Chapter I

Distribution and Diversity of Agriculturally important insects of Vadodara District

1.1 Introduction

Biodiversity is one of the cornerstones of natural ecosystems and represents the biological wealth of the universe. It contributes magnificently to ecological welfare and facilitates ecosystems to be resilient and to survive significant changes (Timpane-Padgham *et al.,* 2017). Nevertheless, due to human activities, biodiversity is being significantly lost at a faster rate, and the world is currently facing its maximum biodiversity crisis. Insects play a pivotal role in sustaining the ecosystem's biodiversity and are the most diverse and plenteous invertebrate on the earth (Paulson *et al.,* 2020). They are significant because of their diversity, ecological role, and influence on agriculture, human well-being, and natural resources (Scudder, 2017). They are distinctive in their way and contribute all sorts of services to the environment and play an essential ecological part for the existence of life on earth; their diversity is indeed an inherent part of the earth's ecosystem (Kuruvila *et al.,* 2019; Cardoso *et al.,* 2020). Insects have been used as landmark studies in biomechanics, climate change, developmental biology, ecology, evolution, genetics, and physiology. Their diverse and varied characters are familiar to the public, and their conservation is challenging (Jalali *et al.,* 2015).

Insects are representing about 90 percent diversity documented for the animal kingdom. Globally there are approximately 5.5 million insect species, of which around 1.5 million species are beetles (Stork, 2018). Around some 63,760 species of the insect under 658 families representing 29 orders are known in India. Of these, eight orders constitute the bulk 94% of the insect fauna, and the remaining 21 orders are signified by small numbers (6% of species), which represents nearly 7% of global insect diversity (Joshi *et al.,* 2016; Sankarganesh, 2017). Insects are associated with a high diversity and stability of crops in a landscape and can provide forage and nesting ground for insects. Agro-biodiversity of insects helps regulate the effectiveness of ecological network by improving the level of biological processes that support agricultural crop production (Duru *et al.,* 2015). Insect diversity and composition are mostly dependent on vegetation, and any change in the habitat is likely to impact their distribution and relative abundance (Kerchev *et al.,* 2012). Density-independent factors like climate and weather are responsible for regulating the population abundance of insects and can cause catastrophic changes in the population. The insect species population of particular regions is ascertained by factors like light, temperature, humidity, and vegetation (Savopoulou-Soultani *et al.,* 2012). Insects are more sensitive to seasonal change and cause them to be more responsive to it. Seasonal difference in the abundance of a species is an adaptive phenomenon evolved to take maximum benefit from the ambient ecological situations (Shimadzu *et al.,* 2013).

Insects are vital for regulating ecological functions and ecosystem processes. As a dominant form of animal biomass and life on earth, insects have adapted to a broad range of habitats and represent many different trophic niches, including herbivore, carnivore, and detritus feeding. Insects found on agriculture land perform their ecological role in different ways, as natural enemies, pollinators, decomposers, productive insects, biocontrol agent, scavengers, weed killer, soil builders, and also threat to the crop production as a pest (Priesnitz and Schork, 2013; Rai *et al.,* 2015).

Being the major part of the agriculture ecosystem, insects are most apparent as pests or potential pests. Agriculture fields are comparatively more in danger to insect pest infestation due to the threat of varied climatic situations (Heeb *et al.,* 2019). The larvae of insects are a voracious feeder and cause heavy damage to agriculture crops. Dhaliwal *et al.,* (2015) reported that in India, agriculture is currently suffering an annual loss of about 36 billion U.S. dollars due to insect pests. Pests have occurred for as long as humans practiced crop agriculture, and insects have been apparent mostly as competitors in the race for existence. Insect pests are linked to different agriculture crops, vegetables, woody plants, and ornamental plants. Almost 50% of insect species are pest (Schoonhoven *et al.,* 2005), of which, as reported by Losey and Vaughan (2006), 18% are herbivorous species that forage on plants in one or another way. Herbivorous insects are extremely diverse, with species number estimates ranging from 500 000 to 2 million (Stork *et al.,* 2015). Most plant species in the wild support complex herbivores (Schoonhoven *et al.,* 2005; Bernays, 2009). The amount of damage sustained is quite small as plants appear to have broad-spectrum physical and chemical defences against insect herbivores and pathogens (Giron *et al.,* 2018) However, plant domestication and breeding involving selection for improved yield and quality have diminished the crops' defensive capability, making them more susceptible to pest damages (Chen *et al.*, 2015). Further, Mono-cropping of certain crops is one of the major issues for increased pest infestation.

Information on the Insect diversity present in the agroecosystem is a key to sustainable agricultural production in general and food security. Thus, understanding the function of insects in agroecosystems enables us to recognize their importance in agricultural systems' sustainable functioning. Despite their ecological importance, there is a paucity of information for the important agricultural insects. Studies on agricultural insect diversity are concerned; they are largely focused on rice fields, fruit orchards concerning their role as pests, parasitoids, and predators (Shah, Walling, Walling, *et al.*, 2017).

Gujarat is the Growth Engine of India". Gujarat, Leading as Second in the "Green Revolution," has achieved an Agricultural Growth table at 9.6% and has carved a niche in Agricultural Development in India. Situated on India's western coast, Gujarat has long been considered one of India's most progressive states on both the industrial and agricultural fronts. Gujarat is endowed with abundant natural resources in terms of fertile land, river systems, good soil, and climatic conditions in many parts of the state, contributing significantly to Gujarat's vibrant agricultural sector. Strengths of Gujarat's Agriculture Business Sector is due to diversified crops and cropping patterns, Climatic diversities – eight agriculture climatic zones, strong agricultural research capabilities, increasing adoption of hi-tech agriculture technologies like tissue culture, greenhouses, and shed-net houses leading to higher yield and production. Gujarat is the main agriculture export zones for mangoes, many vegetables, onion, sesame. Till date, Gujarat has a record of 1446 species belonging to 147 families of orders Orthoptera (Thakkar *et al.*, 2015); Coleoptera (Thakkar and Parikh, 2016); Lepidoptera (Kataria and Kumar, 2012; Bhatt and Nagar, 2017; Kumar *et al.*, 2019); Hemiptera (Kataria and Kumar, 2012); Hymenoptera (Thakkar and Parikh, 2018); Diptera (Parikh and Sonavane, 2008); Odonata (Parikh, and Sonavane, 2010; Rathod *et al.,* 2016; Patel *et al.*, 2016; Patel, and Ghetiya, 2018). The majority of studies investigating insect diversity in the agriculture fields have focused on the crop infestation in cotton, Groundnut, rice, and mangoes fields. The work to date has been focused on general diversity; however, there is very scanty information available regarding systematic studies on agriculturally important insect diversity of Gujarat in general and Vadodara.

Hence, the present study's key motivation is to fill up the lacunae of the Diversity of agriculturally important Insects with particular reference to their ecological and pest status of the Vadodara district in Gujarat.

1.2 Material and Methods

Collection of insects

A preliminary survey was carried out for the presence of agriculture fields based on the crop pattern and type. Taking into the consideration of the accessibility, location, and different types of habitat, four sites were selected, i.e., Ajwa (22.3751° N, 73.3851° E), Chhani (22.3633° N, 73.1658° E), Karjan (22.0535° N, 73.1202° E) and Padra (22.2394° N, 73.0848° E) areas of the Vadodara district.

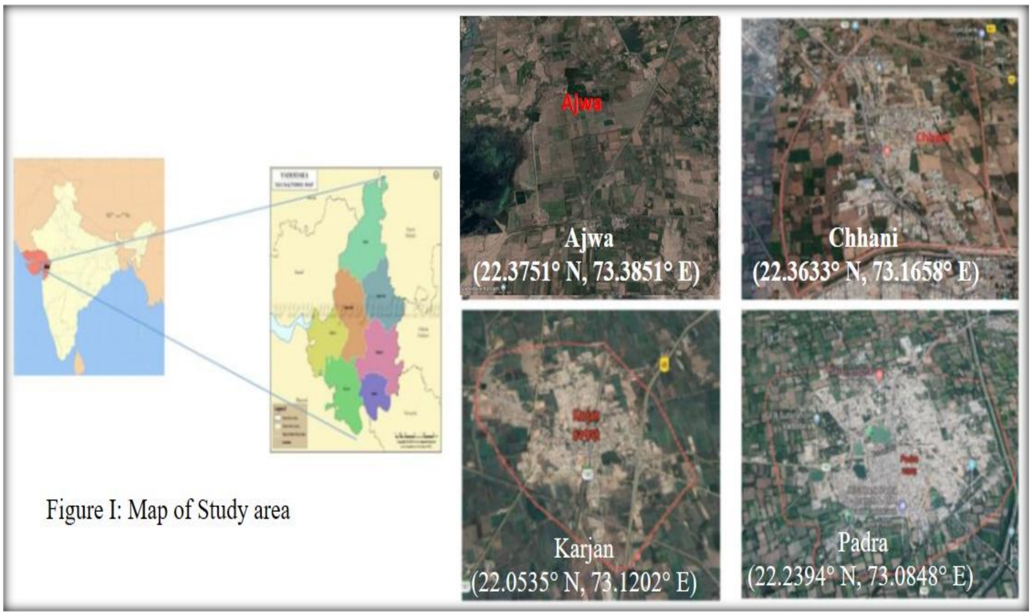


Figure 1. 1: Map of Study areas

Site 1: Ajwa: - Area has good vegetation, and in most of the agriculture fields, the farmers follow a multi-cropping pattern. The dominant crops and flora are Cotton, Chickpea, Pigeon pea, Maize, Ladies finger, Beans, Cabbage, Banana, Wheat, paddy, Drumstick, Sponge gourd, and Ivy gourd.

Site 2: Chhani:- Region is more of herbs, and dominant crops are Cotton, Castor, Pigeon pea, Sorghum, Bajra, Brinjal, Spinach, Cabbage, Cauliflower, Beans, Mango, Banana, Hibiscus, Nerium, Marigold, Calotropis, Nerium, Hibiscus and Drumstick.

Site 3: Karjan:- Area is found with a great cover of vegetation, and the prominent type includes Pigeon pea, Castor, Sorghum, Cabbage, Spinach, Nerium, Hibiscus, Marigold, Canna, Calotropis, Datura, Sponge gourd, Cotton, Pomegranate and Guava.

Site 4: Padra:-The fields are covered to be flourished with herbage, and the flora were Cotton, Castor, Sugarcane, Brinjal, Radish, Banana, Guava, Nerium, Hibiscus, Vinca, Calotropis, Pearl millet, Paddy, Jowar, Spinach, Mango, Lemon, Ladies finger and Fodder grass.

All the four sites were visited twice a month, and the sampling was done twice in a day: a) Morning hrs (6:30 am to 9:30 am) b) Evening hrs (4:30 pm to 6:30 pm). Along with direct observation and photo documentation, insects were collected manually through scientific methods.

Methods of Collection

i. **Wide net:** Sweeping net was used for capturing active flying insects. Insects trapped in the insect collecting net were then processed for further study.

ii. **Light trap:** Positively phototaxis insects or nocturnal insects were pulled together by the light trap method, where a halogen bulb was kept at the study site, and the insect thus attracted were collected in the plastic container.

iii. **Pitfall trap:** Small plastic cups filled with a mixture of 70% Ethyl alcohol and Glycerine were buried up to the rim in the ground to pass insects may fall. This method was used to sample surface-active hymenopterans like ants.

iv. **Handpicking:** Insects were collected from the barks of the tree by handpicking method and also leaf miners. Soil insects were also collected by handpicking and using berlese funnel.

v. **Beating Umbrella:** Hang an umbrella ups and down on a branch of a tree or bush and beat on the branch those insects on the branch will fall in the umbrella. Collect it in the plastic containers.

vi. **Litter Sifting:** Large litter and soil Insects were gathered delimiting 1.0 sq.m. sample area. Soil and litter were sequentially removed to a desired depth of 6cm. The soil was processed through a series of sieves. Large Arthropods were then handpicked from the sieves and the soil residue was extracted for smaller.

