder
Ichneumon wasp	13	*Ichnemon* sp.	Ichneumonidae	Hymenoptera	Parasitoid
Eusocial wasp	2	*Vespula* sp.	Vespidae	Hymenoptera	Predator
Robber fly	2	*Promachus* sp.	Asilidae	Diptera	Predator
Digger wasp	5	*Sphex* sp.	Sphecidae	Hymenoptera	Parasitoid
Cockroach	5	*Periplaneta americana*	Blattidae	Blattodea	Omnivore, scavenger
Ant	66	*Formica* sp.	Formicidae	Hymenoptera	Predator, scavenger
June beetle	3	*Phyllophaga sp.*	Scarabaeidae	Coleoptera	Saprophagous, herbivore
Mole cricket	1	*Gryllotalpa* sp	Gryllotalpidae	Orthoptera	Herbivore, predator
May beetle	2	*Phyllophaga* sp.	Scarabaeidae	Coleoptera	Herbivore, predator scavenger
House cricket	3	*Acheta domesticus*	Gryllidae	Orthoptera	Vector, human food
Click beetle	8	*Melanotus* sp.	Elateridae	Coleoptera	Saprophagou, herbivore, predator
Plant bug	1	Unidentified	Miridae	Hemiptera	Herbivore, predator
Termite	2		*Termitidae*	Isopteran	Wood eater, human food
Field cricket	1	*Gryllus* sp.	Gryllidae	Orthoptera	Predator, seed feeder, plant feeder
	790				

Appendix 9. Monthly temperature (ºC) of Sylhet during 2017-2018

Month	2017			2018		
	Max(°C)	Min(°C)	Mean(°C)	Max(°C)	Min(°C)	Mean(°C)
January	27.64	14.04	20.84	24.81	13.48	19.15
February	29.08	16.05	22.57	28.50	16.30	22.40
March	36.77	18.17	27.47	31.50	19.60	25.55
April	29.59	21.18	25.39	31.0	21.10	26.05
May	32.83	23.21	28.02	-	-	-
June	31.36	25.00	28.18	-	-	-
July	32.92	25.70	29.31	-	-	-
August	32.40	25.54	28.97	-	-	-
September	32.28	25.64	28.96	-	-	-
October	32.05	23.55	27.80	-	-	-
November	30.78	19.45	25.12	-	-	-
December	26.18	16.08	21.13	-	-	-
Mean	31.16	21.13	26.15	-	-	-

Appendix 10. Monthly mean relative humidity (%) of Sylhet during 2017-2018

Month	Relative humidity (%) during three years		
	2016	2017	2018
January	69.44	59.04	72
February	60.10	51.68	60
March	57.68	64.81	57
April	74.60	74.90	67
May	74.45	70.23	-
June	76.07	81.60	-
July	81.08	79.50	-
August	73.26	83.58	-
September	77.53	82.67	-
October	73.58	76.52	-
November	68.50	67.47	-
December	61.44	67.44	-
Mean	70.64	71.62	-

Appendix 11. Monthly total rainfall (cm) of Sylhet during 2017- 2018

2017		2018	
Month	Rainfall (cm)	Month	Rainfall (cm)
July	85.21	January	0
August	107.42	February	3.83
September	58.39	March	9.48
October	30.11	April	39.33
November	0.35	-	
December	9.29	-	

Appendix 12. Number of tea bush/16 m^2 surrounding each Malaise trap, Lakkatura Tea Estate, Sylhet

