ASSESSMENT OF DIVERSITY MEASURES OF BIOLOGICAL HETEROGENEITY USING INSECTS ATTRACTED TO LIGHT

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Thesis submitted to the

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inpartial fulfillment of the requirements
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BANGALORE **JULY, 2017**

Affectionately
Dedicated

To My Wife Angelina
Matata and Sons
Brian Kimanthi and
Fabian Kimondiu and
Daughter
DelphinaNdithya

DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE
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CERTIFICATE

This is to certify that the thesis entitled "**ASSESSMENT OF DIVERSITY MEASURES OF BIOLOGICAL HETEROGENEITY USING INSECTS ATTRACTED TO LIGHT"** submitted in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in **FORESTRY AND ENVIRONMENTAL SCIENCE** to the University of Agricultural Sciences, GKVK, Bengaluru, is a record of bonafide research work done by **Mr. JOSHUA MATATA KIMONDIU** during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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Bangalore
July, 2017 *Joshua MatataKimondiu*

ASSESSMENT OF DIVERSITY MEASURES OF BIOLOGICAL HETEROGENEITY USING INSECTS ATTRACTED TO LIGHT

ABSTRACT

A study was undertaken to assess (a) temporal patterns of insect activity and diversity, (b) evaluate the measures of biological diversity and, (c) identify possible indicator groups of total insect diversity in an agroecosystem at GKVK Campus, University of Agricultural Sciences, Bengaluru. The study used light traps to collect insects from 8th May, 2015 to 6th December, 2016 at 21 day intervals. A total of 209,098 individuals belonging to 764 morpho-species or Operational Taxonomic Units (OTUs), representing 101 families from 12 orders were collected. The Simpson's index of diversity was 0.9732, the Shannon-Wiener index was 4.4443 and Avalanche index was 1.1693. Five orders, *viz.*, Coleoptera, Hemiptera, Lepidoptera, Diptera and Hymenoptera dominated the collections. The relative proportions of these five orders at GKVK agroecosystem were different from those of the global and Indian insect communities; Coleoptera was over represented at GKVK while Lepidoptera, Diptera and Hymenoptera were under represented. Order Coleoptera was found to be a good indicator of the total insect diversity and this perhaps is because it was the most predominant component of the collections. The study recommends that light traps may be used for addressing broad ecological questions and to estimate the total insect diversity. While Simpson and Shannon-Weiner indices were strongly correlated with the species richness, Avalanche Index (AI) was not; probably because the biological heterogeneity that AI captures was not strongly reflected in species richness.Insect diversity and abundance was higher during summer and post monsoon and less during winter and rainy seasons. Rainfall and relative humidity over three days negatively affected the insect diversity and activity. Temperature cumulated over three week period negatively impacted the species richness though the abundance was not affected. Width of body increased with length at higher rate in Coleoptera and Hemiptera than Hymenoptera and Diptera suggesting that the former tend to become broader than the later. Coleoptera also had higher rate of increase in body weight with length probably due to the elytra. We have argued that insects adopt varying degrees of the two competing strategies for their protection: Thickening of forewing and adoption of flight agility. While Coleoptera and Hemiptera adopt the former, the Lepidoptera, Diptera and Hymenoptera adopt the later strategy.

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July, 2017

ಬೆಳಕಿಗೆ ಆಕರ್ಶಿತಗೊಳ್ಳುವ ಕೀಟಗಳ ಮೂಲಕ ಜೀವವೈವಿಧ್ಯ

ಸೂಚಕಗಳ ಮೌಲ್ಯಮಾಪನ

ಸಾರಾಂಶ

ಬೆಳಕಿಗೆ ಆಕರ್ಷಿತಗೊಳ್ಳುವ ಕೀಟಗಳ ಸಮೂಹವನ್ನಾಧರಿಸಿ ಮೂರು ವಿಭಿನ್ನ ವಿಷಯಗಳ ಅಧ್ಯಯನವನ್ನು ಕೈಗೊಳ್ಳಲಾಯಿತು: (ಅ) ಋತುಗಳು ಬದಲಾದಂತೆ, ಕೀಟಗಳ ಸಂಕ್ಯೆ ಮತ್ತು ಪ್ರಭೇದಗಳ ವೈವಿಧ್ಯತೆಗಳಲ್ಲಿ ಕಂಡು ಬರುವ ಪ್ರಕಾರಗಳು, (ಆ) ಜೀವವೈವಿಧ್ಯತೆಯನ್ನು ಅಳೆಯಲು ಉಪಯೋಗಿಸುವ ಸೂಚಕಗಳ ಮೌಲ್ಯಮಾಪನ, ಹಾಗೂ, (ಇ) ಇಡೀ ಕೀಟಸಂಕುಲದ ವೈವಿದ್ಯತೆಯನ್ನು ಸೂಚಿಸಬಲ್ಲ ಏಕೈಕ ಕೀಟಕುಲಕ್ಕಾಗಿ ಹುಡುಕಾಟ. ಇದಕ್ಕಾಗಿ, ಬೆಂಗಳೂರಿನ ಕೃಷಿ ವಿಶ್ವವಿಧ್ಯಾನಿಲಯದ ಗಾಂದಿ ಕೃಷಿ ವಿಜ್ಞಾನ ಕೇಂದ್ರ(ಜಿಕೆವಿಕೆ)ದ ಕೃಷಿ–ಪರಿಸರದಲ್ಲಿ 2015, ಮೇ 8ರಿಂದ, 2016, ಡಿಸೆಂಬರ್ 6ರವರೆಗೆ, 21 ದಿನಗಳ ಅಂತರದಲ್ಲಿ ರಾತ್ರಿಯ ವೇಳೆ ಬೆಳಕಿನ ಬಲೆಯನ್ನು ನೆಲೆಗೊಳಿಸಿ ಅಲ್ಲಿ ಆಕರ್ಶಿತಗೊಂಡ ಕೀಟಗಳನ್ನು ಸಂಗ್ರಹಿಸಲಾಯಿತು. ಆ ಕೀಟ ಸಂಗ್ರಹದಲ್ಲಿ ದೊರಕಿದ 2,09,098 ಕೀಟಗಳಲ್ಲಿ 764 ಭಿನ್ನವಾದ 'ಸೂಚಕ ಪ್ರಭೇದ' (OTU)ಗಳು ದೊರಕಿದ್ದು, ಇವು 12 ಶ್ರೇಣಿಗಳ 101 ಕುಲ ಅಥವ ಕುಟುಂಬಕ್ಕೆ ಸೇರಿದ್ದವು. ಅವುಗಳಲ್ಲಿನ ಸಂಪೂರ್ಣ ವೈವಿಧ್ಯತೆಯು, 'ಸಿಂಪ್ಸನ್' ಸೂಚಕದಂತೆ, 0.9732 ಇದ್ದರೆ, ಶಾನಾನ್ ಸೂಚಕದಂತೆ 4.4443, ಹಾಗು, ಅವಲಾಂಚ್ ಮಾಪಕದ ರೀತ್ಯ 1.693 ಇತ್ತು. ಕೋಲಿಯೋಪ್ಟೆರ (ದುಂಬಿಗಳು; Coleoptera), ತಿಗಣೆಗಳು (Hemiptera), ಚಿಟ್ಟೆಗಳು (Lepidotera), ನೊಣಗಳು (Diptera), ಹಾಗೂ ಕಣಜ ಮತ್ತು ಜೇನು ನೊಣಗಳ (Hymenoptera) ಶ್ರೇಣಿಗಳು ಇತರೆ ಎಲ್ಲ ಶ್ರೇಣಿಗಳಿಗಿಂತ ಹೆಚ್ಚಿನ ಸಂಕ್ಯೆಯಲ್ಲಿದ್ದವು. ಭಾರತ ಮತ್ತು ಪ್ರಪಂಚದ ಕೀಟ ಸಮುದಾಯಕ್ಕೆ ಹೋಲಿಸಿದಾಗ, ಜಿಕೆವಿಕೆಯಲ್ಲಿ ಕೋಲಿಯೋಪ್ಟೆರ ಶ್ರೇಣಿಯ ವೈವಿಧ್ಯತೆ ಹೆಚ್ಚಿತ್ತು, ಹಾಗೂ ಕೋಲಿಯೋಪ್ಟೆರ ಕೀಟಗಳ ಸಂಕ್ಯೆ ಸಮಗ್ರ ಕೀಟಗಳನ್ನು ಸ್ಪಷ್ಟವಾಗಿ ಬಿಂಬಿಸಬಲ್ಲ ಶ್ರೇಣಿ ಎಂದು ಕಂಡು ಬಂದಿತು. ಕೀಟ ಸಮುದಾಯದಲ್ಲಿ ಪರಿಸರದ ಹಾಗೂ ಜಾಗತಿಕ ಮಟ್ಟದಲ್ಲಾಗುವ ಬದಲಾವಣೆಗಳನ್ನು ಪ್ರತಿಬಿಂಬಿಸಲು ಬೆಳಕಿಗೆ ಆಕರ್ಶಿತಗೊಂಡ ಕೀಟಗಳನ್ನು ಸಾವಕಾಶವಾಗಿ ಉಪಯೋಗಿಸಬಹುದೆಂದೂ ಸೂಚಿಸಬಹುದು. ಸಿಂಪ್ಸನ್ ಮತ್ತು ಶಾನನ್ ವೈವಿದ್ಯ ಸೂಚಕಗಳು ಪ್ರಬೇದಗಳ ಸಿರಿವಂತಿಕೆಯನ್ನು ಸ್ಪಷ್ಟವಾಗಿ ಸೂಚಿಸುತ್ತಿದ್ದವು ಆದರೆ ಅವಲಾಂಚ್ ಸೂಚಕವು ಜೀವಾಂತರ ಬಿನ್ನೆ ತೆಯನ್ನು ಕೂಡ ಸೂಚಿಸುವುದರಿಂದ ಅದು ಪ್ರಬೇದ ಸಿರಿವಂತಿಕೆಯನ್ನು ಸ್ಪಷ್ಟವಾಗಿ ಬಿಂಬಿಸಲಿಲ್ಲ. ಕೀಟ ವೈವಿಧ್ಯತೆ ಮತ್ತು ಅವುಗಳ ಸಂಕ್ಯಾಪ್ರಮಾಣಗಳು, ಬೇಸಿಗೆ ಮತ್ತು ಮಳೆಯ ನಂತರದಲ್ಲಿ ಅಧಿಕವಾಗಿದ್ದು, ಮಳೆಗಾಲದಲ್ಲಿ ಮತ್ತು ಚಳಿಗಾಲದಲ್ಲಿ ಕುಂಟಿತಗೊಂಡಿದ್ದವು. ಸಂಗ್ರಹದ ಹಿಂದಿನ ಮೂರುದಿನಗಳ ಒಟ್ಟು ಮಳೆ ಮತ್ತು ತೇವಾಂಶವು ಕೀಟ ವೈವಿದ್ಯತೆಯನ್ನು ಕುಂಟಿತಗೊಳಿಸಿದರೆ, ಮೂರು ವಾರಗಳ ಒಟ್ಟು ಉಷ್ಣಾಂಶವು ವೈವಿದ್ಯತೆಯನ್ನು ಹೆಚ್ಚಿಸುವುದೆಂದು ಕಂಡುಬಂತು. ಕೋಲಿಯೋಪ್ಟೆರ, ಮತ್ತು ತಿಗಣೆ ಶ್ರೇಣಿಗಳಲ್ಲಿ ಶರೀರದ ಉದ್ದ ಹೆಚ್ಚಾದಂತೆ, ಅದರ ಅಗಲವೂ ಹೆಚ್ಚಾದರೆ, ನೊಣ, ಕಣಜ ಮತ್ತು ಜೇನು ನೊಣಗಳಲ್ಲಿ ಶರೀರದ ಅಗಲವು ಸಣ್ಣದಾಗಿಯೇ ಉಳಿದು ಅವು ಹಾರಲು ಸಹಾಯ ಮಾಡುತ್ತದೆಂದು ಕಂಡುಬಂದಿತು. ಹಾಗೆಯೇ ಕೋಲಿಯೋಪ್ಟೆರದಲ್ಲಿ ಶರೀರದ ಉದ್ದದ ಜೊತೆಗೆ, ತೂಕವೂ ಹೆಚ್ಚಿತ್ತು. ಈ ಮಾಹಿತಿಯನ್ನಾಧರಿಸಿ, ಕೀಟಗಳು ತಮ್ಮ ರಕ್ಷಣೆಗೆ ಎರಡು ವಿಭಿನ್ನ ರೀತಿಯ ತಂತ್ರಗಳನ್ನು ಅಳವಡಿಸಿಕೊಂಡಿವೆ ಎಂದು ವಾದಿಸಬಹುದು: ಕೋಲಿಯೋಪ್ಟೆರ, ತಿಗಣೆ ಮುಂತಾದ ಶ್ರೇಣಿಗಳು ತಮ್ಮ ಮುಂದಣ ರೆಕ್ಕೆಗಳನ್ನು ಬಲಿಷ್ಟಗೊಳಿಸಿಕೊಂಡಿದ್ದರೆ, ಚಿಟ್ಟೆ, ಕಣಜ ಮತ್ತು ನೊಣಗಳಲ್ಲಿ ತೆಳುವಾದ ರೆಕ್ಕೆ ಮತ್ತು ನೀಳವಾದ ಶರೀರದಿಂದಾಗಿ ಹಾರುವ ಕುಶಲತೆಯನ್ನು ರೂಡಿಸಿಕೊಂಡಿವೆ ಎನ್ನಬಹುದು.

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I INTRODUCTION

Biodiversity is the sum total of all biotic variation from the level of genes to ecosystems. The current loss in biodiversity and degradation of natural habitats emphasize the need to take inventory of species and to monitor changes in diversity. Consequently, the recent interest in conservation of biodiversity has raised serious discussion on the tools and techniques for assessing the richness and on the heterogeneity of biological systems.

Diverse methods have been developed to assess biological diversity but as yet there is no consensus either on the techniques of sampling the biological systems, or on tools used for measuring the diversity of insects. In fact this subject has become highly confusing with poor terminology and array of measures or indices (Chiarucci, 2012; Magurran and McGill, 2011). Many different measures (or *indices*) of biodiversity have been developed that attempt to quantify the diversity of biological communities (Magurran, 2004). The most popular and widely used measures are Shannon's, Simpson's, Fisher's alpha-log series and Avalanche indices (Ganeshaiah *et al.,* 1997; Van Valen, 1979). However, a great deal of disagreements exists between these indices over their efficiencies in reflecting biological diversity (Ganeshaiah *et al.,* 1997; Magurran, 1988).

For long, biodiversity assessment has been using `species' as the taxonomic unit irrespective of their affiliation to higher taxonomic level. In fact, Shannon, Simpson and Fisher's alpha –log series indices assume that all species within and across systematic groups contribute equally to its biodiversity. However,Ganeshaiah*et al.* (1997); Magurran (1988); Williams and Humphries (1996) have pointedout that assessment of biological diversity purely on the basis of species richness may not be a satisfactory method especially when habitats are to be compared, because habitats with a similar species richness may differ in several biological features such as (a) taxonomic diversity at higher level, (b) genetic and morphological diversity,(c) ecological function of the species, and (d) evolutionary and conservation significance of the species. Unfortunately, all these are generally ignored when the biological diversity is estimated using merely species as the units.

Therefore, a few alternate indices have been suggested by Ganeshaiah *et al.* (1997), Van valen (1979) and Gore *et al.* (2001). Among these, Avalanche Index developed by Ganeshaiah *et al.* (1997) tries to incorporate the diversity at all levels of taxonomic hierarchy and has been found useful in comparing habitats. Blackmore, (1996), Humphries *et al.* (1995), May (1988), Magurran (1988) and Raven and Wilson (1992) concur that measures of biodiversity provide the base-line information on distribution, richness, and relative abundance of taxa required for conservation decisions, studies of ecosystems ecology, cladistic biogeography, and phylogenetic measures of conservation value. Pearsall *et al.* (1986), Fuller and Langslow (1986) and Usher (1986) suggest that species richness in particular is an increasingly important statistic in conservation evaluation.

Another important component that influences the measurement of biological diversity is the sampling methodology. Owing to the fact that the living systems differ widely in their size, distribution, ecology and behavior, it is difficult to arrive at sampling methods common to all. At the same time, for a given taxanomic group of insects also, there are no defined sampling techniques: within plants, there are diverse sampling tools for herbs, shrubs, climbers and trees, all of which cannot be extended to the other lower taxa of plants. Similarly, given the behavioural and ecological diversity of insects it has not been possible to arrive at common sampling techniques. However, given that sampling is the basis for assessing the diversity across space and time, it is important to arrive at some commonly agreed upon techniques of sampling such that the estimates by different studies become comparable (Kremen *et al.,* 1993; Heywood, 1995; Humphries *et al.,* 1995; Stork and Samways, 1995; Yoccoz *et al.,* 2001; Coscaron *et al.,* 2009). Further, these sampling techniques need to be simple, adequate and most effective (Southwood and Henderson, 2000; Magurran, 2004).

Analysis of community structure offers insights into many ecological issues. Species composition, seasonal activity of different species, temporal changes in the composition and community parameters need attention. Such studies help raise many ecologically and evolutionarily relevant questions for broader understanding of the fauna. Comprehensive studies of a broader group of taxa involved also help formulate new

hypotheses to pursue research in ecology and evaluation and for better management of organisms in their own natural world (Aparna, 2015).

Considering their immense contribution to the world's biota, any general explanation of diversity should account for patterns in insects (MacArthur, 1965). The advantage of working with mega diverse taxa is that they surely exhibit many repeated patterns, which can be used as clues to underlying processes. But tracking insect species richness is challengingthis group is always underestimated.

In this background, the present study was undertaken with a view to assess the effectiveness of light traps as a method of sampling insects. The study also aimed at identifying the indicator taxonomic group that reflects the total diversity of insects, assess temporal patterns in taxonomic diversity of insect groups and the drivers of the observed temporal patterns. In particular the study aimed at addressing the following objectives:

1. To evaluate different indices of diversity as measures of biological heterogeneity using light trapped insects
2. To assess relative differences among the diversity indices in measuring diversity of different groups of insects
3. To identify the indicator taxonomic group that reflects the total diversity of insects
4. To assess temporal patterns in taxonomic diversity of insect groups
5. To identify the drivers of the observed temporal patterns

II REVIEW OF LITERATURE

2.1 Biodiversity

Although the word 'biodiversity' might be familiar to many, its definition is often subject to individual interpretation. Abraham Lincoln grappled with a similar concern over the word 'liberty'. In an 1864 speech, Lincoln opined, 'The world has never had a good definition of the word liberty, and the American people, just now, are much in want of one ... but in using the same word we do not all mean the same thing' (Simpson, 1998).

Hubbell (2001) defines biodiversity to be "synonymous with species richness and relative species abundance in space and time." According to Magurran (2004) biodiversity is simply "the variety and abundance of species in a defined unit of study."

To the layperson, Gaston (1996), affirms that 'biodiversity' might conjure a forest, a box of beetles, or perhaps the entire fabric of life. Among scientists, the word has been defined, explicitly and implicitly, ad nauseum, producing a range of variants. In its original context, the term 'biodiversity' encompassed a broad range of topics (Wilson, 1988), and we embrace that perspective that biodiversity, then, is big biology, describing a holistic view of life.

Additional definition by Faith (1995), biodiversity is 'the variety of all forms of life, from genes to species, through to the broad scale of ecosystems'. The fundamental units of biodiversity – species – serve as focal points for studying the full panoply of life, allowing workers to zoom in and out along a scale from molecule to ecosystem.

The species-centered view also provides a vital focus for conserving life forms and understanding the causes of declining biodiversity. Despite disagreements over issues ranging from definitions of biodiversity to phylogenetic approaches, biologists can agree on five major points. (1) The world supports a great number of insects. (2) We do not know how many species of insects occupy our planet. (3) The value of insects to humanity is enormous. (4) Too few specialists exist to inventory the world's

entomofauna. (5) By virtue of the sheer numbers of individuals and species, insects, more than any other life form, command the attention of biologists.

According to Williams (1964) the number of individual insects on earth at any given moment has been calculated at one quintillion an unimaginably large number on par with the number of copepods in the ocean and roughly equivalent to the number of sand grains along a few kilometers of beach(Schubel and Butman, 1998). The total number of insect species similarly bankrupts the mind. Estimates offered over the past four centuries have increased steadily from 10,000 species to as many as 80 million (Erwin, 2004).

Harper and Hawksworth (1995) point out that Norse *et al.*(1986) werethe first to explicitly dissect biological diversity into three components: genetic diversity (within species diversity), species diversity (number of species) and ecological diversity(diversity of communities).

The United Nations Environment Programme defines Biological Diversity as: "The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Heywood, 1995). Biological diversity can be portioned into two components: species richness and evenness (Simpson, 1949). The term "species richness" was coined by Mc Intosh (1967) and refers to the number of species in a unit of study. "Evennes" describes the variability in species abundances.

Biodiversity is in essence a comparative science becasuse the researcher would wish to establish if one domain is more diverse than another or whether the diversity has changed overtime due to processes such as succession or enrichment. However, the entities and scales to be used in comparison tends to present a chain of challenges.

2.1.1 Importance of biodiversity

The 1992, Rio Earth Summit marked a sea change in emphasis of biodiversity. Biological diversity was no longer the sole concern of ecologists and environmental

activists but instead became a matter of public preoccupation and political debate. Many people outside the scientific community are now conscious that biodiversity is being eroded at an accelerating rate even if few fully comprehend the magnitude of the loss. It has been estimated that around 50 per cent of all species in the range of mammal, bird and reptiles will be lost in the next 300-400 years (Mace, 1995) while on average, only a handful of species evolve each year at a rate of three species per year (Sepkoski, 1999) and extinction rates may be as great as three species per hour (Wilson, 1992).

2.1.1.1 Species diversity

Species diversity refers to the measure of diversity in an ecological community. Species diversity takes into consideration species richness, which is the total number of different species in a community. It also takes into account evenness, which is the variation of abundance in individuals per species in a community. Communities with more species are considered more diverse than those with fewer. A community with less variation in the relative abundance of individuals per species is considered more even than one with more variation. Communities that are more even are also said to be more diverse. Several mathematical equations exist that incorporate evenness and abundance to measure species diversity (Magurran, 2004).

2.1.1.2 Genetic Diversity

Genetic diversity is the total number of genetic characteristics in the genetic makeup of a species. It is distinguished from genetic variability, which describes the tendency of genetic characteristics to vary. Genetic diversity serves as a way for populations to adapt to changing environments. With more variation, it is more likely that some individuals in a population will possess variations of alleles that are suited for the environment. Those individuals are more likely to survive to produce offspring bearing that allele. The population will continue for more generations because of the success of these individuals (Magurran, 2004).

According to Nevo (2001), genotypic and phenotypic diversity have been found in all species at the protein, DNA, and organismal levels; in nature, this diversity is nonrandom, heavily structured, and correlated with environmental variation and stress.

The interdependence between genetic and species diversity is delicate. Changes in species diversity lead to changes in the environment, leading to adaptation of the remaining species. Changes in genetic diversity, such as in loss of species, leads to a loss of biological diversity.

2.1.1.3 Ecological Diversity

Though synonymous with biodiversity in its broadest sense, Harper and Hawksworth (1995) are for the opinion that it is associated with the diversity of communities (or ecosystems) and covers matters such as the numbers of tropic levels, the range of life cycles and the diversity of biological resources as wellas the the variety and abundance of species.

The invertebrate fauna is less well documented and many new species undoubtedly await discovery and description. Appealing taxa e.g. birds and butterflies tend to be the most comprehensively studied and recorded as opposed to difficult to identify and lesser popular organisms that are challenging due to uncertainty, frustrating and require an increase in sampling efforts. The members of the class Insecta are arranged in 29 orders (Grimaldi and Engel, 2005; Arillo and Engel, 2006). Four of these orders – the Coleoptera, Diptera, Hymenoptera, and Lepidoptera – account for 81 per cent of all the described species of living insects with beetles leading as the largest order.

2.1.2 Concepts of species diversity

According to Whittaker (1972), tropical areas are said to have contained more species of plants and animals than did temperate areas. To describe and compare different communities, ecologists broke the idea of diversity down into three components –alpha, beta, and gamma diversity. Alpha diversity is local diversity (the diversity of spatially defined units), the diversity of a forest stand, grassland, or a stream. At the other extreme is gamma (γ) diversity, the total regional diversity of a large area that contains several communities. Beta (β) diversity is a measure of how different community samples (differences in the compositional diversity of areas of α- diversity) are in an area or along a gradient like from the headwaters of a stream to its mouth, or from the bottom of a mountain to the top. Beta diversity links alpha and gamma diversity, or local and regional

diversity. As ecological ideas about diversity matured and ideas of quantitative measurement were introduced, it became clear that the idea of species diversity contains two quite distinct concepts.

2.1.2.1 Species Richness

McIntosh (1967) coined the name species richness as theoldest and the simplest concept of species diversity - the number of species in the community or the region. The basic measurement problem is that it is often not possible to enumerate all of the species in a natural community or region, particularly if one is dealing with insect communities or tropical plant assemblages. However, Magurran (2004) maintains that the focus on species as a common currency for diversity measurement is paramount. The question of "how many species" should not preclude phylogenetic information and relative abundance in the estimation of species richness.

2.1.2.2 Heterogeneity

The term heterogeneity was first applied to species diversity concept by Good (1953) and for many ecologists this concept is synonymous with diversity (Hurlbert, 1971). To address the concept of heterogeneity, Simpson (1949) proposed a second concept of diversity which combines two separate ideas, species richness and evenness.

2.1.2.3 Evenness

Since heterogeneity contains two separate ideas – species richness and evenness – it was only natural to try to measure the evenness component separately. Lloyd and Ghelardi (1964) were the first to suggest this concept. For many decades field ecologists had known that most communities of plants and animals contain a few dominant species and many species that are relatively uncommon. Evenness measures attempt to quantify this unequal representation against a hypothetical community in which all species are equally common.

2.3 Insects ecological role

Insects are important because of their diversity, ecological role, and influence on agriculture, human health, and natural resources. They have been used in landmark studies in biomechanics, climate change, developmental biology, ecology, evolution, genetics, paleolimnology, and physiology. Because of their many roles, they are familiar to the general public. However, their conservation is a challenge.

Wheeler (1990) in his 'species scape', pictorially illustrated the current dominance of insects, and Samways (1993) noted that if all insect species on earth were described, the beetle representing the proportion of insect species in the world might have to be drawn up to 10 times larger. Wheeler (1990) used a beetle to depict the arthropods in his species scape because the Coleoptera are the dominant insect group, constituting 40 per cent of the estimated total number of insects (Nielsen and Mound, 2000). Dominance of the Coleoptera was said to have led Haldane (1926), when asked what he could infer about the work of the Creator, to respond that the Creator must have had 'an inordinate fondness for beetles', although there is some doubt about the provenance of this phrase (Fisher, 1988). The success of the order Coleoptera is claimed to have been enabled by the rise of flowering plants (Farrell, 1998).

Such statistics led Fisher (1998) to state that 'whether measured in terms of their biomass or their numerical or ecological dominance, insects are a major constituent of terrestrial ecosystems and should be a critical component of conservation research and management programs'. In terms of biomass and their interactions with other terrestrial organisms, insects are the most important group of terrestrial animals (Grimaldi and Engel, 2005), so important that if all were to disappear, humanity probably could not last more than a few months (Wilson, 1992). On land, insects reign (Grimaldi and Engel, 2005) and are the chief competitors with humans for the domination of this planet (Wigglesworth, 1976).

Insects create the biological foundation for all terrestrial ecosystems. They cycle nutrients, pollinate plants, disperse seeds, maintain soil structure and fertility, control populations of other organisms, and provide a major food source for other taxa (Majer,

1987). Virtually any depiction of a food web in a terrestrial or freshwater ecosystem will show insects as a key component, although food-web architectures in these two ecosystems are quite different (Shurin *et al*., 2006).

Insects are of great importance as a source of food for diverse predators (Carpenter, 1928). Aquatic insect larvae serve as food for fishes, and many stream fish appear to be limited by the availability or abundance of such prey, at least on a seasonal basis (Richardson, 1993). Insects provide the major food supply of many lizards. Many amphibia are carnivorous, especially after they reach maturity, and insects form the bulk of their animal food (Brues, 1946). Birds of many families take insects as their staple food, at least during part of the year (Carpenter, 1928), with martins, swallows, and swifts virtually dependent on flying insects for survival. For the yellow-headed blackbird in the Cariboo region of British Columbia, success in rearing young is linked to the emergence of damselflies (Orians, 1975). Mammals such as the American anteater, sloth bears, sun bears, and the African and Oriental pangolins are especially tied to ant and termite colonies, and a number of mammalian predators use insects as food.

Insects are an important supplementary human food source of calories and protein in many regions of the world (Bodenheimer,1951; DeFoliart, 1989; 1992; 1995), with some 500 species in more than 260 genera and 70 families of insects known to be consumed (DeFoliart, 1989; Groombridge, 1992). Insects of most major orders are eaten, but the most widely used species are those, such as termites, that habitually occur in large numbers in one place or that periodically swarm, such as locusts, or large species such as saturniid moth larvae.

The seasonal abundance at certain times of the year makes them especially important when other food resources may be lacking (Groombridge, 1992). No accurate estimates are available for the total number of insect natural enemies of other insects, but probably as many, or perhaps more, entomophagous insects exist as do prey or hosts (DeBach, 1974). The habit of feeding upon other insects is found in all major insect orders (Clausen, 1940). Included here are predators and parasitoids, both of which are involved in natural and practical control of insects (Koul and Dhaliwal, 2003). Thus, phytophagous insects make up approximately 25 per cent of all living species on earth

(Strong *et al.,* 1984). The members of many orders of insects are almost entirely phytophagous (Brues, 1946), conspicuous orders being the Hemiptera, Lepidoptera, and Orthoptera. The influence of insects, as plant-feeding organisms, exceeds that of all other animals (Grimaldi and Engel, 2005). Under natural conditions, insects are a prime factor in regulating the abundance of all plants, particularly the flowering plants, as the latter are especially prone to insect attack (Brues, 1946).

Because insects in particular respond readily to changes in temperature more promptly and with greater intensity than other components of the terrestrial biota, they are providing evidence that major climatic changes in the past took place with unexpected suddenness, moving from glacial cold to interglacial warmth in decades rather than in millennia. Such evidence is vital for current decision making with respect to the management of ecosystems and gives an indication of what might occur with climate change in the near future (Crozier, 2004).

Ample evidence now shows that insects are one of the first groups of living organisms to respond to ongoing global warming (Franco *et al*., 2006; Wilson *et al*., 2006). Predicting insect response is now an active area of investigation (Williams and Liebhold, 1997). Understanding insect strategies for survival under these circumstances, such as how they cope with new food sources (Thomas *et al*., 2001; Braschler and Hill, 2007) and adjust to more acute temperature and humidity fluctuations is still a challenge (Philogene, 2006). Research on butterflies in Britain has shown that many species fail to track recent climate warming because of a lack of suitable habitat (Hill *et al.,* 2001), leading to local extinctions at low-latitude range boundaries of species (Franco *et al.,* 2006).

2.4 Diversity analysis

2.4.1 Importance of Diversity Measures

Whittaker (1972) and Magurran (1988) recommend that to proceed with the study and measurement of biodiversity, we need to pin the concept down. We cannot even begin to look at how biodiversity is distributed, or how fast it is disappearing, unless we can put units on it. However, any attempt to measure biodiversity quickly runs into the

problem that it is a fundamentally multidimensional concept: it cannot be reduced sensibly to a single number.

Species richness and evenness are two (among many) of biodiversity's facets that are used in measurement but no single number can incorporate them both without loss of information. This should not be disappointing; indeed we should probably be relieved that the variety of life cannot be expressed along a single dimension. No single measure will always be appropriate (indeed, for some conservation questions, no single measure can probably ever be appropriate).

2.4.2 Economic importance of Diversity Measures of Insects

Xu *et al*. (2012) concurs that the problem at present is that we have a diversity of measures for communities which does not always perform well since *biodiversity* has a broader meaning than species diversity because it includes both *genetic diversity* and *ecosystem diversity*.

Considering the value of insects as ecological indicators, diversity assessments are critical if monitoring programs and management plans are to be successful. Insects, occupy a vital position in the ecosystem and their occurrence and diversity are considered as good indicators of the health of any given terrestrial biotope (Thomas, 2005). Insects are also good indicators of environmental changes as they are sensitive to habitat degradation and climate change.

Insects are the world's most diverse group of animals, making up more than 58 per cent of the known global biodiversity. They inhabit all habitat types and play major roles in the function and stability of terrestrial and aquatic ecosystems. Insects are closely associated with our lives and affect the welfare of humanity in diverse ways. At the same time, large numbers of insect species, including those not known to science, continue to become extinct or extirpated from local habitats worldwide.Only a relatively few species of insects have been studied in depth. There is urgent need to explore and develop an up-to-date, quantitative assessment of what insect biodiversity entails in order to understand the biology and ecology of insects if ecosystems are to be managed sustainably and if the effect of global environment change is to be mitigated.

2.4.3 Biodiversity documentation challenges

In any investigations of insect biodiversity, the role of inventory tends to be emphasized. Documenting numbers of species (however they are delimited or defined) gives us foci for conservation advocacy and is pivotal in helping to elucidate patterns of evolution and distribution. Recognizing and naming species allow us to transfer information, but high proportions of undescribed or unrecognizable species necessitate the use of terms such as 'morphospecies' in much ecological interpretation of diversity(Boulangeat *et al*., 2012).

Every species is thus a mosaic of physical variety and genetic constitution that can lead to both taxonomic and ecological ambiguity in interpreting its integrity and the ways in which it may evolve and persist. Entomologists will continue to debate the number of insect 'species' that exist and the levels of past and likely future extinctions. Documenting and cataloging insect biodiversity as a major component of Earth's life is a natural quest of human inquiry but is not an end in itself and, importantly, is not synonymous with conserving insects or a necessary prerequisite to assuring their well-being. Despite many ambiguities in projecting the actual numbers of insect species, no one would query that there are a lot and that the various ecological processes that sustain ecosystems depend heavily on insect activity(Boulangeat *et al*., 2012; Baskerville *et al*., 2011).

2.4.4 Biodiversity estimation controversies and different opinions

Several concerns on biodiversity (Boulangeat *et al*., 2012) centres on questions related to our ignorance of the fundamental matters of 'how many are there?' and 'how important are they?' to which the broad answers of 'millions and 'massive' may incorporate considerable uncertainty.

2.4.5 Indices of diversity measurements

Evaluation measures play a vital role in analyzing the performance of a system, comparing two or more systems, and optimizing systems to perform some task. Most measures of diversity assume that the classes (species) are all equally different. There

seems to be no easy away around this limitation. In an ecological sense sibling species may be very similar functionally while more distantly related species may play other functional roles. Boulangeat *et al.* (2012) concurs that measures of diversity can address these kinds of functional differences among species only if species are grouped into *functional groups*

The choice of what to include in a "community" is critical to achieving ecological understanding, yet there are no rules available to help you make this decision. The functionally interacting networks can be determined only by detailed natural history studies of the species in a community (Baskerville *et al.,* 2011).

Diversity measures require an estimate of species importance in the community. The simple choices are numbers, biomass, cover, or productivity. The decision in part will depend on the question being asked, and as in all questions about methods in ecology you should begin by asking yourself what the problem is and what hypotheses you are trying to test. Numbers are used by animal ecologists in many cases as a measure of species importance, plant ecologists may use biomass or cover, and limnologists may use productivity.

Rarely do diversity measures cross trophic levels and only rarely are they applied towhole communities. Colwell (1979), argues convincingly that ecologists should concentrate their analyses on parts of the community that are functionally interacting, the guilds of (Root, 1973). These guilds often cross trophic levels and include taxonomically unrelated species in them.

2.4.6 Diversity Index

A “diversity index” is a single statistic that incorporates information on richness and evenness. This blend is often referred to as “heterogeneity” (Good, 1953; Hurlbert, 1971) and for the same reason diversity measures that incorporates the two concepts may be termed “heterogeneity” measures. Despite the recent progress on methods used to estimate species richness there is still a perceived need of “indices” of diversity that capture both species richness and evenness characteristics of an assemblage to be considered for inclusion (Magurran, 2004).

According to Molinari (1996) there are endless ways of emphasizing different aspects of species abundance relationships and therefore, the number of candidate diversity indices are infinite. As a result, a plethora of indices from which to choose from exists making it rather quite difficult to select the best elegant approach. McIntosh (1967) agrees that there is no perfectly unified diversity index possible to estimate diversity (richness or evenness). Nonetheless, existing and most popular indices are not necessarily the best.

2.5 Species richness measures

Species richness estimation require clearly delineated objectives of study in an effort to select a diversity mreasure. Adequate sampling however is vital for the purposes of study.Some communities are simple enough to permit a complete count of the number of species present, and this is the oldest and simplest measure of species richness. Complete counts can often be done on bird communities in small habitat blocks, mammal communities, and often for temperate and polar communities of higher plants, reptiles, amphibians and fish(Magurran, 2004).

But it is often impossible to enumerate every species in communities of insects, intertidal invertebrates, soil invertebrates, or tropical plants, fish, or amphibians. How can we measure species richness when we only have a sample of the community's total richness? Three approaches have been used in an attempt to solve this sampling problem.

2.5.1 Diversity measures assumptions

There are a whole series of background assumptions (Peet, 1974) that one must make in order to measure species diversity for a community. Ecologists tend to ignore most of these difficulties but this is untenable if we are to achieve a coherent theory of diversity.

The first assumption is that the subject matter is well defined. Measurement of diversity first of all requires a clear taxonomic classification of the subject matter. In most cases ecologists worry about *species diversity* but there is no reason why *generic* diversity or *subspecific* diversity could not be analyzed as well. Within the classification system, all the individuals assigned to a particular class are assumed to be identical. This

can cause problems. For example, males may be smaller in size than females – should they be grouped together or kept as two groups? Should larval stages count the same as an adult stage? This sort of variation is usually ignored in species diversity studies.

(i) All species are equal: - this implies that species of notable conservation value or species that make a disproportionate contribution to community function do not receive special weighting. The relative abundance of a species in an assemblage is the only factor that determines its importance in the in a diversity measure. Richness measures make no distinctions amongst species at all and treatsall the species that are exceptionally abundant in the as same manner as those that are extremely rare.

(ii) All individuals are equal: - There is no distinction between the largest and smallest species. In this case, sampling tends to be selective.

(iii) Biodiversity measures assume that species abundance has been recorded using the appropriate and compararble units. *E.g*., diversity estimates based on different units are not directly comparable and it is unwise to include different types of abundance measures such as number of individuals and biomass in the same investigation.

2.5.2 Functional groups in diversity measures

Functional diversity has attracted considerable interest as a consequence of the current debate on ecosystem performance. Indeed the positive relationship between ecosystem functioning and species richness is often attributed to the greater number of functional groups that are found in richer assemblages (Diaz and Cabido, 1997; Tilman 1997,2000; Hector *et al.,* 1999; Chapin *et al.,* 2000; Loreau *et al*., 2001 and Tilman *et al.,* 2001).

According to Petchey and Gaston (2002), functional diversity is a powerful technique for evaluating the functional consequences of species extinctions and has the potential to shed light on the number of key issues in ecology such as species packing and community saturation.

Most measures of diversity assume that the classes (species) are all equally different. There seems to be no easy way around this limitation. In an ecological sense sibling species may be very similar functionally while more distantly related species may play other functional roles. Measures of diversity can address these kinds of functional differences among species only if species are grouped into *functional groups* (Boulangeat *et al.,* 2012).