Figure 1. 2:Insect collection methods

Preservation and Morphological identification of the insects

All the collected insects were then processed for further identification; the specimens were narcotized by exposure to Cyanide vapours for maintaining its original colour. Different features like the pinning of insects, spreading, and mounting of insect specimens were done before going for taxonomic study. Identification was done by using standard reference books, published articles and was confirmed by comparing with the authentic samples at the Department of Zoology, Faculty of Science, The Maharaja Sayajirao University of Baroda, Bombay Natural History Society (BNHS) Mumbai, and Zoological Survey of India (ZSI) Kolkata, India.

The insects' occurrence was checked during the study period and noted down of four study sites. Based on the number of times they were encountered; they were given an abundance rating. Those species sighted 32 of visits were rated COMMON, less than 15 of the visits were UNCOMMON, and less than five visits were rated as RARE.

Seasonal variations of insect Orders and their comparisons.

Data were analyzed, and the insects' seasonal occurrence was checked concerning summer, monsoon, and winter seasons. A yearly comparison of each order has been carried out with consideration of seasonal occurrence. The Two-Way ANOVA test was carried out to determine whether there are any statistically significant differences between the means of three seasons at each Site.

Data Analysis:

All the four site samples were analysed separately, and then the data were pooled to get year wise comparison of each Site. Data were quantitatively analyzed using standard analytical and statistical methods with computer software Past 3x.

Ecological Distribution of Insects

Considering their occurrence and diversity, Insects species were categorized into various habits like; Bioindicators, Pests, Pollinators, Predators, and Scavengers.

1.3 Result

Phylum: Arthropoda

Class: Insecta

Order: Tysanura

Family: Lepismetidae

1. *Lepisma scacchirina*
2. *Lepisma sp.*

Order: Odonata

Family: Aeshnidae – Darners

1. *Anax parthenope*

Family: Gomphidae – Clubtails

2. *Ictinogomphus australis* (Selys, 1873)

Family: Libellulidae – Skimmers

3. *Bradinopyga geminate* (Rambur, 1842)
4. *Celithemis eponina* (Drury, 1773)
5. *Crocothemis servilia* (Drury, 1773)
6. *Libellula luctuosa*
7. *Orthetrum Sabina* (Drury, 1770)
8. *Pantala flavescens* (Fabricius, 1798)
9. *Rhyothemis variegate (Linnaeus, 1763)*
10. *Unidentified 1*
11. *Unidentified 2*

Family: Coenagrionidae - Narrow-winged Damselflies

12. *Enallagma geminatum* (Kellicott, 1895)
13. *Ischnura aurora* (Brauer, 1865)
14. *Ischnura hastate* (Say, 1839)
15. *Ischnura nursei* (Morton, 1907)

Order: Orthoptera

Family: Acrididae - Short-horned Grasshoppers

1. *Acrida conica* (Fabricius, 1781)
2. *Acrida exaltata* (Walker, 1859)
3. *Acrida ungarica* (Herbst , 1786)
4. *Acrida willemsei*

5. *Acrotylus humbertianus*
6. *Aiolopus thalassinus* (Fabricius, 1781)
7. *Aiolopus thalassinus tamulus*
8. *Atractomorpha sinensis*
9. *Calliptamus sp*
10. *Choroedocus robustus* (Serville, 1838)
11. *Chorthippus curtipennis* (Harris, 1835)
12. *Chorthippus sp.*
13. *Euthystria brachyptera* (Ocskay, 1826)
14. *Gastrimargus sp.*
15. *Hieroglyphus banian* (Fabricius , 1798)
16. *Locusta migratoria* (Linnaeus, 1758)
17. *Melanoplus femurrubrum* (De Geer, 1773)
18. *Metaleptea brevicornis* (Johannson, 1763)
19. *Omecestus sp.*
20. *Omocestus viridulus* (Linnaeus, 1758)
21. *Orphulella pelidna* (Burmeister, 1838)
22. *Oxya hyla hyla* (Serville, 1831)
23. *Oxya hyla intricata* (Stål, 1861)
24. *Phlaeoba infumata*
25. *Schistocera gregaria* (Forskål, 1775)
26. *Schistocera sp.*
27. *Sphingonatus sp.*
28. *Trilophidia annulata* (Thunberg, 1815)
29. *Xenocatantops humilis* (Serville, 1838)

Family: Pyrgomorphoidea – gaudy grasshoppers

30. *Atractomorpha lata* (Saussure, 1862)
31. *Atractomorpha sp*
32. *Chrotogonus sp* (Saussure, 1862)
33. *Poekilocerus pictus* (Fabricius, 1775)

Family: Tetrigidae - Pygmy Grasshoppers

34. *Tetrix arenosa* (Burmeister, 1838)
35. *Tetrix bipunctatus* (Linnaeus, 1758)

Family: Tridactylidae-Pygmy Mole Crickets

36. *Neotridactylus apicialis*
37. *Xya variegate*

Family: Gryllotalpidae - Mole Crickets

38. *Gryllotalpa fossar* (Scudder, 1869)
39. *Gryllotalpa gryllotalpa* (Linnaeus, 1758)
40. *Gryllotalpa orientalis* (Burmeister, 1838)
41. *Gryllotalpa ornata* (Walker, 1869)
42. *Gryllotalpa africana* (Palisot de Beauvois, 1805)

Family: Gryllidae - True Crickets

43. *Acheta domesticus* (Linnaeus, 1758)
44. *Gryllodes sigillatus* (Walker, 1869)
45. *Gryllus bimaculatus* (De Geer, 1773)
46. *Gryllus domesticus* (Linnaeus, 1758)
47. *Gryllus sp. 1*
48. *Gryllus sp.2*
49. *Loxoblemmus doenitzi* (Stein, 1881)
50. *Loxoblemmus sp.*
51. *Prozvenella sp.*
52. *Teleogryllus oceanicus* (Le Guillou, 1841)
53. *Trigonidium cicindeloides* (Rambur, 1838)

Family: Rhaphidophoridae - Camel Crickets

54. *Ceuthophilus sp.*

Family: Tettigoniidae – Katydids

55. *Paracaedicia sp. 1*
56. *Paracaedicia sp. 2*
57. *Amblycorypha rotundifolia* (Scudder, 1862)
58. *Mecopoda elongate* (Linnaeus, 1758)
59. *Neoconocephalus velox* (Rehn and Hebard, 1914)
60. *Conocephalus discolour* (Fabricius, 1793)
61. *Conocephalus dorsalis* (Latreille, 1804)
62. *Conocephalus melaenus*
63. *Ducetia japonica* (Thunberg, 1815)

64. *Euthystria brachyptera* (Ocskay, 1826)
65. *Hexacentrus sp*
66. *Holochlora sp*
67. *Sathrophyllia sp.*
68. *Scudderia furcata* (Brunner von Wattenwyl, 1878)
69. *Trigonocorypha unicolor* (Stoll, 1787)
70. *Zichya baranovi* (Bey-Bienko, 1933)
71. *Unidentified 1*
72. *Unidentified 2*

Order: Dictyoptera

Family: Mantidae (Rehn and Hebard, 1909)

1. *Empusa fasciat*

Family: Empusidae

2. *Stagmomantis californica* (Rehn and Hebard, 1909)

Family Ectobiidae

3. *Parcoblatta sp.*

Family Blattidae

4. *Blattella germanica* (Linnaeus, 1767)

Order: Isoptera

Family: Termitidae

1. *Microtermes obesi*
2. *Microtermes mycophagus*
3. *Odontotermes redemanni*
4. *Odontotermes guptai*

Order: Hemiptera

Family: Cicadellidae (Eurymelidae, Hylicidae, leafhoppers)

1. *Empoasca decipiens* (Paoli, 1930)

Family: Membracidae (Nicomiidae, treehoppers)

2. *Acanthuchus trispinifer* (Fairmaire, 1846)
3. *Leptocentrus tarsus*
4. *Oxyrachis tarandus*

Family: Derbidae

5. *Pamendanga sp.*
6. *Proutista moesta* (Westwood, 1851)

Family: Dictyopharidae

7. *Rhynchomitra microrhina* (Walker, 1851)

Family: Lophopidae

8. *Pyrilla perpusilla* (Walker, 1851)

Family: Aleyrodidae

9. *Aleurodicus disperses* (Russell, 1965)

Family: Reduviidae (assassin bugs)

10. *Melanolestes picipes* (Herrich-schaeffer, 1848)

Family: Coreidae (Leaf-footed bugs and sweetpotato bugs)

11. *Acanthocephala femorata* (Fabricius 1775)
12. *Cletomorpha Benita* (Kirby, 1891)
13. *Cletus punctiger* (Dallas, 1852)
14. *Homoeocerus signatus* (Walker, F., 1871)
15. *Unidentified 1*
16. *Unidentified 2*

Family: Lygaeidae (seed bugs)

17. *Lygaeus kalmii* (Stal, 1874)

Family: Rhyparochromidae (seed bugs)

18. *Myodocha serripes* (Olivier)

Family: Pentatomidae (stink bugs or shield bugs)

19. *Agonoscelis nubilis*
20. *Bagrada hilaris* (Burmeister, 1835)
21. *Eocanthecona furcellata*
22. *Eysarcoris guttiger* (Scopoli, 1763)
23. *Halyomorpha halys* (Stål, 1855)
24. *Megacopta cribraria* (Fabricius, 1798)
25. *Carbula insocia*
26. *Nezara antennata*
27. *Nezara viridula* (Linnaeus, 1758)
28. *Nezara mendax*
29. *Palomena prasina* (Linnaeus, 1761)

30. *Plautia affinis* (Dallas, 1851)

Family: Dinidoridae

31. *Coridius janus* (Fabricius, 1775)

Family: Aphididae (aphids)

32. *Aphis gossypii* (Glover, 1877)

Family: Aleyrodidae (whiteflies)

33. *Aleurodicus disperses* (Russell, 1965)

Family: Coccidae (soft scales)

34. *Drepanococcus cajani* (Maskell, 1891)
35. *Phenacoccus madeirensis* (Halima-Kamel - 2014)

Family: Pseudococcidae (mealybugs)

36. *Planococcus sp.*

Order: Thysanoptera

Family: Thripidae

1. *Caliothrips indicus*
2. *Scirtothrips dorsalis*
3. *Thrips tabaci* (Lindeman, 1889)

Order: Neuroptera

Family: Chrysopidae (green lacewings, stinkflies)

1. *Chrysoperla carnea* (Stephens,1836)
2. *Chrysoperla sp*.

