Species Richness and Diversity of Insects in an Argo-ecosystem in Bhabar region of Uttarakhand

Abstract

The aim of the presented study was to estimate the species richness and diversity of insects were investigated in an agro-ecosystem in Bhabar region of Uttarakhand. In total, 992 individuals were collected representing 7 orders (Lepidoptera, Coleoptera, Hemiptera, Hymenoptera, Orthoptera, Diptera and Odonata), 30 families and 91 species that included herbivores, predators, omnivores and saprophages. The most dominant order was Lepidoptera with a relative abundance of (46.15%) and, the least was Diptera (6.59%). The five most abundant families by numbers of individuals were Pieridae (14.8%), Nymphalidae (13.9%), Lycaenidae (6.1%), Papilionidae (5.9%), and Libellulidae (5.4%). The five most diverse families by species were Nymphalidae (13), Pieridae (9), Lycaenidae (8), Papilionidae (7), and Libellulidae (6). The diversity index showed significant Diversity (H′=1.832), Evenness (E=0.9449) and Margalef species richness (d=2.076) of insect fauna. Diversity indices of insect orders showed that Lepidoptera was the most diverse (H′=1.641), Dipterans had highest Evenness (E=0.9449), and Coleopterans had the maximum species richness as per Margalef's Index (d=2.056). There were 720 individuals of insect pollinators visitors were observed, which belonged to 62 species in 4 orders (Lepidoptera, Coleoptera, Hymenoptera, and Hemiptera).

Keywords Species diversity, Species abundance, Shannon Index (H′), Pollinators/Visitors, agro-ecosystem.

Introduction

"The insects are known to be the most successful and diverse animals on earth. They comprise more than 75% of the known species and have adopted for almost every conceivable type of environment, almost everywhere" (Westfall & Tennesen, 1996). "Insects are important because of diversity, ecological role and their influence on agriculture" (Adetundan *et al*., 2005).

"The diversity of fauna associated with agro ecosystems are well documented and include pests, predators, parasitoids, insect pollinators and non-economic importance species" (Woolwine & Reagen, 2001; Cherry & Robert, 2009; Banu *et al*., 2016; Sayuthi *et al*., 2018; Emmanuel & Anuluwa, 2019; and Naz *et al*., 2020). However, the beneficial entomofauna i.e. pollinators, predators, parasitoids and decomposers are highly susceptible to the adverse effects of farming practices, particularly the indiscriminate use of fertilizers and chemical insecticides (Altieri & Nicholls, 2004; Tilman *et al.*, 2006).

"Pollination is an important process in maintaining healthy and bio diverse ecosystem. Insects constitute one among many groups of pollinating agents, as the association between insects and flowers are well established” (Free, 1993; Kearns *et al*., 1998; Bhowmik *et al*., 2014, 35-37).

The aim of this investigation was to study abundance, species richness, trophic guilds, diversity indices, and diversity of insect Pollinators/visitors in an agricultural ecosystem of Bhabar region in district Nainital, Uttarakhand, and this is very first time that this work was carried out.

Material and Methods:

The study area

Geographically, village Sawal Deh is located in the sub-tropical zone at 29.40 ^{0}N latitude and 79.12 ^{0}E longitude at an altitude of 320 m in the Bhabar region of Uttarakhand. The study area has sub-humid tropical climate and is situated in the foothills of central Himalayas. The climatic data indicates hot dry summer and cold winter. The maximum temperature reaches up to 39 ^{o}C (May) in summer, and minimum 8.0 ^{o}C (January) in winter. The maximum humidity ranged from 23% (May) to 78% (August). The average rainfall was 1734 mm and 75.8% of rainfall occurred in the rainy season. On this basis, the year can be divided in into three seasons, namely rainy (July to October), winter (November to February) and summer (March to June).

Three crops are grown in a year: July to October (Paddy/Soybean), November to April (wheat/mustard) and seasonal vegetables (May-June).

The agricultural field are under manage tillage in the shallow layers of the soil (5 cm). The agro-ecosystems are highly productive, resources rich (water and nitrogen input form irrigation and livestock) and experience a fair amount of disturbance due to anthropogenic activities throughout the growing season.