2.5.3 Taxonomic diversity

Communities may be identical in terms of richness and evenness but differ in the taxonomic diversity of their species. If two assemblages have identical numbers of species and equivalent patterns of species abundance, but differs in the diversity of taxa to which the species belong, it seems intuitively appropriate the most taxonomically varied assemblage is the more diverse. Moreover, measures of taxonomic diversity can be used in conjunction with species richness and rarity scores in the context of conservation (Virolainen *et al.,* 1998). This approach of taxonomic distinctiveness has gainedimpetus as a consequence of its perceived role in setting conservation priorities (Vane-Wright *et al*., 1991; Vane- Wright, 1996; Williams, 1996) andas a further potential application in environmental monitoring (Warwick and Clarke, 1995; Clarke and Warwick, 1998, 1999). It is worth mentioning that as long as the phylogeny of the assemblage of interest is reasonably well resolved, the measures of taxonomic (or hierarchical) diversity will be in principle possible (Pielou, 1975).

2.5.4 Temporal patterns of insect diversity

Temporal changes in diversity are usually referred to as “turnover”, although the term may be applied to spatial changes as well. From a broader perspective, it is clear that diversity will increase as the similarity in species composition decreases. Insects are the most species-rich taxon with about one million species described worldwide, corresponding to more than half of all known species (Gulland and Cranston, 2010; Groombridge, 1992).

Due to their high ecological diversification and short generation times, insects are useful indicators of environmental change (Schowalter, 2011 and Thomas, 2005).

Lepidoptera (butterflies and moths) is one of the largest insect orders with 160,000 described species, of which 95 per cent are moths (Kristensen *et al.,* 2007 and New, 2004).

Moths play important role in many ecosystems as pollinators, herbivores, and prey for a wide range of species such as birds and bats (Wickramasinghe *et al*. 2004). The distribution and ecology of moths are well known in comparison to many other invertebrates (Fox *et al.,* 2013). For instance, in recent decades, steep declines of moth populations have been observed in Great Britain, where the abundance of macro-moths decreased by 28 per cent between 1968 and 2007 and similar negative trends have been found in Sweden and the Netherlands. Such declines are expected to have cascading effects at both higher (bats, birds) and lower (plants) trophic levels due to the keystone role of moths in many ecosystems (Kristensen *et al.,* 2007; Fox *et al.,*2013)

2.6Insect faunistic studies in India

There is ample proof that insects were systematically investigated many centuries before Aristotle. Hymns of Atharva Veda on the control of insects attacking crops reflect the variety of pests. Identification of bees and biting insects such as mosquitoes and ants, the classification of ants (piplika) and flies (mahashikala), the Hexapoda group was studied nearly 1000 years ago (Ananthakrishnan, 2000). Modern entomological systematic work was initiated with the establishment of the East India Company, through the abiding interest of amateur entomologists in the armed, civil, forest and medical services.

The first entomologist who made an extensive study of Indian insects was Fabricius (1745-1808), and the publication of Carl Linnaeus' (1758) Systema Naturae (10^{th} edition) provided the earliest record of Indian insects, with descriptions of 28 species. The kingdom Animalia is represented by 15, 52,319 species that have been described so far globally in 40 phyla in a new evolutionary classification. The phylum Arthropoda alone includes 12, 42,040 species, constituting about 80 per cent of the total number of species. The most successful group, Insecta, accounts for about 66 per cent (10, 20,007 species in 39 orders) of all animals. The most successful insect order,

Coleoptera, represents about 38 per cent(3, 87,100 species) of the insect species of the world (Zhang, 2011).

Compilations on the insect fauna of India have been produced from time to time. Maxwell and Howlett (1909) published the book Indian Insect Life, wherein 25,700 species of insect were reported from the Indian region, including adjacent countries. Beeson (1941) and Menon (1965) estimated the number of species from India to be 40,000 and 50,000, respectively. In recent times, Varshney (1997) reported 51,450 species under 589 families. Subsequently, Varshney (1998) reported the occurrence of 59,353 species of insect belonging to 619 families in India.

According to Chandra (1999), the current diversity of insects in India as compared with that of the world points to 39 insect orders known globally, 27 of which are represented in India. Presently, 63,760 species of insect (Hexapoda) in 658 families representing 27 orders and three class are reported from India. Eight orders, *viz*. the Lepidoptera, Coleoptera, Orthoptera, Diptera, Hemiptera, Odonata, Hymenoptera and Thysanoptera, constitute the bulk (94%) of the insect fauna, while the remaining 21 orders are represented by small numbers (6%) of species. The order Coleoptera has the greatest diversity in terms of families—114 families—followed by Hemiptera (92 families), Diptera (87 families), Lepidoptera (84 families) and Hymenoptera (65 families).

2.7 Sampling and method of collection

2.7.1 Light traps

Sampling is fundamental to any diversity studies as well as studies on assessing changes in community structure, composition and function over time (Yoccoz *et al.,* 2001). Different methods are used for sampling different taxa based on the efficiency of sampling method. It is very essential to use the simplest and most effective method that can berepeated many times in space and time since not all taxonomic groups are attracted to light in the same way to different capturing methods. An adequate sampling method must be based on taxon-specific collecting procedures (Magurran, 2004). Behavior and

ecology of the intended community under study should be taken into account before selecting the sampling method (Magurran, 1988).

Light traps can be designed in various ways and operated using different light sources; both of these modifications are known to affect trap performance (Fayle *et al.,* 2007 and Intachat and Woiwod, 1999). Weather factors, such as temperature, and rainfall, also influence catch size (Butler *et al.,*1999; Yela and Holyoak, 1997).

Lopez *et al.* (2011) examination on performance of various light sources demonstrated that ultraviolet light and mercury vapour lamps have significantly better attraction in terms of species and abundance than other light sources tested. A large number of insect taxa respond to electromagnetic radiations from approximately 2537 A°-7000 A° *i.e*. from ultraviolet to the infrared. The maximum effective wavelength for most insects is 6500 A° (Dethier, 1953).

Many different methods for collecting insects have been used for research purposes and inventories depending on their biology (Lobo *et al*. 1988; White *et al.* 1990; Cronin and Hayes, 2000; Falach and Shani, 2000; McIntosh *et al*. 2001; Missa *et al*. 2009). Light traps are assumed to be highly effective for trapping some groups of insects with nocturnal activity, such as Coleoptera, Hemiptera, Diptera, Hymenoptera, Lepidoptera, Isoptera, *etc.*

Experience with Blomberg *et al*. (1976); Watson (1979); Hébert *et al*. (2000); Kato *et al.* (2000); Castro- Ramírez *et al*. (2003); Hirao *et al*. (2008) and Wolda *et al*. (1998), argues that studies using light traps vary in light source, type of trap and period of sampling, which hampers comparison of results from different studies. Standardized sampling methods are therefore essential for comparing species diversity and abundance patterns across different studies and sites. Standardization will help address effects of confounding factors that may impede interpretation of acquired data.

2.7.2 Sampling duration

Commonly, studies on the efficacy of light traps focus their attention on the effect of the light trap wavelength (Carlson, 1972; Walker and Galbreat, 1979; Intachat and

Woiwod, 1999; Nabli *et al.,* 1999), but the capture period during the night when the traps are operating is also an important parameter that influences insect catches (Mikkola, 1972; Scalercio *et al.,* 2009). In this way many groups of insects exhibit peak flight activity during twilight, particularly at dusk when temperatures tend to be higher than at dawn (Racey and Swift, 1985). Restricting sampling to a period during only part of the night could improve the method by minimizing effort while maximizing obtained information (Scalercio *et al.,* 2009). Lopez *et al*. (2011) observed that 95 per cent of scarab beetles were attracted between 6 pm and 11 pm.

However, the use of light traps in ecological studies has many limitations. Only insects that are nocturnal will be caught. The time of flight activity and climatic condition affect the sampling effort (Williams, 1940). Species composition also varies significantly for different sources of light (Viraktamath and Kumar, 2005; Lopez *et al.,* 2011).

2.7.3 Circular statistics applications

According to Zar (1996) circular statistics is fast becoming a key instrument in the analysis of periodical events unlike linear statistical measures. Circular statistics was applied to analyze the data on assessment of insect diversity at GKVK following Batschelet (1981).

Directional statistics (also called circular statistics or spherical statistics) is the sub discipline of statistics that deals with directions (unit vectors), axes (lines through the origin) or rotations. The fact that 0 degrees and 360 degrees are identical angles; other examples of data that may be regarded as directional include statistics involving temporal periods (*e.g*. time of day, week, month, year, *etc*.), compass directions, dihedral angles in molecules, orientations, rotations and so on (Batschelet, 1981).

Circular variables, which indicate direction or cyclical time, can be of great interest to biologists, geographers, and social scientists. The defining characteristic of circular variables is that the beginning and end of their scales meet. For example, compass direction is often defined with true North at 0 degrees, but it is also at 360 degrees, the other end of the scale. A direction of 5 degrees is much closer to 355 degrees than it is to 40 degrees. Likewise, times that represent cycles, such as times of day (best

expressed on a 24 hour clock), day in a reproductive cycle, or month of a year are also circular. January, month 1 is closer to December, month 12, than it is to June, month 6 (Batschelet, 1981).

Examples of circular variables are abundant in biology, geography, and the social sciences.

Note that time can be considered either circular or linear. Time is circular when it measures part of a cycle, such as the timing of a daily event. It is linear when it measures length of time, such as the number of days since an event.

Most familiar statistics do not work with circular variables because they assume that variables are linear–the lowest value is farthest from the highest value. For example, the average of 5 degrees, 60 degrees and 340 degrees (which are all northerly directions) is 135 degrees–a southerly direction. Changing 340 degrees to 20 degrees (an equivalent value) changes the mean to 15 degrees, which is more reasonable(Batschelet 1965, 1972 and 1981).

Because classical statistical analysis does not work for circular variables, an entire field of circular statistics has been developed. In circular statistics, each datum is defined by its length and its angle from a chosen point on the circle. In the case of insects, each insect species final location would be designated by the distance it traveled from its escape point and the angle in degrees from true north. The mean location of all the insects' samples can be found using the sine and cosine of the angle then adjusting for the length. Because the sine of 0 degrees and 360 degrees is the same, this solves the original problem of ends of the scale being near each other. Circular statistics include tests of uniform direction around the circle, confidence intervals, tests for comparing two groups of directions, circular graphs, correlations, and regression, among others (Batschelet,1965, 1972).

One unique system of measurements that frequently cannot be modeled in a linear manner are data produced from circular scales. These variables are distinctive in the sense that points are distributed on a circle instead of the traditional configuration of points on the real number line. Circular scales produce cyclic or periodic data that tends

to complicate traditional analytic procedures. The complexities found in evaluating circular data are largely a manifestation of the special interval level status the circular scale represents (Batschelet, 1965).

Circular scales do not have a true zero point. In addition, the fact that they are circular means that any designation of high or low or more or less is purely arbitrary. For example, observations on a plane surface and rhythmic temporal phenomena can be viewed as being circular in nature, and thus appropriately analyzed by circular statistical methods.More so, the arithmetic mean and standard deviation are shown to be inappropriate descriptive measures for circular data. In addition, the use of average absolute deviations to measure directional errors of judgment can lead to loss of directional information. Finally, the usual methods of statistical inference are shown to fail in accounting for circularity when it exists (Batschelet, 1981).

Notable biomathematical applications of circular distributions in animal behavior studies have been in homing, migration, escape, and exploratory behavior; although this can be extended to cover areas of spatial and temporal performance, such as navigation, work-system design and biological rhythms. Batschelet (1965, 1972 and 1981) has pioneered many of the principles in statistical circular methods.

2.7.3.1. Mathematical Convention

Two different conventions are used with directional measures. The angle α is typically used as a measure of azimuth where 0 represents true north and rotation around the circle is in a clockwise direction. This convention is used in navigation. However, the mathematical convention for angular measures in statistics and computer computational algorithms typically use the polar angle, (Φ, which is taken from the positive X axis (pointing East) in a counterclockwise direction. For both types of angles, rotation opposite to the conventional direction results in negative angles. Negative angles are subtracted from 360^0 to convert them to the corresponding positive angles, unless it is important to retain knowledge of the direction of rotation (Batschelet, 1981).

2.7.3.2Temporal Measures

One particularly important circular scale is time-of-day. The time-of-day scale can be partitioned into 24 hours each representing equal intervals of time. Angular measures are typically taken from midnight or 12:00 AM. In equating 24 hours to 360^0, each hour represents 15 of angle from zero at midnight (*i.e*., 3600/24). Any unit of time similarly can be equated to a proportional part of 360^0. We can convert time measures in any unit to angular direction (in degrees) by the following equation:

$$\alpha = (360\ (t))/\mu$$

where, α is angular degrees, t is a quantity of time and μ is the number of equal interval time units (*i.e*., 24 for hour, 1440 for minute, *etc*.) representing one rotation around the circle.Any circular temporal measure can be translated to angles using this method (*i.e*., dayof-week, day-of-year *etc*.).When time is measured in negative and positive values for events before and after a zero point, the signs of negative angles should be retained to preserve information on the order of events. Then to make these angles positive for further computations, add an integral multiple of 360°.

2.7.3.3 Graphical Representation

A circular data distribution can be displayed as a scatterplot of data points on the circumference of the circle. This method of presentation provides information on salient characteristics of the data, such as central tendency, dispersion (or concentration), and the number of modes that appear in the distribution.Large amounts of data are best displayed in the form of a histogram where concentric circles characterize the frequency attributes of the data. The length and area of the bars represents the frequency of observed measures.

2.7.3.4Circular Functions

It is frequently necessary to change coordinate systems when analyzing circular data. The Cartesian system fixes a point on a plane by referring to the x and y axes of a rectangular representation of the event space. Rectangular coordinates read from the x and y axes give the unique location of the data point in the space. These points however,

satisfy the circular equation: $x^2 + y^2 = 1$.Sines and cosines are the primary trigonometric functions used in circular statistical procedures. However, the tangent, and its cotangent function are also used in several statistical tests.

In many cases polar coordinates are more useful. The polar coordinate system requires the specification of the angle, Φ, with respect to a zero or starting point and a straight line distance, r, from a second reference point located in the center of the circle representing the event space. The pair of numbers, Φ and r, is known as polar coordinates and provide a method of uniquely defining the location of a data point in the circle.

If we specify the angle in respect to a northerly starting direction, and in this case travel clockwise around the circle, our polar values will be in azimuth (*i.e.* α and r). More generally, polar coordinates can be used to specify points anywhere on a plane, not just on a unit circle. Instead of the rectangular coordinates (x_i, y_i), the polarcoordinates (Φ_i, r) define the location of each point in terms of its direction and distance from the origin.

Polar coordinates have the advantage of clearly separating directional and distance information in data analysis, while rectangular coordinates confound these aspects of spatial location[JM1]. Rectangular coordinates, on the other hand, relate location to the frame of reference provided by the coordinate axes, preserving spatial information in terms of the orthogonal dimensions of the event space. Nevertheless, the best choice of coordinate system for a particular problem depends on the questions to be investigated. Often both systems are useful for different purposes.

It is important to recall that when analyzing circular data we restrict angular values to the interval length 0° -360°. Since one rotation around the circle will contain the total set of angles, additional rotations can be mapped over to those angles defining this interval. For example, both 600° (1.66 revolutions) and -840° (negative 2.33 revolutions) determine the same point on the circle as the angle 240°. To find the angle in the 0° -360° interval that corresponds to an angular value outside that interval, the value must be reduced modulo 360°. The angular value can be expressed as the sum of two parts: and integral multiple of 360°, 1(360°), plus a remainder (b) after division by 360°. The remainder b is the desired angle within the interval. The angle 600° = 1(360°) + 240°, and

thus reduces to 240°. Similarly, the angle -840° = -2(360°) + -120° and reduces to -120°, which corresponds to the positive angle 240°. Both 600° and -840° are said to be congruent to the angle 240° (modulo 360°).

Azimuths and polar angles obey the relation $\alpha + \Phi = 90°$ (modulo 360°), since they sum to 90° in the first quadrant, or sum to 450° in other quadrants. Therefore, azimuths can be easily changed to polar angles by $\Phi = (450° - \alpha)$ (modulo 360°). With α and Φ reversed, this equation will change polar angles to azimuths.

2.7.3.5 Circular mean

If we have a number of angular measurements on the circle, then the mean of those measures should offer an estimate of the true population mean parameter μ (in the classic probability sense). However, in order to compute the mean angle, the rectangular coordinates of the data points must be computed.

2.7.3.6Bimodal Samples

In some cases a mixture of unimodal distributions appear in a single sample. The most tractable, from a statistical point of view, are those referred to as axial distributions. In an axial distribution, two groups of data lie diametrically opposite to each other on the diameter of the circle. Thus, the assumption is made that the probability density from which the data are sampled has central symmetry, with modes at μ and $\mu + 180°$. We are indifferent to direction from the origin along the axis, and are only interested in the angle of the axis. We want to estimate one parameter μ rather than two parameters for the senarate modes. It is therefore appropriate to treat angular measures as axial whenever orientation without regard to direction is at issue.

Batschelet (1965, 1981) discusses a procedure for analyzing axial data that requires doubling angular measures. In analyzing axial data, one considers a nondirected rotating line segment whose origin lies at zero direction. A rotating line segment is restricted to angles in the interval of 0° to 180°, as opposed to the directed line that has the full 0° to 360° interval. As a result, axial data can be reduced by a multiple of 180°, or modulo 180°. One treats a full rotation around the circle as falling in the interval of 0° to

180°. Thus, by doubling each angle and reducing modulo 360°, one generates a unimodal circular sample (Taylor and Auburn, 1978).

2.7.3.7Properties of Mean Vector

Because we are working with data points falling on a circle, the mean vector locates the center of mass of the distribution. The mean vector is a directed line from the origin to the point defined by the Cartesian coordinates (x and y)or the polar coordinates (r,Φ) This notion can be illustrated by applying vector algebra in order to determine center of mass. For example, consider four data points falling on a unit circle. Each of these points can be located on the circle by a unit vector, υ, (*i.e.* directed line of length 1.0).

2.7.3.8Angular Variance

It is often useful to have a measure of dispersion around the mean vector in a sample of circular data. The notion of angular variance is similar to that of its linear counterpart, *viz*, the quantity that defines the spread of scores around the circle's circumference. The length of the mean vector, r, plays an important role in the variance estimate. From vector algebra, as the data becomes more dispersed around the circle the value of r tends toward zero. When calculating the mean vector of a distribution whose data points are equally dispersed around the circle, the length of r will be zero. In contrast, when computing the mean vector of sample data whose points all fall on the same location, yields an r = 1.0. In this case, as r decreases from 1.0 to 0, the variance in the destribution increases. Thus, l-r can be considered a measure of dispersion (Batschelet, 1972).

2.7.3.9Detecting bias

One particular application of circular statistics may be found in assessing response biases on circular performance measures. Frequently, errors of judgment in navigation, orientation or other spatial performance tasks are reported as absolute or relative deviations from some true score (Wickens, 1984). Rendering experimental conclusions based on linear deviations of circular measures from a true score, where

deviations fall on both sides of azimuth, means that directional information is lost (Wickens, 1984).

However, these absolute deviation values do not indicate whether errors are symmetric around the true value, or whether there is a systematic tendency (bias) to make errors in one direction. Furthermore, the bias, if any, may be different at different points of the compass. Thus, the use of average absolute deviations tomeasure directional errors of judgment can discard important information on directional bias. The notion of response bias in spatial tasks have been an important dimension in the development of aviation navigation and remote vehicle guidance displays. Frame of reference appears as a key element and has given rise to various frame of reference configurations (inside-out and outside-in). In addition, detecting direction errors in judgments occurring in spatial performance tasks may be very important because of the "rectilinear normalization" bias (Wickens, 1984). This bias characterizes a tendency of human subjects to structure spatial information as though lying on a rectangular N-S-E-W grid, when it may not.

2.7.3.10Uniform Circular Distribution

If directions in a plane can occur with equal probability, then the distribution of data points around the circumference of the circle will tend to be uniform. Thus, the density of data falling around the circle will be constant. The uniform circular distribution is a good model for many random circular stochastic processes. It provides the probability density used to test the null hypothesis of 'no preferred direction'. Several authors have noted that the uniform circular distribution has unique properties. However, one of the more interesting is that it appears as the only circular distribution where, in random samples of a fixed size, the length of the mean vector and therefore the angular variance is statistically independent from the mean angle (Batschelet, 1972; Bingham, 1978).

2.7.3.11Inferential statistics

In this section, we describe a set of functions implemented in Circular Statistics for inferential statistics with angular data. The first set of functions allows to test the popular question of circular uniformity, while other methods allow to investigate more

specific hypothesis about the mean direction of one or multiple samples. For example, researchers studying the migratory behavior of birds (Wiltschko and Wiltschko, 1972; Cochran *et al*. 2004) might want to establish that all animals from one species indeed migrate into a common direction or acertain that two species of birds migrate into differing directions.

In testing for circular uniformity a common question in circular statistics is whether a data sample is distributed uniformly around the circle or has a common mean direction.

H0: The population is distributed uniformly around the circle with alternative hypothesis

HA: The population is not distributed uniformly around the circle.

Rayleigh test

The Rayleigh test asks how large the resultant vector length R must be to indicate a non-uniform distribution (Fisher, 1995). It is particularly suited for detecting a unimodal deviation from uniformity. If the data indeed is unimodal, it is the most powerful test.

2.7.3.12Significance Tests

One of the more frequently needed assessments on experimental data is determining whether obtained sample data has been generated from a population distribution different than one generating a random distribution of measures. In circular data, the question may be whether a mean direction in the population data exits. This question is similar to one found in a linear system, except the null hypothesis characterizes a uniform distribution (*i.e*., equal density of points on the circle) that can yield a computable mean by chance alone. A simple nonparametric test for the competing hypotheses; a) H_0: the data comes from a uniformly distributed population, and b) H_1: the data comes from a non-uniform circular distribution, is the Rayleigh test.

The Rayleigh test essentially asks how large the statistic r must be in order to indicate a significant departure from uniformity. The "Rayleigh R" is computed as follows:

$$R = nr$$

where, n = sample size and r = the mean vector length of the sample data. The Rayleigh z score is used to test the null hypothesis of uniformity:

$$Z = R^2/ n$$

Tabled values for this test are found in Batschelet (1965, 1972, and 1981) and Zar (1974).

If the null hypothesis is rejected using the above test, we may assume that significant directionality exists in the data. In order to interpret the data in this fashion, we must assume that the distribution is unimodal. Similarly, in retaining the null and concluding thedata has been sampled from a uniform population distribution, caution must be used to guarantee the distribution is not multimodal. For example, an axial distribution, while displaying significant directionality, will have an r = 0.

2.8 Morphometry

2.8.1 Body size and biological diversity

Damuth (1981) observed that there is a predictable relationship between body size and abundance:

$$A= kW^{-0.75}$$

Where A= the abundance of a species and W= the average body of a species. Different guilds have different values of k.

Unlike taxonomic and functional diversity measures, “traditional” diversity measures treat all species as equal. Species abundances provides the only weighting in heterogeneity and evenness statistics. Species abundance (typically measured as the number of individuals or biomass) is an intuitive measure of species importance.

Animals undergo interrelated changes in size and shape on both developmental and evolutionary time scales. For example, the dramatic size changes from fetal development through adolescence occurs on a developmental time scale. Many evolutionary lineages also show a pronounced size increase through time, with early species being considerably smaller than later species. Accompanying these size changes are significant modifications of shape. These shape changes occur because specific body plans are not infinitely expandable; the physical constraints on body form are known to vary with size.

The fundamental problem faced by all organisms is called surface area - volume paradox, where the ratio between surface area and volume does not increase linearly. For example, consider two cubes, A = 1 cm on each side and B = 3 cm on each side. If L = length of a side, then the surface area L^2 (= squared, or L^2, function) and volume L^3 (= cubic, or L^3 function). Consequently, cube B has 9 times the surface area and 27 times the volume of cube A.

This creates severe problems at larger sizes, since nutrients and oxygen are consumed and waste and CO□ are produced at rates proportional to volume (*i.e.*, they are cubic functions), while exchange rates at body surfaces are proportional to surface area and are squared functions. In all systems there occurs a critical size above which squared functions can not keep up with cubic functions.

The mathematical basis for analyzing the scaling relationships within organisms can be described mathematically as:

$$y=axb$$

or, alternatively

$$\log y=\log a+b(\log x)$$

where: a is the y-intercept and b is the slope

If the slope (b) is equal to 1, then the variables exhibit equal proportional changes, and demonstrate isometry. In isometric relationships shape does not change as size increases. Instead, organisms exhibit geometric similarity for the variables being studied.

2.8.2 Allometric relations

All allometric relationships are manifested as size-related changes in shape, which are necessary to maintain functional efficiency. Species' body size distributions are right-skewed, symmetric or left-skewed, but right-skewness strongly prevails. Explanations into species' body size distributions should focus not on the forces that are shaping the size distributions but on the forces that are shaping the distributions of the parameters that describe the size dependency of production and mortality.

Alterations of the environment due to climate change is expected to affect the optimal size maximization of insects and therefore lifetime reproductive success. Size of specimens, including length and weight, is a central factor to key ecological processes. Adaptive trade-offs are important in determining assemblage vulnerability and resilience in the face of climate change (Bennett and Lenski, 2007). Organism biomass is inarguably one of the more important variables in ecology, playing a central role in studies ranging from ecophysiology and community and food web regulation, to whole-ecosystem metabolism(Enquist and Niklas, 2001).

Experience with Sabo *et al.* (2002) and Smock (1980) points that ecological theory supported by empirical data suggests body mass scales predictably with length in the form of power relations. Based on this criterion one might expect indications concerning the effects of the body allometry trade-offs and particularly how their mathematical functions can suggest changes in metabolic rate on body size and temperature(Gillooly *et al.,* 2001).

According to Marquez *et al*. (2001) geometric morphometrics could be useful when attempting to detect the effect of environmental pollution variables on insect assemblages and structure. Fundamental relationships between body length-weight allometry and the environment have been shown in insect's assemblages (Schoener, 1980).

2.8.2.1 Length, width, weight relations

Differences in the shapes of the size distributions between orders may result from differences in the body plans and physiology(Brown and Nicoletto, 1991). The length-

width (L-W) and length-weight (L-We) relationships are important parameters to know when attempting to gather information about insect growth patterns and about the conditions of the region they inhabit. Efforts to conserve or manage insect communities require some knowledge of their body size distributions.

2.9 Effect of weather parameters on insect species richness and abundance

Insect activity is important because the movement of insects is associated with various ecological services ranging from pollination (Johnson, 1996), pest control (Johnson,1992) to seed dispersal (Bond,1994), but also spread of disease(Epstein*et al.,* 1998) and predation of economically important crops (Ward and Masters, 2007; Sasa and Samways, 2015). While many arthropod species depend on plants for food, and are influenced by vegetation structure(Scherber*et al.,* 2014), their activity is also influenced by different abiotic factors like rainfall, altitude, temperature or wind (Addo-Bediako *etal.,* 2000; Briers*etal.,* 2003 and Rahbek, 2005). This can result in seasonal peaks in abundance and species richness.

Terradas *et al*.(2004) affirms, that the relationships between species abundance and factors driving the biodiversity are often largely unknown. However, it has been proven that many variables are statistically related to species richness and abundance distribution: *e.g*., climate (McCain, 2007), altitude (Kessler, 2009), latitude (Andrew and Hughes, 2005), physical factors of the soil (Sesnie *et al.,* 2009), disturbance degree (Davis and Philips, 2009) and temporal dynamics (Gobbi *et al.,* 2007). Studies by Wolda (1988) point that rainfall influences the variations in insect activity. However, community structure is not only determined by ecological causes but it also depends on historic and evolutionary factors (Hawkins *et al.,* 2003).

2.9.1 Seasonality of insects

The abiotic environment often varies along altitudinal gradients, with consequences for composition and activity of arthropod assemblages. Insects often show specific annual activity patterns frequently linked to phenology often triggered by photoperiod in combination with temperature and humidity(Van Asch and Visser, 2007) causing high insect activity in some seasons than others. In this paper we identify

cumulated temperature over a period of three weeks to impact negatively on species richness.

Seasonal variation in abundance of tropical insects is a common phenomenon (Wolda, 1988). Prevailing weather and long term climatic conditions have great influence on insect activity, spatial and temporal patterns in general. In the tropics, temperature changes are slight, and seasonal changes in rainfall exert the most dramatic effect on the environment (Wolda, 1988). However, there is a general belief that the tropical insects tend to be active for longer periods within a year and the seasonal peaks are less well defined relative to temperate insects. This aspect seems to have not been properly tested.

III MATERIAL AND METHODS

A two year study was conducted from May, 2015 to December, 2016 to assess the diversity of insects and their temporal patterns of activity by analyzing the insects attracted to light traps. The details of the materials used and techniques adopted during the course of investigation are described in this chapter.

3.1 Study site

3.1.1GKVK

The study was taken up at Gandhi Krishi Vignana Kendra (GKVK) campus of the University of Agricultural Sciences, Bengaluru, Karnataka State, India, located about 15 kms away from Bengaluru City on the Bengaluru Bellary Road (National Highway No.7). Geographically, the place is located at 12°58' latitude North and 77°35' longitude East. The campus is at an altitude of 930 meters above sea level. The annual rainfall ranges from 679.1 mm to 888.9 mm and falls under the Eastern Dry Agroclimatic zone of Karnataka.

3.1.2 Climate

The weather parameters for the period of study were collected from the Zonal Agricultural Research Station, GKVK, Bengaluru and are graphically presented as Appendix to this study.

3.1.2.1 Rainfall

Bengaluru received 107.6 mm of rainfall during the entire sampling period. The rainfall pattern had two distinct peaks, one in July (highest) and the other October (lowest).

3.1.2.2 Temperature

Highest mean maximum temperature was 35.6°C, observed during April followed by 34.8°C in March. The lowest monthly mean temperature of 11.2°C was in January

followed by 17.0 °C in February. Monthly mean maximum temperature was similar from July 2016 to December 2016.

3.1.2.3 Humidity

Relative humidity recorded at 7 am and 2 pm indicated the maximum and minimum relative humidity during the day, respectively. These observations are labeled as Relative Humidity 1 and Relative Humidity 2. Highest mean monthly Relative Humidity was observed (7 am; 96 per cent) during May and October followed by March (95 per cent), and the lowest was observed during February (80 per cent). Mean monthly relative humidity exhibited varying levels between maximum and minimum with lowest relative humidity recorded during April.

3.2. Sampling Method

Insects were collected using a light trap. The source of light used was a mercury vapour lamp of 165 Watts (Philips). Light traps were run at an interval of every 21 days from 8/05/2015 to 6/12/2016 period. Insects attracted to light were collected in a container placed at the bottom of the trap provided with an insecticide as the killing agent.

3.3 Processing of collections

All collected specimens were air dried and processed. Larger specimens were easily separated and smaller ones sorted under a stereo-zoom microscope. All insects were further sorted into different morpho-types.

3.3.1 Identification of specimens

Each morpho-type was then verified for distinctness and uniformity among a type based on the external morphology and assigned an OTU (Operational Taxonomic Unit). As a consequence, each morpho-type was in principle, represented as known or unidentified species. Assistance from Entomology Department was sought to identify OTUs according to their taxonomic positions. Identified morpho-types were classified into their respective orders and families and their numbers counted. All the specimens

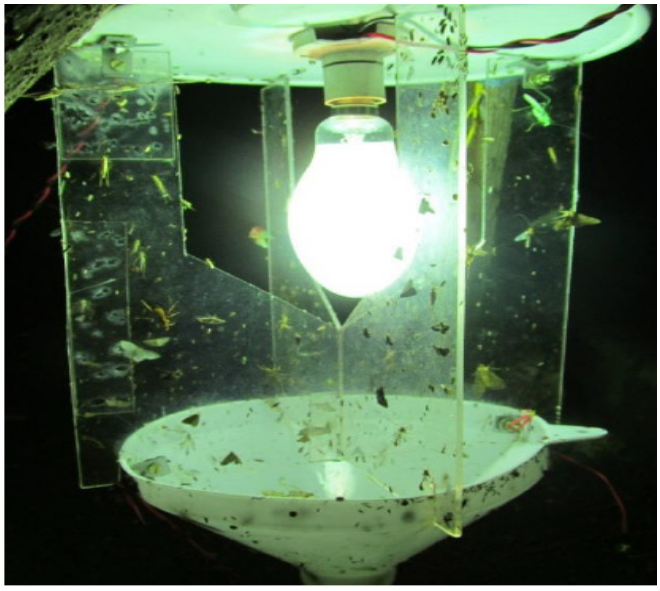

Plate 1. Light trap used to attract and capture insects from 6.00 p.m to 6.00 a.m. set up at 21 days interval.

Plate 2. Insect sample collected from a single light trap

were stored in packets labeled with sampling date, OTU (Operational Taxonomic Units) and numbers of count for further examination. In this study only order Psocoptera was not identified to family level, but the numbers of this were very few.

3.4 Data Analysis

3.4.1 Patterns of insectabundance and species richness

Species richness (OTU) were tabulated foreach of the 26 sampling periods and plots were developed. While number of OTUs were used as species richness, total count was used as abundance.

3.4.2 Indices of Diversity

Species abundance distributions were used to describe the structure of the communities and shed light on the ecological processes that underlie that structure. Despite the recent progress on methods to estimate species richness there is still a perceived need of "indices" of diversity that capture both species richness and evenness characteristics of an assemblage.We used the following indices.

Diversity indices used for analyses are hereunder shown:-

1. **Simpson Index of Diversity (D)**

$$D=1-\sum (P_i)^2$$

Where, P_i= the proportion of individuals of species i = S/N.

2. **Shannon Weiner Diversity Index(H)**

Diversity index= $H= -\sum Pi \ln Pi$

Where, Pi= S/N

S= Number of individuals of one species

N= Total number of all individuals in the sample

Ln= logarithm to base e

3. Avalanche Index

$$AI=\sum\sum P_i\, d_{ij}\, P_j$$
$$d_{ij}=[\sum (X_{ik}-X_{jk})^2\,]^{1/2}$$

Where P_i and P_j are frequencies of i^{th} and j^{th} species, X_{ik} and X_{jk} are values of i^{th} and j^{th} species for k^{th} character.

For calculating the evenness of species, the Pielou's Evenness Index (E) was used (Pielou, 1966).

E= H/ln S, Where,

H= Shannon-wiener index

S= total number of species in the sample

3.4.3 Correlation Coefficients

Extent of relationship among orders and among families were assessed by correlation coefficients.

3.4.4Circular statistics

Species richness, abundance and diversiyty indices were subjected to circular statistical analysis. For this, the sampling days were converted to Julian days as angles within a circle. The mean vector was represented as two properties *viz.,* mean angle 'μ' and its length 'r'.

For each set of data, the following circular statistic parameters were calculated: mean vector, length of mean vector, median, circular variance, circular standard deviation, standard error of mean, and Watson U^2 test for theoretical distribution and Rayleigh test for uniformity of distribution. Watson U^2 two sample test was used to compare the distributions (Batschelet, 1981).

All statistical analyses were initially calculated manually and later verified using the software, *Oriana version 4.00* (www.kovcomp.co.uk/oriana). Graphs were obtained using the same software.

3.4.5 Allometry

Morphometric analysis were done to assess the inter-relationships between size, body weight and abundance. The study adoptedKolmogorov-Smirnov (K-S) test to decide on the distributional adequacy of the samples from the population. K-S Test can be used to compare Non-parametric tests for equality in continuous, one dimensional probability distributions with a reference probability distribution (sample K-S Test). It quantifies a distance between the empirical distribution function of the sample and the cumulative distribution of the reference distribution or between the empirical distributions of two samples.

The Kolmogorov-Smirnov (K-S) test is based on the empirical distribution function (ECDF). Given *N ordered* data points $Y_1, Y_2, \text{----} Y_N$, the ECDF is defined as

$$E_N = n(i)/N$$

where $n(i)$ is the number of points less than Y_i and the Y_i are ordered from smallest to largest value. This is a step function that increases by 1/*N* at the value of each ordered data point.

3.4.5.1 Characteristics and Limitations of the K-S Test

An attractive feature of K-S test statistic is that:-

- ✓ Does not depend on the underlying cumulative distribution function being tested.
- ✓ It is an exact test.

K-S test has several important limitations:

1. It only applies to continuous distributions.
2. It tends to be more sensitive near the center of the distribution than at the tails.
3. Perhaps the most serious limitation is that the distribution must be fully specified. That is, if location, scale, and shape parameters are estimated from the data, the

critical region of the K-S test is no longer valid. It tyjpically must be determined by simulation.

3.4.5.2 Definition

The Kolmogorov-Smirnov test is defined by:-

Ho: The data follow a specified distribution

Ha: The data do not follow the specified distribution

Test Statistic: The Kolmogorov-Smirnov test statistic is defined as

$$D=\max 1\leq i\leq N\ (F\ (Yi)\ -i-1N,\ iN-F\ (Yi))$$

Where ***F*** is the theoretical cumulative distribution of the distribution being tested which must be a continuous distribution (*i.e.*, no discrete distributions such as the binomial or Poisson), and it must be fully specified (*i.e.*, the location, scale and shape parameters cannot be estimated from the data).

3.4.5.3 Significance Level and Critical Values

The hypothesis regarding the distributional form is rejected if the test statistic, *D*, is greater than the critical value obtained from a table.

3.4.5.4 Importance of the K-S test

Many statistical tests and procedures are based on specific distributional assumptions. The assumption of normality is particularly common in classical statistical tests. There are many non-parametric and robust techniques that are not based on strong distributional assumptions. By robust, we mean a statistical technique that performs well under a wide range of distributional assumptions. However, techniques based on specific distributional assumptions are in general more powerful than these non-parametric and robust techniques. By power, we mean the ability to detect a difference when that difference actually exists. Therefore, if the distributional assumptions can be confirmed, the parametric techniques are generally preferred. If you are using a technique that makes a normality (or some other type of distributional) assumption, it is important to confirm that this assumption is in fact justified. If it is, the more powerful parametric techniques

can be used. If the distributional assumption is not justified, using a non-parametric or robust technique may be required. The present study adopted K-S test;it also employed Student t-test to evaluate mean differences of various body size parameters.

3.4.6 Seasonality

Seasonal pattern of insects can be defined as a phenomenon such as the abundance of active adults, appearance of reproductive activity or of dispersal that may occur only at certain times of the year or it may occur year-round if there are well defined seasonal maxima (Wolda, 1988). Variation in insect abundance in tropical regions is a well established fact (Wolda, 1978; Wolda and Fisk, 1981; Pinheiro *et al.,* 2002), but little is known about the factors that determine this seasonality. In the tropics there is variation of climate conditions that can affect the seasonal patterns of insects (Wolda and Fisk, 1981). One of the most important factors in many regions is the change from the dry to the rainy season (Wolda, 1988). However, it cannot be expected that ecologically and taxonomically different groups respond in the same manner to shifts in climate variables (Wolda and Fisk, 1981). Seasonality patterns of insects were assessed through plots of species richness and abundance over time in an effort to discern the behavior that arise. Further analysis was attempted by application of circular statistics to help elucidate on the patterns that were particularly difficult to interpret.

3.4.7 Weather parameters and insect activity

Assessment of the effect of temperature, relative humidity and rainfall impacts on the species richness and abundance through correlations and multiple regression analysis were attempted at three levels (a) on the day of sampling, (b) cumulated over the period of three days, and (c) cumulated over three weeks.

IV RESULTS AND DISCUSSION

The insects collected from the light trap at 21day interval set up at GKVK campus of University of Agricultural Sciences, Bengaluru, from 5th May, 2015 to 6thDecember, 2016 were classified in to OTUs and each OTU counted during each sample. In the following, the data sets obtained during the study are presented in detail and then the most salient inferences and interpretations are discussed in detail.