Microclimatic habitats	Trap number	No. of tea bush inside 16m^2 area surrounding each trap	No. of tea bush on borderline of 16 m^2 area	No. of tea bush per trap
Large gap stand (Gap dia>2.5 m)	LgR_1	15	4	17
	LgR_2	14	4	16
	LgR_3	11	3	12
	LgR_4	12	6	15
	LgR_5	16	5	18
Mean				**16**
Small gap stand (Gap dia = 1.5m to 2.5m)	SgR_1	22	4	24
	SgR_2	18	2	19
	SgR_3	26	6	29
	SgR_4	17	5	19
	SgR_5	20	3	21
Mean				**22**
Gapless stand	GlR_1	23	4	25
	GlR_2	26	3	27
	GlR_3	23	5	25
	GlR_4	19	6	22
	GlR5	25	4	27
Mean				**25**
Shade tree stand (1 tree per trap location)	StR_1	30	8	34
	StR_2	24	7	27
	StR_3	25	6	28
	StR_4	20	6	23
	StR_5	22	7	25
Mean				**27**

Appendix 13. Light intensity (Lux) differences in four microclimatic habitats in March 2018, Lakkatura Tea Estate, Sylhet

Day time	Trap	Light intensity (Lux) in four microclimatic habitats			
		Large gap stand	Small gap stand	Gapless stand	Shade tree stand
9.00am	1	81550	71550	62600	34200
	2	80650	72100	63100	33200
	3	79300	73750	61950	32300
	4	81750	72350	61150	36550
	5	77800	69050	64050	53100
Mean ± SEM	-	80210 ± 663	71760 ± 687	62570 ± 441	37870 ± 3464
12.00pm	1	93350	87300	75500	38800
	2	94300	86900	62500	44200
	3	91500	85500	69100	49000
	4	90400	84800	75100	62500
	5	93700	82400	66300	73500
Mean ± SEM	-	92650 ± 654	85380 ± 780	69700 ± 2250	53600 ± 5670
3.00pm	1	80600	58100	45700	23500
	2	77800	53100	47500	34200
	3	76300	54500	50100	19000
	4	77800	56100	41800	28300
	5	72000	48000	54000	21000
Mean ± SEM	-	76900 ± 1260	53960 ± 1527	47820 ± 1836	25200 ± 2446
Mean ± SEM	-	83253 ± 4795	70367 ± 9097	60030 ± 6443	38890 ± 8214

*500 light intensity (Lux) data were recorded every one hour interval during 05-27 March 2018.

SEM = Standard errors of the means.

Appendix 14. Temperature (°C) differences in four microclimatic habitats in March 2018, Lakkatura Tea Estate, Sylhet

Day	Date of data recording	Recording time range	*Temperature (°C) in four microclimatic habitats			
			Large gap	Small gap	Gapless	Shade tree
1	5-6 March	6.12-5.12 PM	22.47	22.19	21.35	21.53
2	6-7 March	6.12-5.12 PM	26.37	26.05	24.26	24.9
3	7-8 March	6.12-5.12 PM	25.22	25.3	24.2	24.63
4	8-9 March	6.12-5.12 PM	26.87	26.99	25.38	26.22
5	9-10 March	6.12-5.12 PM	24.1	24.55	22.94	23.4
6	10-11 March	6.12-5.12 PM	23.42	23.58	22.47	23
7	11-12 March	6.12-5.12 PM	26.18	26.31	24.53	25.55
8	12-13 March	6.12-5.12 PM	28.05	28.28	26.16	27.24
9	13-14 March	6.12-5.12 PM	25.15	24.93	23.68	24.35
10	14-15 March	6.12-5.12 PM	27.93	28.18	26.43	27.42
11	15-16 March	6.12-5.12 PM	28.38	28.25	26.78	27.74
12	16-17 March	6.12-5.12 PM	26.09	26.03	24.59	25.31
13	17-18 March	6.12-5.12 PM	26.84	26.75	25.27	26.31
14	18-19 March	6.12-5.12 PM	24.96	24.73	23.53	24.1
15	19-20 March	6.12-5.12 PM	24.78	24.76	23.47	23.91
16	20-21 March	6.12-5.12 PM	23.43	23.33	22.48	22.63
17	21-22 March	6.12-5.12 PM	24.35	24.18	23.04	23.33
18	23-24 March	6.12-5.12 PM	28.32	28.37	26.52	27.59
19	24-25 March	6.12-5.12 PM	27.37	27.57	26.03	26.63
20	25-26 March	6.12-5.12 PM	27.99	27.94	26.39	27.51
21	26-27 March	6.12-1.12 PM	23.72	23.54	23.13	23.19
-	**-**	**Mean**	**25.81**	**25.80**	**24.41**	**25.07**
-	-	STDEV	1.828	1.890	1.585	1.876
-	-	SEM	0.399	0.412	0.346	0.409
-	-	Range	5.85	6.18	5.43	6.21
-	-	Variance	3.34	3.57	2.51	3.52
-	-	CV	7.0	7.0	6.0	7.0