Family: Myrmeleontidae: antlions

3. *Palpares libelloides*

Order: Coleoptera

Family: Carabidae (including Cicindelidae, Paussidae)

1. *Bembidion conforme*
2. *Brachinus crepitans* (Linnaeus, 1758)
3. *Brachinus exhalans* (Rossi, 1792)
4. *Calosoma maderae* (Fabricius, 1775)
5. *Chlaenius bimaculatus* (Boheman, 1848)
6. *Chlaenius sp.*
7. *Cicindela oregona* (LeConte, 1857)

8. *Craspedophorus saundersi* (Chaudoir, 1869)
9. *Drypta lineola* (Macleay, 1825)
10. *Microcosmodes sp.* (Murray, 1857)
11. *Neocollyris fuscitarsis* (Horn, 1901)
12. *Paranchus albipes* (Fabricius, 1796)
13. *Paranchus sp.*
14. *Pheropsophus catoire* (Dejean, 1825)
15. *Pheropsophus verticalis* (Dejean, 1825)
16. *Pterostichus sp.*(Bonelli, 1810)
17. *Pterostichus aethiops* (Panzer, 1796)
18. *Pterostichus oblango punctata* (Fabricius, 1787)

Family: Gyrinidae-whirligig beetles

19. *Gyrinus natator* (Linnaeus, 1758)

Family: Dytiscidae-predaceous diving beetles

20. *Cybister fimbriolatus* (Say, 1823)
21. *Cybister tripunctatus* (Olivier, 1795)
22. *Eretes sp.*
23. *Eretes sticticus* (Linnaeus, 1767)

Family: Histeridae (Niponiidae)-clown beetles

24. *Euspilotus sp*.

Family: Staphylinidae (rove beetles)

25. *Ocypus brunnipes* (Fabricius, 1781)
26. *Paederus riparius* (Linnaeus, 1758)

Family: Scarabaeidae-scarab beetles

27. *Anomala bengalensis* (Blanchard, 1851)
28. *Aphodius fossor* (Linnaeus, 1758)
29. *Catharsius molossus* (Linnaeus, 1758)
30. *Cetonia funesta* (Poda, 1761)
31. *Chiloloba orientalis* (Wiedemann, 1823)
32. *Copris incertus* (Say, 1835)
33. *Copris numa* (Lansberge, 1886) (Lansberge, 1886)
34. *Cremastocheilus sp.*

35. *Cyclocephala pasadenae* (Casey, 1915)
36. *Gymnopleurus cyaneus* (Fabricius, 1798)
37. *Gymnopleurus gemmatus*
38. *Gymnopleurus miliaris* (Fabricius, 1775)
39. *Heliocopris bucephalus* (Fabricius, 1775)
40. *Heliocopris gigas* (Linnaeus, 1758)
41. *Holotrichia reynaudi* (Blanchard, 1851)
42. *Onitis alexis*
43. *Onthophagus dama* (Fabricius, 1798)
44. *Onthophagus gazelle*
45. *Onthophagus lemur* (Fabricius, 1781)
46. *Onthophagus sp.*
47. *Onthophagus Taurus* (Schreber, 1759)
48. *Oryctes nasicornis*
49. *Oryctes rhinoceros*
50. *Oxycetonia jucunda* (Falderman, 1835)
51. *Oxycetonia versicolor* (Fabricius, 1775)
52. *Phyllophaga nebulosa* (Polihronakis, 2007)
53. *Phyllophaga obsolete* (Blanchard, 1851)
54. *Phyllophaga sp.*
55. *Protaetia alboguttata* (Vigors, 1826)
56. *Protaetia aurichalcea* (Fabricius, 1775)
57. *Protaetia squamipennis* (Burmeister, 1842)
58. *Rhyssemus sp.*
59. *Scarabaeus sp.*
60. *Xyloryctes jamaicensis* (Drury, 1773)
61. *Unidentified sp. 1*
62. *Unidentified sp. 2*

Family: Buprestidae - metallic wood-boring beetles

63. *Acmaeodera sp.*
64. *Acmaeodera viridaenea* (Eschscholtz, 1829)
65. *Agrilus acutus* (Thunberg, 1787)
66. *Sternocera chrysis*

67.*Psiloptera sp.*(Olivier, 1790)

Family: Elateridae -click beetles

68. *Agriotes ustulatus* (Schaller, 1783)

69. *Athous haemorrhoidalis* (Fabricius, 1801)

70. *Lanelater fuscipes* (Fabricius, 1775)

Family: Lampyridae-fireflies, lightning bugs

71. *Luciola anceyi* (E.Olivier, 1883)

Family: Aphodidea

72. *Rhyssemus sp.*

Family: Apionidae

73. *Apion sp.*

Family: Cantharidae -soldier beetles

74.*Anthia sexguttata* (Fabricius, 1775)

75.*Cantharis livida* (Linnaeus, 1758)

76.*Rhagonycha fulva* (Scopoli, 1763)

Family: Dermestidae -skin beetles

77.*Dermestes sp.*

Family: Anobiidae -death watch and spider beetles

78.*Lasioderma serricorne* (Fabricius, 1792)

Family: Nitidulidae-sap-feeding beetles

79.*Glischrochilus quadripuntatus* (Linnaeus, 1758)

Family: Silvanidae

80.*Oryzaephilus surinamensis* (Linnaeus, 1758)

Family: Laemophloeidae-lined flat bark beetle

81.*Cryptolestes pusillus* (Schönherr, 1817)

Family: Coccinellidae-ladybird beetles

82.*Adalia bipunctata* (Linnaeus, 1758)

83.*Adonia variegata* (Goeze, 1777)

84.*Anegleis cardoni*

85.*Brumoides suturalis* (Fabricius)

86.*Cheilomenes sexmaculate* (Fabricius, 1781)

87.*Cheilomenos sp.*

88.*Chilocorus circumdatus* (Gyllenhall, 1808)

89. *Chilocorus nigritus* (Fabricius, 1798)
90. *Coccinella repanda* (Thunberg, 1781)
91. *Coccinella septempunctata* (Linnaeus, 1758)
92. *Coccinella transversalis* (Fabricius, 1781)
93. *Coccinella undecimpunctata* (Linnaeus, 1758)
94. *Epilachna ocellata* (Redtenbacher)
95. *Harmonia expallida* (Weise, 1907)
96. *Harmonia octomaculata* (Fabricius, 1781)
97. *Harmonia sedecimnotata* (Fabricius, 1801)
98. *Henosepilachna vigintioctopunctata* (Fabricius, 1775)
99. *Menochilus sexmaculatus* (Fabricius, 1781)
100. *Propylea dissecta*

Family: Tenebrionidae -darkling beetles

101. *Gonocephalum sp.*
102. *Mesostena sp.*
103. *Tenebrio molitor* (Linnaeus, 1758)
104. *Zophosis punctate*
105. *Unidentified sp.*

Family: Meloidae-blister beetles

106. *Alosimus syriacus* (Linnaeus, 1758)
107. *Synhoria maxillosa*
108. *Lytta caragana* (Pallas, 1798)
109. *Mylabris cichorii* (Linnaeus, 1767)
110. *Mylabris pustulata* (Thunberg, 1821)
111. *Mylabris variabilis* (Pallas, 1782)
112. *Psalydolytta rouxi*
113. *Unidentified sp. 1*
114. *Unidentified sp. 2*

Family: Anthicidae-antlike flower beetles

115. *Formicomus sp.*
116. *Anthelephila sp.*

Family: Cerambycidae –longhorned beetles

117. *Acanthophorus serraticornis* (Olivier, 1795)

118. *Batocera rufomaculata* (De Geer, 1775)
119. *Callichora sp.*(Meyrick, 1915)
120. *Celosterna scabrator* (Fabricius)
121. *Dectes texanus*
122. *Derobrachus hovorei* (Santos-Silva, 2007)
123. *Niphona picticornis*
124. *Monochamus scutellus*
125. *Trachysida sp.*
126. *Xylotrechus stebbingi* (Gahan 1906)

Family: Chrysomelidae -leaf beetles

127. *Altica sp* (Woods 1917)
128. *Aspidomorpha miliaris* (Fabricius, 1775)
129. *Aulacophora indica*
130. *Aulacophora nigripennis* (Motschulsky, 1857)
131. *Aulocophora foveicollis* (Lucas, 1849)
132. *Cassida circumdata*
133. *Cassida sp.*
134. *Charidotella sp.* (Weise, 1896)
135. *Chiridopsis bipunctata* (Linnaeus, 1767)
136. *Altica cyanea*
137. *Chrysolina coerulans* (Scriba, 1791)
138. *Chrysolina fastuosa* (Scopoli, 1763)
139. *Clytra laeviuscula* (Ratzeburg, 1837)
140. *Clytra sp.*
141. *Liloceris sp.*
142. *Metriona bicolor* (Fabricius)
143. *Monolepta signata*
144. *Oides bipunctata* (Fabricus, 1781)
145. *Oides palleata* (Fabricius, 1781)
146. *Podagrica fuscicornis* (Linnaeus, 1767)
147. *Sindia clathrata* (Olivier,1808)

Family: Attelabidae -tooth-nosed snout beetles

148. *Paratrachelophorus sp*

Family: Brentidae -straight-snouted weevils

149. *Amorphocephalus coronatus*
150. *Apion clavipes*

Family: Curculionidae-snout beetles, troe weevils

151. *Brachyderes incanus* (Linnaeus, 1758)
152. *Cleonus sp.*
153. *Cosmopolites sordidus* (Germar, 1824)
154. *Hypera postica* (Gyllenhal, 1813)
155. *Myllocerus dorsatus*
156. *Myllocerus subfasciatus* (Guerin-Meneville, 1843)
157. *Myllocerus undecimpustulatus*
158. *Myllocerus viridanus*
159. *Notaris scirpi* (Fabricius, 1792)
160. *Odoiporus longicollis* (Olivier, 1807)
161. *Polydrusus formosus* (Mayer, 1779)
162. *Sitophilus oryzae*

Order: Diptera

Family: Tipulidae (crane flies)

1. *Nephrotoma appendiculata*

Family: Psychodidae (moth flies)

2. *Chloromyia Formosa* (Scopoli, 1763)
3. *Hermetia illucens* (Linnaeus, 1758)
4. *Psychoda alternate* (Say, 1824)

Family: Culicidae (mosquitoes)

5. *Aedes albopictus* (Skuse, 1894)
6. *Culex quinquefasciatus* (Say, 1823)
7. *Culex pipiens* (Linnaeus, 1758)

Family: Stratiomyidae -soldier flies

8. *Odontomyia sp.*

Family: Tabanidae (horseflies, deerflies; march flies in Australia)

9. *Tabanus eggeri* (Schiner, 1868)
10. *Philoliche sp.*

Family: Bombyliidae (bee flies)

11. *Xenox tigrinus* (Evenhuis, 1984)

Family: Syrphidae (hover flies)

12. *Meliscaeva cinctella*
13. *Syrphus ribesii*

Family: Lauxaniidae

14. *Homoneura flavofemorata*
15. *Minettia flaveola*

Family: Chloropidae (frit flies)

16. *Oscinella frit* (Linnaeus, 1758)

Family: Drosophilidae (small fruit flies)

17. Gitona distigma
18. *Drosophila melanogaster* (Meigen, 1830)

Family: Dolichopodidae

19. *Condylostylus longicornis*

Family: Anthomyiidae

20. *Delia antiqua* (Meigen, 1826)

Family: Muscidae (housefly and allies)

21. *Atherigona soccata* (Rondani 1871)
22. *Musca domestica*
23. *Musca autumnalis* (De Geer, 1776)
24. *Unidentified sp.1*
25. *Unidentified sp.2*

Family: Diopsidae-stalked-eyed flies

26. *Ropalidia marginata* (le Peletier, 1836)