A. Data sets: Patterns and Associations

4.1 Diversity and abundance of insects

Activity of insects through seasons could be represented both by their abundance and diversity. While the former indicates the total population of all the species available at a given time, the diversity reflects the number of different ecological and functional taxa active during that period. The latter also helps understanding the rate of turn over of the species with time (Adler and Lauenroth, 2003). Therefore, we studied these two parameters *viz*., diversity and abundance through the study period. While the abundance was represented as total number of insects collected, the diversity was assessed through number of OTUs, families, orders and also through the diversity indices (Mugurran, 2004). The following provides the general patterns of insect activity.

4.1.1 Number of OTUs, families, orders, and diversity

4.1.1.1 All insects

A total of 209,098 individuals belonging to 764 morpho-species or Operational Taxonomic Units (OTUs), representing 101 families from 12 orders were collected through the two years of sampling (Table 1). The Simpson's index of diversity computed for all insects was 0.97, the Shannon-Wiener index was 4.44 and Avalanche index was 1.17.

4.1.1.2 Different orders

Order Coloeptera had the highest number of species (348) followed by Hemiptera (135) and Lepidoptera (110); orders Psocoptera (2), Odonata (2) and Mantodea (2) were

least diverse in terms of OTUs (Figure 1; Table 2). Order Hemiptera dominated by number of insects attracted (97488) followed by Coleoptera (86191) and Diptera (12632). Psocoptera (6), Odonata (3) and Mantodea (2) were least collected (Figure 2). Order Coleoptera had the highest number of families (29), followed by Diptera (25), Hemiptera (23), Lepidoptera (11) and Hymenoptera (4).

Table 1. List of OTUs and their numbers collected at light trap from 8/05/2015 to 6/12/16 period at GKVK. The table also provides their taxonomic positions

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
1	1	Dictyoptera	Termitidae	383	383	Hemiptera	Tingidae
2	2	Dictyoptera	Blattidae	384	384	Coleoptera	Carabidae
3	3	Dictyoptera	Blattidae	385	385	Hemiptera	Miridae
4	4	Hemiptera	Rhyparochromidae	386	386	Hemiptera	Miridae
5	5	Hemiptera	cydnidae	387	387	Hemiptera	Reduviidae
6	6	Hemiptera	Reduviidae	388	388	Hemiptera	Reduviidae
7	7	Hemiptera	Rhyparochromidae	389	389	Hymenoptera	Formicidae
8	8	Hemiptera	Rhyparochromidae	390	390	Hemiptera	Tingidae
9	9	Hemiptera	Corixidae	391	391	Hemiptera	Rhyparochromidae
10	67	Hemiptera	Rhyparochromidae	392	392	Hemiptera	Dictyopharidae
11	68	Hemiptera	Rhyparochromidae	393	393	Coleoptera	Hydrophilidae
12	170	Hemiptera	Rhyparochromidae	394	394	Hemiptera	Reduviidae
13	171	Hemiptera	Cydnidae	395	395	Neuroptera	Mantispidae
14	172	Hemiptera	Cydnidae	396	396	Mantodia	Pseudopactybractus
15	173	Hemiptera	Rhyparochromidae	397	397	Odonata	Coenagrionidae
16	174	Hemiptera	Miridae	398	398	Odonata	Libellulidae
17	175	Hemiptera	Ryparochromidae	399	399	Hemiptera	Tingidae
18	176	Hemiptera	Miridae	400	400	Lepidoptera	Gelechiidae
19	177	Hemiptera	Cydnidae	401	401	Lepidoptera	Gelechiidae
20	178	Hemiptera	Rhyparochromidae	402	402	Lepidoptera	Crambidae
21	181	Hemiptera	Mesovellidae	403	403	Orthoptera	Gryllidae
22	182	Hemiptera	Miridae	404	404	Coleoptera	Languridae
23	183	Hemiptera	Miridae	405	405	Diptera	Chrorophidae
24	184	Hemiptera	Miridae	406	406	Diptera	Chrorophidae
25	185	Hemiptera	Miridae	407	407	Diptera	Chrorophidae
26	186	Hemiptera	Delphacidae	408	408	Diptera	Muscidae
27	187	Hemiptera	Rhyparochromidae	409	409	Diptera	Mycetophylidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
28	188	Hemiptera	Tingidae	410	410	Diptera	Chironomidae
29	189	Hemiptera	Rhyparochromidae	411	411	Diptera	Chironomidae
30	190	Hemiptera	Delphacidae	412	412	Diptera	Chironomidae
31	191	Hemiptera	Cicadellidae	413	413	Diptera	Chironomidae
32	192	Hemiptera	Cicadellidae	414	414	Diptera	Stratiomyidae
33	193	Hemiptera	Cicadellidae	415	415	Diptera	Calliphoridae
34	194	Hemiptera	Cicadellidae	416	416	Diptera	Phoridae
35	195	Hemiptera	Miridae	417	417	Hymenoptera	Formicidae
36	196	Hemiptera	Corixidae	418	418	Diptera	Phoridae
37	197	Hemiptera	Cicadellidae	419	419	Coleoptera	Hydrophilidae
38	198	Hemiptera	Corixidae	420	420	Coleoptera	Hydrophilidae
39	199	Hemiptera	Cicadellidae	421	421	Coleoptera	Hydrophilidae
40	200	Hemiptera	Cicadellidae	422	422	Coleoptera	Hydrophilidae
41	201	Hemiptera	Miridae	423	423	Coleoptera	Hydrophilidae
42	202	Hemiptera	Miridae	424	424	Coleoptera	Hydrophilidae
43	203	Hemiptera	Rhyparochromidae	425	425	Coleoptera	Hydrophilidae
44	204	Hemiptera	Cicadellidae	426	426	Coleoptera	Hydrophilidae
45	205	Hemiptera	Delphacidae	427	427	Coleoptera	Hydrophilidae
46	206	Lepidoptera	Pyralidae	428	428	Coleoptera	Hydrophilidae
47	207	Hemiptera	Notorectidae	429	429	Lepidoptera	Tortricidae
48	208	Hemiptera	Delphacidae	430	430	Lepidoptera	Pyralidae
49	209	Hemiptera	Cicadellidae	431	431	Lepidoptera	Pyralidae
50	210	Hemiptera	Delphacidae	432	432	Lepidoptera	Pyralidae
51	211	Hemiptera	Cicadellidae	433	433	Lepidoptera	Pyralidae
52	212	Hemiptera	Cicadellidae	434	434	Lepidoptera	Pyralidae
53	213	Hemiptera	Cicadellidae	435	435	Lepidoptera	Pyralidae
54	214	Hemiptera	Cicadellidae	436	436	Lepidoptera	Pyralidae
55	215	Hemiptera	Cicadellidae	437	437	Lepidoptera	Pyralidae
56	216	Hemiptera	Delphacidae	438	438	Lepidoptera	Pyralidae
57	217	Hemiptera	Cicadellidae	439	439	Lepidoptera	Pyralidae
58	218	Hemiptera	Delphacidae	440	440	Lepidoptera	Pyralidae
59	219	Hemiptera	Miridae	441	441	Lepidoptera	Pyralidae
60	220	Hemiptera	Miridae	442	442	Lepidoptera	Pyralidae
61	221	Hemiptera	Cicadellidae	443	443	Lepidoptera	Pyralidae
62	222	Hemiptera	Cicadellidae	444	444	Lepidoptera	Pyralidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
63	223	Hemiptera	Miridae	445	445	Lepidoptera	Pyralidae
64	224	Hemiptera	Vellidae	446	446	Lepidoptera	Pyralidae
65	225	Hemiptera	Miridae	447	447	Lepidoptera	Pyralidae
66	226	Hemiptera	Miridae	448	448	Lepidoptera	Pyralidae
67	227	Hemiptera	Vellidae	449	449	Lepidoptera	Pyralidae
68	228	Hemiptera	Anthocoridae	450	450	Lepidoptera	Pyralidae
69	229	Hemiptera	Miridae	451	451	Lepidoptera	Arctidae
70	69	Coleoptera	Heteroceridae	452	452	Lepidoptera	Arctidae
71	70	Coleoptera	Ditycidae	453	453	Lepidoptera	Arctidae
72	71	Coleoptera	Elateridae	454	454	Lepidoptera	Noctuidae
73	72	Coleoptera	Scarabidae	455	455	Lepidoptera	Crambidae
74	73	Coleoptera	Chrysomelidae	456	456	Lepidoptera	Gelechiidae
75	74	Coleoptera	Scirtidae	457	457	Lepidoptera	Gelechiidae
76	75	Coleoptera	Staphylinidae	458	458	Lepidoptera	Gelechiidae
77	76	Coleoptera	Hydrophilidae	459	459	Lepidoptera	Gelechiidae
78	77	Coleoptera	Hydrophilidae	460	460	Trichoptera	Trichoptera
79	78	Coleoptera	Scarabidae	461	461	Trichoptera	Trichoptera
80	79	Coleoptera	Hydrophilidae	462	462	Hymenoptera	Apidae
81	80	Coleoptera	Staphylinidae	463	463	Hemiptera	Pentatomidae
82	81	Coleoptera	Elateridae	464	464	Coleoptera	Staphylinidae
83	82	Coleoptera	Hydrophilidae	465	465	Coleoptera	Carabidae
84	83	Coleoptera	Noteridae	466	466	Coleoptera	Languridae
85	84	Coleoptera	Carabidae	467	467	Coleoptera	Tenebrionidae
86	85	Coleoptera	Elateridae	468	468	Coleoptera	Nitidulidae
87	86	Coleoptera	Staphylinidae	469	469	Coleoptera	Nitidulidae
88	87	Coleoptera	Chrysomelidae	470	470	Coleoptera	Curculionidae
89	88	Coleoptera	Hydrophilidae	471	471	Coleoptera	Scotylidae
90	89	Coleoptera	Dermastidae	472	472	Coleoptera	Helipidae
91	90	Coleoptera	Noteridae	473	473	Coleoptera	Helipidae
92	91	Coleoptera	Silvaridae	474	474	Coleoptera	Nitidulidae
93	92	Coleoptera	Scarabidae	475	475	Coleoptera	Nitidulidae
94	93	Coleoptera	Staphylinidae	476	476	Coleoptera	Carabidae
95	94	Coleoptera	Carabidae	477	477	Coleoptera	Carabidae
96	95	Coleoptera	Carabidae	478	478	Hemiptera	Nabidae
97	96	Coleoptera	Heteroceridae	479	479	Hemiptera	Cicadellidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
98	97	Coleoptera	Anthiciidae	480	480	Coleoptera	Carabidae
99	98	Coleoptera	Carabidae	481	481	Coleoptera	Ditycidae
100	99	Coleoptera	Anobiidae	482	482	Coleoptera	Ditycidae
101	100	Coleoptera	Heteroceridae	483	483	Coleoptera	Mycetophagidae
102	101	Coleoptera	Mordilidae	484	484	Hemiptera	Pyrrhocoridae
103	102	Coleoptera	Carabidae	485	485	Coleoptera	Chrysomelidae
104	103	Coleoptera	Staphylinidae	486	486	Coleoptera	Chrysomelidae
105	104	Coleoptera	Staphylinidae	487	487	Hemiptera	Rhyparochromidae
106	105	Coleoptera	Hydrophilidae	488	488	Hemiptera	Rhyparochromidae
107	106	Coleoptera	Anobiidae	489	489	Hemiptera	Miridae
108	107	Coleoptera	Anthiciidae	490	490	Coleoptera	Hydrophilidae
109	108	Coleoptera	Noteridae	491	491	Coleoptera	Hydrophilidae
110	109	Coleoptera	Curculionidae	492	492	Coleoptera	Carabidae
111	110	Coleoptera	Silvaridae	493	493	Coleoptera	Carabidae
112	111	Coleoptera	Curculionidae	494	494	Coleoptera	Carabidae
113	112	Coleoptera	Curculionidae	495	495	Coleoptera	Carabidae
114	113	Coleoptera	Dermastidae	496	496	Coleoptera	Carabidae
115	114	Coleoptera	Scarabidae	497	497	Diptera	Chironomidae
116	115	Coleoptera	Tenebrionidae	498	498	Diptera	Chironomidae
117	116	Coleoptera	Carabidae	499	499	Coleoptera	Silvaridae
118	117	Coleoptera	Coccinelidae	500	500	Lepidoptera	Pyralidae
119	118	Coleoptera	Tenebrionidae	501	501	Lepidoptera	Pyralidae
120	119	Coleoptera	Tenebrionidae	502	502	Hemiptera	Miridae
121	120	Coleoptera	Scarabidae	503	503	Hemiptera	Miridae
122	121	Coleoptera	Scarabidae	504	504	Hymenoptera	Braconidae
123	122	Coleoptera	Cerambicidae	505	505	Coleoptera	Curculionidae
124	123	Coleoptera	Elateridae	506	506	Coleoptera	Chrysomelidae
125	124	Coleoptera	Nitidulidae	507	507	Coleoptera	Dermastidae
126	125	Coleoptera	Scarabidae	508	508	Lepidoptera	Noctuidae
127	126	Coleoptera	Erotylidae	509	509	Hemiptera	Pentatomidae
128	127	Coleoptera	Nitidulidae	510	510	Diptera	Tipulidae
129	128	Coleoptera	Tenebrionidae	511	511	Hemiptera	Mesovellidae
130	129	Coleoptera	Tenebrionidae	512	512	Coleoptera	Coccinelidae
131	130	Coleoptera	Scarabidae	513	513	Coleoptera	Anthiciidae
132	131	Coleoptera	Carabidae	514	514	Coleoptera	Noteridae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
133	132	Coleoptera	Lampyridae	515	515	Diptera	Muscidae
134	133	Coleoptera	Languridae	516	516	Neuroptera	Hemerobiidae
135	134	Coleoptera	Scarabidae	517	517	Hemiptera	Corixidae
136	135	Coleoptera	Scarabidae	518	518	Coleoptera	Scarabidae
137	136	Coleoptera	Scarabidae	519	519	Coleoptera	Scarabidae
138	137	Coleoptera	Scarabidae	520	520	Coleoptera	Scarabidae
139	138	Coleoptera	Carabidae	521	521	Coleoptera	Chrysomelidae
140	139	Coleoptera	Scarabidae	522	522	Coleoptera	Chrysomelidae
141	140	Coleoptera	Anobiidae	523	523	Coleoptera	Chrysomelidae
142	141	Coleoptera	Scarabidae	524	524	Coleoptera	Chrysomelidae
143	142	Coleoptera	Scarabidae	525	525	Coleoptera	Chrysomelidae
144	143	Coleoptera	Bostrichidae	526	526	Coleoptera	Chrysomelidae
145	144	Coleoptera	Scarabidae	527	527	Coleoptera	Chrysomelidae
146	145	Coleoptera	Scarabidae	528	528	Coleoptera	Scirtidae
147	146	Coleoptera	Curculionidae	529	529	Coleoptera	Silvaridae
148	147	Coleoptera	Carabidae	530	530	Coleoptera	Cantharidae
149	148	Coleoptera	Elateridae	531	531	Hemiptera	Pleidae
150	149	Coleoptera	Carabidae	532	532	Coleoptera	Elateridae
151	150	Coleoptera	Dermastidae	533	533	Coleoptera	Tenebrionidae
152	151	Coleoptera	Scarabidae	534	534	Coleoptera	Tenebrionidae
153	152	Coleoptera	Staphylinidae	535	535	Coleoptera	Tenebrionidae
154	153	Coleoptera	Scarabidae	536	536	Coleoptera	Tenebrionidae
155	154	Coleoptera	Staphylinidae	537	537	Coleoptera	Tenebrionidae
156	155	Coleoptera	Carabidae	538	538	Coleoptera	Languridae
157	156	Coleoptera	Tenebrionidae	539	539	Coleoptera	Erotylidae
158	157	Coleoptera	Carabidae	540	540	Coleoptera	Ditycidae
159	158	Coleoptera	Scarabidae	541	541	Coleoptera	Ditycidae
160	159	Coleoptera	Carabidae	542	542	Coleoptera	Anobiidae
161	160	Coleoptera	Carabidae	543	543	Coleoptera	Hydrophilidae
162	161	Coleoptera	Carabidae	544	544	Coleoptera	Hydrophilidae
163	162	Coleoptera	Carabidae	545	545	Coleoptera	Hydrophilidae
164	163	Coleoptera	Curculionidae	546	546	Coleoptera	Hydrophilidae
165	164	Coleoptera	Scarabidae	547	547	Coleoptera	Hydrophilidae
166	165	Coleoptera	Carabidae	548	548	Coleoptera	Hydrophilidae
167	166	Coleoptera	Carabidae	549	549	Coleoptera	Hydrophilidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
168	167	Coleoptera	Staphylinidae	550	550	Coleoptera	Carabidae
169	168	Coleoptera	Curculionidae	551	551	Coleoptera	Carabidae
170	169	Coleoptera	Tenebrionidae	552	552	Coleoptera	Carabidae
171	255	Coleoptera	Staphylinidae	553	553	Coleoptera	Carabidae
172	256	Coleoptera	Staphylinidae	554	554	Coleoptera	Carabidae
173	22	Lepidoptera	Pyralidae	555	555	Coleoptera	Carabidae
174	23	Lepidoptera	Arctidae	556	556	Coleoptera	Carabidae
175	24	Lepidoptera	Pyralidae	557	557	Coleoptera	Carabidae
176	25	Lepidoptera	Crambidae	558	558	Coleoptera	Carabidae
177	26	Lepidoptera	Crambidae	559	559	Coleoptera	Carabidae
178	27	Lepidoptera	Crambidae	560	560	Coleoptera	Carabidae
179	28	Lepidoptera	Crambidae	561	561	Coleoptera	Carabidae
180	29	Lepidoptera	Geometridae	562	562	Coleoptera	Carabidae
181	30	Lepidoptera	Geometridae	563	563	Coleoptera	Carabidae
182	31	Lepidoptera	Geometridae	564	564	Coleoptera	Nitidulidae
183	32	Lepidoptera	Geometridae	565	565	Coleoptera	Nitidulidae
184	33	Lepidoptera	Noctuidae	566	566	Coleoptera	Anthiciidae
185	34	Lepidoptera	Crambidae	567	567	Coleoptera	Anthiciidae
186	35	Lepidoptera	Pyralidae	568	568	Coleoptera	Anthiciidae
187	36	Lepidoptera	Geometridae	569	569	Coleoptera	Anthiciidae
188	37	Lepidoptera	Pyralidae	570	570	Coleoptera	Anthiciidae
189	38	Lepidoptera	Crambidae	571	571	Coleoptera	Anthiciidae
190	39	Lepidoptera	Crambidae	572	572	Coleoptera	Anthiciidae
191	40	Lepidoptera	Bomycidae	573	573	Coleoptera	Curculionidae
192	41	Lepidoptera	Pyralidae	574	574	Coleoptera	Curculionidae
193	42	Lepidoptera	Crambidae	575	575	Coleoptera	Curculionidae
194	43	Lepidoptera	Crambidae	576	576	Coleoptera	Curculionidae
195	44	Lepidoptera	Noctuidae	577	577	Coleoptera	Curculionidae
196	45	Lepidoptera	Pyralidae	578	578	Coleoptera	Curculionidae
197	46	Lepidoptera	Pyralidae	579	579	Coleoptera	Chrysomelidae
198	47	Lepidoptera	Pyralidae	580	580	Coleoptera	Chrysomelidae
199	48	Lepidoptera	Crambidae	581	581	Coleoptera	Chrysomelidae
200	49	Lepidoptera	Noctuidae	582	582	Coleoptera	Carabidae
201	50	Lepidoptera	Pyralidae	583	583	Coleoptera	Carabidae
202	51	Lepidoptera	Lymantridae	584	584	Coleoptera	Dermastidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
203	52	Lepidoptera	Noctuidae	585	585	Coleoptera	Dermastidae
204	53	Lepidoptera	Crambidae	586	586	Coleoptera	Languridae
205	54	Lepidoptera	Noctuidae	587	587	Coleoptera	Curculionidae
206	55	Lepidoptera	Pyralidae	588	588	Coleoptera	Carabidae
207	56	Lepidoptera	Arctidae	589	589	Coleoptera	Elateridae
208	57	Lepidoptera	Geometridae	590	590	Coleoptera	Coccinelidae
209	58	Lepidoptera	Noctuidae	591	591	Coleoptera	Chrysomelidae
210	59	Lepidoptera	Noctuidae	592	592	Coleoptera	Chrysomelidae
211	60	Lepidoptera	Crambidae	593	593	Coleoptera	Curculionidae
212	61	Lepidoptera	Noctuidae	594	594	Coleoptera	Curculionidae
213	62	Lepidoptera	Pyralidae	595	595	Coleoptera	Curculionidae
214	63	Lepidoptera	Geometridae	596	596	Coleoptera	Curculionidae
215	64	Lepidoptera	Crambidae	597	597	Coleoptera	Carabidae
216	65	Lepidoptera	Crambidae	598	598	Hymenoptera	Apidae
217	66	Lepidoptera	Noctuidae	599	599	Hymenoptera	Formicidae
218	10	Hymenoptera	Formicidae	600	600	Hymenoptera	Formicidae
219	11	Hymenoptera	Formicidae	601	601	Hymenoptera	Braconidae
220	12	Hymenoptera	Braconidae	602	602	Hymenoptera	Formicidae
221	13	Hymenoptera	Braconidae	603	603	Hymenoptera	Apidae
222	14	Hymenoptera	Formicidae	604	604	Hymenoptera	Braconidae
223	15	Hymenoptera	Apidae	605	605	Diptera	Muscidae
224	16	Hymenoptera	Apidae	606	606	Trichoptera	Trichoptera
225	243	Hymenoptera	Braconidae	607	607	Hymenoptera	Formicidae
226	244	Diptera	Phoridae	608	608	Diptera	Chrorophidae
227	245	Diptera	Ephydridae	609	609	Diptera	Tipulidae
228	246	Hymenoptera	Formicidae	610	610	Diptera	Ephydridae
229	247	Diptera	Mycetophylidae	611	611	Diptera	Drosophilidae
230	248	Hymenoptera	Formicidae	612	612	Diptera	Drosophilidae
231	249	Hymenoptera	Formicidae	613	613	Diptera	Chironomidae
232	250	Hymenoptera	Braconidae	614	614	Diptera	Phoridae
233	251	Diptera	Phoridae	615	615	Diptera	Chironomidae
234	252	Diptera	Chironomidae	616	616	Diptera	Mycetophylidae
235	253	Hemiptera	Delphacidae	617	617	Hymenoptera	Formicidae
236	254	Diptera	Culicidae	618	618	Diptera	Ephydridae
237	17	Diptera	Bibionidae	619	619	Diptera	Mycetophylidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
238	18	Diptera	Anthomyiidae	620	620	Hymenoptera	Formicidae
239	19	Diptera	Calliphoridae	621	621	Diptera	Phoridae
240	20	Diptera	Calliphoridae	622	622	Hymenoptera	Formicidae
241	230	Diptera	Phoridae	623	623	Hymenoptera	Braconidae
242	231	Diptera	Phoridae	624	624	Coleoptera	Staphylinidae
243	232	Diptera	Chrorophidae	625	625	Diptera	Ulididae
244	233	Diptera	Phoridae	626	626	Hymenoptera	Braconidae
245	234	Diptera	Drosophilidae	627	627	Diptera	Chironomidae
246	235	Diptera	Chrorophidae	628	628	Diptera	Drosophilidae
247	236	Diptera	Ulididae	629	629	Hemiptera	Miridae
248	237	Diptera	Phoridae	630	630	Hemiptera	Rhyparochromidae
249	238	Diptera	Culicidae	631	631	Hemiptera	Miridae
250	239	Diptera	Ephydridae	632	632	Hemiptera	Cicadellidae
251	240	Diptera	Chrorophidae	633	633	Hemiptera	Miridae
252	241	Diptera	Ephydridae	634	634	Hemiptera	Delphacidae
253	242	Diptera	Muscidae	635	635	Hemiptera	Rhyparochromidae
254	21	Orthoptera	Gryllidae	636	636	Hemiptera	Miridae
255	179	Coleoptera	Chrysomelidae	637	637	Hemiptera	Miridae
256	257	Lepidoptera	Pyralidae	638	638	Hemiptera	Cicadellidae
257	258	Diptera	Phoridae	639	639	Hemiptera	Delphacidae
258	259	Trichoptera	Trichoptera	640	640	Hemiptera	Vellidae
259	260	Hemiptera	Delphacidae	641	641	Hemiptera	Miridae
260	261	Hemiptera	Rhyparochromidae	642	642	Hemiptera	Rhyparochromidae
261	262	Hemiptera	Gerridae	643	643	Hemiptera	Rhyparochromidae
262	263	Hemiptera	Pentatomidae	644	644	Hemiptera	Miridae
263	264	Hemiptera	Nabidae	645	645	Hemiptera	Rhyparochromidae
264	180	Coleoptera	Tenebrionidae	646	646	Hemiptera	cydnidae
265	265	Lepidoptera	Erebidae	647	647	Hemiptera	Rhyparochromidae
266	266	Coleoptera	Scarabidae	648	648	Hemiptera	cydnidae
267	267	Coleoptera	Scarabidae	649	649	Hemiptera	Miridae
268	268	Coleoptera	Scarabidae	650	650	Hemiptera	Rhyparochromidae
269	269	Coleoptera	Scarabidae	651	651	Coleoptera	Tenebrionidae
270	270	Coleoptera	Carabidae	652	652	Lepidoptera	Noctuidae
271	271	Coleoptera	Carabidae	653	653	Coleoptera	Tenebrionidae
272	272	Coleoptera	Carabidae	654	654	Hemiptera	Ryparochromidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
273	273	Coleoptera	Carabidae	655	655	Coleoptera	Nitidulidae
274	274	Coleoptera	Carabidae	656	656	Coleoptera	Nitidulidae
275	275	Coleoptera	Chrysomelidae	657	657	Coleoptera	Staphylinidae
276	276	Coleoptera	Chrysomelidae	658	658	Diptera	Muscidae
277	277	Coleoptera	Chrysomelidae	659	659	Neuroptera	Hemerobiidae
278	278	Coleoptera	Chrysomelidae	660	660	Diptera	Dolichopopidae
279	279	Coleoptera	Chrysomelidae	661	661	Diptera	Sirphidae
280	280	Coleoptera	Dermastidae	662	662	Diptera	Tephritidae
281	281	Coleoptera	Dermastidae	663	663	Coleoptera	Ditycidae
282	282	Coleoptera	Tenebrionidae	664	664	Diptera	Ephydridae
283	283	Coleoptera	Tenebrionidae	665	665	Coleoptera	Tenebrionidae
284	284	Coleoptera	Tenebrionidae	666	666	Diptera	Tephritidae
285	285	Coleoptera	Hydrophilidae	667	667	Coleoptera	Curculionidae
286	286	Coleoptera	Hydrophilidae	668	668	Diptera	Pyrgotidae
287	287	Coleoptera	Hydrophilidae	669	669	Diptera	Calliphoridae
288	288	Coleoptera	Curculionidae	670	670	Dictyoptera	Blattidae
289	289	Coleoptera	Bruchidae	671	671	Hemiptera	Cicadellidae
290	290	Coleoptera	Bruchidae	672	672	Coleoptera	Tenebrionidae
291	291	Coleoptera	Anthiciidae	673	673	Hymenoptera	Formicidae
292	292	Coleoptera	Elateridae	674	674	Hemiptera	Rhyparochromidae
293	293	Coleoptera	Curculionidae	675	675	Coleoptera	Anthecidae
294	294	Diptera	Ephydridae	676	676	Coleoptera	Curculionidae
295	295	Coleoptera	Cleridae	677	677	Coleoptera	Hydrophilidae
296	296	Orthoptera	Gryllidae	678	678	Coleoptera	Scirtidae
297	297	Coleoptera	Chrysomelidae	679	679	Coleoptera	Ditycidae
298	298	Diptera	Calliphoridae	680	680	Coleoptera	Carabidae
299	299	Coleoptera	Nitidulidae	681	681	Coleoptera	Chrysomelidae
300	300	Coleoptera	Curculionidae	682	682	Coleoptera	Tenebrionidae
301	301	Coleoptera	Nitidulidae	683	683	Coleoptera	Carabidae
302	302	Hemiptera	Pleidae	684	684	Coleoptera	Hydrophilidae
303	303	Coleoptera	Curculionidae	685	685	Coleoptera	Hydrophilidae
304	304	Coleoptera	Coccinelidae	686	686	Coleoptera	Carabidae
305	305	Coleoptera	Coccinelidae	687	687	Diptera	Scaridae
306	306	Diptera	Ephydridae	688	688	Diptera	Pyrgotidae
307	307	Diptera	Chrorophidae	689	689	Coleoptera	Dermastidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
308	308	Diptera	Chrorophidae	690	690	Coleoptera	Nitidulidae
309	309	Diptera	Chrorophidae	691	691	Coleoptera	Tenebrionidae
310	310	Diptera	Sarcophagidae	692	692	Diptera	Sepsidae
311	311	Diptera	Chrorophidae	693	693	Coleoptera	Heteroceridae
312	312	Diptera	Chrorophidae	694	694	Diptera	Ascilidae
313	313	Diptera	Chrorophidae	695	695	Hymenoptera	Formicidae
314	314	Diptera	Chrorophidae	696	696	Diptera	Muscidae
315	315	Diptera	Chrorophidae	697	697	Coleoptera	Chrysomelidae
316	316	Diptera	Drosophilidae	698	698	Coleoptera	Tenebrionidae
317	317	Diptera	Drosophilidae	699	699	Coleoptera	Hydrophilidae
318	318	Trichoptera	Trichoptera	700	700	Coleoptera	Carabidae
319	319	Orthoptera	Gryllidae	701	701	Coleoptera	Nitidulidae
320	320	Orthoptera	Gryllidae	702	702	Diptera	Calliphoridae
321	321	Diptera	Culicidae	703	703	Coleoptera	Tenebrionidae
322	322	Diptera	Tipulidae	704	704	Hymenoptera	Braconidae
323	323	Hymenoptera	Ichneumonidae	705	705	Diptera	Scaridae
324	324	Dictyoptera	Blattidae	706	706	Diptera	Dolichopopidae
325	325	Hymenoptera	Formicidae	707	707	Diptera	Sepsidae
326	326	Hymenoptera	Formicidae	708	708	Hemiptera	Aphididae
327	327	Psocoptera	Psocoptera	709	709	Diptera	Tephridae
328	328	Coleoptera	Curculionidae	710	710	Coleoptera	Hydrophilidae
329	329	Coleoptera	Ditycidae	711	711	Lepidoptera	Pyralidae
330	330	Coleoptera	Nitidulidae	712	712	Diptera	Tephridae
331	331	Coleoptera	Chrysomelidae	713	713	Coleoptera	Staphylinidae
332	332	Coleoptera	Bostrichidae	714	714	Lepidoptera	Pyralidae
333	333	Coleoptera	Chrysomelidae	715	715	Lepidoptera	Pyralidae
334	334	Coleoptera	Curculionidae	716	716	Hemiptera	Saldidae
335	335	Coleoptera	Scarabidae	717	717	Hemiptera	Cicadellidae
336	336	Coleoptera	Scarabidae	718	718	Neuroptera	Chrysopidae
337	337	Coleoptera	Scarabidae	719	719	Neuroptera	Mantispidae
338	338	Coleoptera	Scarabidae	720	720	Hemiptera	Cicadellidae
339	339	Coleoptera	Hydrophilidae	721	721	Lepidoptera	Pyralidae
340	340	Coleoptera	Dermastidae	722	722	Lepidoptera	Pyralidae
341	341	Coleoptera	Nitidulidae	723	723	Lepidoptera	Crambidae
342	342	Diptera	Lauxaniidae	724	724	Lepidoptera	Pyralidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
343	343	Coleoptera	Noteridae	725	725	Lepidoptera	Geometridae
344	344	Coleoptera	Hydrophilidae	726	726	Diptera	Ephydridae
345	345	Coleoptera	Staphylinidae	727	727	Hymenoptera	Ichneumonidae
346	346	Coleoptera	Ditycidae	728	728	Psocoptera	Psocoptera
347	347	Coleoptera	Tenebrionidae	729	729	Lepidoptera	Noctuidae
348	348	Coleoptera	Hydrophilidae	730	730	Lepidoptera	Geometridae
349	349	Coleoptera	Anthiciidae	731	731	Coleoptera	Ditycidae
350	350	Coleoptera	Coccinelidae	732	732	Lepidoptera	Arctidae
351	351	Coleoptera	Ditycidae	733	733	Lepidoptera	Arctidae
352	352	Coleoptera	Hydrophilidae	734	734	Lepidoptera	Arctidae
353	353	Coleoptera	Noctuidae	735	735	Lepidoptera	Sphyngidae
354	354	Lepidoptera	Pyralidae	736	736	Diptera	Scaridae
355	355	Lepidoptera	Tortricidae	737	737	Diptera	Scaridae
356	356	Diptera	Muscidae	738	738	Coleoptera	Curculionidae
357	357	Lepidoptera	Erebidae	739	739	Diptera	Tephritidae
358	358	Coleoptera	Staphylinidae	740	740	Diptera	Ephydridae
359	359	Coleoptera	Hydrophilidae	741	741	Diptera	Muscidae
360	360	Hemiptera	Hydrometridae	742	742	Coleoptera	Tenebrionidae
361	361	Diptera	Ephydridae	743	743	Hemiptera	Miridae
362	362	Diptera	Mycetophylidae	744	744	Coleoptera	Dermastidae
363	363	Lepidoptera	Crambidae	745	745	Hymenoptera	Braconidae
364	364	Lepidoptera	Geometridae	746	746	Hymenoptera	Ichneumonidae
365	365	Diptera	Sarcophagidae	747	747	Lepidoptera	Noctuidae
366	366	Lepidoptera	Pyralidae	748	748	Trichoptera	Trichoptera
367	367	Lepidoptera	Noctuidae	749	749	Hemiptera	Rhyparochromidae
368	368	Lepidoptera	Geometridae	750	750	Coleoptera	Bostrichidae
369	369	Diptera	Stratiomyidae	751	751	Coleoptera	Chrysomelidae
370	370	Coleoptera	Scarabidae	752	752	Coleoptera	Nitidulidae
371	371	Hemiptera	Vellidae	753	753	Orthoptera	Gryllidae
372	372	Orthoptera	Gryllidae	754	754	Coleoptera	Tenebrionidae
373	373	Hemiptera	Cecadidae	755	755	Coleoptera	Tenebrionidae
374	374	Mantodea	Mantidae	756	756	Coleoptera	Chrysomelidae
375	375	Hemiptera	Reduviidae	757	757	Coleoptera	Chrysomelidae
376	376	Hemiptera	Reduviidae	758	758	Coleoptera	Chrysomelidae
377	377	Coleoptera	Nitidulidae	759	759	Coleoptera	Chrysomelidae

Sl. No.	Species Code	Order	Family	Sl. No.	Species Code	Order	Family
378	378	Hemiptera	Reduviidae	760	760	Coleoptera	Carabidae
379	379	Hemiptera	Alydidae	761	761	Coleoptera	Lampyridae
380	380	Hemiptera	Anthocoridae	762	762	Coleoptera	Carabidae
381	381	Coleoptera	Curculionidae	763	763	Coleoptera	Anthiciidae
382	382	Hemiptera	Pentatomidae	764	764	Coleoptera	Curculionidae

4.1.1.3 Different families

The most species (OTU) rich families of Coleoptera were Carabidae (57), Hydrophilidae (39) and Scarabidae (33), while, Miridae (29) in Hemiptera had the highest number of species. In Coleoptera, families Staphylinidae (28487), Scarabidae (13631) and Hydrophilidae (12786) respectively, were the most abundant while in Hemiptera families Cicadellidae (43329) and Delphacidae (23707) had largest number of individuals (Table 2).