Collection of Insects

Sampling of insects was conducted at an interval of 30 days from March, 2018 to February, 2020. The insects were collected by “Sweep Sampling Method”, as per Gadagkar *et al.* (1990) and hand picking (Jonathan, 1990). The net sweeps were used to collect the insects The nets used in sweeping were made of thick cotton cloth with a diameter of 30 cm and a bag length of 60 cm. A randomly selected area of each study sites was divided into a quadrate of 10x10 m. Hand picking method was used for dwelling insects and insects living under the stones.

“Collected insects were identified with the help of keys and through the available literature” (Singh 2018; Zahradník & Severa, 1977). Insects were then separated into different orders and families and to the species level. The representative species were preserved in the laboratory. The species which could not be identified in the laboratory were sent to the Forest Research Institute, Dehradun for identification.

The trophic level of an organism is the position, which it occupies in a food chain. Different insect species occupy different trophic positions in a food chain in the cropland ecosystem, according to their dissimilar food habitats *viz*., phytophagous, predators, omnivores, saprophages and decomposers. The collected insect species were identified and placed into five trophic levels.

Diversity Indices

Using Shannon-Wiener Diversity Index, species and seasonal diversity of insect was calculated as follows (1963):

(A) Species diversity: $$H'(S) = -\sum_{i=1}^{s} pi \log pi$$

(B) Seasonal diversity: $$H'(P) = -\sum_{i=1}^{s} qj \log qj$$

Where,

Pi= ni/N and qj= nj/N

ni = Number of individuals of a species at a time i

nj = Number of individual present in a season j

N = Size of whole community

$\sum$ = Number of species/ Number of seasons

S = Total number of species

P = Number of seasons

(C) Evenness (Buzas and Gibson's Evenness) E2:

$$E2= e^{H/S}$$

Where, S is the number of taxa and H is the Shannon Index

(D) Margalef's Species Richness Index (d):

Species richness was calculated using Margalef's Index (1970)

Margalef's Index (d) = (S-1)/ In N

Where, S = total number of species

N = total number of individuals in sample
In = natural logarithm

Results and Discussion

Diversity and abundance of Insect Fauna

Table 1: Diversity and Relative Abundance (%) of insect species and trophic components in the study site (Sawal Deh-Bhabar) during March, 2018 to February, 2020

S. No.	Taxonomic Composition	Trophic level	No. of individuals	Relative Abundance (%)	No. of individuals	Relative Abundance (%)
ORDER: LEPIDOPTERA **Family: Pieridae**						
1.	*Pieris brassicae* (Linnaeus)	Phytophagous	16	3.80	22	3.85
2.	*Pieris canidia indica* (Sparrman)	Phytophagous	5	1.19	10	1.75
3.	*Eurema brigitta* Cramer	Phytophagous	4	0.95	8	1.40
4.	*Gonepteryx rhamni* (Linnaeus)	Phytophagous	5	1.19	7	1.23
5.	*Catopsilia pyranthe* (Linnaeus)	Phytophagous	11	2.61	16	2.80
6.	*Catopsilia pomona* (Fabricius)	Phytophagous	12	2.85	18	3.15
7.	*Cepora nerissa phryne* Fabricius	Phytophagous	0	0.00	2	0.35
8.	*Aporia agathon* (Gray)	Phytophagous	0	0.00	2	0.35
9.	*Leptosia nina* (Fabricius)	Phytophagous	3	0.71	6	1.05
	Family: Nymphalidae					
10.	*Vanessa indica* Herbst	Phytophagous	5	1.19	8	1.40
11.	*Symbrenthia hippoclus* (Cramer)	Phytophagous	2	0.48	3	0.53
12.	*Aglais cashmiriensis* (Kollar)	Phytophagous	5	1.19	7	1.23
13.	*Cynthia cardui* Linnaeus	Phytophagous	1	0.24	2	0.35
14.	*Precis lemonias lemonias* Linnaeus	Phytophagous	18	4.28	21	3.68
15.	*Precis almana* (Linnaeus)	Phytophagous	5	1.19	10	1.75