Family: Tephritidae - fruit flies

27. *Bactrocera tryoni* (Froggatt, 1897)
28. *Diarrhegma modestum*
29. *Bactrocera cucurbitae* (Coquillett, 1849)
30. *Bactrocera curvifera* (Walker, 1864)
31. *Bactrocera dorsalis* (Hendel, 1912)
32. *Euaresta bellula*
33. *Unidentified sp.1*

Family: Calliphoridae (blow flies)

34. *Calliphora vomitoria*
35. *Chrysomya megacephala* (Fabricius, 1794)

Family: Sarcophagidae (flesh flies)

36. *Sarcophaga bullata*
37. *Sarcophaga sp.*

Order: Lepidoptera

Family: Eupterotidae

1. *Eupterote germinate*
2. *Eupterote mollifera* (Walker, 1865)

Family: Noctuidae (owlet moths)

3. *Helicoverpa armigera* (Hübner, 1808)
4. *Helicoverpa zea*
5. *Olene mendosa*
6. *Spodoptera sunia*
7. *Spodoptera exigua*
8. *Spodoptera frugiperda*
9. *Spodoptera litura* (Hübner, 1823)
10. *Trichoplusia ni*

Family: Erebidae

11. *Amsacta albistriga*
12. *Asota caricae* (Fabricius, 1775)
13. *Eudocima maternal*
14. *Orgyia leucostigma*
15. *Orvasca subnotata*
16. *Spilarctia oblique*
17. *Trigonodes hyppasia*

Family: Lymantriidae (tussock moths)

18. *Euproctis lunata* (Walker, 1855)

Family: Pyralidae (pyralid, or snout, moths)

19. *Euzophera perticella* (Ragonot, 1888)

Family: Crambidae (webworms)

20. *Cnaphalocrocis medinali*
21. *Hellula undalis* (Fabricius, 1794)

22. *Leucinodes orbonalis* (Guenée, 1854)

23. *Noorda blitealis* (Walker, 1859)

24. *Scirpophaga incertulas* (Walker, 1863)

25. *Spoladea recurvalis* (Fabricius, 1775)

Family: Plutellidae

26. *Plutella xylostella* (Linnaeus, 1758)

Family: Gelechiidae (twirler moths)

27. *Pectinophora gossypiella* (Saunders, 1844)

Family: Nymphalidae (brush-footed butterflies)

28. *Ariadne merione* (Cramer, 1777)

29. *Athyma kanwa* (Moore, 1858)

30. *Danaus chrysippus* (Linnaeus, 1758)

31. *Danaus genutia* (Cramer, 1779)

32. *Hypolimnas misippus* (Linnaeus, 1764)

33. *Junonia almanac* (linnaeus 1758)

34. *Unidentified sp. 1*

Family: Pieridae (white, orange-tip, and sulfur butterflies)

35. *Anthocharis cardamines* (Linnaeus, 1758)

36. *Delias eucharis* (Drury, 1773)

37. *Eurema hecabe* (Linnaeus, 1758)

Family: Papilionidae (swallowtails and parnassians)

38. *Pachliopta aristolochiae* (Fabricius, 1775)

Family: Nolidae

39. *Earias insulana* (Boisduval, 1833)

40. *Earias vitella*

Order: Hymenoptera

Family: Tenthredinidae (typical sawflies)

1. *Athalia proxima* (Rottemburg, 1775)

Family: *Ichneumonidae*

2. *Ichneumon sp.*

Family: Chrysididae (cuckoo wasps)

3. *Chrysis angolensis* (Radoszkowski, 1881)

Family: Formicidae (ants)

4. *Camponotus pennsylvanicus* (De Geer, 1773)
5. *Formica fusca* (Linnaeus, 1758)
6. *Oecophylla longinoda* (Latreille, 1802)
7. *Oecophylla smaragdina* (Fabricius, 1775)
8. *Opisthopsis haddoni* (Emery, 1893)
9. *Podomyrma gratiosa* (Smith, 1858)
10. *Solenopsis invicta* (Buren, 1972)
11. *Tetraponera rufonigra Jerdon,*
12. *Unidentified sp. 1*
13. *Unidentified sp. 2*

Family: Vespidae (paper wasps, potter wasps)

14. *Abeja carpintera*
15. *Eumenes latreilli*
16. *Eumenes sp.*
17. *Polistes Carolina*
18. *Ropalidia marginata* (le Peletier, 1836)
19. *Vespa crabro* (Linnaeus, 1758)
20. *Vespa tropica* (Linnaeus, 1758)
21. *Unidentified sp. 1*
22. *Unidentified sp. 2*

Family Sphecidae (Sphecid wasps)

23. *Chalybion californicum* (Saussure, 1867)
24. *Delta dimidiatipenne* (Saussure, 1852)
25. *Ectemnius cavifrons* (Thomson, 1870)
26. *Larra anathema* (Rossi, 1790)
27. *Sceliphron caementarium* (Drury, 1773)
28. *Sceliphron spirifex* (Linnaeus, 1758)
29. *Sphex pennsylvanicus* (Linnaeus, 1763)

Family Halictidae (mining bees)

30. *Agapostemon virescens* (Fabricius, 1775)
31. *Halictus sp.*
32. *Nomia sp.*

Family Megachilidae

33.Megachile sp

Family Apidae (bumblebees, honeybees, and bees)

34.Amegilla cingulate

35.Amegilla zonata (Linnaeus, 1758)

36.Apis cerana (Fabricius, 1793)

37.Apis dorsata (Fabricius, 1793)

38.Apis florea (Fabricius, 1787)

39.Colletes daviesanus (Smith, 1846)

40.Tetraloniella braunsiana (Friese, 1905)

41.Xylocopa aestuans (Linnaeus, 1758)

42.Xylocopa micans

43.Xylocopa pubescens (Spinola, 1838)

44.Xylocopa virginica

45.Xylocopa violaceae

In the present study, 423 species of insects representing 12 orders and 101 families are recorded. Orders Coleoptera, Orthoptera, Hymenoptera, Lepidoptera, Hemiptera, Diptera, and Odonata were the more dominant orders in the study. A total of 162 Coleopteran species belonging to 113 genera under 26 families consist of Scarabaeidae (36 species), Chrysomelidae (21 species), Coccinellidae (19 species), Carabidae (18 species), Cucurlionidae (12 species), Cerambycidae (10 species), Meloidae (9 species), Buprestidae and Tenebrionidae (5 species), Dysticidae (4 species), Elateridae and Cantharidae (3 species), Anthicidae, Brenthidae, and Staphylinidae (2 species), and Gyrinidae, Histeridae, Lemophloeidae, Lampyridae, Nitidulidea, Silvanidea, Aphodidea, Anobiidea, Apionidae, Attelabidea, and Dermestidae (1 species). A total of 72 species of Orthoptera belonging to 51 genera representing 8 families were found during the study period. The highest numbers of species were recorded from the Acrididae (29 species), Tettigonidae (18 species), Gryllidae (11 species), Gryllotalpidae (5 species), Pyrgomorphidae (4 species), Tetrigidae, and Trydactylidae (2 species), and Raphidophoridae (1 species) families. A total of 45 species of Hymenoptera belonging to 31 genera representing 9 families were found during the study period. The highest numbers of species were recorded from the Apidae (12 species), Formicidae (10 species), Vespidae (9 species), Sphecidae (7 species), Halictidae (3 species), Ichneumonidae, Chrysididae, Megachilidae , and Tenthredinidae (1 species) families. A total of 40 species of Lepidopterans belonging to 34 genera representing 12 families were found during the study period. The highest numbers of species were recorded from the Nymphalidae (8 species), Erebidae (7 species), Crambidae and Noctuidae (6 species), Pieridae (3 species), Papilionidae, Nolidae, and Eupterotidae (2 species), Gelechiidae, Lymantridae, Plutellidae, and Pyralidae (1species) families. A total of 36 species of Hemiptera belonging to 32 genera representing 16 families were found during the study period. The highest numbers of species were recorded from the Pentatomidae (11 species), followed by Coreidae (6 species), Membracidae (3 species), Derbidae, Coccidae and Pyrrhocoridae (2 species) and Dictyopharidae, Dinidoridae, Lophophidae, Lygaeidae, Pseudococcidae, Reduviidae, Rhyparochromidae, Aleryrodidae, Aphididae, and Cicadellidae (1 species) families. Followed by a total of 37 species belonging to 28 genera with 17 families of Diptera were reported, which consists of Tephritidae (7 species), Muscidae (5 species), Culicidae and Psychodidae (3 species), Calliphoridae, Sacrophagidae, Drosophilidae, Lauxaniidae, Syrphidae, and Tabanidae (2 species), and Chloropidae, Bombyliidae, Stratiomyidae, Dolichopodidae, Anthomyiidae, Tipulidae, and Diopsidae (1 species). A total of 15 species of Odonata belonging to 11 genera representing 4 families were observed in the present study. The highest numbers of species were recorded from the Libellulidae (9 species), followed by Coenagrionidae with 4 representatives, and Gomphidae and Aeshindae had one representative each.

Order	Site I	Site II	Site III	Site IV
Thysanura	UC	UC	R	UC
Odonata	C	C	C	C
Orthoptera	C	C	C	C
Dictyoptera	UC	UC	UC	UC
Isoptera	C	R	UC	UC
Hemiptera	C	C	C	C
Thysanoptera	UC	UC	UC	UC
Neuroptera	UC	R	UC	R
Coleoptera	C	C	C	C
Diptera	C	C	C	C
Lepidoptera	C	C	C	C
Hymenoptera	C	C	C	C

Table 1. 1: The Insect species occurrence concerning Common(C), Uncommon (UC), and Rare (R) in four sites

Based on the number of times they were encountered; they were given an abundance rating. Orders Odonata, Orthoptera, Coleoptera, Hemiptera, Lepidoptera, Diptera, and Hymenoptera were Common at all four sites Thysanoptera and Neuroptera were Uncommon at all the Sites. Order Thysanura was Uncommon at Site I, II, and IV, and was Rare at Site III. The representatives from Dictyoptera was Uncommon at Site I and III as well as Rare at Site II and IV. Termites were representing order Isoptera was Uncommon at Site I, Site III, and Site IV and Rare at Site II. (Table 1.1).

An analysis of percentage distribution of the species richness is presented in Figure 1.3, which reveals that the maximum species belongs to order Coleoptera with 38%, followed by Orthoptera (17%), Hymenoptera (11%), Diptera, and Lepidoptera (9%), Hemiptera (8%), Odonata (4%) and the least representatives were observed in Thysanura, Dictyoptera, Isoptera, Thysanoptera and Neuroptera (1%).

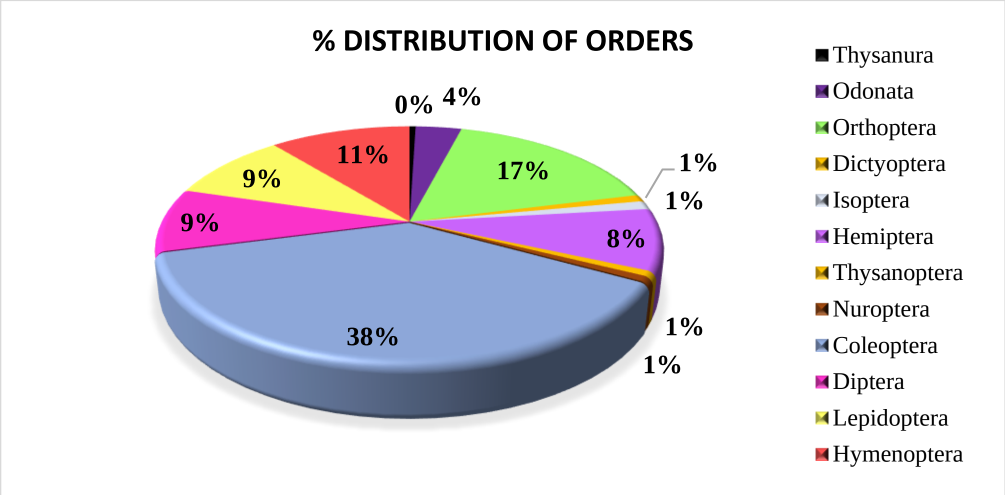


Figure 1. 3: Overall Percentage Distribution of Insect Orders

An analysis of the total number of the individuals collected exhibited marked variations. Percentage distribution of the species in each Site revealed that Coleoptera and Hymenoptera were found to be the more at Site III than the other three Sites. Lepidoptera was reported almost the same at Site II compared to the other three Sites. Site IV has many Orthopterans among four Sites, and Hemiptera and Diptera are observed equally at all the four Sites (Figure 1.4).