*Temperature (°C) data were recorded every one hour interval for 500 times during 05-27 March 2018.
SEM = Standard errors of the means.

Appendix 15. Relative humidity (%) differences in four microclimatic habitats in March 2018 at Lakkatura Tea Estate, Sylhet

Day	Date of data recording	Recording time range	*Relative humidity (%) in four microclimatic habitats			
			Large gap	Small gap	Gapless	Shade tree
1	5-6 March	6.12-5.12 PM	84.21	86.19	88.90	88.39
2	6-7 March	6.12-5.12 PM	75.88	77.49	81.96	81.35
3	7-8 March	6.12-5.12 PM	85.77	84.89	88.59	87.16
4	8-9 March	6.12-5.12 PM	78.60	78.65	82.83	80.94
5	9-10 March	6.12-5.12 PM	86.76	85.77	90.30	89.61
6	10-11 March	6.12-5.12 PM	87.91	87.45	90.73	89.21
7	11-12 March	6.12-5.12 PM	78.96	80.52	84.24	81.20
8	12-13 March	6.12-5.12 PM	75.47	74.37	80.45	77.45
9	13-14 March	6.12-5.12 PM	81.18	82.70	85.78	82.85
10	14-15 March	6.12-5.12 PM	75.90	75.78	79.85	77.07
11	15-16 March	6.12-5.12 PM	74.56	74.15	78.19	74.75
12	16-17 March	6.12-5.12 PM	74.81	74.75	79.24	75.57
13	17-18 March	6.12-5.12 PM	74.79	74.99	78.71	74.81
14	18-19 March	6.12-5.12 PM	86.40	88.01	91.37	90.02
15	19-20 March	6.12-5.12 PM	86.93	87.89	91.95	91.36
16	20-21 March	6.12-5.12 PM	91.86	92.71	95.87	95.21
17	21-22 March	6.12-5.12 PM	90.17	91.08	95.01	94.05
18	23-24 March	6.12-5.12 PM	79.30	78.71	85.52	81.78
19	24-25 March	6.12-5.12 PM	79.63	79.75	83.97	83.44
20	25-26 March	6.12-5.12 PM	72.71	73.15	77.66	73.88
21	26-27 March	6.12-1.12 PM	78.17	78.38	80.68	78.44
-	-	**Mean**	**80.95**	**81.30**	**85.32**	**83.26**
-	-	STDEV	5.801	6.040	5.698	6.671
-	-	SEM	1.266	1.318	1.243	1.456
-	-	Range	19.15	18.56	18.20	21.34
-	-	Variance	33.65	36.48	32.46	44.50
-	-	CV	7.2	7.4	6.7	8.0

*Relative humidity (%) data were recorded every one hour interval for 500 times during 05-27 March 2018.
SEM = Standard errors of the means.