Table 2. Families, species richness and abundance of insects collected in different orders during the study period at GKVK, Bangalore

A. COLEOPTERA			
Sl. No.	**Family**	**Species richness**	**Abundance**
1	Anobiidae	5	565
2	Anthiciidae	14	1557
3	Bostrichidae	3	84
4	Bruchidae	2	41
5	Cantharidae	1	1
6	Carabidae	57	7008
7	Cerambicidae	1	12
8	Chrysomelidae	33	1370
9	Cleridae	1	1
10	Coccinelidae	6	1166
11	Curculionidae	31	739
12	Dermastidae	11	2008
13	Elateridae	8	848
14	Erotylidae	2	4

15	Helipidae	2	20
16	Heteroceridae	4	7050
17	Hydrophilidae	39	12786
18	Lampyridae	2	67
19	Languridae	5	148
20	Mordilidae	1	5
21	Mycetophagidae	1	2
22	Ditycidae	11	510
23	Nitidulidae	18	4223
24	Noteridae	5	701
25	Scarabidae	33	13631
26	Scotylidae	8	485
27	Silvaridae	4	1433
28	Staphylinidae	17	28487
29	Tenebrionidae	29	690
	TOTAL	**348**	**86191**
B. HEMIPTERA			
Sl. No.	**Family**	**Species richness**	**Abundance**
1	Alydidae	1	1
2	Anthocoridae	2	54
3	Anthomyiidae	1	55
4	Aphididae	1	16
4	Cecadidae	1	9
5	Cicadellidae	23	43329
6	cidnidae	6	3508
7	Corixidae	4	12097
8	Delphacidae	11	23707
9	Dictyopharidae	1	1
10	Gerridae	1	5
11	Hydrometridae	1	19
12	Mesovellidae	2	404
13	Miridae	29	6361
14	Nabidae	2	28
15	Notorectidae	1	60
16	Pentatomidae	4	81
17	Pleidae	2	202

18	Pyrrhocoridae	1	9
19	Reduviidae	7	68
20	Ryparochromidae	26	4017
21	Saldidae	1	125
22	Tingidae	4	54
23	Vellidae	4	3272
	TOTAL	**135**	**97488**
C. DIPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1		1	55
2	Ascilidae	1	1
3	Bibionidae	1	60
4	Calliphoridae	6	59
5	Lauxaniidae	1	3
6	Chironomidae	10	3069
7	Chrorophidae	15	5922
8	Culicidae	3	205
9	Dolichopopidae	2	4
10	Drosophilidae	6	274
11	Ephydridae	11	1919
13	Muscidae	8	163
15	Mycetophylidae	6	328
16	Phoridae	11	324
17	Pyrgotidae	2	6
18	Sarcophagidae	2	7
19	Scaridae	4	117
20	Sepsidae	2	3
21	Sirphidae	1	1
22	Stratiomyidae	2	10
23	Tephridae	5	12
24	Tipulidae	3	58
25	Ulididae	2	35
	TOTAL	**104**	**12632**
D. LEPIDOPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	Arctidae	8	190

2	Bomycidae	1	23
3	Crambidae	18	766
4	Gelechiidae	6	466
5	Geometridae	11	357
6	Lymantridae	1	4
7	Noctuidae	16	1336
8	Pyralidae	44	2869
9	Sphyngidae	1	6
10	Erebidae	2	187
11	Tortricidae	2	185
	TOTAL	**110**	**5379**
E. HYMENOPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	Apidae	5	224
2	Braconidae	11	489
3	Formicidae	19	4123
4	Ichneumonidae	3	3
	TOTAL	**38**	**4839**
F. DICTYOPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	Termitidae	1	840
2	Blattidae	4	47
	TOTAL	**5**	**887**
G. MANTODEA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	Mantidae	2	2
	TOTAL	**2**	**2**
H. NEUROPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	Hemerobiidae	2	3
2	Mantispidae	1	4
	TOTAL	**3**	**7**
I. ODONATA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	Coenagrionidae	1	1
2	Libellulidae	1	2

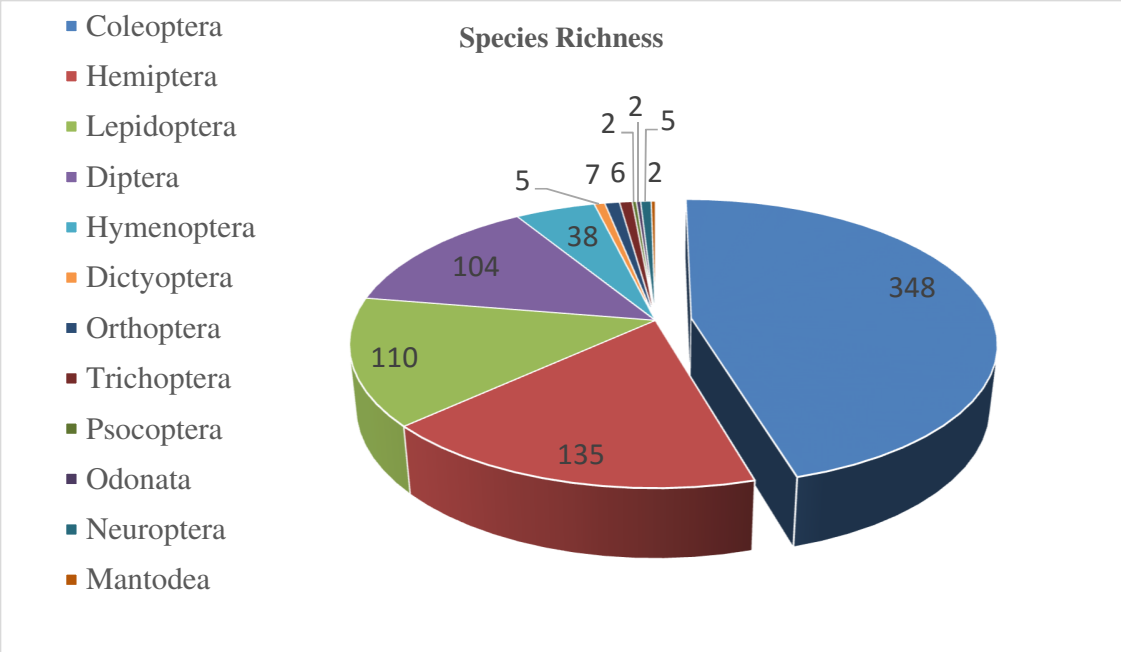

Figure 1. Proportion of insect species from different orders collected from light traps at GKVK, Bangalore from 8th May, 2015 to 6th December, 2016

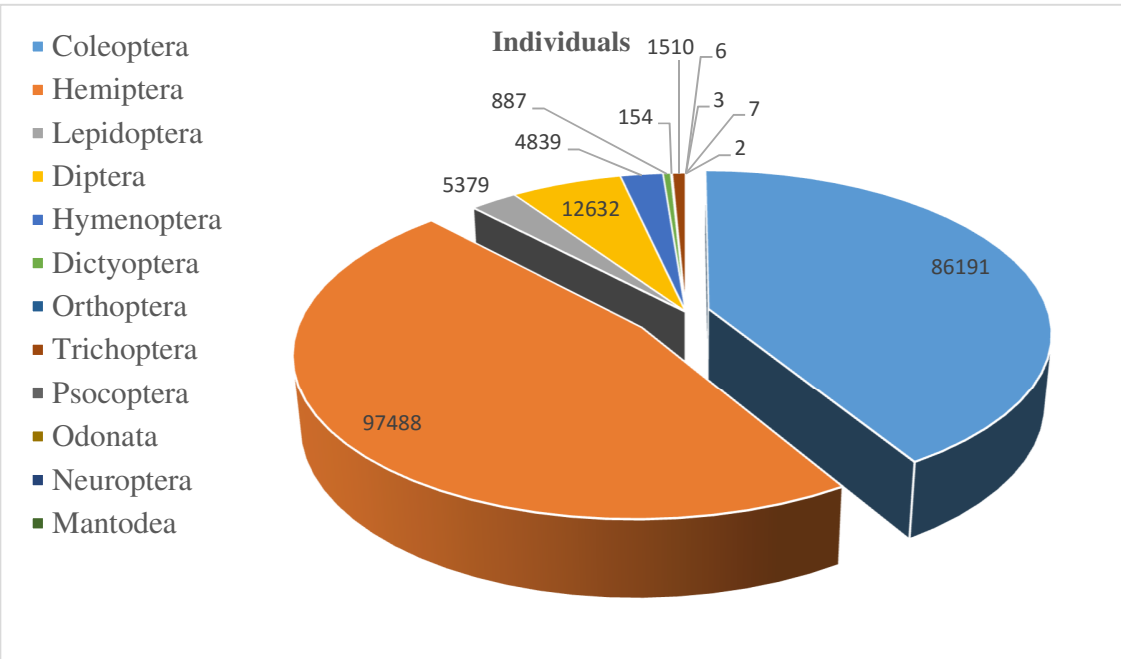

Figure 2. Numbers of insects of different orders attracted to light trap at GKVK, Bangalore from 8th May, 2015 to 6th December, 2016

	TOTAL	**2**	**3**
J. ORTHOPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	Gryllidae	7	154
	TOTAL	**7**	**154[JM2]**
K. PSOCOPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	?	2	6
	TOTAL	**2**	**6**
L. TRICHOPTERA			
Sl. No.	**Family**	**Species Richness**	**Abundance**
1	?	6	1510
	TOTAL	**6**	**1510**

*? Indicates unidentified insects

Table 3. Diversity indices of insect orders collected using light trap at GKVK

	Coleoptera	**Hemiptera**	**Lepidoptera**	**Diptera**	**Hymenoptera**	**Dictyoptera**	**Orthoptera**	**Trichoptera**	**Psocoptera**	**Odonata**	**Neuroptera**	**Mantodea**
Number of families	29	23	11	25	4	2	1	1	1	2	2	1
Species Richness	348	135	110	104	38	5	7	6	2	2	5	2
Individuals (Abundance)	86191	97488	5379	12632	4839	887	154	1510	6	3	7	2
SimpsonDiversity* Index	0.95	0.95	0.9478	0.937	0.9351	0.9012	0.9364	0.934	0.5	0.4444	0.8878	0
Shannon- Wiener Index*	3.098	3.092	2.906	2.933	2.909	2.399	2.846	2.774	0.6931	0.6365	2.243	0
Evenness Index*	0.887	0.881	0.7315	0.7517	0.7974	0.9179	0.9065	0.9422	1	0.9449	0.9421	1

***The indices were calculated as per Magurran (2004)**

Simpson's index of diversity showed that orders Coleoptera (0.95) and Hemiptera (0.95) are the most diverse groups with equal levels of index; Mantodea was found to be the least diverse group. This does reflect in general the diversity of these groups (Ghosh, 1996) though in terms of proportions, the GKVK insects differed from Indian and global level diversity of different taxa (analysed later). Shannon-Wiener index also showed order Coleoptera (3.098) to be the most diverse followed by Hemiptera (3.092) and Mantodea to be least diverse. Orders Psocoptera (1) and Mantodea (1) had the highest species evenness (Table 3; Figure 3 and 4).

4.1.2 Relation between species richness and family richness of orders

The plot of number of species per order on the number of families per showed nonlinear increase and the relationship could best be explained by the power function ($\mathbf{y = 2.8429x^{1.2985}}$; $R^2 = 0.87$). However, an exponential function ($\mathbf{y = 4.0927e^{0.1555x}}$; $R^2 = 0.7885$) seemed also to apply considering the dominating nature of order Coleoptera that appears to influence on the exponential curve (Figure 5). This indeed has been shown earlier by Ganeshaiah (1998).

4.1.3 Comparative assessment of diversity of insects attracted to light trap at GKVK, Campus with the total insect diversity in India and worldwide.

An assessment was done to compare the diversity of insects attracted to light trap at GKVK, campus with the total insect diversity in India and at the global level considering only the five most speciose orders *viz*., Coleoptera, Hemiptera, Hymenoptera, Lepidoptera and Diptera that constituted 909,345 insects. At the global level, Coleoptera represents 42.5 per cent while in India, it constitutes 32.8 per cent out of the 45,593 insects known from these five orders (Ghosh, 1996 and Mackerras, 1970). However, in our collection at GKVK 47.3 per cent were from coleoptera, 18.3per cent were from Hemipteran, 14.9per cent were from Lepidopteran, 14.1per cent were from Dipteran and 5.2per cent were from Hymenopteran (Table 4; Figure 6).

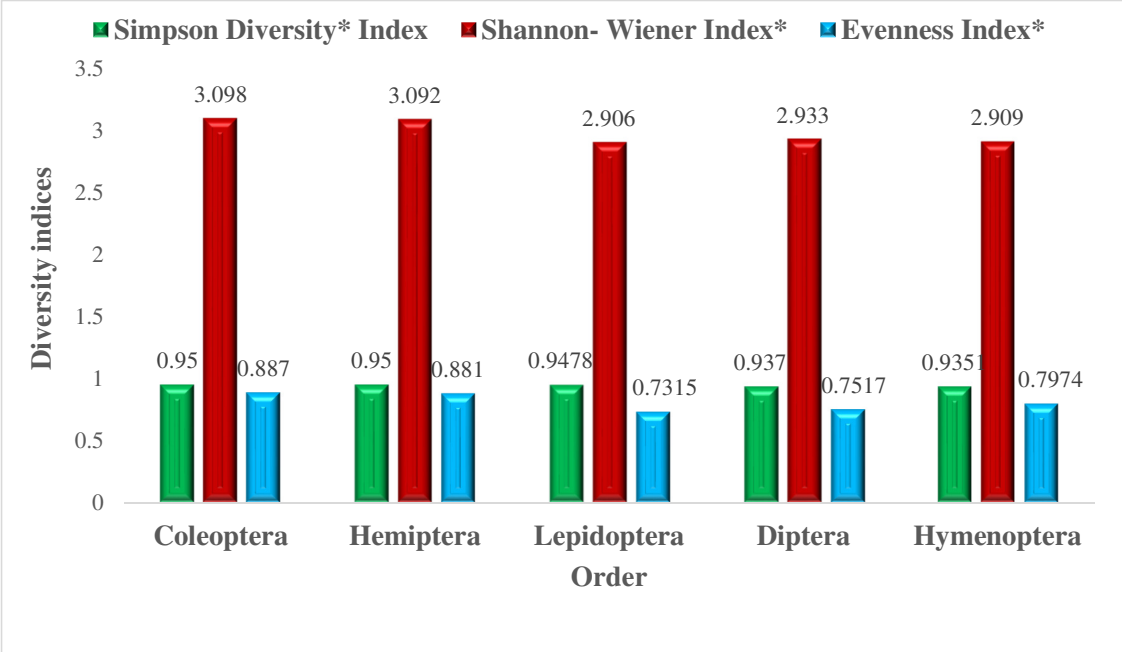

Figure 3. Diversity indices distributions of five most speciose and abundant insect orders.

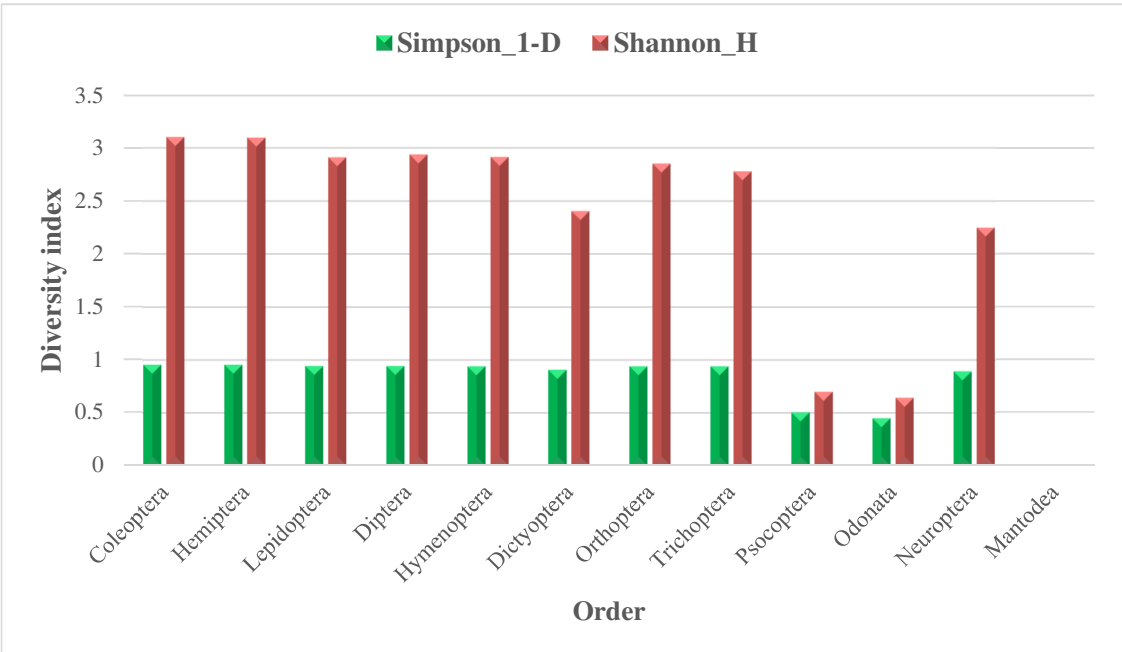

Figure 4. Diversity indices for all insect orders

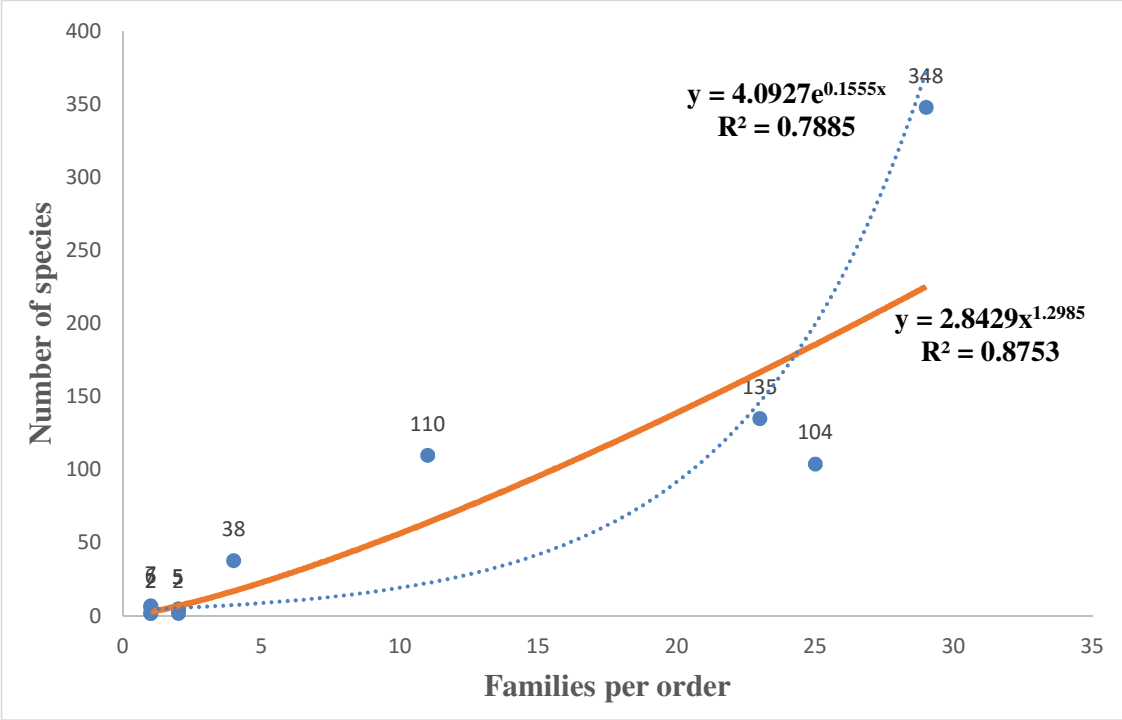

Figure 5. Relation between species richness of orders and their family richness

Table 4. Comparison of number of species in different orders of insects at World level, India and at GKVK Campus

Order	No. of species(World)*	No. of species(India)*	No. of species (GKVK, Campus)
Coleoptera	387100 (42.5 %)	15000 (32.8 %)	348(47.3 %)
Hemiptera	103590 (11.4 %)	6500 (14.2 %)	135 (18.3 %)
Lepidoptera	142500 (15.6 %)	13000 (28.5 %)	110 (14.9 %)
Diptera	159294 (17.5 %)	6093 (13.3 %)	104 (14.1 %)
Hymenoptera	116861 (12.8 %)	5000 (10.9 %)	38 (5.2 %)
Total	909,345	45,593	735

*From Ghosh, 1996 and Mackerras, 1970

Table 5. Comparison of the proportions of five speciose orders at GKVK with those of global and Indian insects

	No. of species observed (O)(GKVK)	No. of species expected (E)(Global)	No. of species expected (E) (India)	((O –E) ^2)/ E (Global)	((O –E) ^2)/ E (India)
Coleoptera	348	313	241	3.91	47.50
Hemiptera	135	84	105	30.96	8.57
Lepidoptera	110	115	210	0.217	47.62
Diptera	104	129	98	4.84	0.367
Hymenoptera	38	94	81	33.36	22.83
χ^2				**73.29****	**126.88****

** Chi square values are significant at 1 %

On species richness, out of the total 735 species of insects belonging to the five speciose families 348 were Coleopterans, 135 Hemipterans, 110 Lepidopterans, 104 Dipterans and 38 Hymenopterans. Chi-square computation reveal significant differences between observed and expected species richness at global and national levels (Table 5). Order Coleoptera was found to be over represented while Lepidoptera, Diptera and Hymenoptera were under represented while order Hemiptera was within range (Figure 7).

4.2 Relationship between species richness and abundance

4.2.1 Among all insects

Number of OTUs increased significantly with the number of insets collected in the 26 samples from the light trap (R^2= 0.7165; p< 0.01; Table 6, Figure 8); the relationship was non-linear and could be explained better by a power function ($y = 8.8334x^{0.3597}$). In other words, the species richness may either plateau off or would increase very little after a large number of insects are collected. However, the rate of species richness increase to that of collected insects was 0.36 (Figure 8).

4.2.2 Among the five speciose orders

Plots of species richness against abundance increased in a similar pattern in three orders *viz*., Coleoptera, Hemiptera, and Lepidoptera; species richness increased non-linearly (Table 6, Figure 9) and could be best fit to power functions (Coleoptera: $Y = 4.0145x^{0.4067}$, $R^2 = 0.6926$, $p < 0.01$; Hemiptera : $Y = 3.7616x^{0.3345}$, $R^2 = 0.7056$, $p< 0.01$; Lepidoptera ($y = 0.7732x^{0.6693}$, $R^2 = 0.7669$). For Hymenoptera, the relation was more linear ($Y = 0.0199x + 3.3844$, $R^2 = 0.5345$, $p <0.01$). In Diptera, the species richness increased in an exponential pattern with the number of its insects ($y = 8.1062e^{0.0008x}$; $R^2 = 0.1826$, $P < 0.05$).

Table 6. Relation between diversity and abundance of the five speciose orders with those of all the insects

	All insects	Coleoptera	Hemiptera	Lepidoptera	Diptera	Hymenoptera
Best Line Fit	$y = 8.8334x^{0.3597}$	$y = 4.0145x^{0.4067}$	$y = 3.7616\ x^{0.3345}$	$y = 0.7732\ x^{0.6693}$	$y = 8.1062e^{0.0008x}$	$y = 0.0199x + 3.3844$
R^2	0.7165	0.6926	0.7056	0.7669	0.1826	0.5345
P<	0.01	0.01	0.01	0.01	0.05	0.01

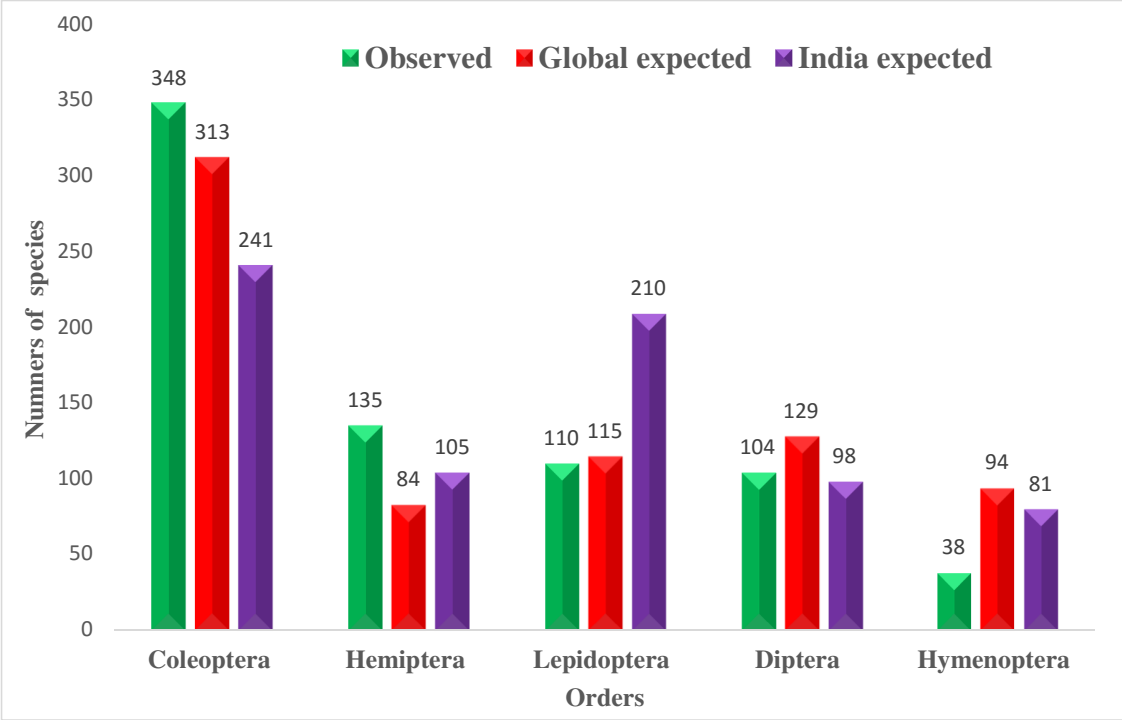

Figure 6: Number of species recovered at GKVK through light trap in the five orders along with those expected based on the proportions for India and world (Global level)

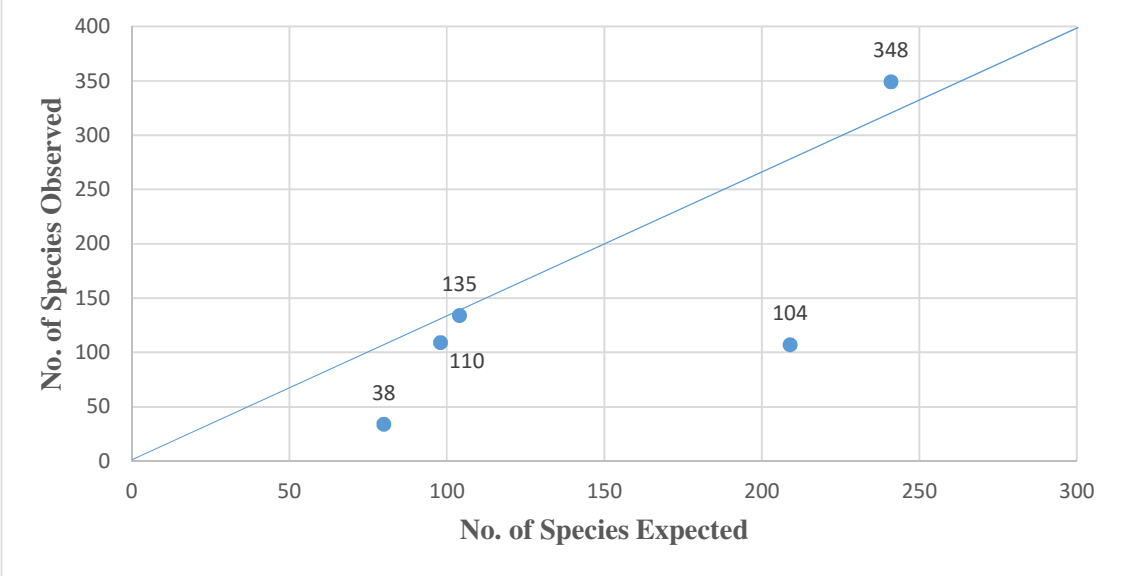

Figure 7. Relationship between Species observed and Species expected based on proportions from India in five most speciose orders.

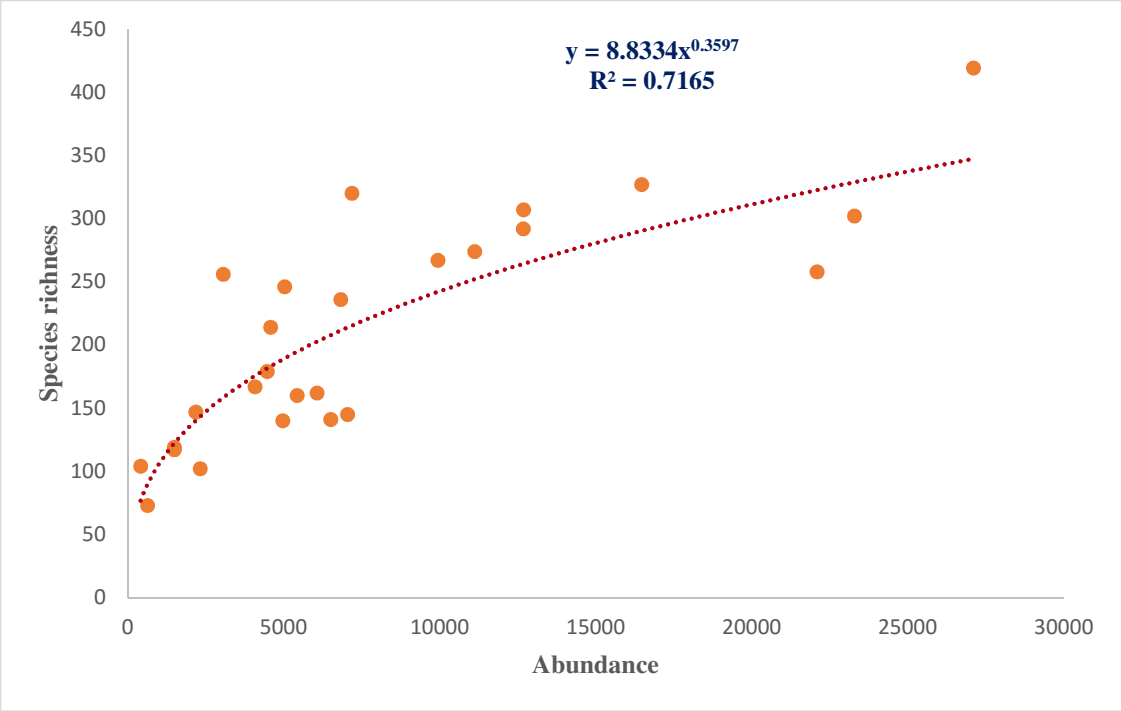

Figure 8. Relationship between abundance and species richness among all insects collected from the light trap catches during the study period.

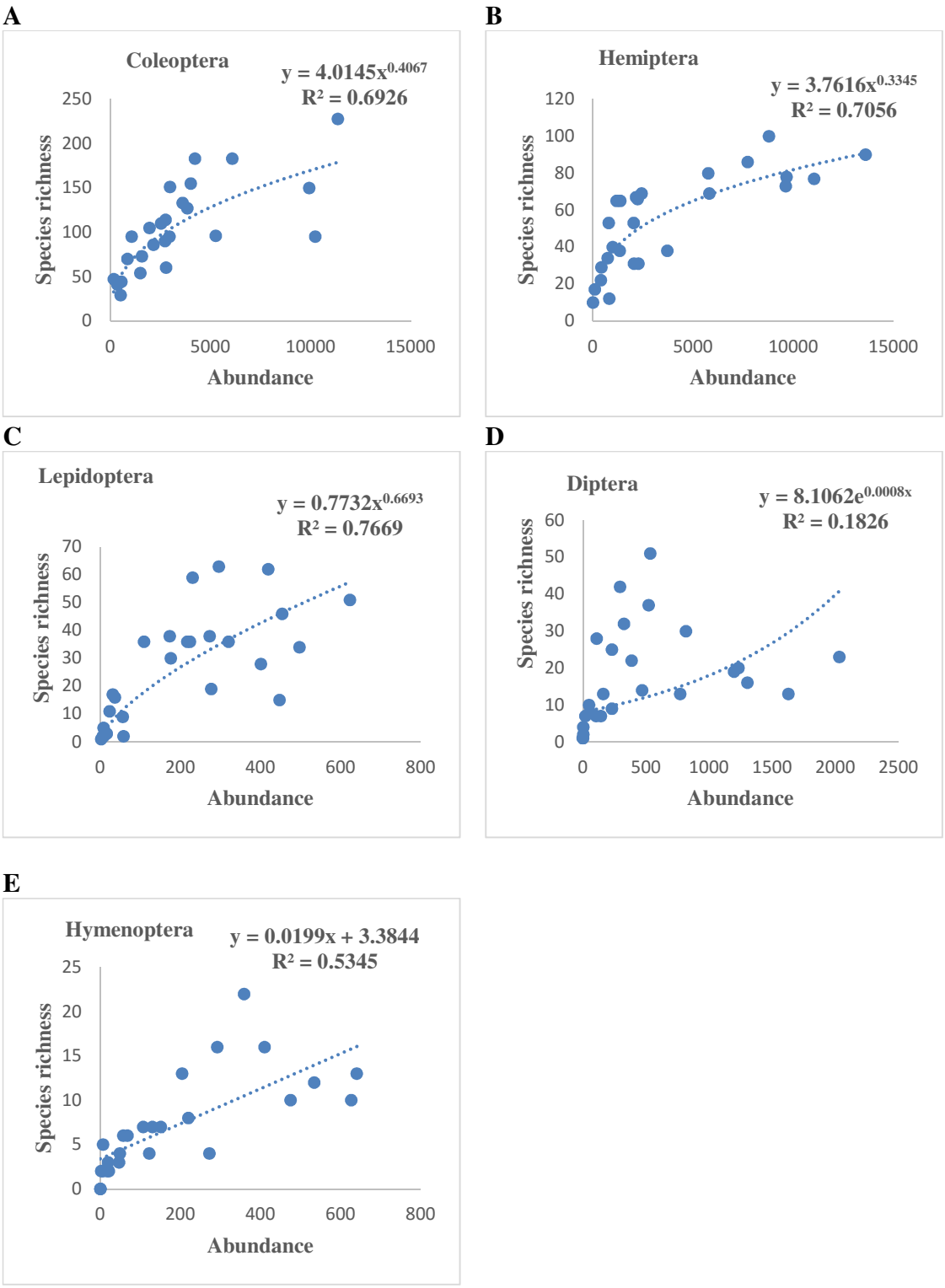

Figure 9. Relationship between abundance and species richness within each of the five orders collected from the light trap during the study period.

4.3 Relation between diversity and abundance of all insects with those of the five orders

4.3.1 Species richness

Plots of species richness of all the insects against that of each of the most speciose orders for all the 26 sampling dates showed a strong positive relationship and followed linear function for Coleoptera ($Y = 1.626x + 46.3$; $R^2 = 0.8625$; $p<0.01$), Lepidoptera ($y = 2.8617x + 135.62$; $R^2 = 0.41$; $p < 0.01$) and Hymenoptera ($y = 7.0142x + 162.48$; $R^2 = 0.193$; $p < 0.05$), while the diversity of all insects followed a non-linear exponential relations with that of the Hemiptera ($Y = 83.244e^{0.0158x}$; $R^2 = 0.8321$; $p<0.01$); species richness of Diptera ($y = 0.6317x + 201.09$; $R^2 = 0.0088$) was not reflecting the richness of all insects (Table 7, Figure 10).

Table 7. Relation between species richness of all insects with species richness, abundance, Simpson index and Shannon-Wiener index of each of the five speciose orders

	Coleoptera	Hemiptera	Lepidoptera	Diptera	Hymenoptera
Species richness					
Best Line Fit	$y = 1.6236x + 46.13$	$y = 83.244e^{0.0158x}$	$y = 2.8617x + 135.62$	$y = 0.6317x + 201.09$	$y = 7.0142x + 162.48$
R^2	0.86	0.83	0.41	0.0088	0.193
P<	0.01	0.01	0.01	NS	0.05
Abundance					
Best Line Fit	$y = 104.73x - 2664.8$	$y = 25.691x^{1.3904}$	$y = 235.89x + 1736.7$	$y = 6781.9e^{-0.015x}$	$y = 179.81x + 6769.7$
R^2	0.5427	0.69	0.42	0.033	0.02
P<	0.01	0.01	0.01	NS	NS
Simpson index					
Best Line Fit	$y = 1.0961x - 0.1259$	$y = 2.3823x - 1.4268$	$y = 2.7546x - 1.8581$	$y = 0.3465x + 0.2899$	$y = 0.5438x + 0.0459$
R^2	0.447	0.241	0.102	0.0019	0.0043
P<	0.01	0.01	NS	NS	NS
Shannon-Wiener index					
Best Line Fit	$y = 0.9132x - 0.2265$	$y = 0.8065x - 0.5982$	$y = 1.0197x - 1.5955$	$y = 0.4841x - 0.2738$	$y = 0.4689x - 0.5357$
R^2	0.762	0.357	0.18	0.07	0.095
P<	0.01	0.01	0.05	NS	NS

4.3.2 Abundance

Significant and positive linear correlations were found between orders Coleoptera ($y = 104.73x - 2664.8$; $R^2 = 0.5427$; $p<0.01$), Lepidoptera ($y = 235.89x + 1736.7$; $R^2 = 0.42$; $p < 0.01$). Order Hemiptera ($y = 25.691x^{1.3904}$; $R^2 = 0.69$; $p < 0.01$) showed significant and positive power relations with all insects. Diptera ($y = 6781.9e^{-0.015x}$; $R^2 = 0.033$) and Hymenoptera ($y = 179.81x + 6769.7$; $R^2 = 0.019$) showed insignificant relationships with all insects (Table 7, Figure 11).

4.3.3 Simpson's index of diversity

Plots of Simpson's index of diversity relationships between speciose orders and those of all insects were linear functions for all the orders. Significant relations were evident for orders Coleoptera ($y = 0.4082x + 0.568$; $R^2 = 0.4474$, $p<0.01$) and Hemiptera ($y = 0.1013x + 0.8537$; $R^2 = 0.2414$, $p<0.01$). Orders Lepidoptera ($y = 0.0371x + 0.9082$; $R^2 = 0.102$), Diptera ($y = 0.0055x + 0.9314$; $R^2 = 0.0019$) and Hymenoptera ($y = 0.0079x + 0.9304$; $R^2 = 0.0043$) showed insignificant relations for Simpson's index of diversity (Table 7, Figure 12).

4.3.4 Shannon-Wiener index of diversity

Shannon-Wiener diversity index relationships between speciose orders and those of all insects were positive linear functions for all the orders. Orders Coleoptera ($y = 0.8345x + 1.055$; $R^2 = 0.762$, $p < 0.01$), Himeptera ($y = 0.4428x + 2.6044$; $R^2 = 0.3572$, $p < 0.01$) and Lepidoptera ($y = 0.1783x + 3.262$; $R^2 = 0.1818$, $p < 0.05$) showed significant positive relationships. However, orders Diptera ($y = 0.1473x + 3.4201$; $R^2 = 0.071$) and Hymenoptera ($y = 0.2036x + 3.4009$; $R^2 = 0.095$) showed insignificant relations for Shannon-Wiener index with all insects (Table 7, Figure 13).