16.	*Ariadne merione* (Cramer)	Phytophagous	5	1.19	2	0.35
17.	*Euthalia patala* Kollar	Phytophagous	4	0.95	5	0.88
18.	*Symphaedra nais* (Forster)	Phytophagous	1	0.24	2	0.35
19.	*Ypthima* sp.	Phytophagous	9	2.0	8	1.40
20.	*Neptis sankara* Kollar	Phytophagous	0	0.00	2	0.35
21.	*Danauschrysippus* (Linnaeus)	Phytophagous	5	1.19	6	1.05
22.	*Euploea core* (Cramer)	Phytophagous	2	0.48	0	0
	Family: Lycaenidae					
23.	*Heliophorus androcles* (Doubleday & Hewitson)	Phytophagous	0	0.00	2	0.35
24.	*Heliophorus sena* Kollar	Phytophagous	2	0.48	3	0.53
25.	*Talicada nyseus* (Guerin-Meneville)	Phytophagous	5	1.19	6	1.05
26.	*Leptotes plinius* (Fabricius)	Phytophagous	4	0.95	8	1.40
27.	*Neopithecops zalmora* Butler	Phytophagous	5	1.19	2	0.35
28.	*Zizeeria* sp	Phytophagous	8	1.90	10	1.75
29.	*Zemeros flegyas* Cramer	Phytophagous	0	0.00	1	0.18
30.	*Catochrysops strabo* Fabricius	Phytophagous	2	0.48	3	0.53
	Family: Papilionidae					
31.	*Atrophaneura aristolochioae* Fabricius	Phytophagous	5	1.19	4	0.70
32.	*Papilio polytes* (Linnaeus)	Phytophagous	6	1.43	8	1.40
33.	*Graphium doson axionides* (Page and Treadway)	Phytophagous	0	0.00	2	0.35
34.	*Papilio romulus* Linnaeus	Phytophagous	5	1.19	6	1.05
35.	*Papilio cyrus* Linnaeus	Phytophagous	4	0.95	5	0.88
36.	*Papilio demoleus* (Linnaeus)	Phytophagous	2	0.48	4	0.70
37.	*Papilio stichius* Linnaeus	Phytophagous	3	0.71	5	0.88
	Family: Hesperiidae					
38.	*Telicota* sp.	Phytophagous	5	1.19	7	1.23
39.	*Polytremis eltola* Hewitson	Phytophagous	3	0.71	4	0.70
	Family: Erebidae					
40.	*Amata* sp.	Phytophagous	5	1.19	8	1.40
41.	*Ceryx imaon* Cramer	Phytophagous	5	1.19	7	1.23
42.	*Erebus sp.*	Phytophagous	7	1.66	6	1.05

	ORDER: COLEOPTERA					
	Family: Scarabaeidae					
43.	*Phyllophaga* sp.	Phytophagous	4	0.95	7	1.23
	Family: Chrysomelidae					
44.	*Sagra femorata* (Drury)	Phytophagous	2	0.48	1	0.18
45.	*Mimastra* sp.	Phytophagous	5	1.19	8	1.40
46.	*Raphidopalpa foveicollis* (Lucas)	Phytophagous	10	2.38	7	1.23
	Family: Coccinelidae					
47.	*Coccinella septempunctata* (Linnaeus)	Predator	8	1.90	11	1.93
	Family: Elateridae					
48.	*Adelocera* sp.	Phytophagous	7	1.66	9	1.58
	Family: Meloidae					
49.	*Mylabris cichorii* Linnaeus	Predator	0	0.00	6	1.05
	ORDER: HYMENOPTERA					
	Family: Apidae					
50.	*Apis cerena* Fabricius	Phytophagous	8	1.90	12	2.10
51.	*Apis dorsata* Fabricius	Phytophagous	5	1.19	9	1.58
52.	*Bombus* spp.	Phytophagous	6	1.43	8	1.40
	Family: Formicidae					
53.	*Camponotus* sp.	Predator	8	1.90	10	1.75
54.	*Lasius niger* (Linnaeus)	Predator	11	2.61	21	3.68
	Family: Sphecidae					
55.	*Isodontia apicalis* (F. Smith)	Predator	1	0.24	0	0.00
56.	*Sceliphron caucasicum* Dalla Torre	Predator	5	1.19	8	1.40
57.	*Sceliphron coromandelicum* Lepeletier	Predator	7	1.66	8	1.40
	Family: Vespidae					
58.	*Vespa cincta* Fabricius	Predator	5	1.19	5	0.88
59.	*Polistes* sp.	Predator	2	0.48	3	0.53
60.	*Vespa* sp.	Predator	5	1.19	9	1.58
	Family: Xylocopidae					
61.	*Xylocopa auripennis* Lepeletier	Phytophagous	8	1.90	10	1.75
	ORDER: ORTHOPTERA					
	Family: Acrididae					
62.	*Patanga japonica* Bolivar	Phytophagous	2	0.48	1	0.18