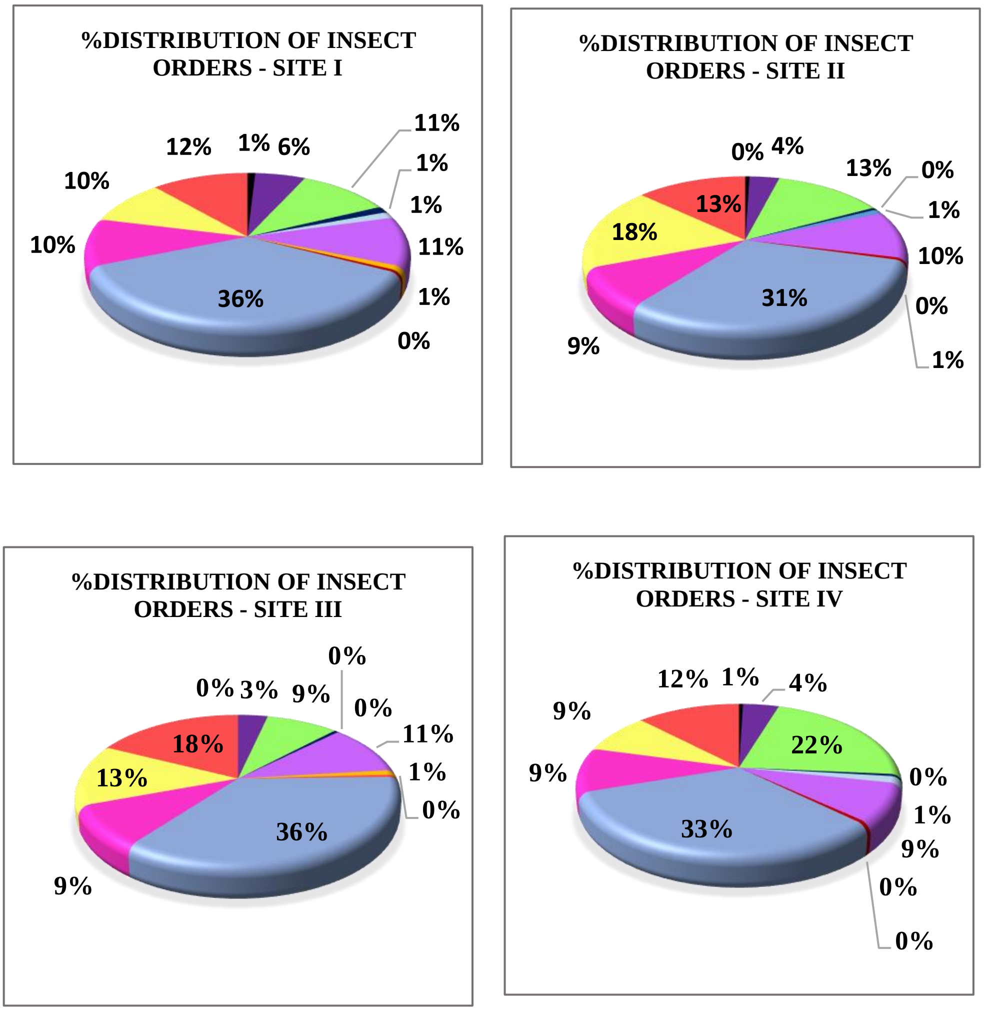
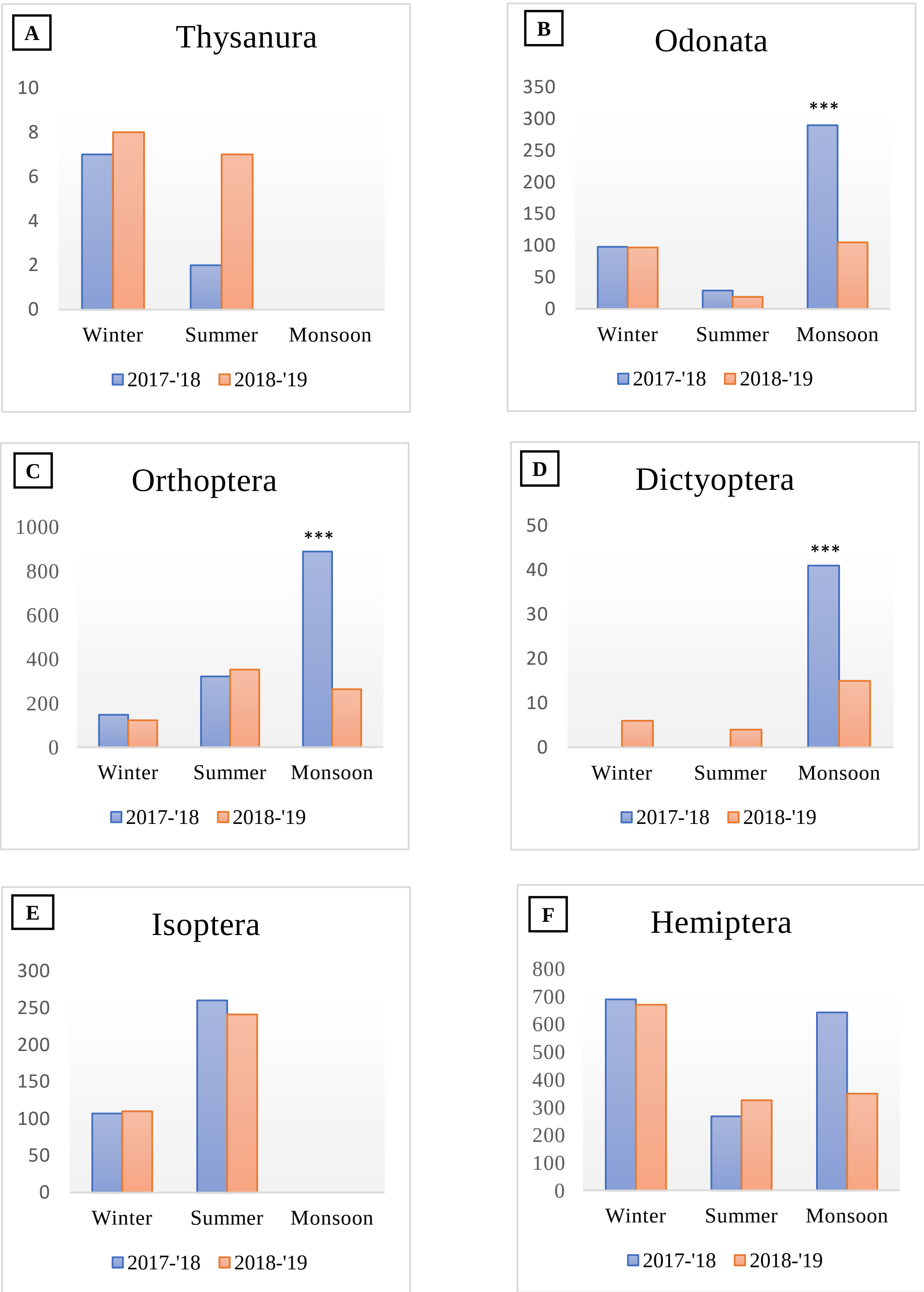


Figure 1. 4: Percentage Distribution of Insect Orders in the four Sites

Species	2017-'18			2018-'19		
	Winter	Summer	Monsoon	Winter	Summer	Monsoon
Thysanura	7	2	0	8	7	0
Odonata	84	29	282	97	19	103
Orthoptera	147	321	888	122	352	359
Dictyoptera	0	0	70	6	4	23
Isoptera	107	260	0	110	241	0
Hemiptera	689	267	641	631	325	373
Neuroptera	9	3	20	15	8	0
Thysanoptera	0	0	21	0	2	6
Coleoptera	286	245	1402	594	324	880
Diptera	130	111	510	191	137	310
Lepidoptera	332	66	410	335	83	202
Hymenoptera	176	422	1626	187	527	790

Table 1. 2: Seasonal variation of orders from 2017 to 2019

There was a distinct seasonal variation in the abundance of insects. The majority of the orders were monsoon dominant (Odonata, Orthoptera, Dictyoptera, Thysanoptera, Coleoptera, Diptera, and Hymenoptera), and the year-wise comparison revealed that 2017-'18 had a good assemblage compared to 2018-'19 (Figure 1. 5 and Table 1.2). The winter dominant orders were (Thysanura, Hemiptera, Neuroptera, and Lepidoptera). The summer season had the minimum representatives.