4.4 Relation between diversity and abundance among the five orders

4.4.1 Species richness

Among the five most speciose orders, temporal associations were very strong between Coleoptera and Hemiptera for both species richness ($r = 0.80$; $p<0.01$; Table 8,

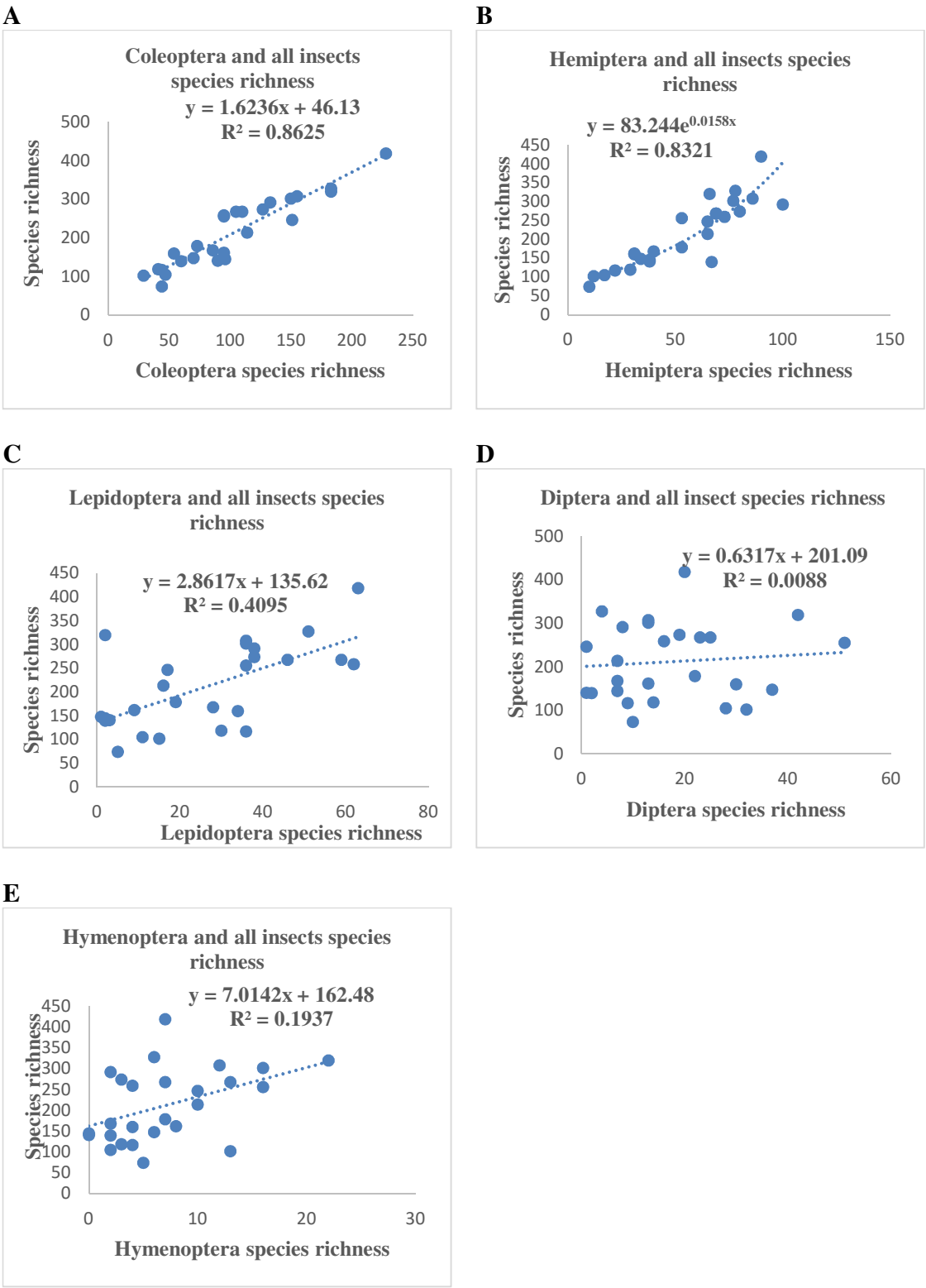

Figure 10. Relationships between diversity and species richness of the five speciose orders with those of all the insects

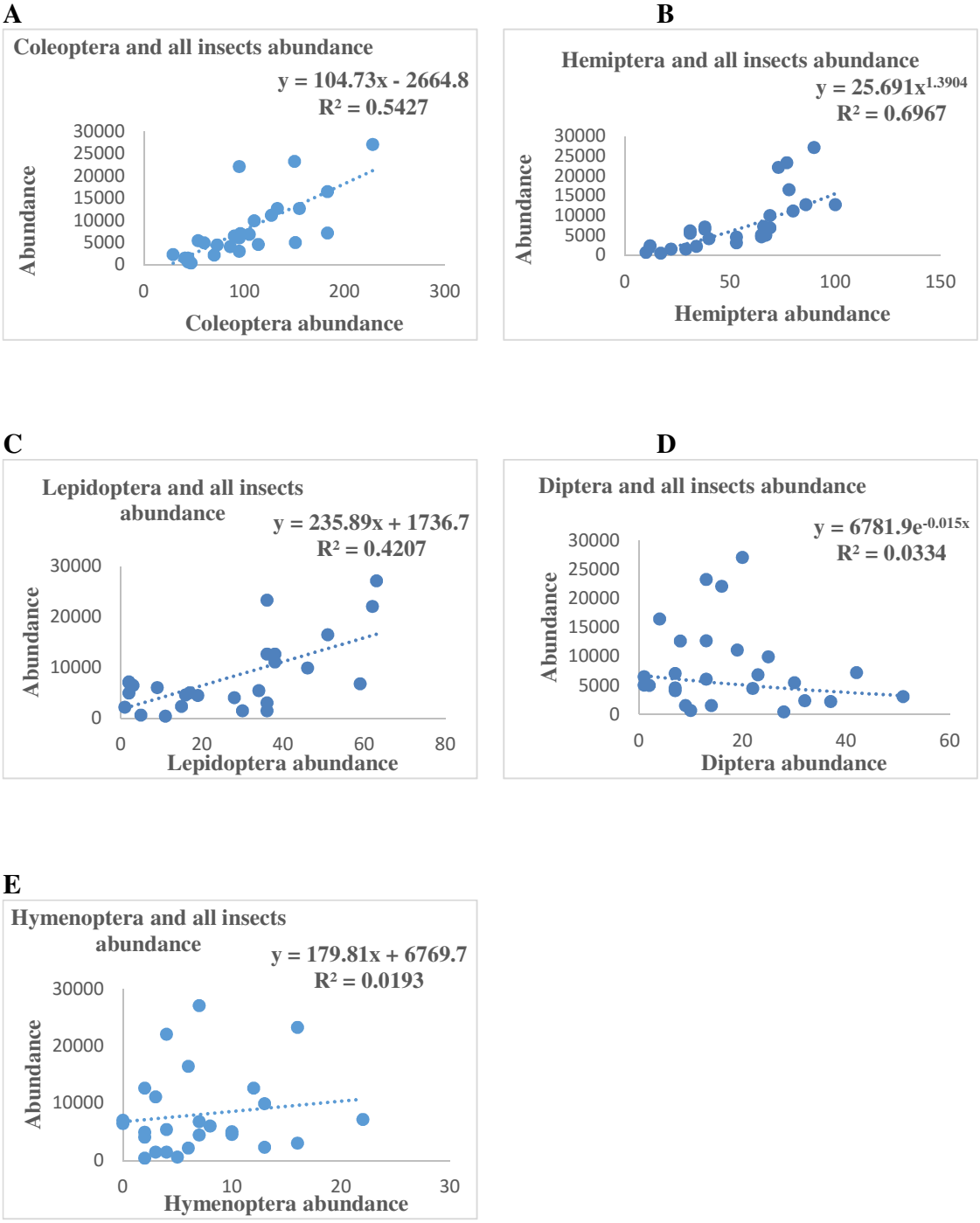

Figure 11. Relationships between all insects' abundance and abundance of the five speciose orders with those of all the insect

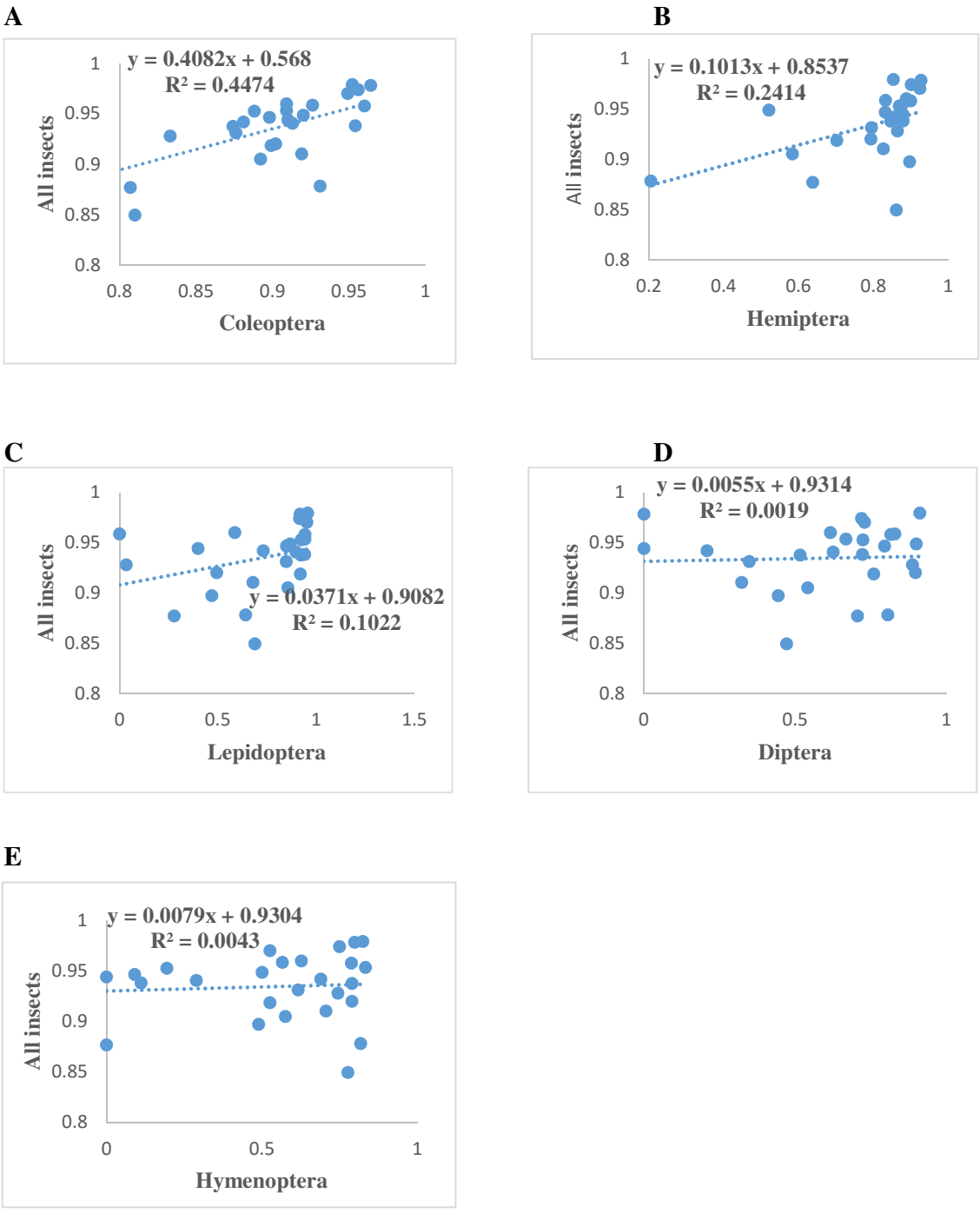

Figure 12. Simpson's index of diversity relationships between speciose orders and all insects

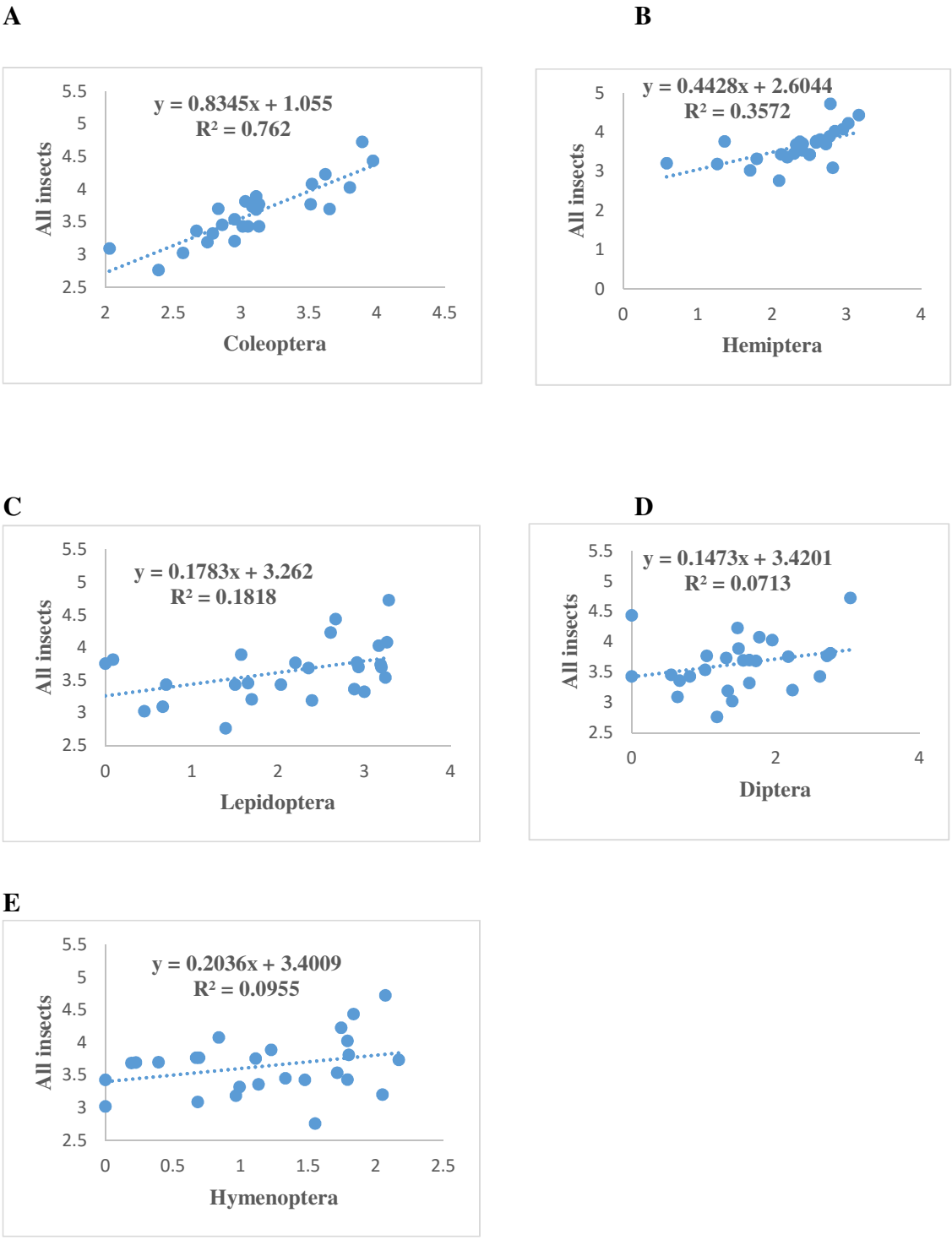

Figure 13. Shannon-Wiener diversity index relationships between speciose orders and all insects

Figure 14) and abundance (0.86; p<0.01; Table 8, Figure 15). Similarly, Lepidoptera and Hemiptera also were strongly correlated in their diversity and abundance (r = 0.55; p<0.001; Table8, Figure 14; and 0.43; p<0.05; Table 8, Figure 15 respectively). Coleoptera also showed significant association with Lepidotera and Hymenoptera in species richness (Table 8, Figure 14a and b).

Table 8. Relationship (correlation coefficient) for species richness (above the diagonal) and for abundance (below the diagonal) amongthe five speciose orders

	Coleoptera	**Hemiptera**	**Lepidoptera**	**Diptera**	**Hymenoptera**
Coleoptera	1	**0.80****	**0.40***	-0.08	**0.39***
Hemiptera	**0.86****	1	**0.55****	-0.15	0.22
Lepidoptera	0.24	**0.43***	1	0.03	0.04
Diptera	**0.45***	**0.39***	0.24	1	**0.54****
Hymenopterea	0.11	0.13	0.12	0.02	1

Values in bold are significant at 5 % (*) or at 1 % (**)

4.4.2 Abundance

Strong and positive significant relationships were shown between order Coleoptera and Hemiptera (0.86). Significant relations were also revealed between orders Coleoptera and Diptera (0.45), Hemiptera and Lepidoptera (0.43) and Hemiptera and Diptera (0.39). Other order inter-relationships showed insignificant results (Table 8, Figure 15a and b).

4.4.3 Relationship among the diversity index of different orders

a. Simpson's index of diversity

Simpson's index of diversity showed very strong and positive significant relations between Coleoptera and Lepidoptera (r = 0.454; p< 0.01) but weak and insignificant relations were found between orders Hemiptera and Diptera (-0.274), Hemiptera and Hymenoptera (-0.032), Lepidoptera and Diptera (-0.0424). (Table 9, Figure 16a and b).

Table9. Diversity indices relationships Simpson's (above the diagonal) and Shannon-Wiener (below the diagonal) between insect speciose orders.

	Coleoptera	Hemiptera	Lepidoptera	Diptera	Hymenoptera
Coleoptera	1	0.007	**0.454****	0.119	0.160
Hemiptera	**0.459****	1	0.071	-0.274	-0.032
Lepidoptera	**0.499****	0.182	1	-0.0424	0.119
Diptera	0.208	-0.254	-0.014	1	0.065
Hymenopterea	0.275	0.080	0.174	0.249	1

**Values in bold are significant at 1 %.

4.4.4 Shannon-Wiener index of diversity

Plots of Shannon-Wiener index of diversity showed very strong and positive significant relations between Coleoptera and Hemiptera ($r = 0.459$; $p < 0.01$) and Coleoptera and Lepidoptera ($r = 0.499$; $p<0.01$). However, weak and negative insignificant relations were witnessed between orders Hemiptera and Diptera (-0.254) and Lepidoptera and Diptera (-0.014). Other order inter-relations were not insignificant (Table 9, Figure 17a and b).

Species richness showed significant and positive relations with Simpson and Shannon-Wiener indices ($r = 0.42$; $p < 0.05$ and $r = 0.44$; $p < 0.05$), respectivelybut showed insignificant relations with Avalanche index. Simpson index showed stronger and positive relations with Shannon-Wiener index ($r = 0.9$; $p < 0.05$) than Avalanche index ($r = 0.56$; $p < 0.05$). Significant and positive relations were also evident between Shannon-Wiener and Avalanche indices (Table 10).

Table 10. Relationships among species richness and diversity indices

	Species richness	Simpson Index	Shannon-Wiener Index	Avalanche Index
Species richness	1	0.42	0.44	0.068
Simpson Index		1	0.902	0.56
Shannon-Wiener Index			1	0.39
Avalanche Index				1

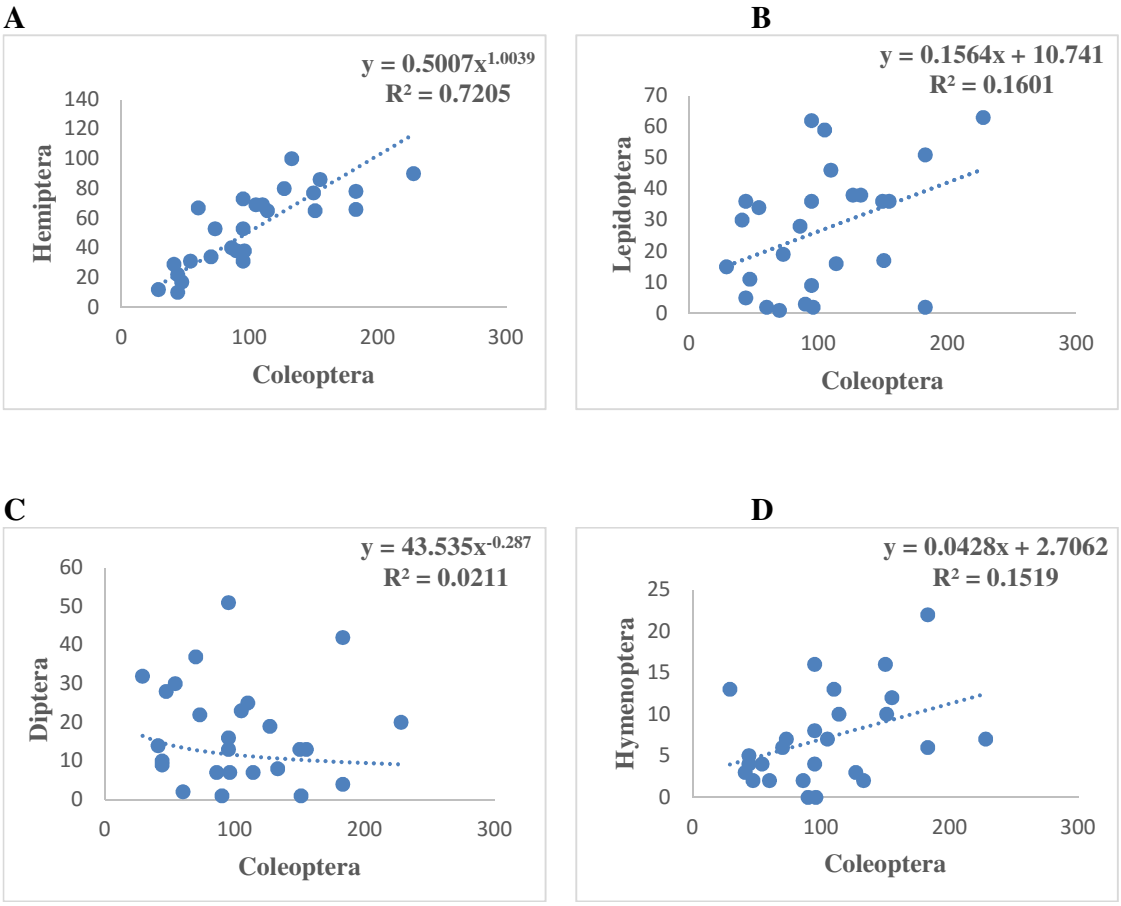

Figure 14a. Inter-relationships among species richness of the five most abundant and speciose orders sampled: Coleoptera and Hemiptera (A); Coleoptera and Lepidoptera (B); Coleoptera and Diptera(C); Coleoptera and Hymenoptera (D)

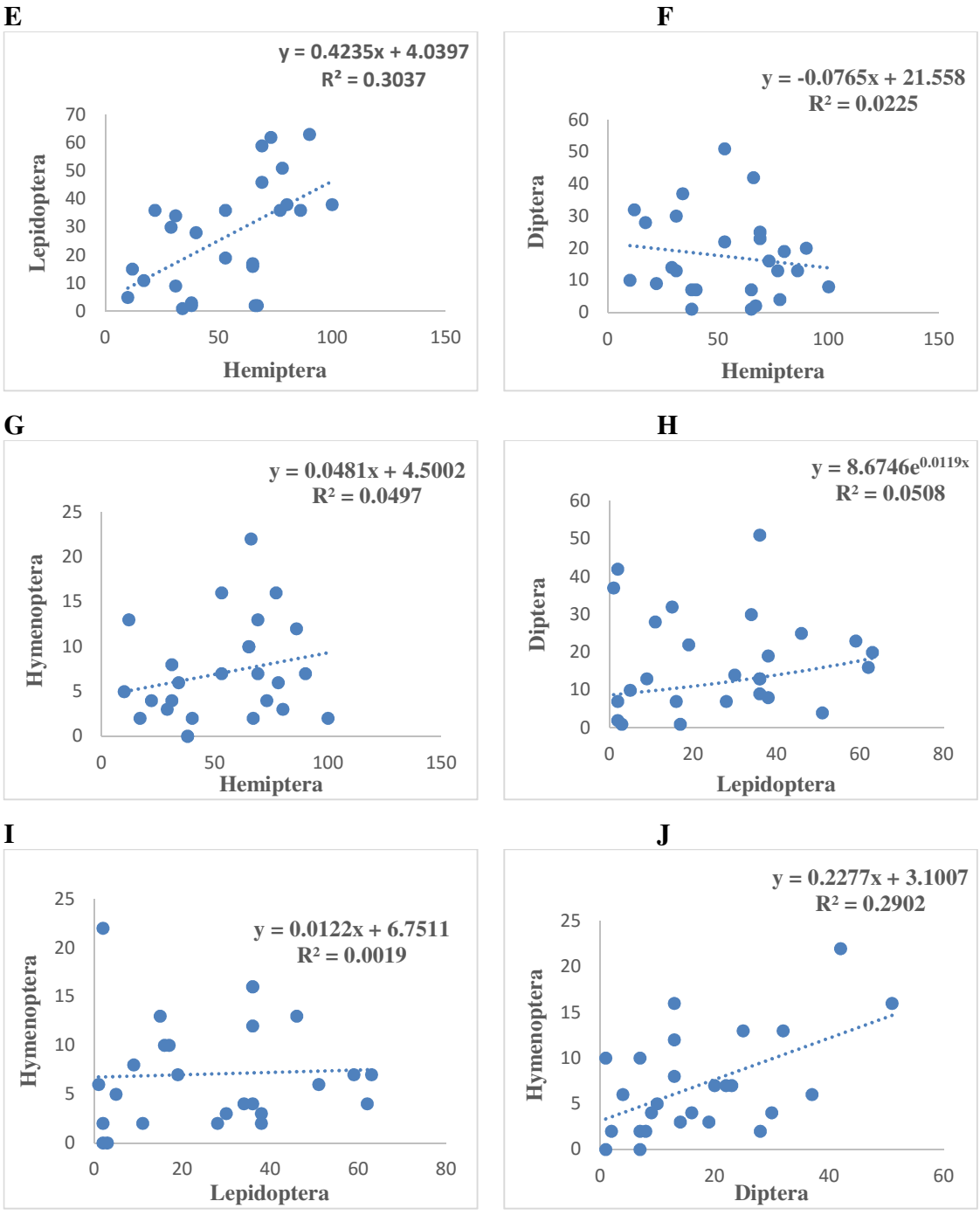

Figure 14b. **Inter-relationships among species richness of the five most abundant and speciose orders sampled: Hemiptera and Lepidoptera (E); Hemiptera and Diptera (F); Hemiptera and Hymenoptera (G); Lepidoptera and Diptera (H); Lepidoptera and Hymenoptera (I) Diptera and Hymenoptera (J).**

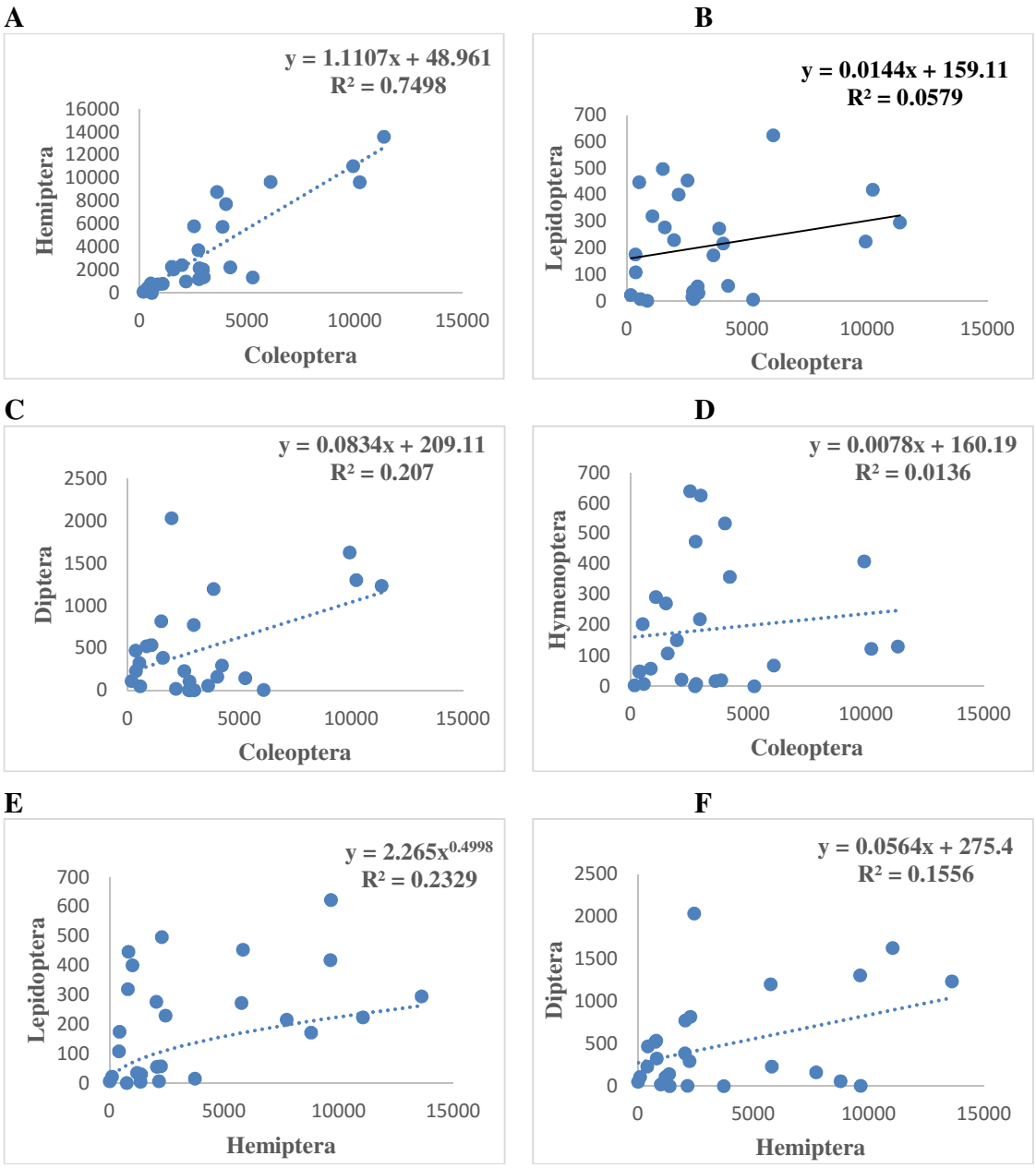

Figure 15a. **Inter-relationships among abundance of the five most abundant and speciose orders sampled: Coleoptera and Hemiptera (A); Coleoptera and Lepidoptera (B); Coleoptera and Diptera(C); Coleoptera and Hymenoptera (D); Hemiptera and Lepidoptera (E); Hemiptera and Diptera (F)**

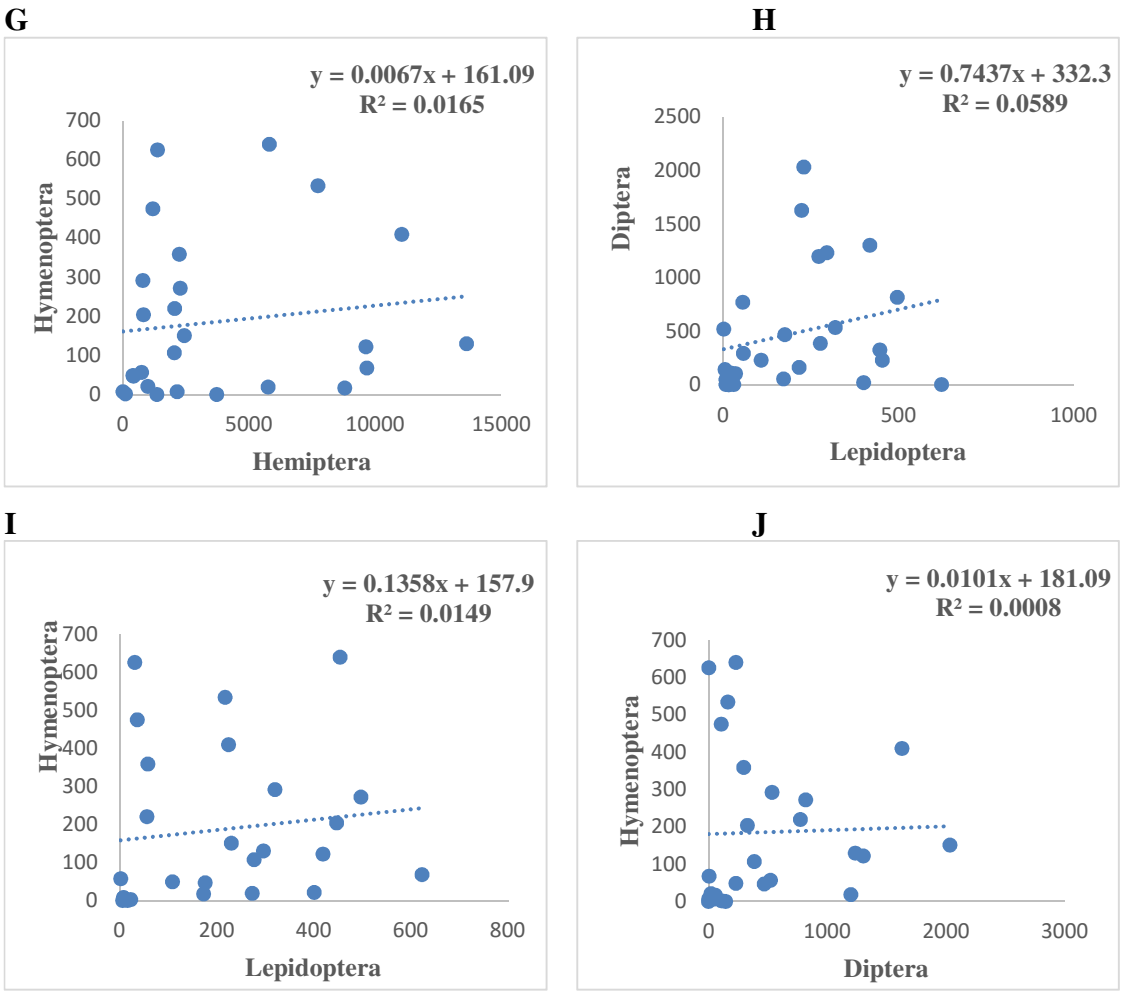

Figure 15b. **Inter-relationships among abundance of the five most abundant and speciose orders sampled: Hemiptera and Hymenoptera (G); Lepidoptera and Diptera (H); Lepidoptera and Hymenoptera (I) Diptera and Hymenoptera (J).**

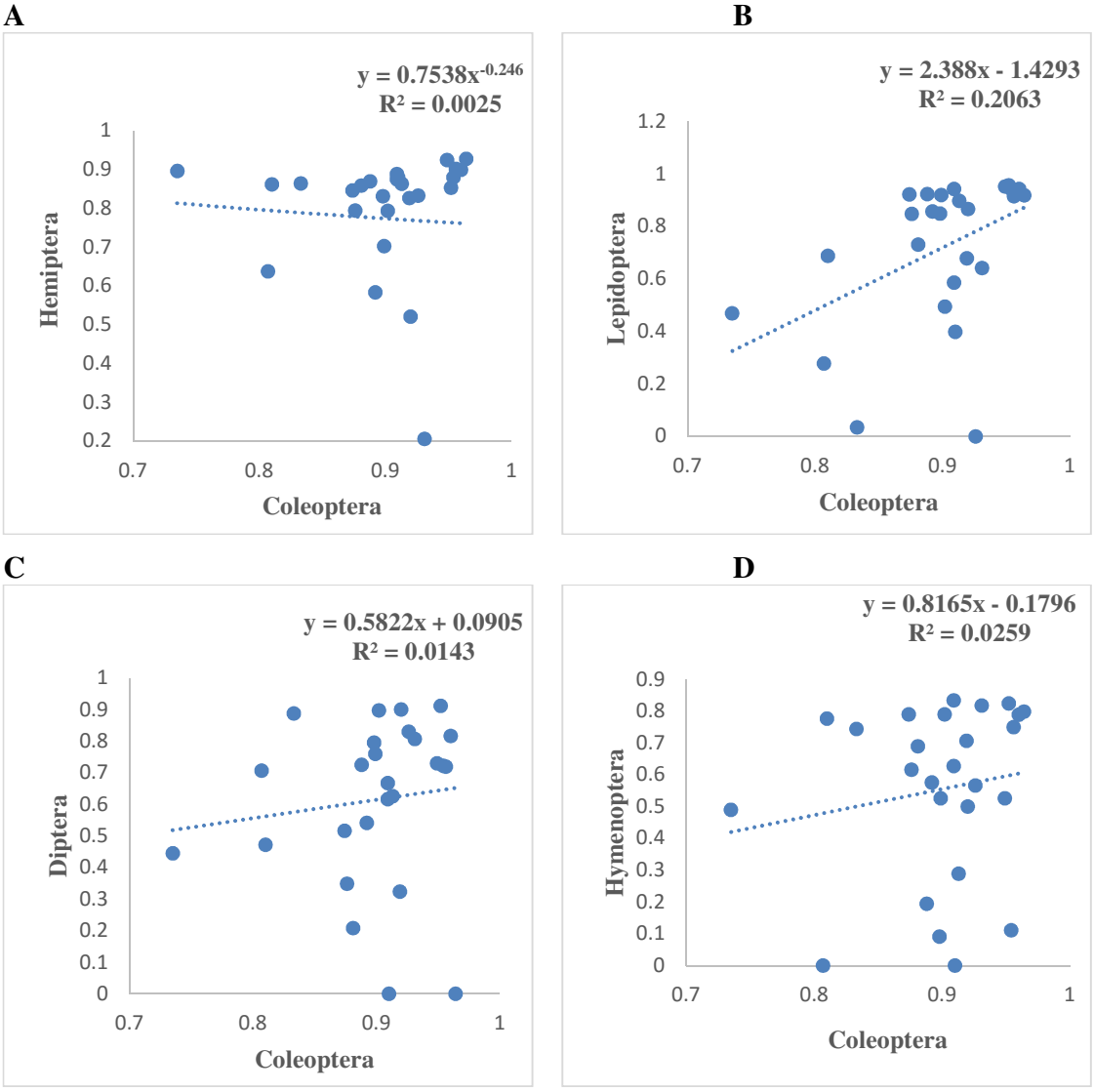

Figure 16a. **Simpson's Index of diversity inter-relationships of the five most abundant and speciose orders sampled: Coleoptera and Hemiptera (A); Coleoptera and Lepidoptera (B); Coleoptera and Diptera(C); Coleoptera and Hymenoptera (D)**

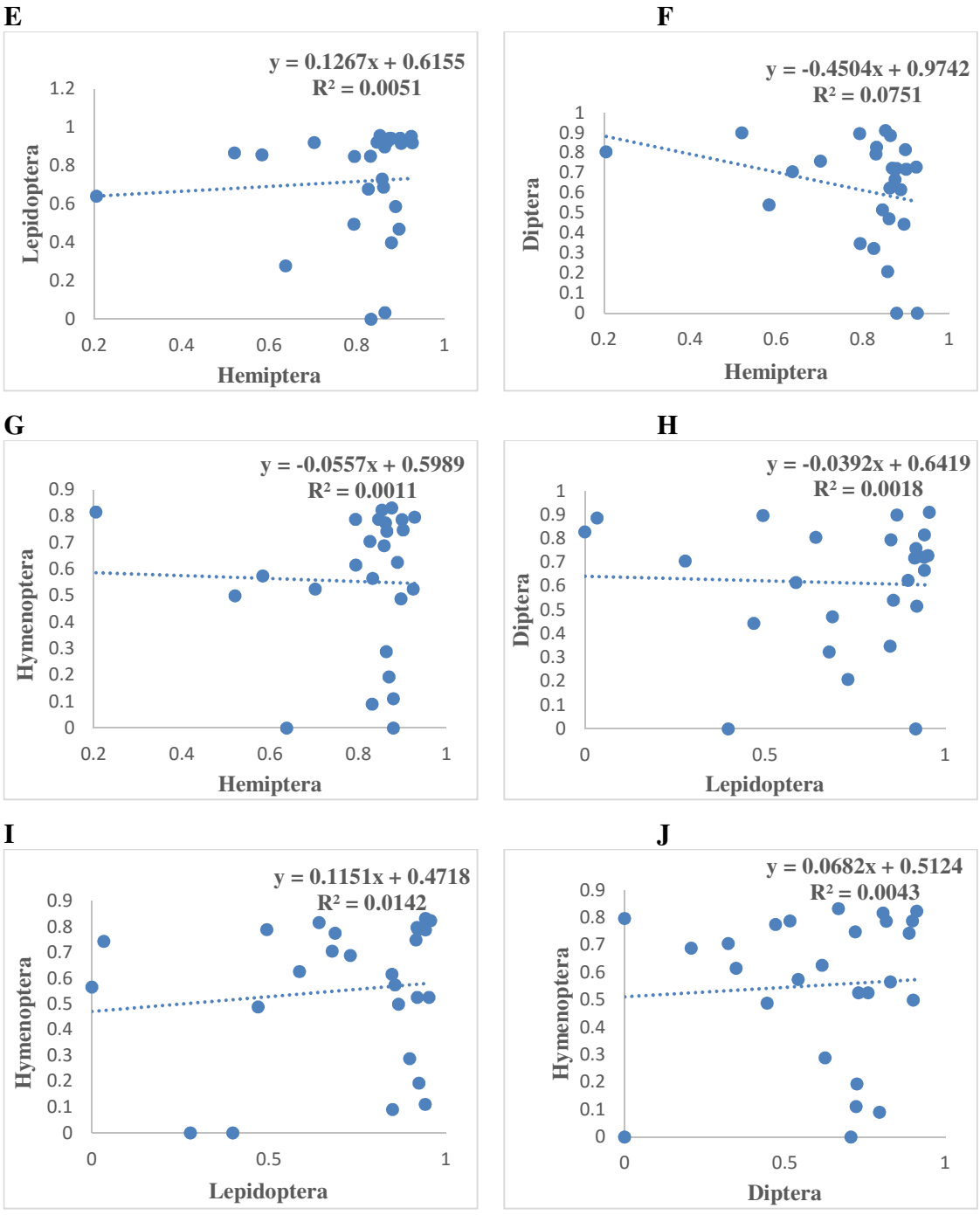

Figure 16b. **Simpson's Index of diversity inter-relationships of the five most abundant and speciose orders sampled: Hemiptera and Lepidoptera (E); Hemiptera and Diptera (F); Hemiptera and Hymenoptera (G); Lepidoptera and Diptera (H); Lepidoptera and Hymenoptera (I) Diptera and Hymenoptera (J).**