63.	*Ceracris fasciata* Brunner von Wattenwyl	Phytophagous	5	1.19	7	1.23
64.	*Spathosternum p. prasiniferum* Walker	Phytophagous	2	0.48	5	0.88
65.	*Acridium melanocorne* Linnaeus	Phytophagous	5	1.19	0	0.00
	Family: Gryllidae					
66.	Gryllus sp.	Omnivore	6	1.43	7	1.23
67.	*Teleogryllus testaceus* Walker	Omnivore	2	0.48	3	0.53
	Family: Tettigonidae					
68.	*Elimaea* sp.	Phytophagous	7	1.66	9	1.57
69.	*Neoconocephalus* sp.	Phytophagous	6	1.43	8	1.40
	ORDER: ODONATA					
	Family: Libellullidae					
70.	*Crocothemis servilia servilia* Drury	Predator	0	0.00	2	0.35
71.	*Orthetrum chrysis* (Burmeister)	Predator	5	1.19	7	1.23
72.	*Neurothemis ramburii* (Brauer)	Predator	4	0.95	5	0.88
73.	*Orthemis ferruginea* (Fabricius)	Predator	2	0.48	3	0.53
74.	*Orthetrum pruinosum* (Burmeister)	Predator	7	1.66	8	1.40
75.	*Orthetrum taeniolatum* Schneider	Predator	6	1.43	5	0.88
	Family: Gomphidea					
76.	*Paragomphus lieantus* (Selys)	Predator	5	1.19	8	1.40
	ORDER: DIPTERA					
	Family: Muscidae					
77.	*Musca* sp.	Saprophagous	6	1.43	8	1.40
	Family: Calliphoridae					
78.	*Calliphora* sp.	Saprophagous	4	0.95	5	0.88
	Family: Tipulidae					
79.	*Tipula himalayensis* Brunetti	Predator	5	1.19	4	0.70
80.	*Tipula* sp.	Predator	4	0.95	5	0.88
	Family: Asilidae					
81.	*Philodious javanus* Wied.	Predator	0	0.00	2	0.35
82.	*Stenopogan oldroydi* Josephs & Pauri	Predator	0	0.00	1	0.18
	ORDER: HEMIPTERA					
	Family: Fulgoridae					
83.	*Lycorma delicatula* (White)	Phytophagous	0	0.00	2	0.35

	Family: Pentatomidae					
84.	*Nezara viridula* Linnaeus	Phytophagous	7	1.66	9	1.57
85.	*Murgantia histrionic* (Hahn)	Phytophagous	5	1.19	6	1.05
86.	*Dalpada* sp.	Phytophagous	6	1.43	7	1.23
87.	*Halyomorpha* sp.	Phytophagous	3	0.71	4	0.70
	Family: Coreidae					
88.	*Cletus punctulatus (*Dallas)	Phytophagous	2	0.48	4	0.70
	Family: Alydidae					
89.	*Leptocorisa varicornis* Fabricius	Phytophagous	5	1.19	6	1.05
90.	*Leptocorisa* sp.	Phytophagous	2	0.48	2	0.35
	Family: Largidae	Phytophagous				
91.	*Physopetata gutta* Brum	Phytophagous	7	1.66	8	1.40
	Total		**421**	**100**	**571**	**100**

Diversity and abundance of insect fauna collected are presented in Table 1. A total of 91 species belonging to 30 families, 7 orders, and 992 individuals were collected. Maximum number of species belonged to the order Lepidoptera (42), followed by Hymenoptera (12), Hemiptera (9), Orthoptera (8), Coleoptera (7), Diptera (6) and Odonata (6)

Species richness was higher in summer (50 species) and rainy season (39 species) than in winter (6 species). Species richness was significantly correlated with maximum temperature (r=0.879; P≤0.01, df=12), minimum temperature (r=0.777; P≤0.05, df=12), and rainfall (r=0.285; P≤<0.05, df=12).