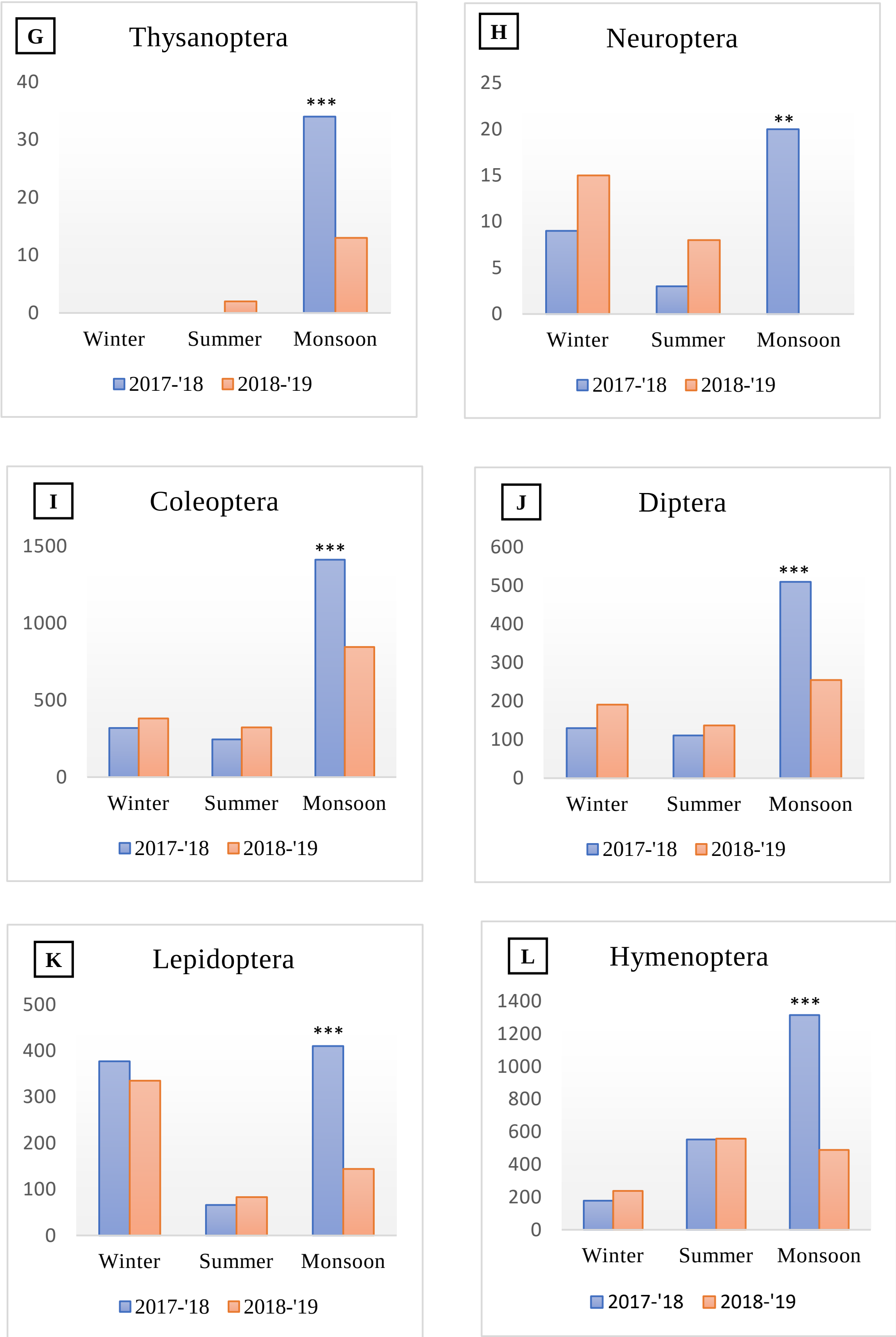


Figure 1. 5: Seasonal variation of Orders from 2017 to 2019
Significant level indicated by *=(p<0.005)**

During the current study, the Shannon Weiner index (Species' diversity), Buzas and Gibson's index (Species' evenness), and Marglef's index (Species'richness) were computed using the data to facilitate comparison among the sites and seasons over two years.

The results revealed that the maximum diversity was in Monsoon season in all the 2017 - '18. The Site I showed much diversity and abundance in terms of insect fauna compared to the other three Sites, and there was a decline of insect species during winter and summer (Figure 1.6 and Table 1.3). The maximum even distribution of insects was found at Site IV in 2017- '18 and the year 2018- '19 at the Site I compared to the other three sites (Figure 1.7 and Table 1.3). As far as the Richness of insects is concerned, season-wise, it was maximum during monsoon in both the years, which was parallel with the diversity and accounted for the similar spatial and temporal changes (Figure 1.8 and Table 1.3).

Shannon_H index						
Seasons	**Winter**		**Summer**		**Monsoon**	
	2017-'18	**2018-'19**	**2017-'18**	**2018-'19**	**2017-'18**	**2018-'19**
Site I	4.1	4.177	4.057	4.11	4.871	3.675
Site II	3.73	3.822	3.854	3.85	4.736	3.511
Site III	4.061	4.14	3.771	4.108	4.759	3.9
Site IV	3.593	3.887	4.133	4.173	4.82	4.158
Buzas and Gibson's index						
Site I	0.642	0.7402	0.5506	0.5302	0.7497	0.8219
Site II	0.587	0.6436	0.5483	0.6184	0.7401	0.7787
Site III	0.7947	0.837	0.6203	0.8688	0.7624	0.852
Site IV	0.4783	0.595	0.7084	0.5954	0.738	0.8096
Marglef's index						
Site I	14.18	13.37	16.17	17.44	23.49	7.58
Site II	11.17	10.99	13.86	12.42	21.4	6.604
Site III	12.92	12.71	11.97	11.67	21.38	8.918
Site IV	11.88	12.73	14.2	16.97	22.86	11.65

Table 1. 3: Diversity Indices of insect species in four sites

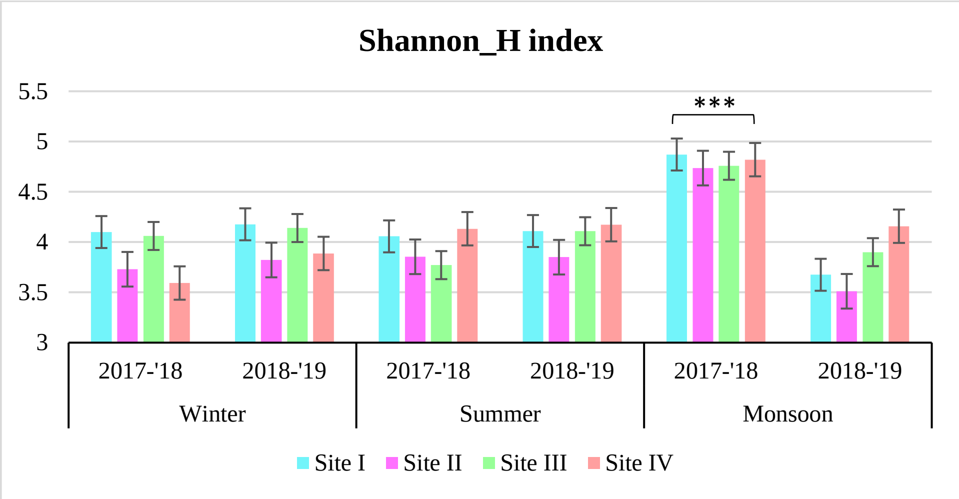


Figure 1. 6: Diversity Index (Shannon_H) of insect species in four sites
Significant level indicated by *=(p<0.005)**

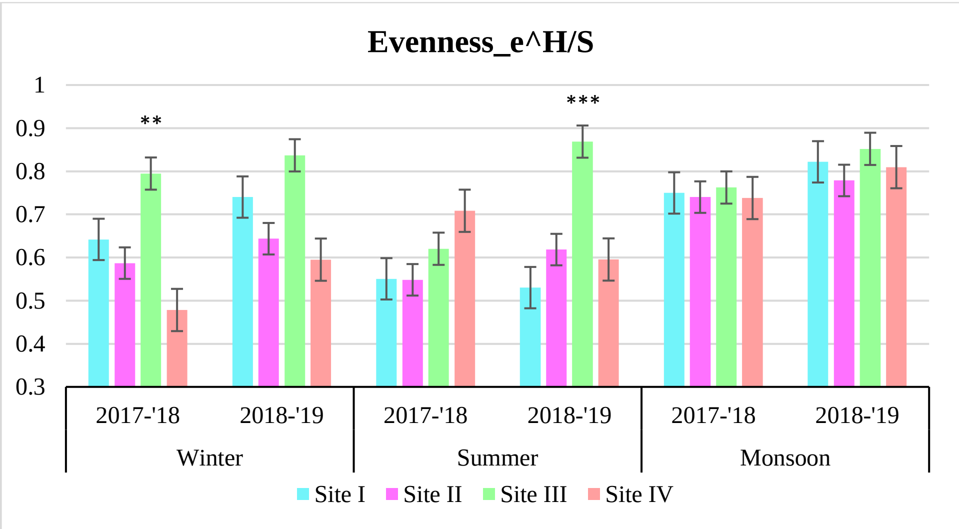


Figure 1. 7: Evenness Index of insect species in four sites
Significant level indicated by **= (p<0.05); *=(p<0.001)**

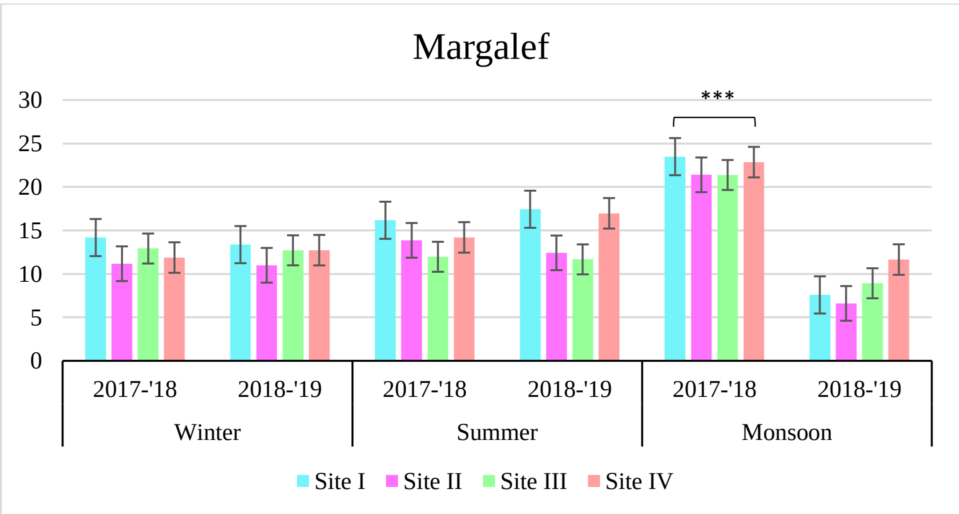


Figure 1. 8: Richness Index (Margalef) of insect species in four sites
Significant level indicated by *=(p<0.005)**

Furthermore, the significance was analyzed using two-way ANOVA, and a significant ($p<0.05$) increase in diversity and richness was found in the Monsoon season in the year 2017-'18. Similarly, among the selected sites, significance ($p<0.05$) was noted in Site III. Thus, combining the results of indices and ANOVA, the study suggest that the insect fauna was found to be highest during monsoon compared to winter and summer.

Based on the insects' ecological role, the collected species were categorized as Bioindicators, Pests, Pollinators, Predators, and Scavengers. When the percentage distribution pattern was studied, it revealed that the Pest species were maximum in number, followed by Scavengers and Predators, whereas the Pollinators and Bio-indicators were found less in number (Figure 1.9).

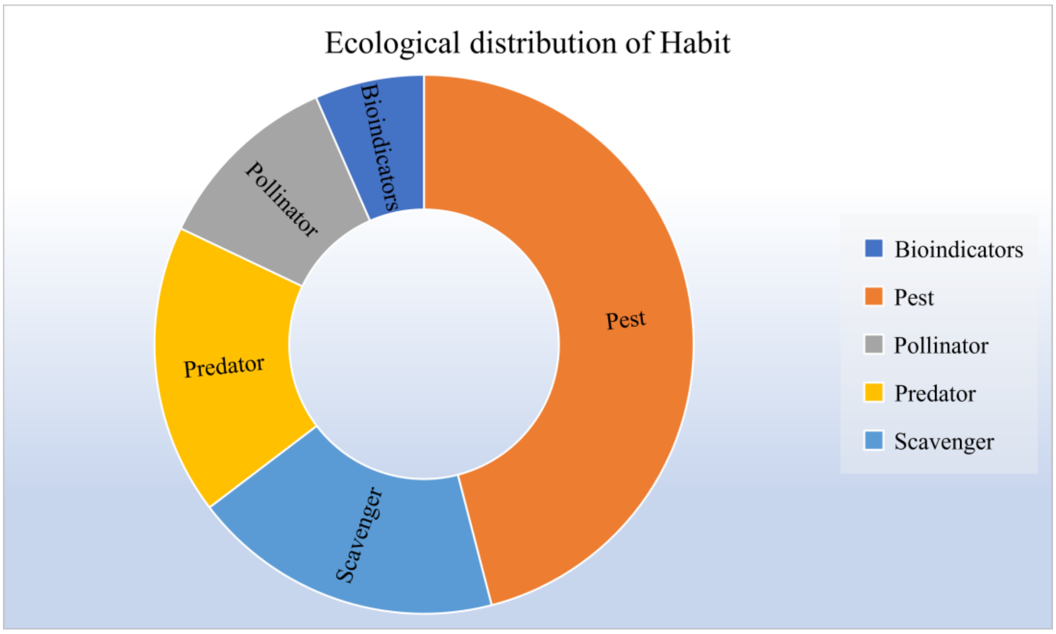


Figure 1. 9: Percentage Distribution of insects according to their Ecological rol

Order: Odonata


Ischnura aurora


Orthetrum sabina


Anax parthenope


Libellula luctuosa.