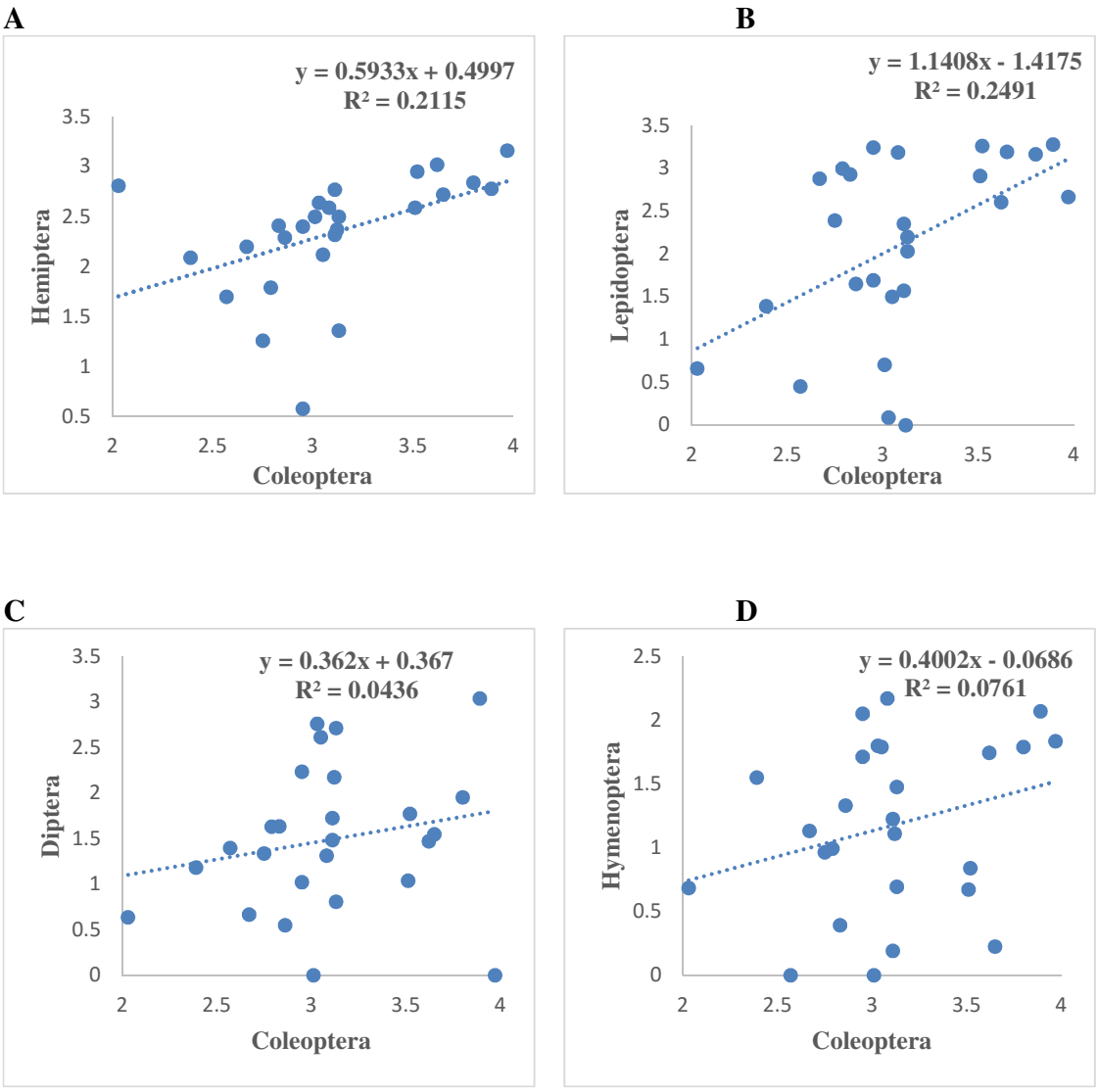

Figure 17a. **Shannon-Wiener index of diversity inter-relationships of the five most abundant and speciose orders sampled: Coleoptera and Hemiptera (A); Coleoptera and Lepidoptera (B); Coleoptera and Diptera(C); Coleoptera and Hymenoptera (D)**

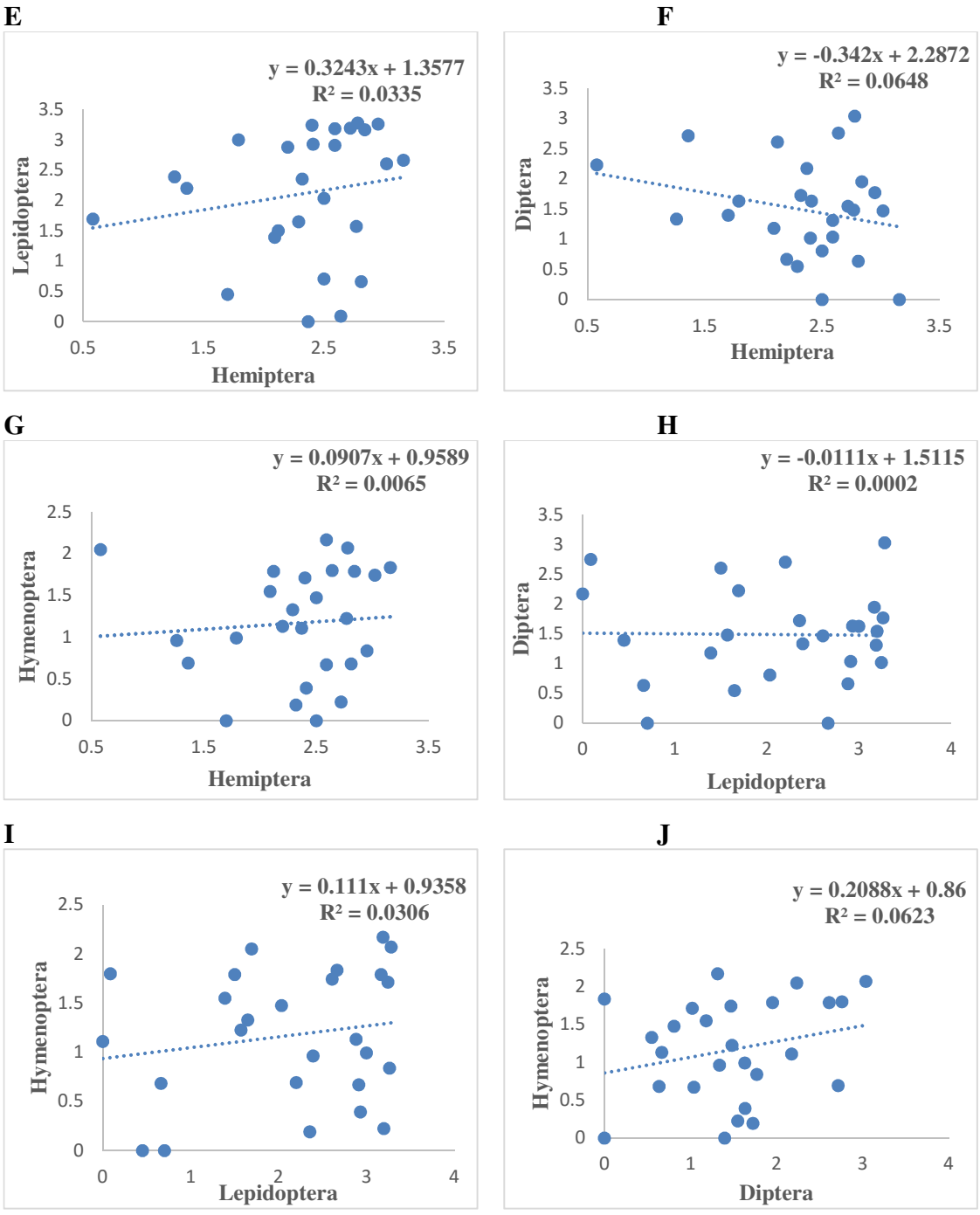

Figure 17b. Shannon-Wiener index of diversity inter-relationships of the five most abundant and speciose orders sampled: Hemiptera and Lepidoptera (E); Hemiptera and Diptera (F); Hemiptera and Hymenoptera (G); Lepidoptera and Diptera (H); Lepidoptera and Hymenoptera (I) Diptera and Hymenoptera (J).

4.5Seasonal patterns

4.5.1Diversity and abundance of all insects

A total of 209,098 individuals belonging to 764 morpho-species or Operational Taxonomic Units (OTUs), representing 101 families from 12 orders were collected through the two years of sampling (Table 1). The Simpson's index of diversity computed for all insects was 0.97, the Shannon-Wiener index was 4.44 and Avalanche index was 1.17.

Total number of OTUs recovered was highest (419; Sample 21) during mid-August 2016, while least number of OTUs (73; Sample 4) were recovered during mid-December, 2015. The highest (27098; Sample 21) number of insects collected was also during the mid-August, 2016 while the least (410; Sample 4) number of insects were collected towards the end of July, 2015. The highest values of Simpson's index, Shannon-Wiener index and Avalanche index were 0.97, 4.727 and 1.255 respectively and were recorded on the 5th sample for both Simpson's and Shannon-Wiener indices and 9th sample for Avalanche i.e. during the months of August and November (Table 11).

Table 11. Number of OTUs and abundance of all insects collected from 8th May, 2015 to 6th December, 2016 using mercury vapour lamp light trap at GKVK, Bangalore

Sl. No.	Sampling Date	Species Richness	Population Size	Simpson's Index	Shannon-Wiener Index	Avalanche Index
1	08/05/2015	267	9943	0.920	3.435	1.116
2	08/06/2015	320	7178	0.928	3.815	1.084
3	08/07/2015	162	6069	0.942	3.457	1.125
4	29/07/2015	104	**410**	0.949	3.769	1.179
5	21/08/2015	256	3055	**0.979**	**4.727**	1.084
6	18/09/2015	102	2323	0.878	3.206	1.203
7	10/10/2015	147	2184	0.959	3.757	1.234
8	31/10/2015	160	5430	0.905	3.192	1.164
9	22/11/2015	119	1487	0.953	3.703	**1.255**
10	13/12/2015	**73**	638	0.849	2.763	0.743

11	03/01/2016	117	1487	0.919	3.325	1.226
12	24/01/2016	167	4079	0.947	3.689	1.158
13	14/02/2016	179	4463	0.960	3.893	1.223
14	06/03/2016	302	12683	0.958	4.029	1.112
15	27/03/2016	292	12675	0.938	3.699	1.072
16	17/04/2016	141	6499	0.938	3.434	1.112
17	08/05/2016	140	4969	0.897	3.093	1.093
18	29/05/2016	246	5026	0.978	4.439	1.152
19	19/06/2016	214	4576	0.974	4.232	1.149
20	17/07/2016	145	7039	0.877	3.026	0.932
21	16/08/2016	**419**	**27098**	0.938	3.542	1.133
22	28/09/2016	258	22094	0.931	3.366	1.069
23	10/10/2016	302	23283	0.954	3.739	1.168
24	25/10/2016	327	16468	0.941	3.771	1.127
25	15/11/2016	274	11117	0.970	4.082	1.157
26	06/12/2016	236	6825	0.911	3.433	1.201
	TOTAL	**764**[$]	**209098**	**0.97**	**4.44**	**1.17**

[$]This represents the total unique OTUs recovered during the study

4.5.2 Temporal patterns

4.5.2.1 Patterns species richness and abundance of insects

Species richness showed three peaks during the 5th, 14th and 21st samples i.e. during the months of June 2015, March 2016 and August 2016. The last peak towards the 24th sample appeared to be part of the small peak found during the early stage of the study (2nd sample). Clearly these peaks correspond to the post-rainy and post-winter seasons. In fact, the richness was least during the winter and rainy seasons for both the years (see sample 4 and 10 of the figure 18). This temporal pattern is also reflected in the circular statistics (Figure 19). The mean vector (μ) was set at 250.233° and the length of

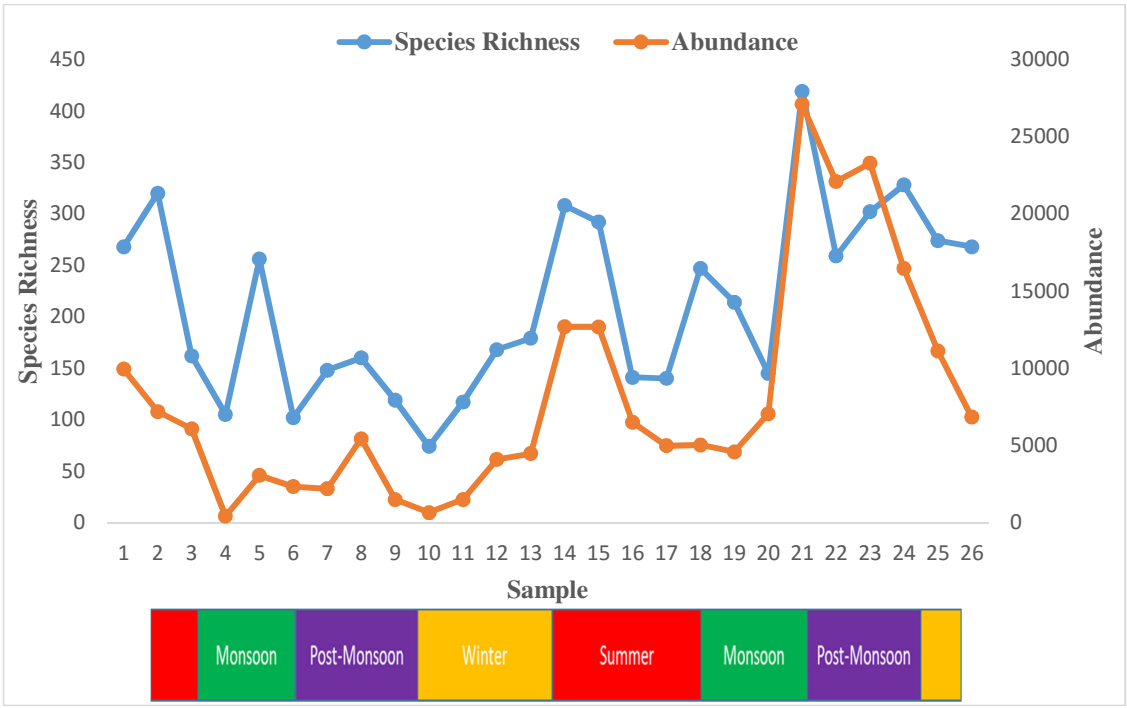

Figure 18. Patterns of species richness and insectscollected from 8th May, 2015 to 6th December, 2016 using mercury vapour light trap at GKVK, Bangalore.

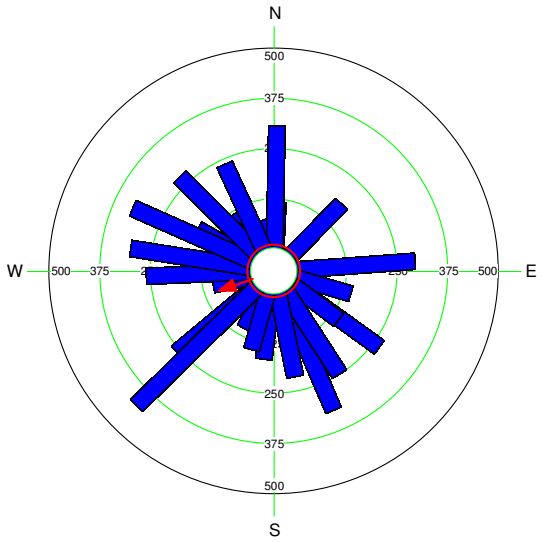

Figure 19. Circular bar graph of insect species collected during the study period. The mean vector length is shown as an arrow. Bars indicate the number of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st .The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

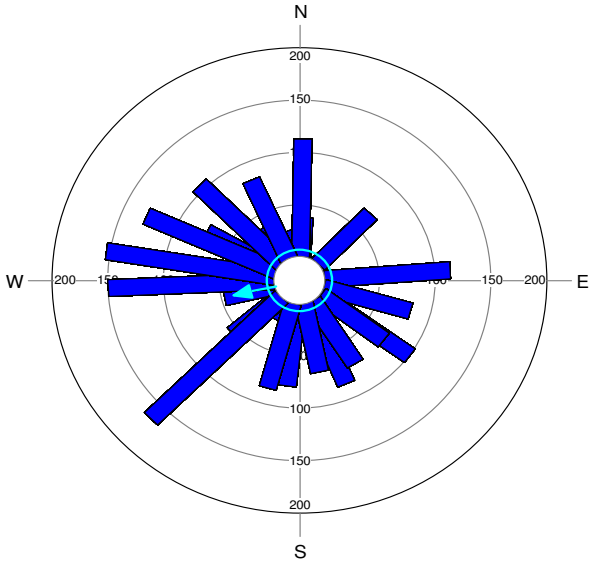

Figure 20. Circular bar graph of number of insects collected during the study period. The mean vector length is shown as an arrow. Bars indicate the number of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st.The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

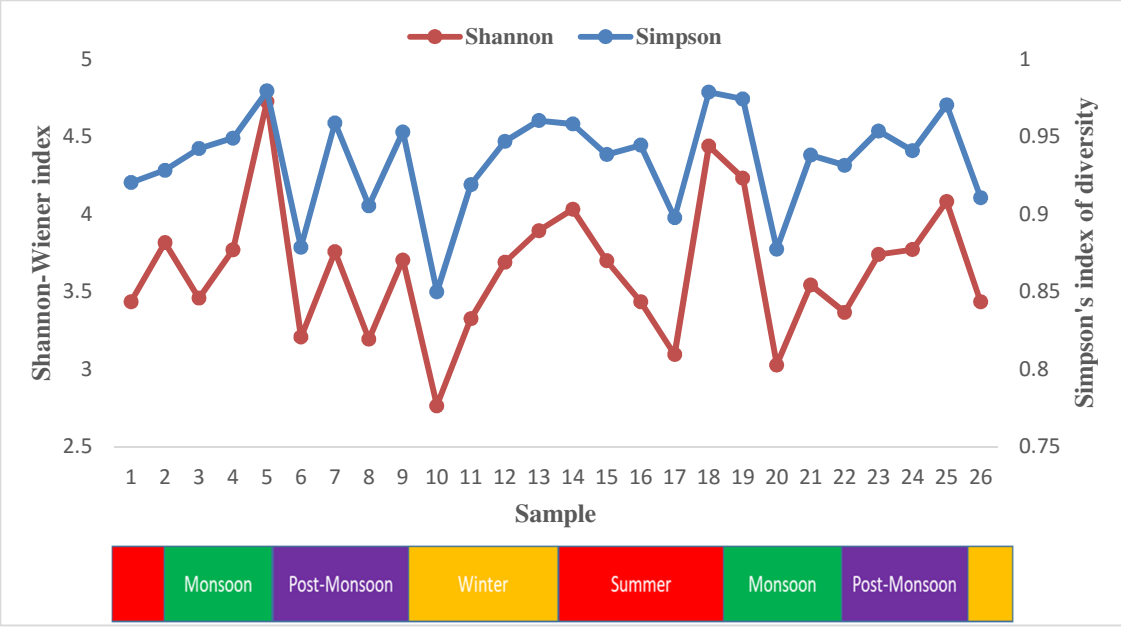

Figure 21. Patterns of diversity indices of insect speciescollected from 8th May, 2015 to 6th December, 2016 using mercury vapour light trap at GKVK, Bangalore.

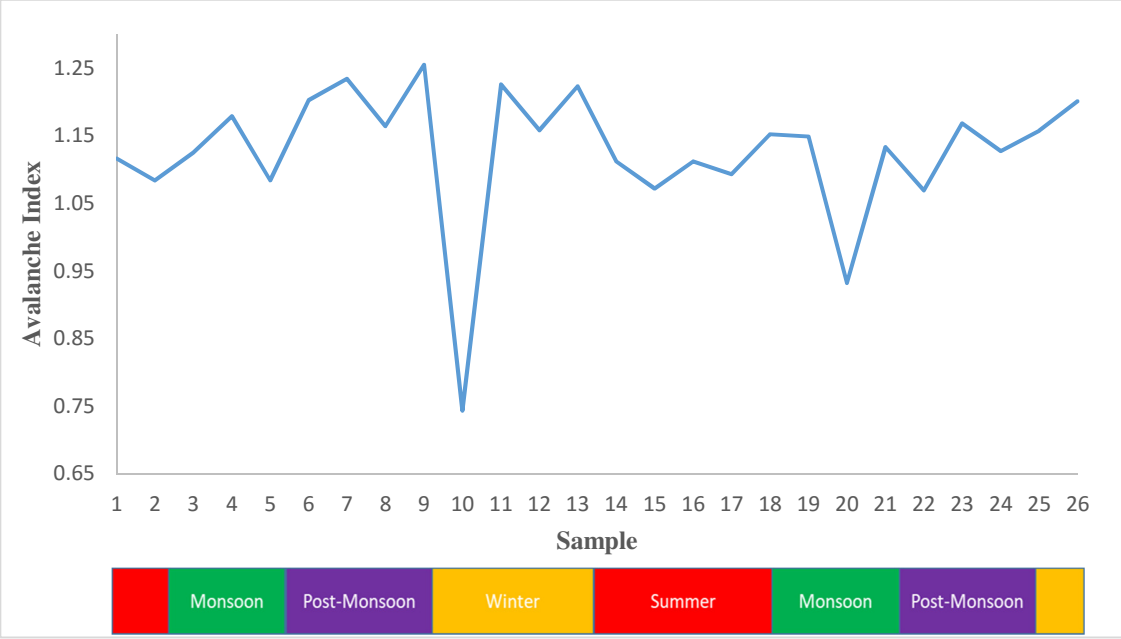

Figure 22. Patterns of Avalanche index of insect speciescollected from 8th May, 2015 to 6th December, 2016 using mercury vapour light trap at GKVK, Bangalore.

mean vector (r) was0.178. The Rayleigh tests, (Z= 173.225, n= 5474, p< 0.001) showed that the concentration of the richness was non-random indicating that the seasonal peaks observed are indeed significant peaks (Table 12).

Number of insects recovered also almost reflected that of richness with clear peaks during the 15th, 16th and 21stsample dates i.e. during end of October 2015, March 2016 and mid-August 2016 (Figure 18). In fact, sample 21stsample recorded highest for both abundance and richness. Least insect catches were recorded during 4th and 10th samples coinciding with those of richness. Circular data (Figure 20) reveal total insect activity to be indifferent from species richness when plotted on a 360° modulo. The mean insects' direction was 257.065° and the length of mean vector (r) was 0.197. Relative azimuths 'α' were not uniformly distributed in all directions (Rayleigh tests, Z= 82.097, n= 2124, p< 0.001) an indication of significant peaks (Table 13).

Table 12. Circular statistical measures of species richness of insects collected from 8th May, 2015 to 6th December, 2016 using mercury vapour lamp light trap at GKVK, Bangalore.

Parameters	Values
Number of observations (N)	5474
Mean vector (μ)	250.233°
Length of mean vector (r)	0.178
Circular standard deviation	106.471°
Standard error of mean	3.054°
Rayleigh test (Z)	173.225
Rayleigh test (p)	p< 0.001

Table 13. Circular statistical measures of abundance of insects collected from 8th May, 2015 to 6th December, 2016 using mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	2124
Mean vector (μ)	257.065°
Length of mean vector (r)	0.197
Circular standard deviation	103.342°
Standard error of mean	4.427°
Rayleigh test (Z)	82.097
Rayleigh test (p)	p< 0.001

4.5.2.2 Diversity indices patterns

Patterns of Simpson's and Shannon-Wiener indices of diversity were similar over the entire sampling period and reflected almost those of richness and of abundance. Both indices showed peaks in the 5th and 18th samples depicting increased richness during the end of rainy and summer seasons respectively. Low peaks for both Simpson's and Shannon-Wiener indices were noted during the 10th sample (start of rains), 17th sample (end of summer season) and 20th sample (monsoon) (Figure 21).

Avalanche index patterns demonstrated very low but clear peaks for samples 10 and 20 while the patterns were unclear for the other samples. This is an indication of poor insect collections during these two samplings (Figure 22).

For Simpson's index, circular statistics showed the mean direction to be 261.529° but the mean vector length 'r' = 0.153; as this angle did not exceed Rayleigh critical value suggesting that the azimuths 'α' were uniformly distributed without any concentration towards a specific period. Thus, according to Simpson's index, identified

peaks could not be associated to the patterns witnessed (Rayleigh tests, Z= 0.608, n= 26, p< 0.589, Table 14; Figure 23).

However, for Shannon Weiner index the mean angle was 260.058° and vector length was 0.164 exceeding the Rayleigh critical value. Thus the relative azimuths 'α' were not uniformly distributed in all directions (Rayleigh tests, Z= 2.522, n= 26, p< 0.08; Table 15; Figure 24). This non-uniform distribution shown by Shannon-Wiener index is an indication of significant peaks found during the sample numbers 4 and 5, 13- 20 and sample 24-26. In other words, there are distinct peaks coinciding with the post –rainy and post winter seasons as can be seen in figure 21and 22.

Table 14. Circular statistics of diversity indices of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	26
Mean vector (μ)	261.529°
Length of mean vector (r)	0.153
Circular standard deviation	111.036°
Standard error of mean	51.65°
Rayleigh test (Z)	0.608
Rayleigh test (p)	0.589

Table 15. Circular statistics of diversity indices of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	26
Mean vector (μ)	260.058°
Length of mean vector (r)	0.164
Circular standard deviation	108.986°
Standard error of mean	25.338°
Rayleigh test (Z)	2.522
Rayleigh test (p)	0.08

4.6 Species richness and abundance of the five orders

4.6.1 Species richness

Temporal patterns of five speciose orders were similar and consistent among the orders Coleoptera, Hemiptera and Lepidoptera but differed from Diptera and Hymenoptera which had their own patterns (Figure 25). However, Order Coleoptera showed sharper peaks compared to Hemiptera and Lepidoptera. Just as for all the insects, notable peaks were recorded during post rainy and post winter seasons. Peaks for Diptera in particular appeared to be spread out and broad throughout the sampling period (Figure 25).

4.6.2 Abundance

Insect activity patterns through the year as depicted from the abundance of different orders captured were not quite different from richness. They showed similar patterns for orders Coleoptera and Hemiptera. Abundance peaks were evident during summer and late rainy seasons. Among the orders Coleoptera and Hemiptera were found to have been more than the other orders during the sampling period (Figure 26).

4.6.3Effect of weather parameters with species richness and abundance

Temporal patterns of all insects attracted to light trap during the study period indicated that both the abundance and richness of insects was high during summer seasons than winter and rainy seasons. Assessment of the effect of temperature, relative humidity and rainfall on the species richness and abundance through correlations and multiple regression analysis was done. Three kinds of analysis were attempted on the impact of these parameters: (a) on the day of sampling, (b) cumulated over the period of three days, and (c) cumulated over three weeks.

Significant negative correlations were observed between species richness and rainfall ($n=26$; $r = 0.339$, $p<0.05$), abundance and rainfall ($n=26$; $r= 0.34$, $p<0.05$), species richness and relative humidity ($n=26$; $r= 0.355$, $p<0.05$) and abundance and relative humidity ($n=26$; $r= 0.355$, $p<0.05$) over three days before sampling (Table 16).

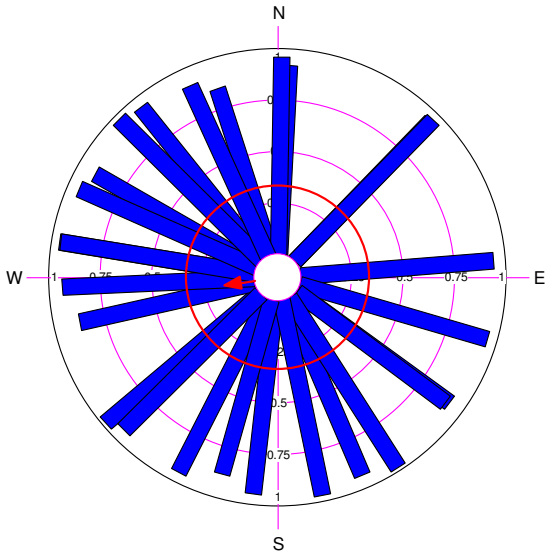

Figure 23. Circular bar graph of Simpson index of diversity and the relative azimuth, 'α', of insect catches collected using mercury vapour lamp light trap at GKVK. Bars indicate the values of Simpson index of diversity Species caught in corresponding days of sampling.The 'N-North' indicates January 1st or December 31st.The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

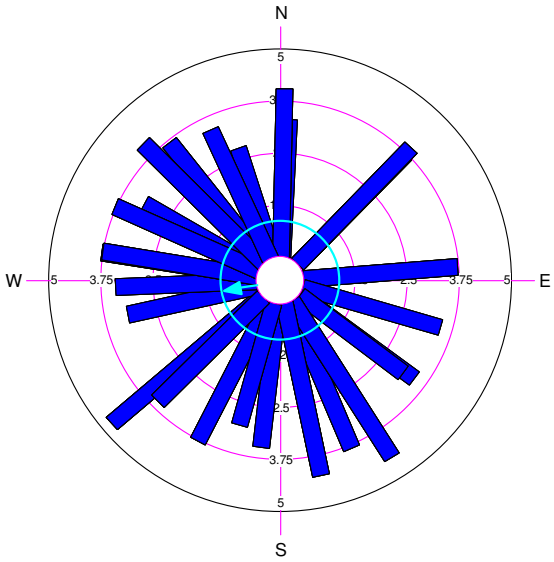

Figure 24. Circular bar graph of Shannon-Wiener index and the relative azimuth, 'α', of insect catches collected using mercury vapour lamp light trap at GKVK. Bars indicate the values of Shannon-Wiener index of species caught in corresponding days of sampling.The 'N-North' indicates January 1st or December 31st.The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

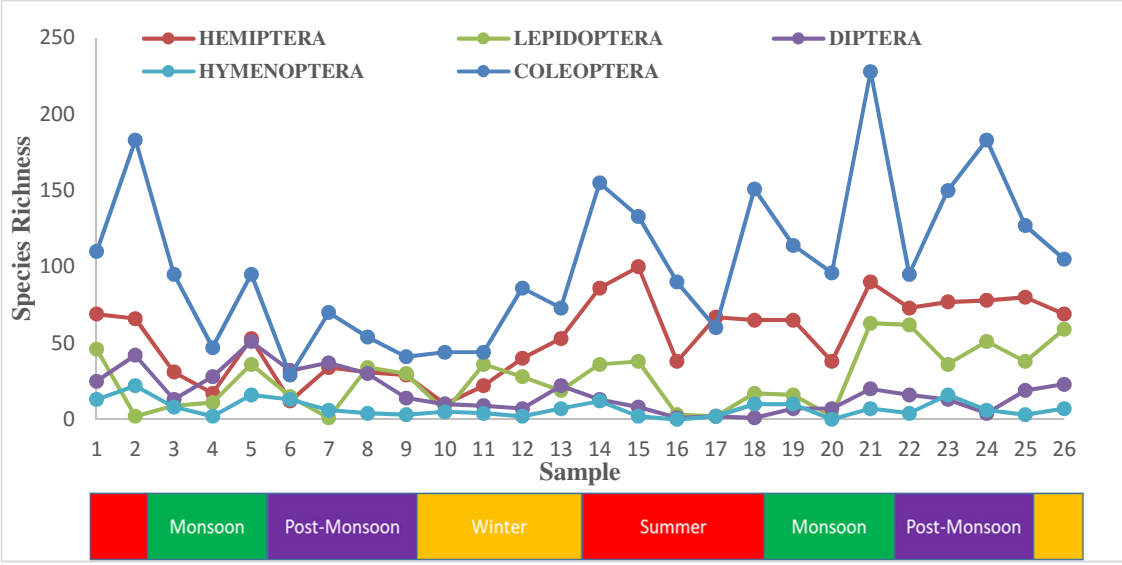

Figure 25. Species richness of five most speciose orders of insect orders collected from 8th May, 2015 to 6thDecember, 2016 using mercury vapour light trap at GKVK, Bangalore.

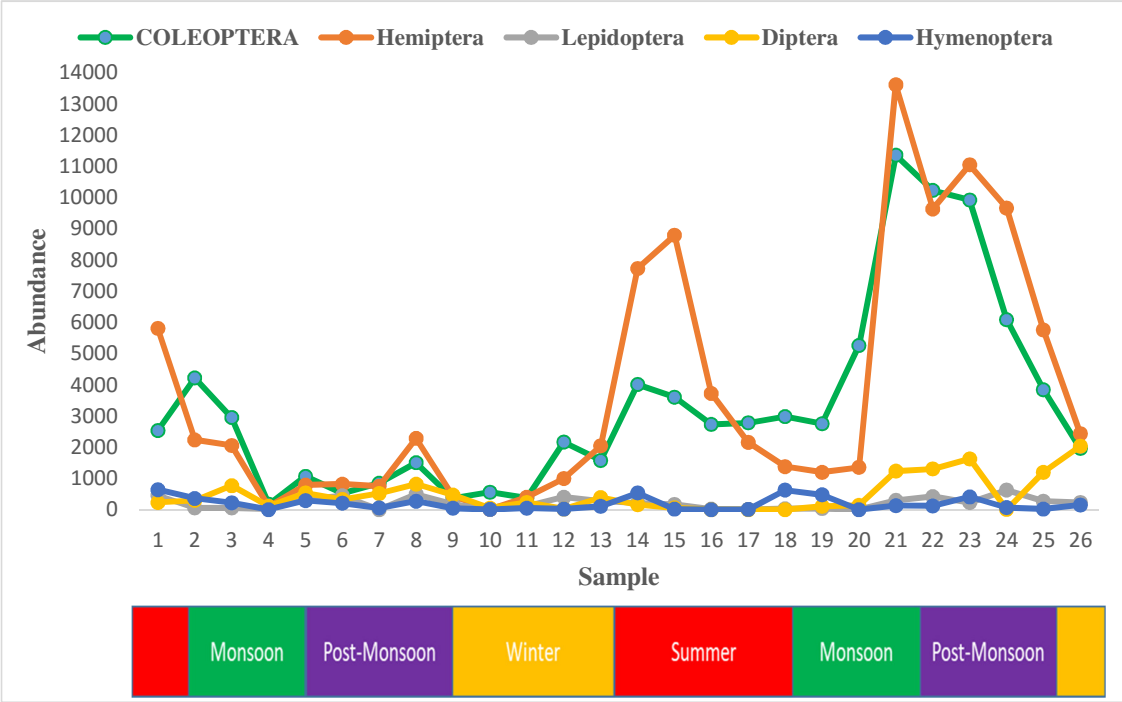

Figure 26. Abundance of five most speciose orders of insect orders collected from 8th May, 2015 to 6thDecember, 2016 using mercury vapour light trap at GKVK, Bangalore.

Temperature did not appear to have any impact on the insect activity and diversity. However, results from multiple regression analysis indicated otherwise (Table 17).

The multiple regression analysis showed that temperature cumulated over three-week period negatively impacted on the species richness and diversity though the abundance was not affected. The temperature on the day of sampling or cumulated over three-day period did not have any direct impact on species richness and abundance (Table 17). Thus our study demonstrates that temperature affect insect activity over long term than short term. Other parameters did not show any direct effect on diversity and abundance of insects.

Table 16. Relationship between species richness, abundance, Simpson index of diversity, Shannon index and meteorological variables

Parameters	Species richness	Abundance	Simpson index of diversity	Shannonindex of diversity
Temperature 21days before sampling	0.064	-0.005	0.079	0.053
Temperature three days before sampling	0.144	0.059	0.094	0.099
Temperature at time of sampling	0.213	0.167	0.083	0.066
Relative humidity 21days before sampling	-0.270	-0.033	-0.150	-0.180
Relative humidity three days before sampling	**-0.355***	-0.217	-0.251	-0.223
Relative humidity at day of sampling	-0.069	-0.028	-0.045	0.011
Rainfall 21days before sampling	0.077	-0.001	0.104	0.121
Rainfall three days before sampling	**-0.339**	**-0.34***	0.187	0.135
Rainfall at day of sampling	-0.100	0.004	-0.240	-0.150

*- correlation is significant at p=0.05 level

Table 17. Multiple regression analysis of species richness, abundance, Simpson index of diversity, Shannon index and meteorological variables

Dependent variable:	Species richness	Meteorological variables	Coeff.	Std.err.	t	p	R^2
N:	26	Constant	1065.4	604.51	1.7625	0.097082	
Multiple R:	0.66293	Temperature 21days before sampling	-28.236	24.413	-1.1566	2.64E-01	0.0041733
Multiple R2:	0.43947	Temperature three days before sampling	9.2672	27.923	0.33189	0.74428	0.020912
Multiple R2 adj.:	0.12418	**Temp** Temperature at time of sampling	8.2816	18.738	0.44197	0.66443	0.045384
		Relative humidity 21days before sampling	-2.5738	6.4756	-0.39746	0.69628	0.073059
ANOVA		Relative humidity three days before sampling	-12.307	7.1959	-1.7102	0.10654	0.12611
F:	1.3938	Relative humidity at day of sampling	5.8647	5.5978	1.0477	0.31036	0.00483
df1, df2:	9, 16	Rainfall 21days before sampling	12.668	7.8563	1.6125	0.12641	0.0059153
p:	2.69E-01	Rainfall three days before sampling	-4.5722	7.0732	-0.6464	0.52718	0.11546
		Rainfall at day of sampling	-0.83162	1.4551	-0.5715	0.5756	0.010112
Dependent variable:	Abundance		Coeff.	Std.err.	t	p	R^2
N:	26	Constant	-3801.9	54977	-0.069155	0.94572	
Multiple R:	0.55533	Temperature 21days before sampling	261.97	2220.2	0.11799	0.90754	2.95E-05
Multiple R2:	0.30839	Temperature three days before sampling	-1920.7	2539.4	-0.75637	0.46042	0.0035395
Multiple R2 adj.:	-0.080644	Temperature at time of sampling	1991.9	1704.1	1.1689	0.25958	0.027785
		Relative humidity 21days before sampling	698.17	588.92	1.1855	0.25313	0.0010887
ANOVA		Relative humidity three days before sampling	-967.36	654.44	-1.4782	0.15878	0.047222
F:	0.79271	Relative humidity at day of sampling	329.07	509.1	0.64638	0.5272	0.00077803
df1, df2:	9, 16	Rainfall 21days before sampling	194.49	714.49	0.27221	0.78895	6.59E-07
p:	0.62781	Rainfall three days before sampling	-762.07	643.28	-1.1847	0.25345	0.11556
		Rainfall at day of sampling	-61.851	132.34	-0.46737	0.64653	1.49E-05
Dependent variable:	Shannon's Index		Coeff.	Std.err.	t	p	R^2
N:	26	Constant	10.421	2.9917	3.4832	0.0030704	
Multiple R:	0.67648	Temperature 21days before sampling	-0.27339	0.12082	-2.2628	3.79E-02	0.0028139
Multiple R2:	0.45763	Temperature three days before sampling	0.24785	0.13819	1.7935	0.091806	0.0097946
Multiple R2 adj.:	0.15255	Temperature at time of sampling	-0.11444	0.092736	-1.234	0.23501	0.0043054
		Relative humidity 21days before sampling	-0.019196	0.032048	-0.59898	0.55757	0.032588
ANOVA		Relative humidity three days before sampling	-0.082373	0.035613	-2.313	0.034355	0.049824
F:	1.5	Relative humidity at day of sampling	0.049395	0.027704	1.7829	0.093576	0.00011892
df1, df2:	9, 16	Rainfall 21days before sampling	0.039748	0.038881	1.0223	0.32185	0.014743
p:	2.30E-01	Rainfall three days before sampling	0.079275	0.035006	2.2646	0.037777	0.018236
		Rainfall at day of sampling	-7.92E-03	7.20E-03	-1.1003	0.28746	2.26E-02
Dependent variable:	Simpson's Index		Coeff.	Std.err.	t	p	R^2
N:	26	Constant	1.335	0.21973	6.0754	1.61E-05	
Multiple R:	0.68519	Temperature 21days before sampling	-0.015727	0.0088738	-1.7723	0.095378	0.006265
Multiple R2:	0.46948	Temperature three days before sampling	0.013301	0.01015	1.3105	0.20853	0.008765
Multiple R2 adj.:	0.17107	Temperature at time of sampling	-0.0062662	0.0068111	-0.92	0.37124	0.0069503
		Relative humidity 21days before sampling	0.00080279	0.0023538	0.34106	0.7375	0.022565
ANOVA		Relative humidity three days before sampling	-0.0074454	0.0026157	-2.8465	0.011666	0.063008
F:	1.5733	Relative humidity at day of sampling	0.0037194	0.0020348	1.8279	0.086266	0.0020275
df1, df2:	9, 16	Rainfall 21days before sampling	0.001668	0.0028557	0.5841	0.5673	0.01084
p:	0.20557	Rainfall three days before sampling	0.0060641	0.0025711	2.3586	0.031397	0.034954
		Rainfall at day of sampling	-0.00093018	0.00052893	-1.7586	0.097754	0.057853

4.7 Seasonal patterns in size of insects

4.7.1 Average length

There did not appear to be a specific pattern in the average length of all insects attracted except that during the 7th, 10th, 16th and 20th sampling periods insects attracted were smaller in length (Figure 27). Circular statistics indicated a random distribution for average length; The Mean vector (μ) was 265.096° with the vector length of 0.142. Relative azimuths 'α' were not uniformly distributed in all directions (Rayleigh tests, Z= 2.474, n= 123, p< 0.084; Table 18, Figure 28) a clear indication that there are no clear peaks or dips in the length of insects attracted through seasons.