Maximum number of individuals belonged to Lepidoptera (462), followed by Hymenoptera (174), Hemiptera (85), Coleoptera (85), Orthoptera (67), Odonata (67) and Diptera (44). Large number of insects were collected during summer and rainy season and lesser number in winter season. Abundance of insects was significantly correlated with maximum temperature (r=0.875; P≤0.01, df=12), minimum temperature (r=0.765; P≤0.01, df=12) and rainfall (r=0.31; P<<0.05, df=12).

Trophic guilds

Four trophic groups were identified on the basis of feeding habits of insects collected: Phytophagous, predators, omnivores and sarcophagous. On the basis of number of species collected, Phytophagous (71.4%) were dominant followed by predators (20.9%), omnivores (5.5%), and sarcophagous (2.2%). On the basis of number of individuals collected, Phytophagous (72.9%) were predominant followed by predators (20.5%), omnivores (4.3 %)

and sarcophagous (2.3%). The current study involved the collection of a total of bioregulator species(predators). The guild structure of insects collected are shown in Figs. 1.

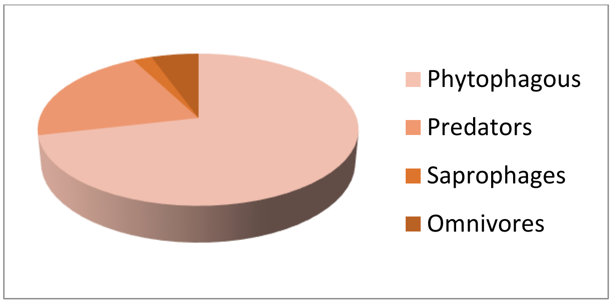

Fig.1. The guild structure of insect fauna

"Many ecologists have classified insects in to various functional trophic guilds to study the ecological interactions between insects, their hosts, their enemies and climate" (Speight *et al.*, 2008). Based on the feeding activities of insects observed, Mokam *et al.* (2014) recognized three guilds: "Phytophagous (carpophagous and sap suckers), saprophagous, and carnivores (predators and parasitoids) in insects collected from two agro-ecological zones", while Chouangthavy *et al.* (2017) classified "coleopterans into five functional trophic groups i.e. Phytophagous, micro-organisms, sarcophagous, polyphagous and carnivores collected from an agricultural ecosystem". "However, phytophagous insects have been reported to be predominant globally representing upto 96.1% of individuals collected in different ecosystems" (Gadakar *et al.*, 1990; Dev *et al.*, 2009; Usha & John, 2015; Atencio *et al.*, 2018; Ghani and Maalik, 2019).

The results obtained in the present study are similar to those reported in different ecosystems.

Diversity indices

Table 2: Species diversity and species richness of insect fauna in the study site (Sawal Deh-Bhabar) during March, 2018 to February, 2020

Months	2018-2019			2019-2020			2018-2020		
	Shannon Index (H′)	Evenness (E)	Margalef (d)	Shannon Index (H′)	Evenness (E)	Margalef (d)	Shannon Index (H′)	Evenness (E)	Margalef (d)
March	1.399	0.5787	1.674	1.322	0.5357	1.595	1.535	0.6629	1.576
April	1.176	0.4629	1.616	1.267	0.5072	1.567	1.469	0.6204	1.534
May	1.499	0.6395	1.801	1.552	0.6743	1.638	1.556	0.6771	1.534

June	1.832	0.892	1.941	1.56	0.6799	1.842	1.705	0.7862	1.627
July	1.603	0.7099	1.941	1.658	0.75	1.82	1.611	0.7152	1.638
August	1.707	0.7878	1.941	1.727	0.8037	1.764	1.661	0.7521	1.638
September	1.561	0.6803	2.076	1.658	0.7499	2.076	1.57	0.6868	1.731
October	1.719	0.7974	2.076	1.722	0.7993	2.003	1.663	0.7534	1.716
November	0.5623	0.8774	0.7213	0	1	0	0	1	0
December	0	1	0	0	1	0	0	1	0
January	0.6365	0.9449	0.9102	0.5623	0.8774	0.7213	0.6931	1	0.5581
February	1.04	0.9428	1.443	0.6931	1	1.443	0.673	0.9801	0.6213

The Shannon-Wiener Diversity Index (H′), Evenness (E) and Margalef’s species richness (d) of insect fauna collected were computed and are presented in Table 2.

The Shannon diversity index ranged from 0 in December to 1.832 in June in the present study which means the insect fauna was moderately rich in the study area.