Pantala flavescens


Ischnura nursei


Ischnura hastata.


Rhyothemis variegate


Ictinogomphus australis


Bradinopyga geminate


Enallagma geminatum


Celithemis eponina

Figure 1. 10 : Representatives of Order Odonata

Order: Orthoptera

Neotridactylus apicialis

Prozvenella sp.

Xya variegate

Gryllotalpa fossar

Trilophidia annulata

Gryllus domesticus

Santhrophylla sp.

Chrotogonus sp.

Mecopoda elongata

Poikilocerus pictus

Neoconocephalus velox

Figure 1. 11: Representatives of Order Orthoptera

Order: Diptera

Hermeta ilucens

Sarcphaga bullata

Nephrotoma appendiculata

Calliphora vomitoria

Anthrax sp

Tabanus sp

Odontomyia sp

Gymnochiromyia flavella

Bactrocera tryoni

Condylostylus longicornis

Oscinella frit

Platensina sp.

Figure 1. 12: Representatives of Order Diptera

Order: Coleoptera

Heliocopris gigas

Paranchus albipes

Anthia sexguttata

Gymnopleurus gemmatus

Ocypus brunnipes

Cybister tripunctatus

Pheropsophus sp.

Hydrophilus Sp

Cheilomenes sexmaculata

Coccinella transversalis

Onthophagus tweedensis

Copris incertus

Figure 1. 13: Representatives of Order Coleoptera

Order: Lepidoptera

Junonia lemonias

Neptis jumbah

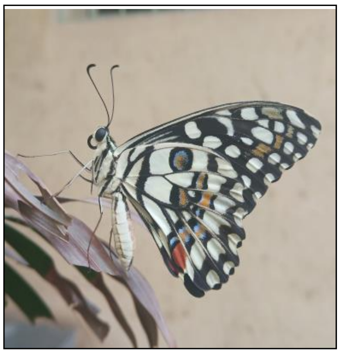
Amata sp.

Ypthima huebneri

Daphnis nerii

Eupterote mollifera

Papilio demoleus.



Melanitis leda

Ariadne merione

Delias eucharis

Trigonodes hyppasia

Eurema hecabe

Figure 1. 14: Representatives of Order Lepidoptera

Order: Hymenoptera

Xylocopa virginica

Amegilla cingulate

Eumenes sp.

Oecophylla smaragdina

Megachile sp

Xylocopa pubescens

Thyreus orbatus

Xylocopa violaceae

Apis dorsata

Tetraponera rufonigra

Chalybion californicum

Tetraloniella braunsiana

Figure 1. 15: Representatives of Order Hymenoptera

1.4 Discussion

The appreciable numbers of Insect species reported at Site I in the present study suggest that the area of Site I has suitable healthy habitat and a good assemblage of vegetation compared to other study sites. The presence of insect species was more prevalent and was found to be parallel with the growth of vegetation. Our results are in agreement with the earlier work of Mata *et al.,* (2017), who are of the view that species richness of herbivore insect groups varies with the type of vegetation volume and plant diversity. Of all the orders it was, Coleoptera, Orthoptera, Hemiptera, Lepidoptera, and Hymenoptera which were common in all the four sites and found in a more significant number of species compared to other orders, possibly due to plant biodiversity within and around crop fields, which improves habitat for insects and thus enhance ecological services in agroecosystems(Nicholls and Altieri, 2016).

Coleoptera is the most speciose group and accounts for around 40% of all described arthropod species, with an estimated 1.5 million beetle species (Stork *et al.,* 2015). The dominance of Coleoptera has been reflected in the Jurassic origin of numerous modern lineages, high lineage survival, and diversification into a wide range of niches, including utilizing all parts of plants (Hunt *et al.,* 2007). Coleoptera was the most dominant among all the Orders at all the Sites during this study. Kritika and Jaimala (2017) reported that Coleopterans are remarkably adapted to a diversified range of environmental conditions and ecosystems. In the present study, Scarab beetles were the most dominant at all the study sites. These beetles' ecological services include nutrient cycling, soil aeration, parasite suppression, secondary seed dispersal, and bioturbation. (Thakkar and Parikh, 2016; Hon, 2019) makes them the most abundant and dominant group.

Further, Chandra and Gupta (2012) while studying the diversity and composition of the dung beetle communities in Singhori Wildlife Sanctuary, have also reported that they are more dominant in agriculture than the mixed forests of the sanctuary. Scarabaeidae play an essential ecological role in agroecosystems. Studies have reported that dung removal and burial by dung beetles have many beneficial ecological consequences, especially for the removal and bury of herbivore faeces, soil fertilization and aeration (Mohammad Din *et al.,* 2015), improved nutrient cycling and uptake by plants (Yamada *et al.,* 2007), increase in pasture quality, biological control of pest flies and intestinal parasites and secondary seed dispersal (Losey and Vaughan, 2006;Costa *et al.,* 2010; Braga *et al.,* 2013) hence the dominance of Scarabaeidae is not a surprise. In the present study, an increase in richness and number of the individuals captured was most prominent in the monsoon season, which indicates their seasonal preference, which was also observed in several other studies (Nyeko, 2009; Lopes *et al.,* 2011). Our results are similar to those encountered by (Abot *et al.,* 2012), who registered a high abundance rainy season. Scarabaeidae is very sensitive to the effects of drought and usually remain underground during this period, this explains the lower abundance and richness of adult beetles in the summer season (Kritika and Jaimala, 2017; Behere *et al.,* 2017; Patole, 2019; Pompeo *et al.,* 2017; Satheesha *et al.,* 2018).

Chrysomelidae is one of Coleoptera's largest families, with about 36,000 species described worldwide (Bouchard *et al.,* 2017) and is estimated to include over 60,000 (Jolivet *et al.,* 2007). These small beetles, which are mainly herbivores and commonly found in the herbaceous and shrub layer, are closely associated with their host plants and respond to changes in environmental quality (Adelita Maria Linzmeier and Ribeiro-Costa, 2009), as well as habitat heterogeneity (Ohsawa and Nagaike, 2006; Bieńkowski and Orlova-Bienkowskaja, 2018). The Chrysomelidae assemblage from the study sites found in the present study is similar to other insect communities previously studied (Flowers, 2004; Linzmeier and Ribeiro-Costa, 2009; Linzmeier and Ribeiro-Costa, 2012; Teles *et al.,* 2019), regarding both the abundance and richness of species. The composition and distribution of the Chrysomelidae are influenced by the grass and herb cover (Sushko, 2017); in the present study also the Site I, which has a good herb and grass cover, showed a high number of this leaf beetles.

Carabidae are important biological control agents in agroecosystems and are positively correlated with grassland and has been reported to be homogeneous in many agricultural fields (Plexida *et al.,* 2014 ; Badieritakis *et al.,* 2016). With their large eyes, powerful spiny legs, and massive jaws, carabid beetles are formidable predators. They live on the surface of the soil where they capture and consume a wide assortment of soil-dwelling insects, including caterpillars, wireworms, maggots, ants, aphids, and slugs. Several ground beetles eat the seeds of troublesome weeds and are considered one of the "many little hammers" that help regulate weed populations (Leslie *et al.,* 2009); habitat and local plant diversity are considered to be the driving force for the altered diversity of carabid assemblages (Leslie *et al.*, 2014). As reported, the ground beetles from the speciose beetle family, since their emergence in the Tertiary period, have populated all habitats except deserts. Most carabids are predatory, consume a wide range of food types, and experience food shortages. Carabids are abundant in agricultural fields worldwide and are important natural enemies of agricultural pests (Holland, 2014). A good congregation of the Carabidae in the present study thus prove its beneficial role in the agricultural fields.

Coccinellid beetles are one of the better-known groups of Coleoptera, and the reason they have received considerable attention is their potential as biological control organisms (Saeed *et al.,* 2016). Predatory Coccinellidae prefers to prey on most destructive and essential crop pests, mostly the hemipteran insects. Phytophagous Ladybird species feed on leaves, flowers, and various plant parts and are considered agricultural pests. In the present study, a total of 19 species were encountered, and the majority of them were predatory; and one of the unique observations was, Coccinellidae rich agro fields were having a sparse occurrence of Hemipterans, confirming their role as predators in the agroecosystem (Khan *et al.*, 2009; Rekha *et al.*, 2009; Omkar and Pervez, 2011; Ali *et al.*, 2018; Patil and Gaikwad, 2019; Maqbool *et al.*, 2020).

Comprising approximately 5,800 genera and more than 60,000 described species (Thomsen *et al.*, 2009; Oberprieler *et al.*, 2014). Curculionoidea (weevils) have been described as one of the most successful adaptive radiations on Earth (McKenna *et al.,* 2019). The evolution of a rostrum, shifts in larval feeding habits, and co-evolutionary relationships with flowering plants have been proposed as likely explanations for their remarkable diversity (Thomsen *et al.*, 2009; Oberprieler *et al.*, 2014). Quantitative evidence has provided insights for the diversification of this phytophagous insects to be dependent on the ecological factors (Hernández-Vera *et al.*, 2019). Summing up the facts mentioned above, the assemblage of the Curculionidae in the present study at no time they were seen as aggregates at any of the sites, and our results are in agreement with the earlier reports of Singhal *et al.*, (2018), who have also reported less diversity of Curculionidae in their studies on the ecological role of cryptic Coleopteran species of Vadodara district. Other families of coleopterans were significantly less in number, and the majority of them were pests (Cerambycidae, Meloidae, Buprestidae, Tenebrionidae, and Elateridae); their distribution and its correlation with the plants have been well explained in the following chapters.

Orthoptera which includes crickets and their allies in the suborder Ensifera. They are the oldest living group of chewing herbivorous insects, observed from the early Triassic around 250 million years ago. The powerful hind legs of these ground-dwelling insects enable them to escape from threats by leaping vigorously. Some grasshopper species can change color, behavior, and form swarms at high population densities under certain environmental conditions. Orthopteriod insects are an essential component of the fauna of many ecosystems in particular grasslands.

Orthopterans are sensitive bioindicators in the assessment of habitat quality and environmental changes (Bazelet and Samways, 2011; Fartmann *et al.,* 2012). It is generally established that the diversity and abundance of grasshopper populations are influenced by the availability of host plants, weather patterns, and location (Whipple *et al.,* 2012; Shah *et al.,* 2018). The highest species abundance of Orthopterans was recorded at site IV and was found to be monsoon dominant. The maximum population observed during monsoon was probably associated with the maximum vegetative growth during that period (Shah *et al.,* 2018). Seasonal fluctuations are one of the main threats to orthopterans, as rainfall plays a vital role in vegetative growth, the richness and the abundance of this herbivorous insects will be affected (Awmack and Leather, 2002). Thus the reduction in orthopteran diversity during the summer and winter season compared to the more number during the monsoon season is possibly due to the vegetation structure(Ananthaselvi *et al.,* 2009; Kuruvila *et al.,* 2019). The Present data also revealed that three families: Acrididae, Tettigonidae, and Gryllidae out of eight families were found to be rich and more diversified, particularly at site IV (Padra). Acrididae species prefer habitats with a variety of host plants, including both grasses and broadleaf weeds. As a result, they prefer crop land settings with nearby undisturbed areas crop borders, and over-grazed pastures or rangeland.