Table 18. Circular statistics of average length of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	123
Mean vector (μ)	265.096°
Length of mean vector (r)	0.142
Circular standard deviation	113.241°
Standard error of mean	25.626°
Rayleigh test (Z)	2.474
Rayleigh test (p)	0.084

4.7.2 Average weighted length

Two sharp peaks were observed for average weighted length during 5th sample and 20th sample. Other peaks were spread out and broad in appearance and occurred at early, intermediate and later stages during the sampling period (Figure 29). Circular statistics showed the mean vector (μ) to be 264.377° with the vector length of 0.175. In other words, peaks were not uniformly distributed in all directions (Rayleigh tests, Z= 2.643, n= 86, p< 0.071) (Table 19, Figure 30). This showed that the peaks witnessed are however significant.

Table 19. Circular statistics of average weighted length of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	86
Mean vector (μ)	264.377°
Length of mean vector (r)	0.175
Circular standard deviation	106.919°
Standard error of mean	24.724°
Rayleigh test (Z)	2.643
Rayleigh test (p)	0.071

4.7.3 Average width

Patterns of average width of collected insects showed multiple peaks. Earlier, intermediate and later stage samples showed spread and broad peaks in appearance. Four sharp lower peaks were found in 7^{th}, 10^{th}, 19^{th} and 16^{th} samples. These occurred during the months of October 2015 (start of rains), December 2015 (mid- winter) and April 2016 (early summer) (Figure 31).

Circular statistics conducted indicated an even distribution for average width, the length of arrow 'r' (0.189) did not exceed Rayleigh critical value while the mean vector (μ) was 253.598°. Relative azimuths 'α' were uniformly distributed in all directions (Rayleigh tests, Z= 1.506, n= 42, p< 0.223) (Table 20; Figure. 32). This is an indication that the depicted peaks were insignificant.

Table 20. Circular distributions of average weighted length of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	42
Mean vector (μ)	253.598°
Length of mean vector (r)	0.189
Circular standard deviation	104.529°
Standard error of mean	32.716°
Rayleigh test (Z)	1.506
Rayleigh test (p)	0.223

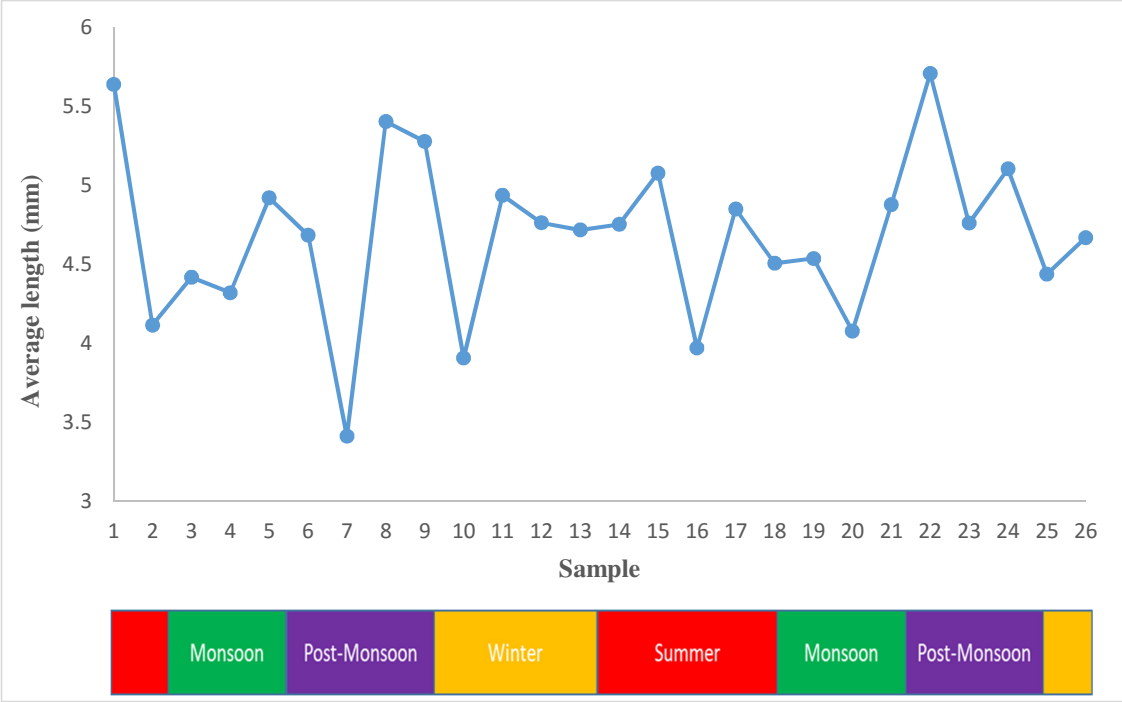

Figure 27. Average length of insects attracted during the sampling period.

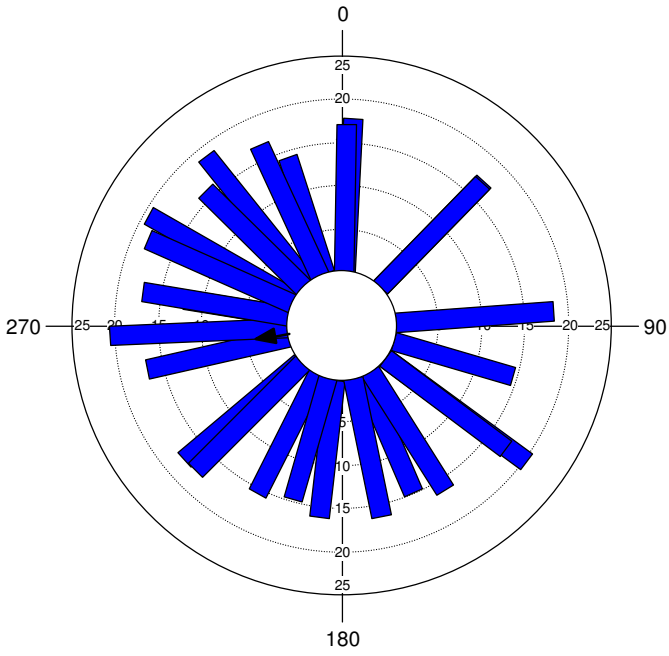

Figure 28. Circular bar graph of average length of insct species collected during the study period. The mean vector length is shown as an arrow. Bars indicate the average length of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st.The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

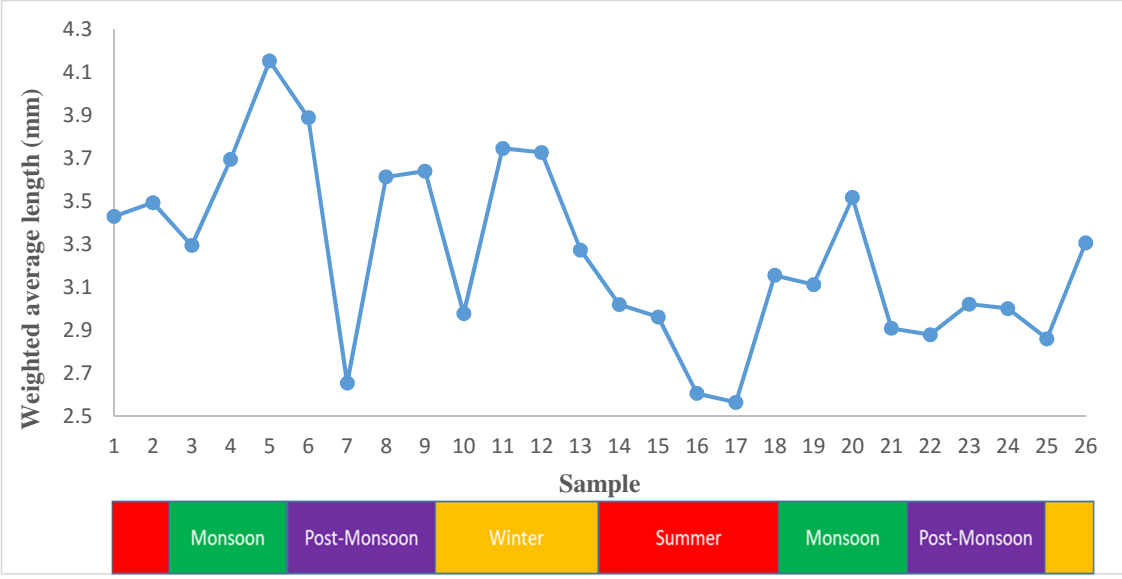

Figure 29. Patterns in size of insects: Weighted Average Length

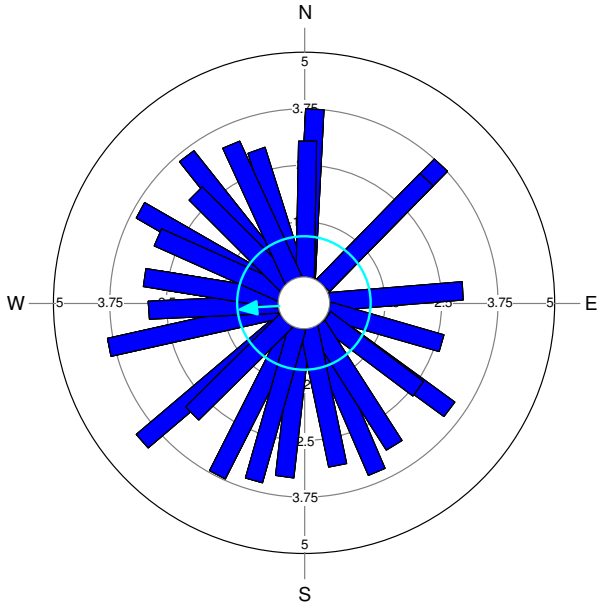

Figure 30. Circular bar graph of weighted average length of insect species collected during the study period. The mean vector length is shown as an arrow. Bars indicate the weighted average length of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st .The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

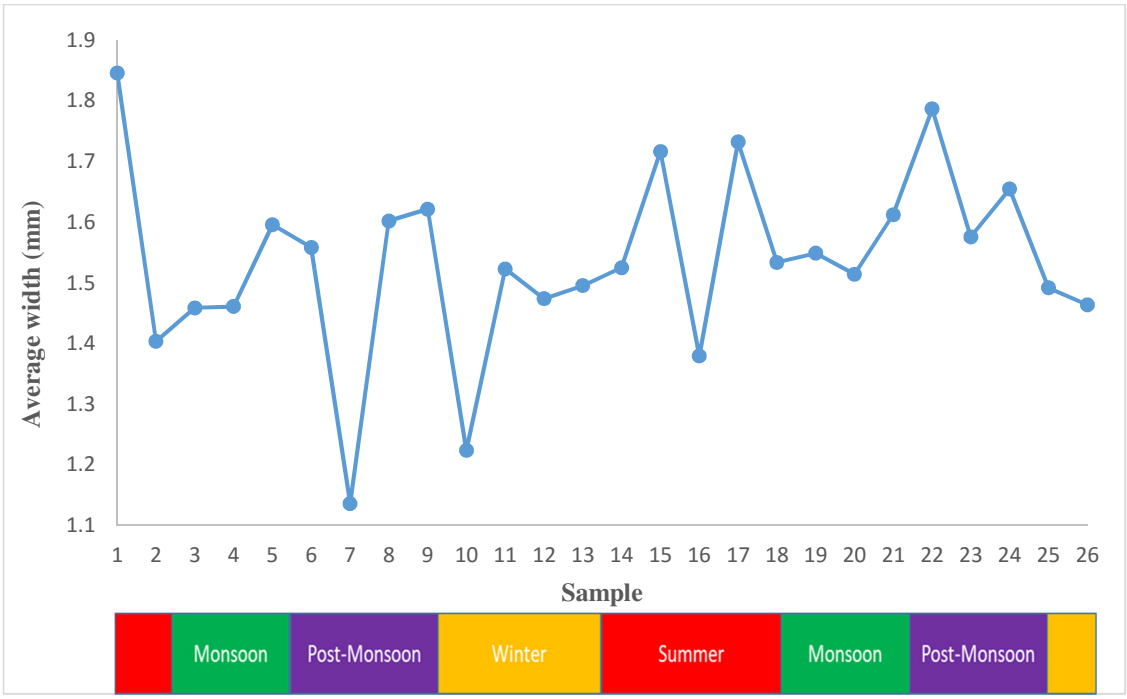

Figure 31. Patterns in size of insects: Average Width

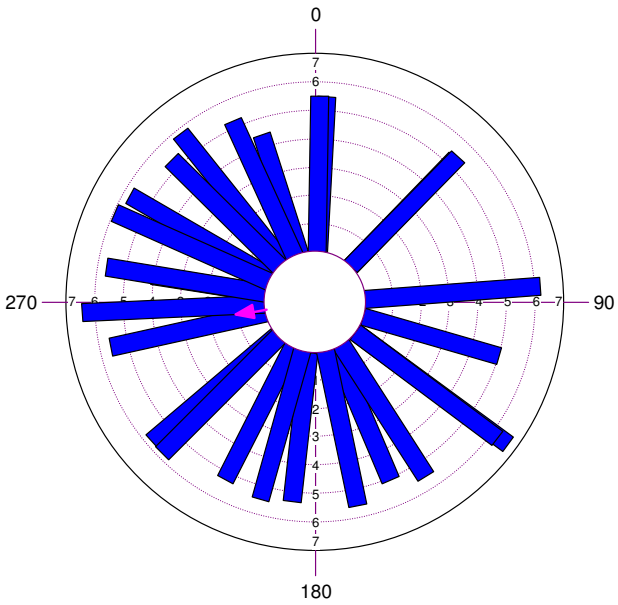

Figure 32. Circular bar graph of average widthof insect species collected during the study period. The mean vector length is shown as an arrow. Bars indicate the average width of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st.The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

4.7.4 Weighted average width

Weighted average width showed four peaks at 5th, 9th, 10thand 20th samples. These occurred during late August 2015 (rainy season), November 2015 and January 2016 (mid-winter season) and mid- July 2016 (start of rains). Intermediate sample peaks were spread and broad in appearance (Figure 33).

Circular statistics attempted indicated an even distribution for weighted average width, the length of arrow 'r' (0.153) did not exceed Rayleigh critical value while the mean vector (μ) was 261.529°. Relative azimuths 'α' were uniformly distributed in all directions (Rayleigh tests, Z= 0.608, n= 26, p< 0.549) (Table 21; Figure. 34). This showed that the peaks for weighted average width were insignificant.

Table 21. Circular statistics of average weighted length of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	26
Mean vector (μ)	261.529°
Length of mean vector (r)	0.153
Circular standard deviation	111.036°
Standard error of mean	51.65°
Rayleigh test (Z)	0.608
Rayleigh test (p)	0.549

4.7.5 Average weight

Just as for the average length, average weight of the insects collected also did not show discernible peaks with seasons (Figure 35) though distinctly smaller insects were recovered during 7th sample, during the month of October 2015 (start of rains). Nevertheless, Circular statistics indicated that there was a non-random distribution of average weight of insects; the mean vector focusing at 241.538°, and with a vector length of 0.157 was significantly higher than expected for a random distribution (Rayleigh tests, Z= 3.359, n= 137, p< 0.035; Table 22, Figure 36). This implied that there are seasonal

patterns in the average weight of the insects collected (Table 22). Thus, the higher weights of insects were found during summer and post rain seasons are indeed clear peaks and the smaller size during winter season corresponding to sample 7, are in fact depicting certain seasonal trend in the insect weight.

Table 22. Circular statistics of average weight of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	137
Mean vector (μ)	241.538°
Length of mean vector (r)	0.157
Circular standard deviation	110.334°
Standard error of mean	21.968°
Rayleigh test (Z)	3.359
Rayleigh test (p)	0.035

4.7.6 Weighted average weight

Plots of weighted average of the weight of insects collected showed three distinct peaks at 2nd,5th and 20th samples corresponding to June 2015 (mid-summer), late August 2015(rainy season) and mid-July 2016 (start of rains). A very low value for weighted average weight was found during the 7th sample that was collected during October 2015 (Figure 37).

Circular statistics, showed that larger size of insects are recovered during summer and rainy season; the mean vector was 216.469° with a vector length 0.3; Rayleigh test indicated that the observed peaks are indeed concentrated towards certain seasons viz., summer and rainy seasons (Rayleigh tests, Z= 4.763, n= 53, p< 0.009; Table 23, Figure 38).

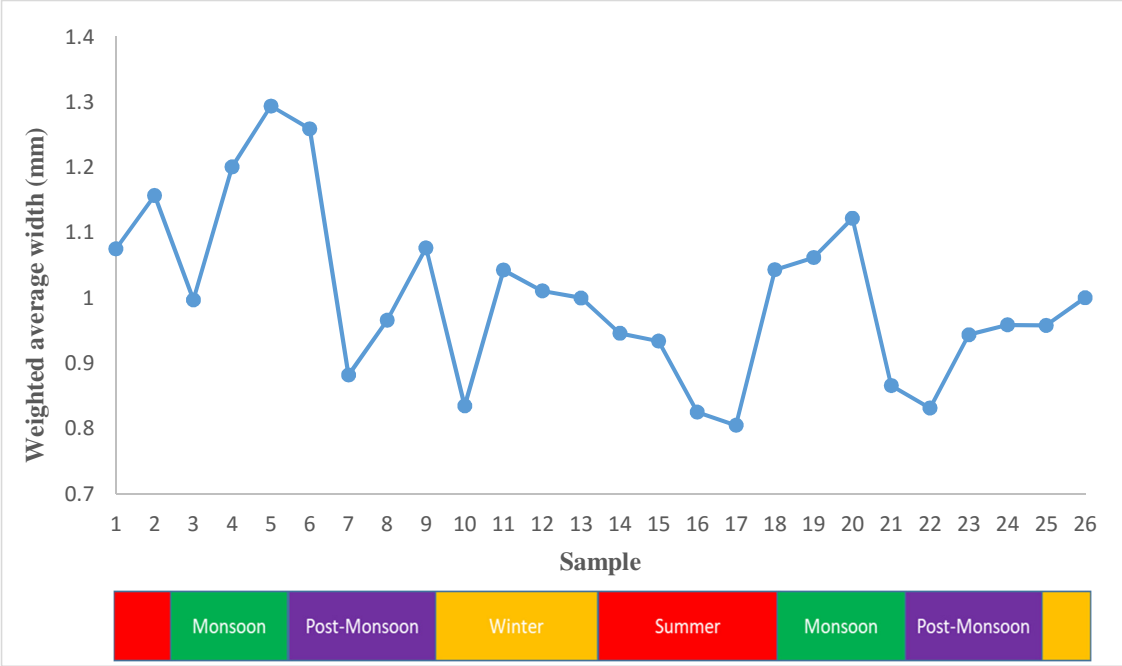

Figure 33. Patterns in size of insects: Weighted Average Width

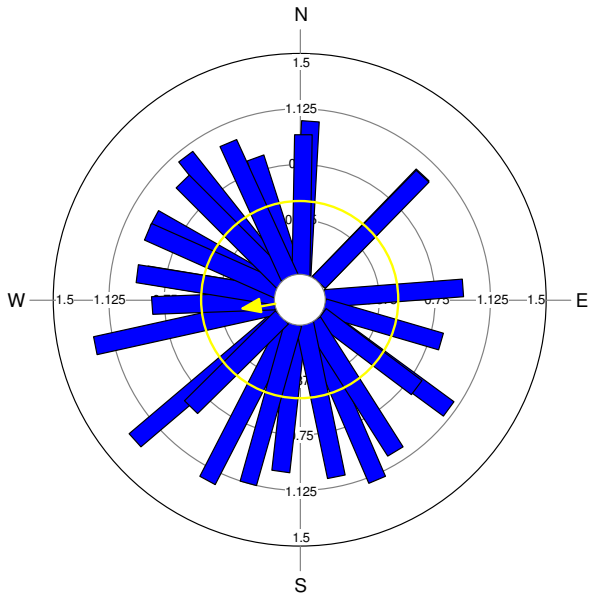

Figure 34. Circular bar graph of weighted average widthof insect species collected during the study period. The mean vector length is shown as an arrow. Bars indicate the weighted average width of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st.The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

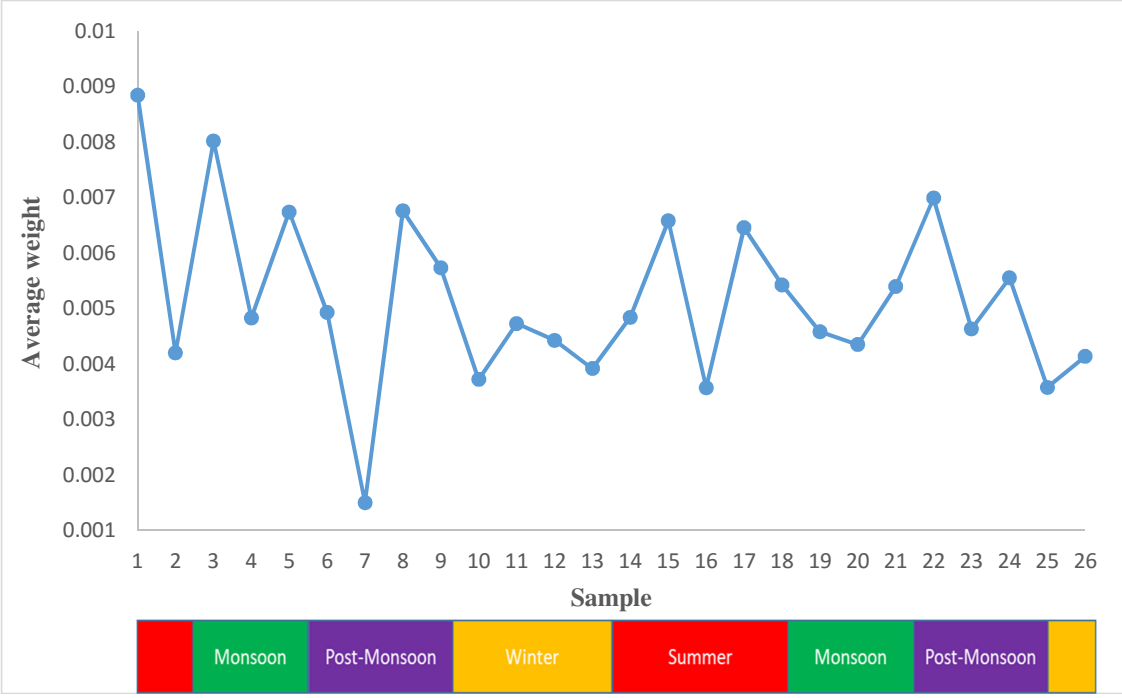

Figure 35. Patterns in size of insects: Average Weight

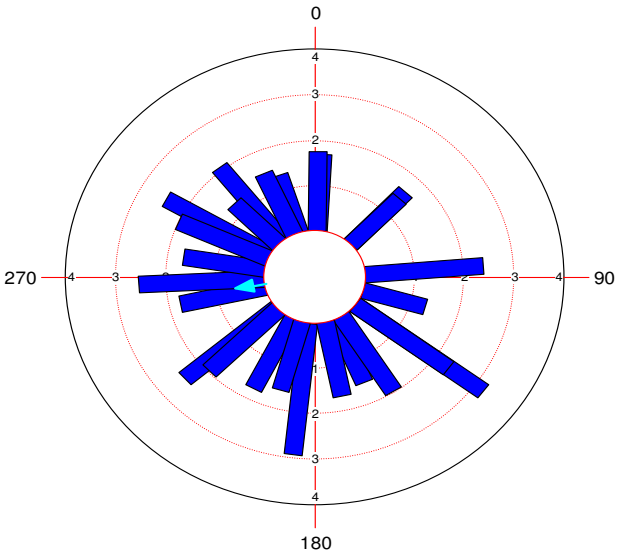

Figure 36. Circular bar graph of average weightof insect species collected during the study period. The mean vector length is shown as an arrow. Bars indicate the average weight of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st.The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

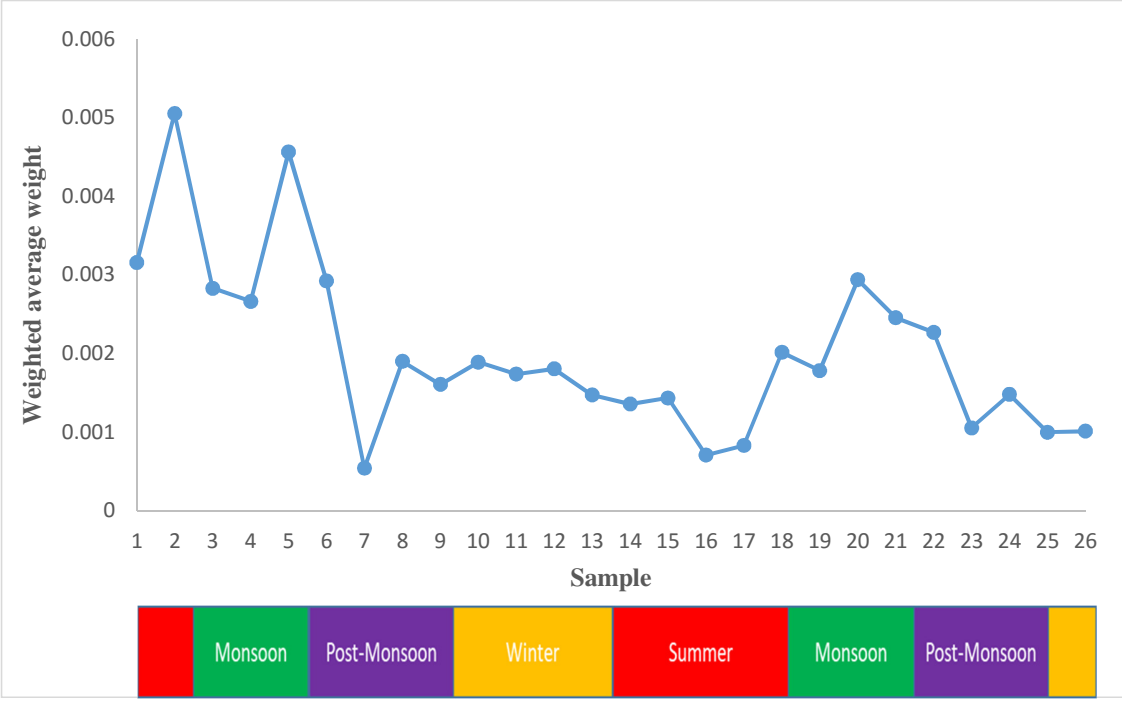

Figure 37. Patterns in size of insects: Weighted Average Weight

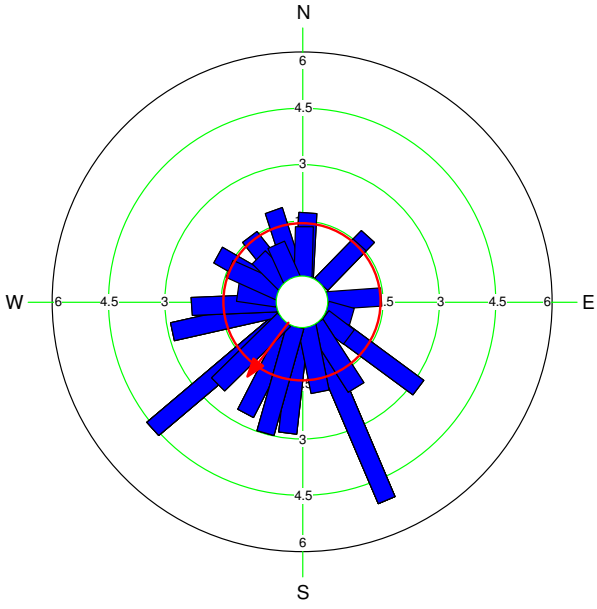

Figure 38. Circular bar graph of weighted average weight of insect species collected during the study period. The mean vector length is shown as an arrow. Bars indicate the weighted average weight of insect species caught on different sampling dates. The 'N-North' indicates January 1st or December 31st .The overlapping bars indicate repeat samples on those sampling days during 2015 and 2016.

Table 23. Circular statistics of weighted average weight of insects collected from May, 2015 to December, 2016 using Mercury vapour lamp light trap at GKVK, Bangalore

Parameters	Values
Number of observations (N)	53
Mean vector (μ)	216.469°
Length of mean vector (r)	0.3
Circular standard deviation	88.937°
Standard error of mean	18.132°
Rayleigh test (Z)	4.763
Rayleigh test (p)	0.009

4.8 Body size relationships

4.8.1 Length relations

The average length of insects collected was 5.069 mm. Order Lepidoptera had the highest average length of insects (6.682 mm) followed by order Hemiptera (6.647 mm), Hymenoptera (5.079 mm), Coleoptera (4.164 mm) and Diptera (3.698 mm) respectively (Table 24). However, insects of Coleoptera differed significantly in their length from that of Hemiptera and of Lepidoptera but not from that of Diptera and Hymeoptera (t test; Table 25).

Lepidoptera showed the highest range in length (27.81 mm) with a CV of 0.675, followed by Hemiptera (23.37 mm) with a CV of 0.606. Diptera and Coleoptera showed the least ranges, 14.52 mm, 14.74 mm, with CV values of 0.638 and 0.631 respectively (Table 24).

The coefficient of variation (CV) was highest for order Hymenoptera (0.803) an indication of greater dispersion of length size around the mean and least for order Hemiptera (0.606) an implication that Hemipterans length size is not widely spread but tends to concentrate around the mean (Table 24). The coefficient of skewness for length was positive for all the insects. The highest coefficient of skewness was found in the order Diptera (2.195) an indication that more Dipterans have their length sizes spread to

the right of mean length. Order Hemiptera (1.074) had the least coefficient of skewness an implication of a more normally distributed length (Figure 39, Table 24).

Kolmogorov-Smirnov (K-S) test of the distributions revealed significant differences due to length relations between orders Coleoptera and Hemiptera (0.106, $p<0.01$), Coleoptera and Lepidoptera (0.553, $p<0.01$), Coleoptera and Hymenoptera (0.145, $p<0.01$), Hemiptera and Lepidoptera (0.554, $p<0.05$), Lepidoptera and Hymenoptera (0.424, $p<0.01$), Lepidoptera and Diptera (0.630, $p<0.01$) and Hymenoptera and Diptera (0.204, $p<0.01$) (Table 26).

Table 24. Measurements of mean, range, standard deviation, coefficient of variation and coefficient of skewness for length relations of all insects and of five speciose orders

	Mean	Range		Standard Dev.	Coefficient Var.	Skewness Coeff.
		Minimum	Maximum			
All insects	5.069	**1**	**28.96**	**3.551**	**0.701**	**1.737**
Coleoptera	4.164	**1.02**	**15.76**	**2.629**	**0.631**	**1.605**
Hemiptera	**6.647**	**1.1**	**24.47**	**4.028**	**0.606**	**1.074**
Lepidoptera	**6,682**	**1.15**	**28.96**	**4.509**	**0.675**	**1.685**
Diptera	**3.698**	**1**	**15.52**	**2.358**	**0.638**	**2.195**
Hymenoptera	**5.079**	**1.68**	**17.07**	**4.079**	**0.803**	**1.654**

Table 25. Student t-Test for the differences in the length (above the diagonal) and width (below the diagonal) of the insects of the five speciose orders. The values are the probability levels of significance of the test between the mean lengths of the orders

	Coleoptera	Hemiptera	Lepidoptera	Diptera	Hymenoptera
Coleoptera	1	0.0001	0.0001	0.1057	0.0567
Hemiptera	0.005	1	0.9486	0.0001	0.036
Lepidoptera	0.253	0.077	1	0.0001	0.055
Diptera	0.464	0.0001	0.03	1	0.01
Hymenoptera	0.479	0.001	0.056	0.733	1

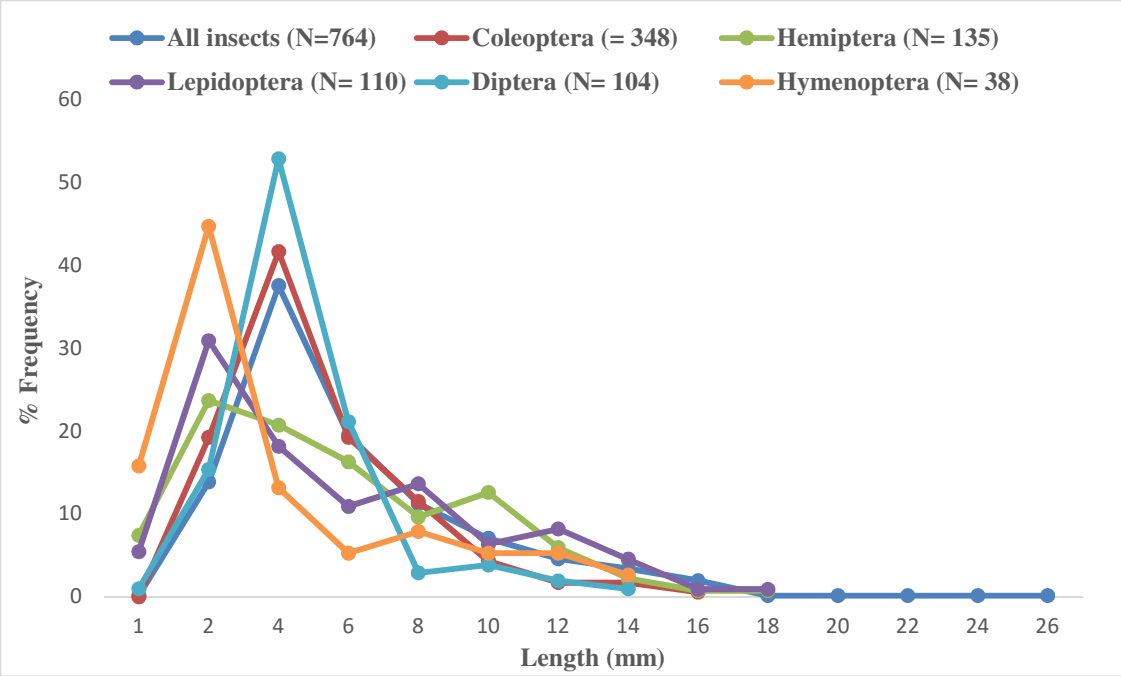

Figure 39: Frequency distribution of length size of all insects and five most speciose insect orders collected from 8th May, 2015 to 6th December, 2016 using mercury vapour light trap at GKVK, Bangalore.

Table 26. Matrix showingKS (Kolmogorov-Smirnov) test for the difference between distributions of length of the five most speciose insect orders collected

Order	Coleoptera	Hemiptera	Lepidoptera	Hymenoptera	Diptera
Coleoptera	0	0.106**	0.553**	0.145**	0.029
Hemiptera	0.087 0.104	0	0.554*	0.134	0.005
Lepidoptera	0.089 0.107	0.123 0.013	0	0.424**	0.630**
Hymenoptera	0.098 0.117	0.148 0.177	0.161 0.193	0	0.204**
Diptera	0.089 0.107	0.123 0.147	0.130 0.156	0.160 0.192	0

The d-max computed values are given above the diagonal with significance shown at 5 % (*) and 1 % (**). The computed critical values (5 %, first row and 1 % second row) are provided below the diagonal.

4.8.2 Width relations

The average width of insects collected was 1.670 mm. Order Hymenoptera had the highest average width of insects (1.939 mm) followed by order Diptera (1.869 mm), Coleoptera (1.743 mm), Lepidoptera (1.549 mm) and Hemiptera (1.315 mm) respectively (Table 27). However, insects of Coleoptera differed significantly in their width from that of Hemiptera but not from that of Lepidoptera, Diptera and Hymeoptera. Order Hemiptera also differed significantly in width from Diptera and Hymenoptera. Significant differences in width were also found to exist between orders Lepidoptera and Diptera (t test; Table 25).

Coleoptera showed the highest range in width (17.37 mm) with a CV of 0.957, followed by Hemiptera (4.93 mm) with a CV of 0.766. Diptera and Hymenoptera showed the least ranges, 3.79 mm, 4.27 mm, with CV values of 0.564 and 0.582 respectively (Table 27). The coefficient of variation (CV) was highest in order Coleoptera (0.957) an indication of great spread in width size and least in order Diptera (0.564) an indication of more concentrated width size.

The coefficient of skewness for width was positive for all the insects. Order Coleoptera (5.439) showed the highest coefficient of skewness in width an indication that

more Coleopterans have their width sizes spread to the right of mean width. Order Diptera was the least skewedan implication of a more normally distributed width (Figure 40).

Table 27. Measurements of mean, range, standard deviation, coefficient of variation and coefficient of skewness for width relations of all insects and of five speciose orders

	Mean	Range		Standard Dev.	Coefficient Var.	Skewness Coeff.
		Minimum	Maximum			
All insects	1.670	0.2	18	1.386	0.829	4.716
Coleoptera	1.743	0.63	18	1.666	0.957	5.439
Hemiptera	1.315	0.38	5.31	1.007	0.766	1.371
Lepidoptera	1.549	0.57	5.2	1.057	0.682	1.909
Diptera	1.869	0.91	4.7	1.054	0.564	1.059
Hymenoptera	1.939	0.91	5.18	1.128	0.582	1.316

4.8.3 Weight relations

The average weight of insects collected was 0.0068 mg. Order Hemiptera had the highest average weight of insects (0.0113 mg) followed by order Lepidoptera (0.0086 mg), Coleoptera (0.0057 mg), Hymenoptera (0.0053 mg) and Diptera (0.0020 mg) respectively (Table 28). However, insects of Coleoptera differed significantly in their weight from that of Hemiptera and Diptera but not from that of Lepidoptera and Hymeoptera (t test; Table 29). Significant differences in weight were also witnessed between orders Hemiptera and Diptera, Lepidoptera and Diptera, Diptera and Hymenoptera (t test; Table 29).

Hemiptera showed the highest range in weight (0.51059 mg) with a CV of 3.939, followed by Coleoptera (0.21909 mg) with a CV of 2.730. Diptera and Hymenoptera showed the least ranges, 0.03529 mg, 0.06509 mg, with CV values of 2.446 and 2.627 respectively (Table 28).