Insect diversity index is usually in conventional agro-ecosystems is usually low because the agriculturists use a monoculture system, the use of chemical fertilizers and pesticides. As a result of this treatment beneficial insects including non-target insects get killed (Altieri & Letoumeau, 1982). Biodiversity indices were highest in agro ecosystems under organic management with species richness index with of 4.68 and D of 2.34 (Sorribas *et al*., 2016). However, high maximum index of 5 has been reported for terrestrial ecosystems (Usha & John, 2015).

Buza’s Evenness which takes into account the distribution of species and their number, ranged from 0.5072 (April) to 0.9801 (February (highest value is 1) indicating no species was dominant in terms of abundance.

Margalef’s Richness Index ranged from 0 in November to 2.076 in September which indicates moderate species richness.

Table 3: Relative abundance, Species diversity and species richness of insect orders in the study site (Sawal Deh) during March, 2018 to February, 2020

Order	Relative Abundance (%)	Shannon Index (H’)	Evenness (E)	Margalef (d)
Lepidoptera	46.15	1.641	0.8601	1.338

Hymenoptera	13.20	1.545	0.938	1.61
Coleoptera	7.69	1.475	0.8743	2.056
Hemiptera	9.89	1.427	0.8333	1.82
Orthoptera	8.79	1.04	0.9428	0.9618
Odonata	7.69	0.4101	0.7535	0.5139
Diptera	6.59	1.33	0.9449	1.679
Total	100.0	8.8681	6.1469	9.9787

Table 3 shows the pooled relative abundance based on orders and their diversity indices. It is evident that Lepidopteran insects had the highest diversity index (H′=1.641), Dipterans had highest Evenness (E=0.9449) and Coleopterans had maximum species richness Margalef's Index (d=2.056).

Diversity of insect pollinators

In total, 720 individuals of insect pollinators belonging to 62 species, 4 orders, and 16 families were recorded (Table 1). Four orders of insect pollinators found were Lepidoptera (family Pieridae, Nymphalidae, Lycaenidae, Papilionidae, Hesperiidae, Erabidae), Coleoptera (family Chrysomelidae, Coccinellidae, Meloidae), Hymenoptera (family Formicidae, Apidae, Vespidae, Xylocopidae). Among them Lepidoptera with 462 individuals (64.2%) was the most dominant insect order visiting the crops followed by Hymenoptera with 145 individuals (20.1%), Coleoptera with 58 individuals (8.1%) and Hemiptera with 55 individuals (7.6%). Family Pieridae (20.4%) was the most abundant among all insect order families reported.

Insect pollinators of all four orders were found to be active throughout the day, but peak foraging activity was different for different orders. Lepidopterans were only flower visitors and active during afternoon but less active in the morning. Hymenopterans and dipterans were active during day time. Foraging activities of coleopterans and hemipterans remained relatively constant throughout the day.

Various studies have shown that insects constitute one among many groups of pollinators and have mutual relationship with flowering plants. Insect pollinators play a significant role in the pollination of agricultural, horticultural and medicinal herbal crops, mainly belong to the insect orders: Hymenoptera, Lepidoptera, Coleoptera, Diptera, Thysanoptera, Hemiptera and Neuroptera (Sihag, 1988; Free, 1993; Mitra *et al*., 2008; Bhowmik *et al*., 2014; Subedi & Subedi, 2019; Singh & Mall, 2020). Our results are very similar to these studies.

Pollinators recorded in the present study through their good management could be utilized for increasing the yield of crops in the agro ecosystem studied.

In the present study, low and higher temperature, and rainfall influence the species richness and abundance of insects and are similar to the findings of Abbas *et al*. (2014), Nadia *et al*. (2015), and Garia *et al*. (2016, 2017).

Conclusions

A total of 992 individuals representing 7 orders, 30 families and 91 species in the agro ecosystem were collected. Phytophagous were the most dominant trophic group in terms of number of species and abundance of individuals collected. Significant Diversity Index (H′=1.832), Evenness (E=0.9449) and Margalef's Index (d=2.076) of insect fauna were recorded. Pollinators visiting the agro ecosystem belonged to the order Lepidoptera, Coleoptera, Hymenoptera and Hemiptera. Through, it is a preliminary report on insect pollinators in the study area, it will certainly help the future workers as a baseline data of the pollinators and pollination of crops in the agro ecosystem of this area.