Appendix 16. Dew point (°C) differences in four microclimatic habitats in March 2018, Lakkatura Tea Estate, Sylhet

Day	Date of data recording	Recording time range	*Dew point (°C) in four microclimatic habitats			
			Large gap	Small gap	Gapless	Shade tree
1	5-6 March	6.12-5.12 PM	19.95	20.13	19.81	19.90
2	6-7 March	6.12-5.12 PM	21.03	21.23	20.78	21.21
3	7-8 March	6.12-5.12 PM	22.87	22.74	22.51	22.61
4	8-9 March	6.12-5.12 PM	22.19	22.32	21.99	22.22
5	9-10 March	6.12-5.12 PM	21.80	22.04	21.54	21.84
6	10-11 March	6.12-5.12 PM	21.50	21.58	21.16	21.35
7	11-12 March	6.12-5.12 PM	21.83	22.31	21.61	21.81
8	12-13 March	6.12-5.12 PM	22.50	22.47	22.23	22.42
9	13-14 March	6.12-5.12 PM	21.50	21.78	21.33	21.26
10	14-15 March	6.12-5.12 PM	22.50	22.76	22.30	22.41
11	15-16 March	6.12-5.12 PM	22.70	22.51	22.28	22.23
12	16-17 March	6.12-5.12 PM	21.07	21.03	20.83	20.60
13	17-18 March	6.12-5.12 PM	21.51	21.53	21.16	21.05
14	18-19 March	6.12-5.12 PM	22.71	22.85	22.40	22.67
15	19-20 March	6.12-5.12 PM	22.55	22.75	22.41	22.71
16	20-21 March	6.12-5.12 PM	22.31	22.41	22.20	22.22
17	21-22 March	6.12-5.12 PM	22.93	22.97	22.60	22.71
18	23-24 March	6.12-5.12 PM	24.15	24.03	23.95	23.98
19	24-25 March	6.12-5.12 PM	23.04	23.35	23.03	23.49
20	25-26 March	6.12-5.12 PM	21.72	21.87	21.70	21.60
21	26-27 March	6.12-1.12 PM	19.97	19.87	19.90	19.53
-	-	**Mean**	**22.01**	**22.12**	**21.80**	**21.90**
-	-	STDEV	1.007	0.997	0.989	1.082
-	-	SEM	0.220	0.218	0.216	0.236
-	-	Range	4.20	3.90	4.14	4.08
-	-	Variance	1.01	0.99	0.98	1.17
-	-	CV	4.6	4.5	4.5	4.9

*Dew point (°C) data were recorded every one hour interval for 500 times during 05-27 March 2018.

SEM = Standard errors of the means.

Competitive Research Grant

Sub-Project Completion Report

On

Status of insect biodiversity and ecosystem functions in tea estates of the Sylhet region

Project Duration
May 2017 to September 2018

Department of Entomology,
Sylhet Agricultural University

Submitted to:

The Director
Project Implementation Unit-BARC, NATP 2
Bangladesh Agricultural Research Council
Farmgate, Dhaka-1215

September 2018

Citation
"Status of insect biodiversity and ecosystem functions in tea estates of the Sylhet region"

Project Implementation Unit
National Agricultural Technology Program-Phase-II Project (NATP-2)
Bangladesh Agricultural Research Council (BARC)
New Airport Road, Farmgate, Dhaka-1215
Bangladesh

Edited and Published by:

Project Implementation Unit
National Agricultural Technology Program-Phase-II Project (NATP-2)
Bangladesh Agricultural Research Council (BARC)
New Airport Road, Farmgate, Dhaka-1215
Bangladesh

Acknowledgement

The execution of CRG sub-project has successfully been complemented by Sylhet Agricultural University using the research grant of USAID Trust Fund and BoB through Ministry of Agriculture. We would like to give thanks to the World Bank for arranging the grant fund and supervising the CRGs by BARC. It is worthwhile to mention the cooperation and quick responses of PIU-BARC, NATP-2, in respect of field implementation of the sub-project in multiple sites. Preparing the project completion report required to contact a number of persons for collection of information and processing of research data. Without the help of those persons, the preparation of this document could not be made possible. All of them, who made it possible, deserve thanks. Our thanks are due to the Director PIU-BARC, NATP 2 and his team who given their whole hearted support to prepare this document. We hope this publication would be helpful to the agricultural scientists of the country for designing their future research projects in order to generate technology and increase production and productivity for sustainable food and nutrition security in Bangladesh. It would also assist the policy makers of the agricultural sub-sectors for setting their future research directions.