Further, they have also been reported to be the major pest of Rice and wheat fields. Studies of the diversity of insect pests in major rice growing areas of the world have been well explored by Gangurde, (2008) in Philippines, by Bambaradeniya and Edirisinghe, (2009) in Sri Lanka, by Nasiruddin and Roy, (2012) in Bangladesh, and by Asghar *et al.,* (2013) in Pakistan, and have reported the dominance of Acrididae in the paddy fields. Vegetation wise Padra has a greater number of fodder grass growing, paddy and wheat, millet fields in addition to the vegetable fields, their dominance and richness is self-explanatory. Additionally, our observations are parallel with the reports of Bhusnar (2015) from Maharashtra, Thakkar et al. (2015) from Gujarat, and Pervaiz *et al.,* (2017) from Pakistan.

Hymenopterans are a few mega-diverse insect orders and play a pivotal role in pollinators in the agricultural ecosystem, especially orchard and floriculture. Most hymenopterans show a great diversity of habits and complexity of behavior, such as social organization (Hiremath and Ganesh, 2016). Hymenoptera is essential for understanding entomophagous habits because they are numerically large and biologically diverse, with all forms of phytophagy, predation, and parasitism expressed within each lineage(Silva and Silveira, 2009). The upsurge interest in Hymenopterans as bioindicators of ecosystem dynamics stems from the recognition that they respond to ecosystem disturbance, and therefore, have become an integral part of monitoring faunal changes with grazing by livestock agricultural practices (Anderson *et al.,* 2008; Jiménez-Soto *et al.,* 2013).

The present study showed that the hymenopteran fauna in vegetable crops was diverse, and the population fluctuated with seasons. Hymenopteran insects were abundant during the monsoon months in both the study years; during these months, the temperature falls below 25^{o}C, and plants and weeds around the agroecosystems flourish well monsoon rain. Due to the availability of abundant nectar and host insects, the parasitoids which included families such as Chrysididae, Ichneumonidae and Vespidae, as well as predators which includes Sphecidae are the possibly playing the role in preventing undue increase of noxious species thereby helping the biological control of various insect pest (Thakkar and Parikh, 2018). The abundance of Formicidae in the present study at all the sites suggest their role as scavengers helping in enriching and ecological fertility (Tangmitcharoen *et al.,* 2006). The good assemblage of Apidae as pollinators indicate a healthy ecosystem (Aguirre and Dirzo, 2008). This order stands out for its greater diversity, utilizing the environment fully and at the same time controlling other insects as noted down by (Taye *et al.,* 2017; Forbes *et al.,* 2018). The abundance of families (formicidae, Sphecidae) at all the sites may be attributed to the admirable availability of the host insects, which in turn may be due to increased floristic diversity (Kannagi *et al.,* 2013; Anbalagan *et al.,* 2015; Thakkar and Parikh, 2018; Haldhar *et al.,* 2018).

Lepidoptera plays a vital role in the pollination and is considered ecosystem engineers; their diversity increases with habitat scale and vegetation structure complex. The Lepidoptera are among the largest groups of insects with great diversity and have different ecological services (Summerville and Crist, 2008; Pereira *et al.,* 2008). The abundance of lepidopterans may be influenced by habitat type (Robinson *et al.,* 2012; Soumya *et al.,* 2017). However, many species are a severe pest in the larvae stage (Salunke and More, 2017). Lepidopteran diversity was reported maximum during monsoon season and was found to decline during winter and summer, possibly with a change in temperature. The reason being for such a trend is that during these seasons, there are the factors that influence the growth of nectar plants, which have a direct impact on the Lepidopteran species (Ramesh *et al.,* 2010; Kathirvelu and Nadu 2018; Paul and Sultana 2020). Field margins are typical semi-natural habitats that are often vegetated with grasses and herbs. Because most caterpillars are herbivores, and a majority of adult moths (and butterflies) visit flowering plants, field margins are a potential habitat for Lepidoptera, especially in agriculture-intensive regions (Hahn *et al.,* 2015). Diversity of adult moths and butterflies were sighted at the field margins of the agriculture fields, which are the most suitable habitat for them (Han *et al.,* 2015).

Hemiptera, the largest non-holometabolous order of insect, has highly specialized morphological adaptations, have explored varied habitats and food sources. In the present study, the contribution of Hemiptera makes it the fifth most speciose insect order to agricultural biodiversity. Although most Hemiptera are herbivorous, the group exhibits a wide spectrum of feeding habits, including predators, fungivores, and parasites. Even within the herbivores there is great variation owing to different host specificity levels, with some species highly monophagous (feeding only from one species of plant), through to species that are highly polyphagous (feeding from different families of plants). The abundance of Coreidae in the present work suggests their contribution to natural and applied biological control of other pests (Torres and Boyd, 2009). Aphidoidea and Coccidae are considered to be the most vulnerable pests of the agriculture, however in the present study both the families were having less representatives suggestive of the indiscriminate use of the pesticides for their elimination by the farmers (Moir and Brennan, 2009). The occurrence of Hemipterans at all the Sites portrays their hyper diversity, associated with plants, floristic composition, and heterogeneous vegetation structure (Moir and Brennan, 2009; Gessé *et al.*, 2014; Li *et al.*, 2017) and their tight ecological interactions with the plants(Kumar and Naidu 2010; Kataria and Kumar 2012). Post –monsoon and pre-winter were the most favoured season , and as reported (Das and Gupta 2012; Gupta and Pathania 2017) seasonal variation in the diversity of Hemiptera has a strong correlation with the biotic factors, which can be confirmed by studying ecological aspects on Hemiptera.

Dipterans are among the most highly specialized members of the class insect. No other insects present so great a diversity of habit and habitat as the Dipterans, and this is the reason why general biologists, parasitologists, medical and veterinary doctors pay serious attention to these insects. They play essential ecological and economic roles either as scavengers/predators (Muscidae and Psychodidae), vectors (Culicidae), predators (Diopsidae), food sources for higher organisms. With the most adaptive capability, the Dipterans have accommodated themselves to every situation of breeding and colonization. As an often neglected but important group of pollinators, they play a significant role in agrobiodiversity and the biodiversity of plants everywhere and as important pollinators, as biocontrol agents also illustrates their double importance for agriculture. (Parikh *et al.,* 2008; Ssymank *et al.,* 2011; Orford *et al.,* 2015).Dipterans respond quickly to a new food or other resources and recover rapidly from unfavourable conditions, so they are found in abundance, ubiquity, and diverse in every condition of the ecosystem(Souza *et al.,* 2014; Adler and Courtney, 2019). The profusion of Dipteran flies has been reported to be heavily dependent on the presence of host plant, flowers, and food for both adult and larvae (Potts *et al.,* 2003); besides this, abiotic factors such as temperature and humidity also play a vital role in abundance and distribution of these flies. The fluctuation in population size of Dipetrans through different seasons observed in the present study thus are self-explanatory and are in accordance with the work of (Guruprasad *et al.,* 2010), who have suggested a close relationship between population density with the monsoon season.

Odonata (dragonflies and damselflies) are well-known but often poorly understood insects. Although not considered high economic importance, they do provide esthetic/spiritual benefits to humans and have some impact as predators of disease vectors and agricultural pests. Besides, their larvae are essential as intermediate or top predators in many aquatic ecosystems (May, 2019). Odonata is a bridge between ecology and evolutionary genomics. These fast-flying insects are incredibly manoeuvrable and do an excellent job of naturally controlling the numbers of many unwanted insects, including mosquitoes, flies, and ants (Bybee *et al.,* 2016).

Due to their highly specific niche, they are susceptible to environmental alterations (Dangles *et al.,* 2009; Silva *et al.,* 2014; Adarsh *et al.,* 2014; Rathod, 2015; Elanchezhyan *et al.,* 2017). Although Odonates occur in almost all aquatic ecosystems, microhabitat with high heterogeneity of vegetation is believed to be the factor primarily responsible for determining their diversity and distribution (P. Parikh & Sonavane, 2010). A total of four families (Coenagrionidae, Libellulidae, Aeshinidae, Gomphidae) were observed, and their maximum assemblage was obtained at Site I (Ajwa), where the agriculture fields were found to have the water bodies in their surroundings, which was well supported by short and tall grasslands, emergent vegetation, free-floating emergent vegetation as well as the open area - the most preferred habitat of Odonates. Our results are in accordance with the work of many scientists who have reported a good diversity of Odonates in the water bodies of from Kerala Adarsh *et al.,* (2014), Elanchezhyan *et al.,* (2017) from Tamil Nadu, and by Baruah and Saikia (2015) from Assam. Peak activity of the Odonates occur by the post monsoon season (Narender *et al.,* 2016); in the present study, there was a remarkable seasonal abundance of Odonates during post monsoon period seen in large numbers towards the end of the monsoon season, due to their peak activity (Narender *et al.,* 2016). Sparse numbers of Odonates during the winter season may be due to their relocation to the protected perches for wanting warmth (Tiple and Koparde, 2015; Kulkarni and Subramanian, 2013; Rathod *et al.,* 2016).

In the ecosystem, the diversity index indicates the diversity of a community and is a value that can assess fauna diversity in a particular area. The diversity index depends on two parameters: the number of species and their evenness in each species (Daly *et al.,* 2018). The Shannon Index of Diversity is considered the full measure of diversity because it considers both species' numbers and abundance. In the present study, the overall distribution of insects over time and space was statistically analysed.

The present study provides that the different seasons markedly influenced the species richness, abundance, diversity, and evenness of insects. Species richness, abundance, and diversity of insects were higher in the rainy season, followed by summer and winter. However, distribution was more even in winter as compared to rainy and summer seasons. A similar pattern of observations has also been recorded earlier in different ecosystems. Arun and Vijayan, (2004) compared the pattern of seasonal fluctuations in insect abundance among different habitats and are of the opinion that the composition of the insect community varies highly among seasons than among habitats. Seasonal variations affect microclimatic conditions and the availability of resources, which predict insect population dynamics (Adedoja and Kehinde, 2017). An even distribution of entomofauna in the agriculture fields of Vadodara can be attributed to the excellent availability of the food, which can translate into an increased output and population densities of insects (Choi and Jung, 2015). Further, this also explains the high abundance of the insects recorded in the monsoon and post-monsoon season. The temporal variation on abundance, species richness, and diversity of insects can be attributed to the extreme rains in the year 2018-19 compared to 2017-18, which implies that the agriculture lands were prone to fluctuations in microclimatic conditions, which could have cascading effects on the entomofauna communities in these habitats (Checa *et al.*, 2014). Thus, from the present work, overall, it can be summarized that the agricultural fields of Vadodara are rich in entomofauna and that it has a strong influence on the season.

1.5 Conclusion

This work concludes that Site I was the most dominant Site in insect diversity and richness among the four selected sites. The astonishing number of the insects in this Site was not surprising as grasslands and plenty of vegetation dominate this area. The study also acquired the species occurrence in the three main seasons, and the result showed the richness of species in the monsoon season. The results presented in this report might be the first comprehensive list of insects in these areas. It is evident that insects contribute much to ecological welfare; therefore, insect conservation has been recognized as vital for a sustainable world because of their critical role in conserving the ecosystem. This study is also derived that insects' pest status of the agricultural fields of Vadodara.