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Details of the AI usage are given below:

1.

2.

3.

References:

1. Abbas, S.A., Rana, A., Mahmood-ul-hassan M., Rana, N., Kausar, S. and M. Iqbal. (2014). Biodiversity and dynamics of macro-invertebrate populations in wheat-weeds agro-ecosystem of Punjab. Journal of Animal and Plant Science, 24(4), 1146-1156.

2. Adetundan, S. A., Ofuya. T. I. and J. A. Fuwape. (2005). Environmental effects of insects herbivores and logging on tree species diversity in Akure Forest Reserve (Apomu). Nigeria Tropical Agriculture, 9(1and2), 12–18.

3. Altieri, M. A. and C. Nicholls. (2004). Biodiversity and Pest Management in

Agroecosystems. Boca Raton: C R C Press.

4. Altieri, M. A. and D. K. Letournean. (1982). Vegetation management and biological control of ecosystems. Crop Protection, 1, 405-430.

5. Atencio, R., Goebel, F. R. and R. J. Miranda. (2018). Entomofauna Associated with Sugarcane in Panama. Sugar Technology. http.//doi.org/10.1007/s12355-018-0661-8

6. Banu. J., Dayana, M. and M. R. D. Rose. (2016). Diversity of Insects in Sugarcane Field at Chinnamanur, Theni District, Tamil Nadu. International Journal for Innovative Research in Multidisciplinary Field, 2(10), 651-655.

7. Bhowmik, B., Mitra, B. and K. Bhadra. (2014). Diversity of Insect Pollinators and Their Effect on the Crop yield of Brassica juncea L., NPJ-93, From Southern West Bengal. International Journal of Recent Scientific Research, 5(6), 1207-1213.

8. Cherry, R. and G. Robert. (2009). The effect of harvesting and replanting on arthropod ground predators in Florida sugarcane. IFAS Extension: University of Florida.

9. Chouangthavy, B., Sanguansub, S. and N. Kamata. (2017). Species Composition, Richness and Diversity of beetles (Coleoptera) in Agricultural Ecosystem: In: 9 th Nakhom Pathom Rajabhat University National Academic Conference. PP 1-7.

10. Dev, P., Tewari, M. and B. R. Kaushal. (2009). Diversity and abundance of insects in a cropland of central Himalayan Bhaber region of Kumaun, Uttarakhand. Entomon, 34(1), 11-21.

11. Emmanuel, O. and Y.O. Anuoluwa. (2019). A Study on the Diversity and Relative Abundance of Insect Funa in Wukari, Taraba State, Nigeria. International Journal of Advanced Biological and Biomedical Research, 7(2), 141-153.

12. Free, J. B. (1993). Insect Pollination of Crops. Academic Press, London.

13. Gadagkar, R., Chandrashaekara, K. and P. Nair. (1990). Insect species diversity in the tropics: Sampling Method and Case Study. Journal of Bombay Natural History Society, 87(3), 328-353.

14. Garia, A., Goswami, D., Pande, H. and B. R. Kaushal. (2016). Species Richness, Abundance and Diversity of Insect Community in Pine Forest of Kumaun Himalaya, Uttarakhand. Academic Journal of Entomology, 9(2), 26-35.

15. Garia, A., Goswami, D., Pande, H. and B.R. Kaushal. (2017). Insect species diversity and abundance in oak forest of Kumaun Himalaya, Uttarakhand. Entomon, 42(1), 13-22.

16. Ghani, A. and S. Maalik. (2019). Assessment of Diversity and relative abundance of insect fauna associated with Triticum aestivum from district Sialkot, Pakistan. Journal of King Saud University-Science. www.sciencedirect.com

17. Godfray, H. C. (2002). Challenges For Taxonomy. Nature, 417, 17-19.

18. Kearns, C. A. Inouye, D. W. and N. M. Waser. (1998). Endangered mutualism: The conservation of plant pollinator interactions. Annual Review of Ecological Systems,29, 83-112.

19. Margalef's, R. (1970). Temporal sucession and spatial heterogeneity in phytoplankton. In: Perspectives in Marine biology, Buzzati- Traverso (ed.), Univ. Calif. Press, Berkeley 323-347.

20. Mitra, B., Banerjee, D., Mukherjee, M., Bhattacharya, K. and P. Pauri. (2008). Flower visiting flies (Diptera: Insecta) of Kolkata and Surroundings, (Pictorial handbook). India: Zoological Survey of India (ZSI), Kolkata.