Published in: September 2018

Printed by: [Name of press with full address]

Acronyms

cm	=	Centimeter
^{o}C	=	Degree Celsius
et al.	=	and others
etc.	=	et cetera
e.g.	=	exempli gratia; for example
i.e.	=	id test; that is
m	=	Meter
m^2	=	Meter square
SAU	=	Sylhet Agricultural University
SRDI	=	Soil Resources Development Institute
viz.	=	Videlicet; namely
%	=	Percentage
@	=	At the rate of
>	=	Greater than
<	=	Less than
PI	=	Principal Investigator
Co-PI	=	Co-Principal Investigator
CBD	=	Convention on Biological Diversity
WHC	=	World Heritage Convention
CMS	=	Conservation of Migratory Species of Wild Animals
NBSAP	=	National Biodiversity Strategies and Action Plans
BTB	=	Bangladesh Tea Board
BTRI	=	Bangladesh Tea Research Institute
BBS	=	Bangladesh Bureau of Statistics
SRDI	=	Soil Resources Development Institute

Table of Contents

Executive Summary

The study was conducted at Lakkatura Tea Estate, Sylhet during November 2017 to March 2018. The goal was to develop conservation strategies for the biocontrol agents in tea estates. The specific objectives were to i) determine variations in insect biodiversity among four microhabitat types in tea estates, ii) determine relationships of various functional groups of insects with understory vegetation and microclimatic changes in tea estates; and iii) recommend biodiversity conservation and management strategy for the tea estates. To achieve these objectives, 20 Malaise traps set to capture arthropod samples from four naturally occurring microclimatic habitats in tea estates of Bangladesh viz., large gap tea stand, small gap tea stand, gapless tea stand and shade tree tea stand. Microclimatic data on light entrance on tea floor, temperature, relative humidity and dew points were collected. Number of tea bush per $16m^2$ area surrounding Malaise was also recorded. Arthropod samples were collected at every 15 day interval samples, identified and grouped into various functional groups like pest, beneficial and neutral. Besides, biocontrol, detritivore and herbivore groups were also made. A total of 3,248 arthropod individuals were identified. Among them, 566, 811, 1081 and 790 individuals of 47, 49, 52 and 48 arthropod species were found in large gap, small gap, gapless and shade tree tea stands. Besides, 184, 333, 408, 358 beneficial arthropods and 206, 246, 279 and 198 harmful arthropods were found in large gap, small gap, gapless and shade tree tea stands. Number of neutral and biocontrol arthropods, identified from large gap, small gap, gapless and shade tree tea stands were 176, 232, 395, 233 and 280, 547, 483, 576 biocontrol arthropods (i.e., predator, parasitoids). A total of 231, 210, 271 and 152 herbivore arthropods (pest/harmful) and 120, 264, 221 and 240 detritivore arthropods (beneficial) were also found respectively in large gap, small gap, gapless and shade tree tea stands. Significantly the highest abundance of biocontrol arthropod individuals was found in shade tree stand. Presence of shade trees in tea estates have been proved to be the most suitable microclimatic habitat for hosting more abundant beneficial arthropod communities. Beneficial arthropods are mostly predators and parasitoids, which naturally regulate crop pest population. These beneficial arthropods need to be augmented to avoid excessive use of toxic pesticides for pest management in tea estates. So, policy makers can adopt strategies to promote the planting of shade trees as well as new tea saplings in large gap areas of the tea estates in the country. Planting of shade trees and tea saplings in large gaps will increase tea productivity and natural regulation of tea pests. New knowledge on habitat preference of beneficial, harmful and neutral arthropod communities generated, which will be helpful to develop future pest management technologies through manipulating habitat attributes and augmenting natural biocontrol arthropod species through conserving beneficial species diversity in tea ecosystems. Two Masters Theses have remained under preparation under this project.