21. Mokam, D. G., Champlain, D. L. and C. F. B. Bilong. (2014). Patterns of Species Richness and Diversity of Insects Associated with Cucurbit Fruits in the Southern Part of Cameroon. Journal of Insect Science, 14(248), 1-9.

22. Nadia, A., Ashraf, I., Hussain, T. and I. Ahmad. (2015). Studies on the Diversity and Relative Abundance of Orthoptera and Lepidoptera species in Urban and Crop Areas of Dera Ghazi Khan. American-Eurasian Journal of Agriculture and Environmental Science, 15(8), 1693-1699.

23. Naz, H., Usmani, M. K., Ali, M., Mobin, S. and M. I. Khan. (2020). Acridoid diversity, species composition and distributional pattern in tarai region of

Uttarakhand, India. International Journal of Tropical Insect Science. https://doi.org/10.1007/s42690-020-00239-z

24. Sayuthi, M., Husni, Hakim L., Hasnah, Rusdy A. and T. Chamzurni. (2018). Composition and biodiversity of insect species in wheat cultivation in Gayo highland, Indonesia. International Journal of Tropical Biomedical Research, 3(1), 25-29.

25. Shnnon, C. E and W. Wiener. (1963). The Mathematical theory of communications, University of lllinois Press, Champaigh.

26. Singh, M., and P. Mall. (2020). Diversity and foraging behaviour of insects on mustard crop at Tarai region of Uttarakhand. International Journal of Chemical Studies, 8(1), 2556-2559.

27. Sorribas, J., Gonzalez, S., Gento, D. A. and R. Vercher. (2016). Abundance, movements and biodiversity of flying predatory insects in crop and non-crop agroecosystems. Agronnomy and Sustainable Development, 36(34), 1-9.

28. Speight, M. R., Hunter, M. D. and A.D. Watt. (2008). Ecology of Insects: Concepts and Applicatrions. Wiley-Blackwell, Singapore.

29. Subedi, N. and I. P. Subedi. (2019). Pollinator Insects and their impact on crop yield of mustard in Kusma, Parbat, Nepal. Journal of Institute of Science and Technology, 24(2), 68-75.

30. Tilman, D., Reich, P. and J. Knops. (2006). Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature, 441 (7093), 629-632.

31. Usha, A.U. and V. K. John. (2015). A study on insect diversity of a selected area in Wadakkanchery (Thrissur, Kerala). The Journal of Zoology Studies, 2(3), 38-50. Westfall, M. J. Jr. and K. J. Tennessen. (1996). "Odonata", An Introduction to the Aquatic Insects of North America 3, 164-211.

32. Woolwine, A. E. and T. E. Reagen. (2001). Potential of winter cover crops to increase abundance of Solenopsis invicta (Hymenoptera: Formicidae) and other arthropods in

sugarcane. Environmental Entomology, 30(6), 1017-1020.

33. Singh A.P (2018). *Butterflies of India*. Om Books International

34. Zahradník, J., & Severa, F. (1977). *A field guide in colour to insects*. Octopus Books.

35. Mbelede, K. C., Akunne, C. E., Ononye, B. U., Chidi, C. A., Okafor, K. P., Okeke, T. E., and Aniefuna, C. O. 2023. “Diversity of Insects of Two Rice (Oryza Sativa L. 1787) Farms in Nnamdi Azikiwe University, Awka, Nigeria”. Asian Journal of Biology 19 (3):44-56. https://doi.org/10.9734/ajob/2023/v19i3371.

36. Mahdi , Shah H. A., Asia Sarker, Md. Nasir Uddin, Istiak Mahfuz, and Md. Abdur Rahim. 2023. “Abundance and Diversity of Leaf Litter and Subsoil Arthropods in Four Different Sites of Three Agroecological Zones of Northwest Part of Bangladesh”. Asian Journal of Research in Zoology 6 (4):107-18. https://doi.org/10.9734/ajriz/2023/v6i4128.

37. Shi P, Hui C, Men X, Zhao Z, Ouyang F, Ge F, Jin X, Cao H, Li BL. Cascade effects of crop species richness on the diversity of pest insects and their natural enemies. Science China Life Sciences. 2014 Jul;57:718-25.