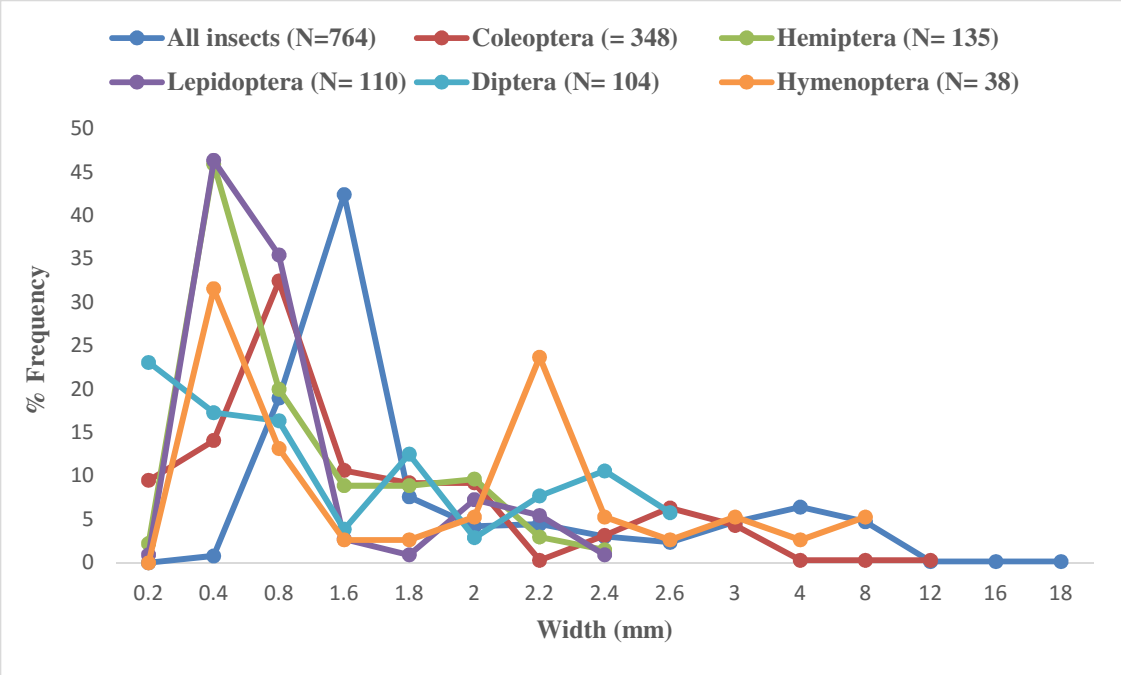

Figure 40: Frequency distribution of width size of all insects and five most speciose insect orders collected from 8th May, 2015 to 6th December, 2016 using mercury vapour light trap at GKVK, Bangalore.

The coefficient of variation for weight was highest for order Hemiptera (3.939) an indication of greater weight dispersion from the mean weight and least for order Lepidoptera (2.048) an indication of more a concentrated weight around the mean weight (Table 28).

The coefficient of skewness for weight was positive for all the insects. The highest coefficient of skewness was found in the order Hemiptera (10.547) an indication that more Hemipterans have their weight sizes spread to the right of mean weight. Order Hymenoptera (3.410) had the least coefficient of skewness an implication of a more normally distributed weight (Figure 41, Table 28).

Kolmogorov-Smirnov (K-S) test distributions revealed significant differences due to weight relations between orders Coleoptera and Hemiptera (0.177, $p<0.01$), Coleoptera and Lepidoptera (0.356, $p<0.01$), Coleoptera and Diptera (0.201, $p<0.01$), Hemiptera and Lepidoptera (0.533, $p<0.01$), Hemiptera and Hymenoptera (0.406, $p<0.01$), Hemiptera and Diptera (0.132, $p<0.05$) and Lepidoptera and Diptera (0.558, $p<0.01$) (Table 30).

Table 28. Measurements of mean, range, standard deviation, coefficient of variation and coefficient of skewness for weight relations of all insects and of five speciose orders

	Mean (mg)	Range difference* (mg)	Standard Dev.	Coefficient Var.	Skewness Coeff.
All insects	0.0068	0.5106	0.0232	3.412	15.071
Coleoptera	0.0057	0.2191	0.0155	2.730	8.613
Hemiptera	0.0113	0.5106	0.0447	3.939	10.547
Lepidoptera	0.0086	0.1302	0.0176	2.048	4.302
Diptera	0.0020	0.0353	0.0049	2.446	4.846
Hymenoptera	0.0053	0.0651	0.0139	2.627	3.410

*Insects that were too small to weigh were considered to have weight <0.00001 mg; since all groups had such small insects, only the maximum weight is represented as range difference

Table 29. Student t-Test for the differences in the weight of the insects of the five speciose orders. The values are the probability levels of significance of the test between the mean lengths of the orders

	Coleoptera	Hemiptera	Lepidoptera	Diptera	Hymenoptera
Coleoptera	1	0.0403	0.100	0.01	0.873
Hemiptera		1	0.544	0.034	0.411
Lepidoptera			1	0.0001	0.294
Diptera				1	0.04
Hymenoptera					1

Table 30. Matrix showing K S (Kolmogorov-Smirnov) test for the difference between distributions of weight of the five most speciose insect orders collected

Order	Coleoptera	Hemiptera	Lepidoptera	Hymenoptera	Diptera
Coleoptera	0	0.177**	0.356**	0.132	0.201**
Hemiptera	0.087 0.105	0	0.533**	0.406**	0.132*
Lepidoptera	0.090 0.108	0.124 0.013	0		0.558**
Hymenoptera	0.098 0.118	0.148 0.178	0.161 0.194	0	
Diptera	0.090 0.107	0.123 0.148	0.130 0.157	0.160 0.192	0

The d-max computed values are given above the diagonal with significance shown at 5 % (*) and 1 % (**). The computed critical values (5 %, first row and 1 % second row) are provided below the diagonal.

4.8.4 Length-width relations

Plots of width on length for all insects and for five speciose orders showed very strong and positive relationships. These relations followed linear functions for all insects ($y = 0.3025x$; $R^2 = 0.5865$; $p < 0.01$), Coleoptera ($y = 0.3475x$; $R^2 = 0.6146$; $p<0.01$), Hemiptera ($y = 0.3551x$; $R^2 = 0.6083$; $p < 0.01$), Lepidoptera ($y = 0.2653x$, $R^2 = 0.5166$, $p < 0.01$), Diptera ($y = 0.235x$; $R^2 = 0.7518$; $p < 0.01$) and Hymenoptera ($y = 0.2623x$; $R^2 = 0.5475$; $p < 0.01$) (Table 31, Figure 42).

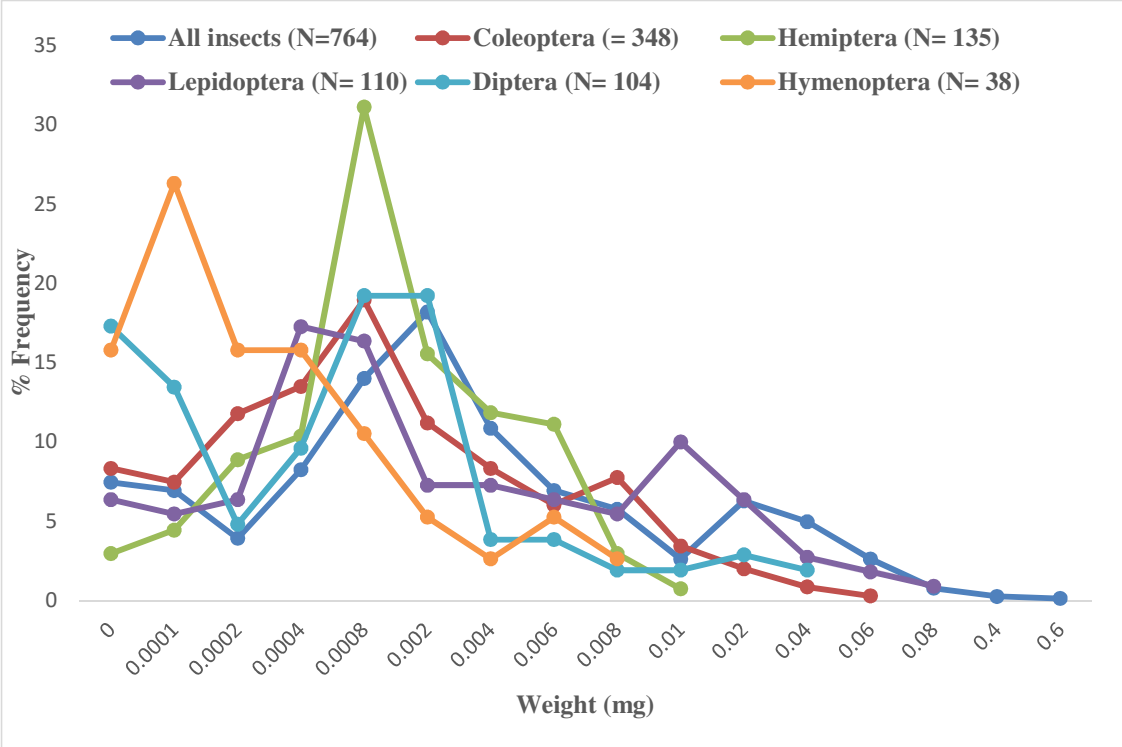

Figure 41. Frequency distribution of weight of all insects and five most speciose insect orders collected from 8th May, 2015 to 6th December, 2016 using mercury vapour light trap at GKVK, Bangalore.

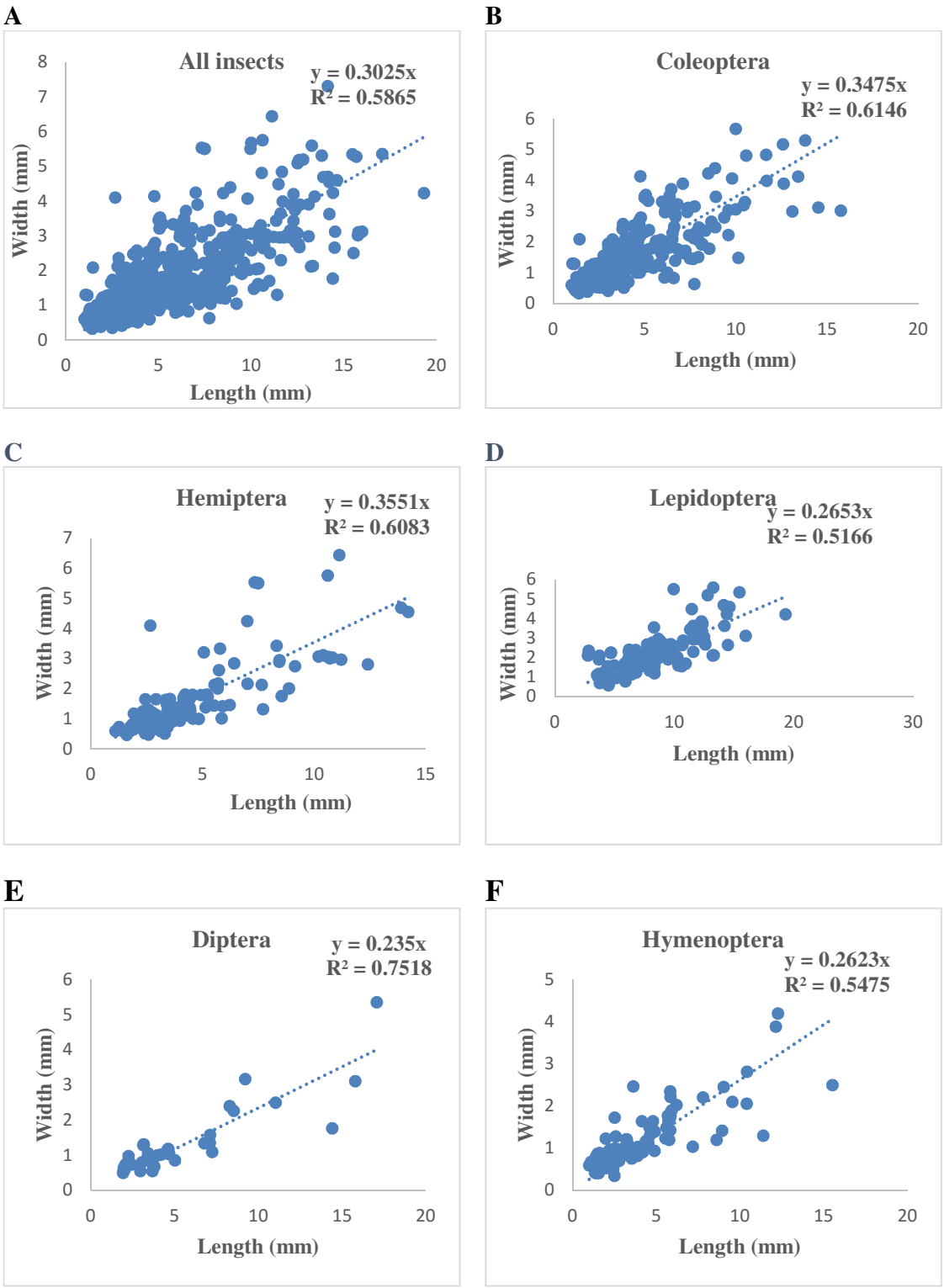

Figure 42. Length-width relations of: All insects(A), Coleoptera(B), Hemiptera (C), Lepidoptera (D), Diptera (E) and Hymenoptera (F).

Thus in general the width of insects increases at a rate of 0.30 times the length. As can be seen from the table 31, this rate of increase in width with length is higher for Coleoptera and Hemiptera (0.3475, 0.3551) respectively, while it is low in Diptera (0.235) Hymenoptera (0.2623) and Lepidoptera (0.2653). In other words, with every unit increase in length, width of Coleoptera and Hemiptera increases at higher rate than in the other three orders.

Table 31. Relationships between length and width for all insects and for five speciose orders

	All insects	**Coleoptera**	**Hemiptera**	**Lepidoptera**	**Diptera**	**Hymenoptera**
Best fit	**y = 0.3025x**	**y = 0.3475x**	**y = 0.3551x**	**y = 0.2653x**	**y = 0.235x**	**y = 0.2623x**
R²	$R^2 = 0.5865$	$R^2 = 0.6146$	$R^2 = 0.6083$	$R^2 = 0.5166$	$R^2 = 0.7518$	$R^2 = 0.5475$
P<	0.01	0.01	0.01	0.01	0.01	0.01

4.8.5 Length and weight relations

Plots of weight of insects on length for all insects and for five species orders revealed very strong non-linear relationships. These relations followed power functions for all insects ($y = 2E\text{-}05x^{2.9174}$; $R^2 = 0.9886$; $p < 0.01$), Coleoptera ($y = 2E\text{-}05x^{3.1772}$; $R^2 = 0.9867$; $p < 0.01$), Hemiptera ($y = 2E\text{-}05x^{2.7236}$; $R^2 = 0.9875$; $p < 0.01$), Lepidoptera ($y = 2E\text{-}05x^{2.7666}$; $R^2 = 0.9879$; $p < 0.01$), Diptera ($y = 1E\text{-}05x^{3.1445}$; $R^2 = 0.9446$; $p < 0.01$) and Hymenoptera ($y = 2E\text{-}05x^{2.5827}$; $R^2 = 0.9688$; $p< 0.01$; Table 32; Figure 43). Thus, the weight of all insects increases as 2.9174 power of the length. This power function was highest for Coleoptera (3.1772) followed by Diptera (3.1445), Lepidoptera (2.7666), Hemiptera (2.7236) and Hymenoptera (2.5827). In other words, the weight of insects of Coleoptera increases at a higher rate than in other orders.

Table 32. Relationships between length and weight for all insects and for five speciose orders.

	All insects	**Coleoptera**	**Hemiptera**	**Lepidoptera**	**Diptera**	**Hymenoptera**
Bestfit	$y= 2E\text{-}05x^{2.9174}$	$y = 2E\text{-}05x^{3.1772}$	$y = 2E\text{-}05x^{2.7236}$	$y= 2E\text{-}05x^{2.7666}$	$y=1E\text{-}05x^{3.1445}$	$y = 2E\text{-}05x^{2.5827}$
R²	$R^2 = 0.9886$	$R^2 = 0.9867$	$R^2 = 0.9875$	$R^2 = 0.9879$	$R^2 = 0.9446$	$R^2 = 0.9688$
P<	0.01	0.01	0.01	0.01	0.01	0.01

4.8.6 Width and weight relations

Plots of weight on width for all insects and for five major orders were strongly inter-correlated and followed power functions for Hemiptera ($y = 1E\text{-}08x^{18.127}$; $R^2 = 0.9213$; $p < 0.01$), Lepidoptera ($y = 1E\text{-}06x^{7.1987}$; $R^2 = 0.9315$; $p < 0.01$), Diptera ($y = 2E\text{-}07x^{26.047}$; $R^2 = 0.8966$; $p < 0.01$), Hymenoptera ($y = 1E\text{-}20x^{46.194}$; $R^2 = 0.8959$; $p < 0.01$) and exponential relations for order Coleoptera ($y = 2E\text{-}07e^{10.743x}$; $R^2 = 0.9662$; $p < 0.01$).

This shows that the weight of all insects increases as 2.8389 power of the width. This power function was highest for order Hymenoptera (46.194) followed by Diptera (26.047), Hemiptera (18.127) and Lepidoptera (7.1987). In other words, the weight of insects in respect to width of Hymenoptera and Diptera increases at a higher rate than either in Hemiptera or Lepidoptera. However, the weight of insects in order Coleoptera increased exponentially with width at a rate of 10.743 times (Table 33; Figure 44).

Table 33. Relationships between width and weight for all insects and for five speciose orders.

	All insects	**Coleoptera**	**Hemiptera**	**Lepidoptera**	**Diptera**	**Hymenoptera**
Best fit	$y = 0.0005x^{2.8389}$	$y = 2E\text{-}07e^{10.743x}$	$y = 1E\text{-}08x^{18.127}$	$y = 1E\text{-}06x^{7.1987}$	$y = 2E\text{-}07x^{26.047}$	$y = 1E\text{-}20x^{46.194}$
R^2	$R^2 = 0.6457$	$R^2 = 0.9662$	$R^2 = 0.9213$	$R^2 = 0.9315$	$R^2 = 0.8966$	$R^2 = 0.8959$
P<	0.01	0.01	0.01	0.01	0.01	0.01

B. Inferences and interpretations:

In the following the most significant patterns and associations are extracted to draw relevant inferences and interpretations and then discussed in the context of the objectives of the study.

4.9 Diversity and abundance of insects

Diversity and abundance of any taxonomic group could indicate their ecological and functional significance in the ecosystem in which they are found in assemblages (Diaz and Cabido, 1997; Hector *et al.,* 1999; Chapin *et al.,* 2000; Loreau *et al.,* 2001; Tilman *et al.,* 2001). In fact, highly diverse ecosystems are known to be more productive

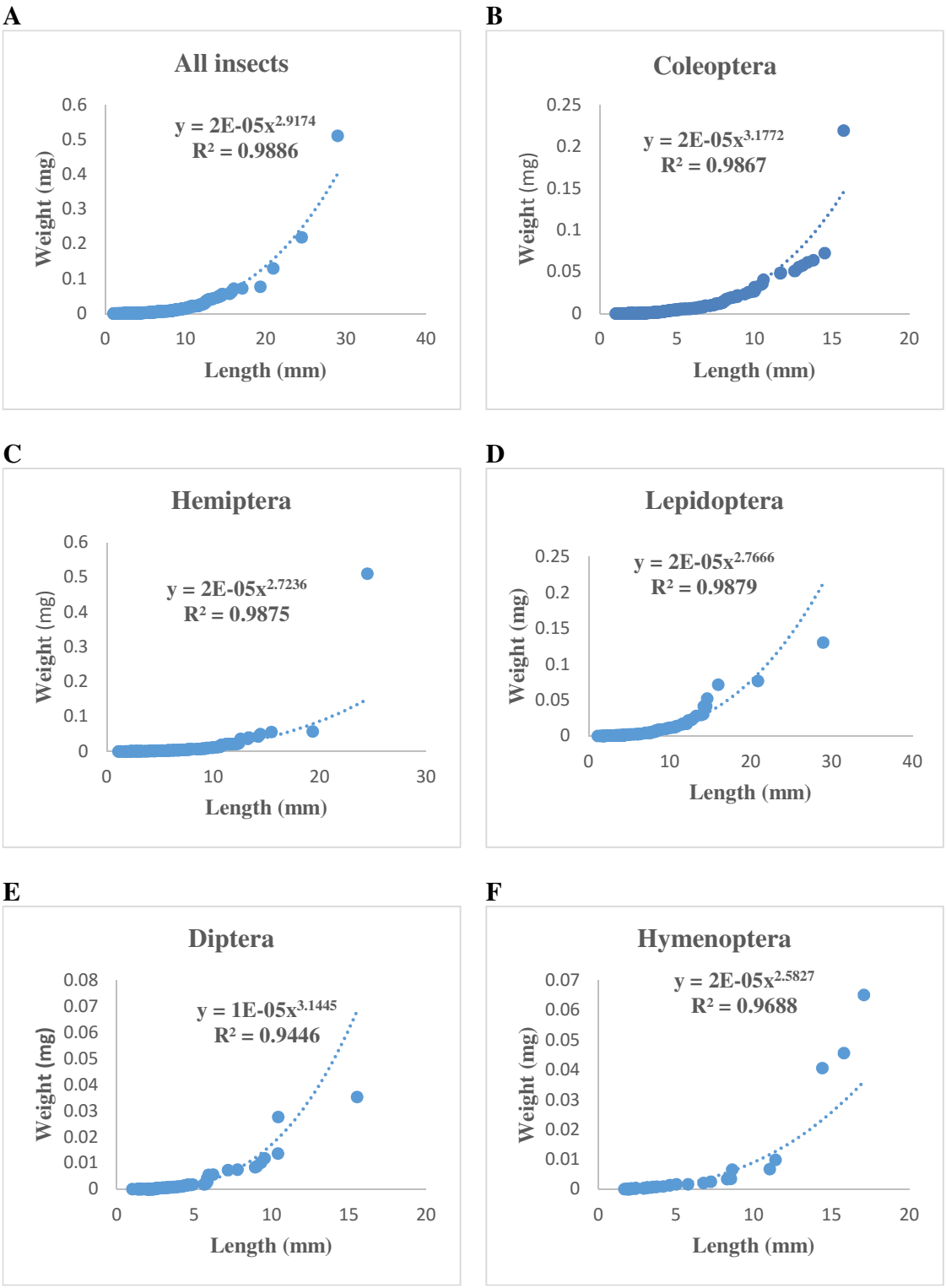

Figure 43. Length-weight relationships for all insects and for five major insect orders

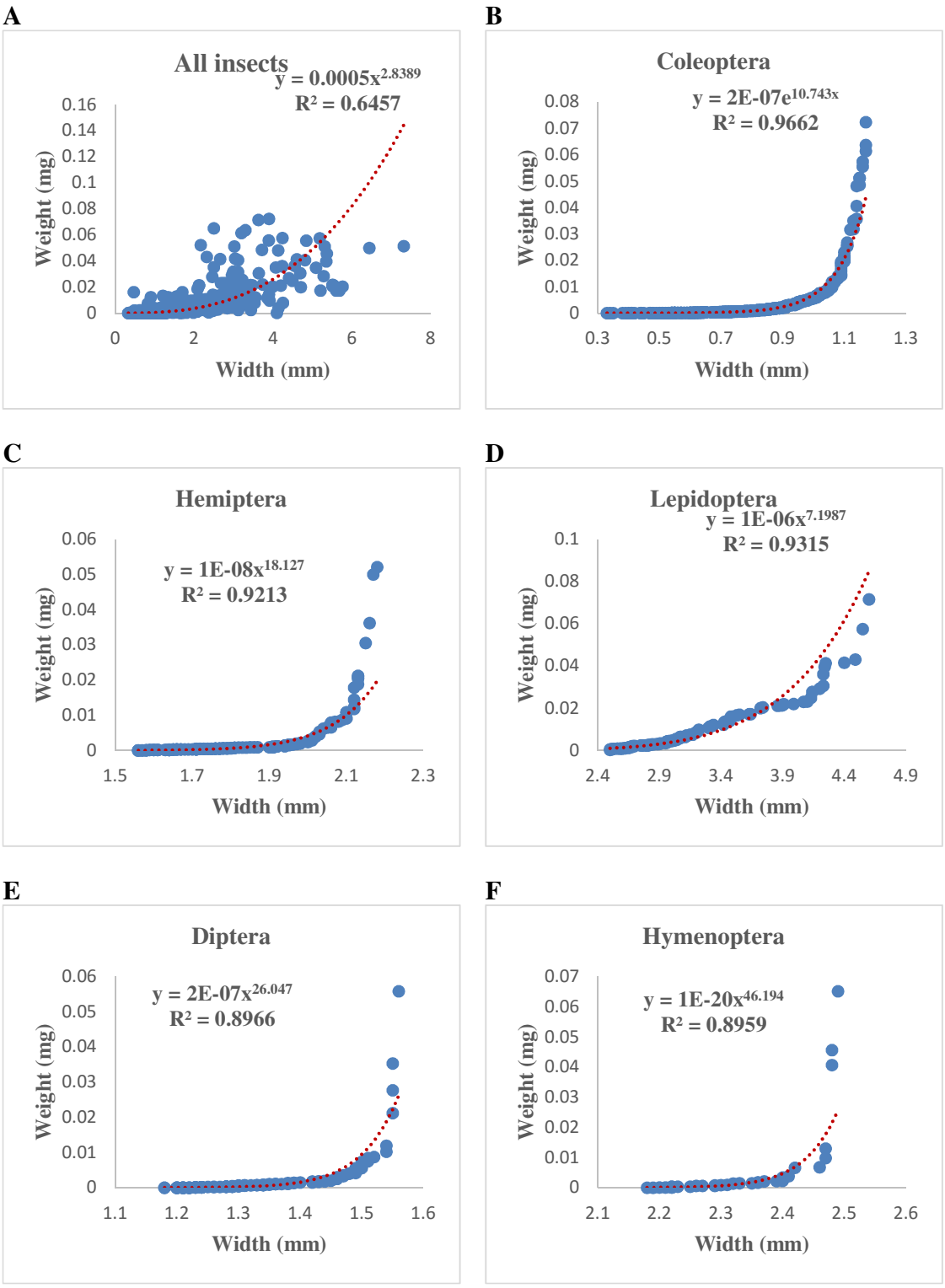

Figure 44. Width-weight relationships for all insects and for five major insect orders

and also stable over time (McCann, 2000; Tilman *et al.,* 2001; Ives and Carpenter, 2007). Therefore, diversity and abundance of taxa may also serve as a good indicator of the health of the ecosystem (Yachi and Loreau, 1999). However, the species richness and abundance of any group may not be stable over space and time (Myers *et al*., 2000; Samways, 2005).

Presently, 63,760 species of insect (Hexapoda) in 658 families representing 27 orders and three class are reported from India (Ramakrishna and Alfred, 2006). The current diversity of insects in India as compared with that of the world out of 29 insect orders known globally, 27 are represented in India (Ramakrishna and Alfred, 2006). Eight orders, viz. the Lepidoptera, Coleoptera, Orthoptera, Diptera, Hemiptera, Odonata, Hymenoptera and Thysanoptera, constitute the bulk (94 %) of the insect fauna, while the remaining 21 orders are represented by small numbers (6 %) of species. The order Coleoptera has the greatest diversity in terms of families—114 families—followed by Hemiptera (92 families), Diptera (87 families), Lepidoptera (84 families) and Hymenoptera (65 families) (Ramakrishna and Alfred, 2006).

In this study, a total of 209,098 individuals belonging to 764 morpho-species or Operational Taxonomic Units (OTUs), representing 101 families from 12 orders were collected through the two years of sampling (Tables 1 and 2). As Williams (1940) stated, "the number of insects caught at any particular time is mainly determined by two factors, that is, the activity of the insect and the total population available for sampling". However, since light traps were our primary source of data used, it is expected that only insects physically attracted to light and those insects that were flying at the time of sampling would be collected. This in a way may have presented some form of biasness to the total insect population collected.

4.10 Indicator group of insect diversity

Using the proportion of five speciose orders we compared insects' diversity collected at GKVK with that of India and global proprtions (Table 4). Accordingly, GKVK was found to have more of Coleoptera and of Hemiptera and less of Lepidoptera

and Hymenoptera. It is likely this could be because our study collected only nocturnal insects.

Our results also showed that the Coleoptera is a good indicator of the total insect diversity perhaps because it is the most predominant component of the collections made in our study; since Coleoptera constitutes about 40 per cent of all insects known, diversity of this group it is not unexpected that it is a good indicator of total diversity. Further diversity of this group was also correlated with the diversity of Hemiptera and Lepidoptera. Wheeler (1990) in his 'species scape', pictorially illustrated the current dominance of insects, and Samways (1993) noted that if all insect species on earth were described, the beetle representing the proportion of insect species in the world might have to be drawn up to 10 times larger. Wheeler (1990) used a beetle to depict the arthropods in his species scape because the Coleoptera are the dominant insect group, constituting 40 per cent of the estimated total number of insects (Nielsen and Mound, 2000). Dominance of the Coleoptera was said to have led Haldane (1926), when asked what he could infer about the work of the Creator, to respond that the Creator must have had 'an inordinate fondness for beetles', although there is some doubt about the provenance of this phrase (Fisher, 1988). The success of the order Coleoptera is claimed to have been enabled by the rise of flowering plants (Farrell, 1998).

The order Hemiptera, dominated in abundance (individuals). This may be due to its distinctively modified mouthparts that are in the form of piercing-sucking beaks that they use to obtain food and to its predatory abilities that enable species to pierce their prey, usually other insects, injecting digestive enzymes to kill and begin the process of digestion (ZSI, 2012).

Low abundance levels of order Hymenoptera during summer is not well understood but may be associated with their foraging difficulties for litter (Bruhl *et al.,* 1999). Decrease in bees (Hymenoptera) during the dry season may be due to lack of floral resources in this season as few plant species are able to produce flowers and leaves in the dry season (Machado *et al*., 1995).

Although several studies (ZSI, 2012) have described Diptera to be unparalleled masters of aerial locomotion due to their distinctive feature in the reduction of the metathoracic wings to a pair of knob-like halteres that act as gyroscopes in flight. The present study did not find the advantage of this modification that has increased their maneuverability and allowed the Diptera to become good fliers to be reflected in their diversity. In fact, Diptera richness was low compared to Coleoptera and Hemiptera and further showed negative correlation with the entire insects. Low Diptera richness may be associated with their low attractiveness to light trap.

4.11 Species richness- abundance relationships

Macarthur (1965) andWilson (1988), argument on island biogeography suggested that species richness increases non-linearly and asymptotically with the island size. This relation has been formalized as "Species –Area Curves", given as:

$$S = KA^z$$

Where, S = Number of species in a given area (A) and z represents the rate at which species increases.

This relation is also extended to explain the way in which number of species increases with area sampled. Since, with increasing area sampled the number of individuals also increases, the same relation can be expressed as: -

$$S = KN^z$$

Where, N = the number of individuals in the sample.

A species–area curve describes the relationship between the area of a habitat, or of part of a habitat, and the number of species found within that area. Larger areas tend to contain larger numbers of species. Typically, species- number relation follows the same patterns as that of Species-Area relation. In our study, the number of OTUs collected increased nonlinearly with the number of insects collected in the 26 samples from the light trap. Thus, the species richness appeared to exhibit the typical `Species-Area relation', with the number of individuals collected.

However, the power function defining the rate at which species richness increases with the abundance was 0.36 for all insects and 0.4067 for Coleoptera. In other words, for a given number of individuals collected, Coleoptera showed high diversity than others.

Studies on Coleoptera by (Hall, 2001; Sawada and Hirowatari, 2002; Sorensson, 2003) have shown Coleoptera to be a potential bio-indicator for moist habitats due to its preference for moist soil, litter and rotting wood. The abundance of Hydrophilids and Staphylinids beetles, known for their preference for wet litter conditions are further evidence for this hypothesis (Borror *et al*., 1996; Lawrence, 1999).

Ganeshaiah (1998) has shown that the number of species in an order increases exponentially with the family richness. Accordingly, he showed that order Coleoptera has more species per family than the other orders. Since families represent a lower order design of morphological structure of a group of species, this relation shows that the number of species increases exponentially with every new design adopted in the order. In fact, this is not necessarily an unexpected relation if diversity of species in an order increases in a linear proportion to the number of families. The exponential relation between the species richness of the order and family richness shows that there is a higher packing of species in each family with increase in the number of families in the order. The present study also showed such a non-linear increase in the number of species with family richness (Figure 5).

Though the relation fits better with a power function, the exponential relation also explain almost 79 per cent of the relation with Coleoptera having the highest number of species in only 29 families. In fact, Ganeshaiah (1998) argued that Coleoptera which is the most species rich group in insects is likely to show lot of similarity among species than other groups.

According to Colwell (1979) and Root (1973), ecologists should concentrate their analyses on parts of the community that are functionally interacting, that is, analysis should cut across trophic levels and include taxonomically unrelated species in them. Although the choice of what to include in a "community" is critical to achieving ecological understanding because there are no rules available to assist in decision

making, the functionally interacting networks (guilds) can be determined only by detailed natural history studies of the species in a community (Baskerville *et al.,* 2011).

This study showed that species richness on abundance increased non-linearly (power model) with slope value of 0.4067, 0.3345 and 0.6693 for Coleoptera, Hemiptera and Lepidoptera respectively. The high value for Lepidoptera shows that more of new species were collected with increase in number of insects than in Coleoptera and Hemiptera. It is likely that in the latter a few species dominate. Order Hymenoptera, showed a linear relationship with regression coefficient 0.0199 an indication that new Hymenopterans added at a rate of 0.0199 times its insects caught while that of Diptera increased exponentially at a rate of 0.0008.

Lepidoptera (moths) plays important role in many ecosystems as pollinators, herbivores, and prey for a wide range of species such as birds and bats (Wickramasinghe *et al.,* 2004). The distribution and ecology of moths are well known in comparison to many other invertebrates (Fox *et al.,* 2013). Infact, the keystone role of moths in manyecosystems (Kristensen *et al.,* 2007; Fox *et al.,* 2013) cannot be under-estimated. These results are however inconsistent with May's (1975) approximation that suggested species richness to be a power function of 0.5 to individuals ($\mathbf{S = I^{0.5}}$).

4.12 Indices of diversity measurements

Diversity index is a single statistic that incorporates information on richness and evenness. This blend is often referred to as "heterogeneity" (Good, 1953; Hurlbert, 1971) and for the same reason diversity measures that incorporate the two concepts may be termed "heterogeneity" measures. Despite the recent progress on methods used to estimate species richness there is still a perceived need of "indices" of diversity that capture both species richness and evenness characteristics of an assemblage to be considered for inclusion in any biodiversity estimation (Magurran, 2004).

The associations between different diversity indices for the 26 sampling periods showed that while species richness is strongly correlated with the Simpson's and Shannon-Wiener index, it was not correlated with Avalanche index (Table 10). Further, Simpson's and Shannon-Wiener index were highly correlated (r = 0.902) while its

association with Avalanche index was poor. Thus, despite the fact that Avalanche index captures taxonomic heterogeneity for large scale ecological studies Simpson's and Shannon-Wiener index seem to be more meaningful. This may be because Avalanche index is more sensitive to differences in taxonomic diversity.

According to Molinari (1996), there are endless ways of emphasizing different aspects of species abundance relationships and therefore, the number of candidatediversity indices are infinite. As a result, a plethora of indices from which to choose from exists making it rather quite difficult to select the best elegant approach. McIntosh (1967) agrees that there is no perfectly unified diversity index possible to estimate diversity (richness or evenness). Nonetheless, it is good to point that existing and most popular indices are not necessarily the best.

The present study used Simpson's index of diversity, Shannon-Wiener Diversity Index and Avalanche index to determine the diversity of insects alongside evenness index. The Simpson's index of diversity computed for all insects was 0.97, the Shannon-Wiener index was 4.44 and Avalanche index was 1.17. Diversity indices values varied through the sampling period as the species richness and abundance varied (Table 11). However, application of circular statistical analysis suggested lack of seasonal pattern in diversity indices of insects though species richness showed a clear pattern. This may be because the frequency of different species varied across seasons. Howevever, Avalanche index showed low values for samples 10 and 20 respectively, while in the other seasons, the patterns were not clear. Thus, it appears that during samples 10 and 20 the taxonomic distribution was poor (Figure 21 b). Ganeshaiah *et al.* (1997) argued that the values of Avalanche index should differ from other classical indices only if taxonomic differences are considered above the species level.

(a) Speciose orders inter-relationships

Simpson's index of diversity showed very strong and positive significant relations between Coleoptera and Lepidoptera but weak and negative insignificant relations were found between orders Hemiptera and Diptera, Hemiptera and Hymenoptera and Lepidoptera and Diptera. Other order inter-relationships showed insignificant results.

Shannon-Wiener index of diversity showed very strong and positive significant relations between Coleoptera and Hemiptera and Coleoptera and Lepidoptera. However, weak and negative insignificant relations were witnessed between orders Hemiptera and Diptera and Lepidoptera and Diptera. Other order inter-relations were not insignificant.

(b) Diversity indices patterns

Patterns of Simpson's and Shannon-Wiener indices of diversity were similar over the entire sampling period and reflected almost those of richness and of abundance. Both indices showed peaks depicting increased richness during post rainy and summer seasons respectively. Low peaks that reflected reduced species richness for both Simpson's and Shannon-Wiener indices were noted during the start of rains, start of summer season and winter season. For Simpson's index, circular statistics showed that the azimuths 'α' were uniformly distributed without any concentration towards a specific period. Thus, according to Simpson's index, identified peaks and drops could not be associated with the patterns so witnessed. However, for Shannon Weiner index the relative azimuths 'α' were not uniformly distributed in all directions an indication of significant peaksfound during the post –rainy and post winter seasons.

4.13 Seasonality of insects and factors shaping it

In the present study, two broad temporal patterns both in species richness and abundance were distinct. We have shown that insects and their different groups exhibit temporal patterns in the species richness and abundance. Summer and post rain seasons showed clear and distinct peaks for both richness and abundance. Among the orders, Coleoptera and Hemiptera were found to be more rich and abundant than the other orders during the sampling period.

Coleoptera and Hemiptera were significantly higher during the entire study period while Lepidoptera, Diptera and Hymenoptera maintained lower peaks across the period. Notable and distinct peaks were witnessed during post rainy and post winter seasons. Rains promotes a significant increase in plant biomass, most species produce flowers and fruits at this season and this may present some overriding impacts on the insect activity due to resources availability.

A plethora of studies point that insect activity is important due to their functional roles in the ecosystemsuch as pollination (Johnson, 1996), spread of disease (Epstein *et al.,*1998) and predation of economically important crops (Ward and Masters, 2007). While many arthropod species depend on plants for food, and are influenced by vegetation structure (Scherber *etal.,* 2014), their activity is also influenced by different abiotic factors like rainfall, altitude, temperature or wind (Addo-Bediako *et al*.,2000). Terradas *et al.* (2004) suggested that the relationships between species abundance and factors driving the biodiversity are often largely unknown. However, studies by Wolda (1988) point that rainfall influences the variations in insect activity to a greater extent than other associated factors like relative humidity and temperature. This variability in activity patterns is expected to dictate on the seasonality of food resources. In the tropics, temperature changes are slight, and seasonal changes in rainfall exert the most dramatic effect on the environment (Wolda, 1988). The abiotic environment often varies along altitudinal gradients, with consequences for composition and activity of arthropod assemblages. Insects often show specific annual activity patterns frequently linked to phenology often triggered by photoperiod in combination with temperature and humidity (Van Asch and Visser, 2007) causing high insect activity in some seasons than others.

Contrary to the expectations on the influence of rain on diversity and abundance, other variables such as relative humidity and temperature that are directly or indirectly related to rainfall will require to be addressed with caution due to their confounding effects (Wagner *et al.,* 2003). Frith and Frith (1990) and Burgess *et al.* (1999) in their studies in Australia and Tanzania respectively, established that a short rainy season and pro-longed summer as was evident in GKVK (Table 17), will result to very low insects due to longer and harsher summer. The increase in insect abundance will certainly affect the predator- prey relations (Wolda, 1978).

Clearly the insect diversity and abundance shows distinct temporal patterns (Matata *et al.,* 2017). Temporal patterns of five speciose orders were similar among themselves and followed that of the total insect diversity and abundance. Insect activity patterns through the year as depicted from the abundance of different orders were not

quite different from richness. They showed similar patterns for orders Coleoptera and Hemiptera. Abundance peaks were evident during summer and late rainy seasons.

Temporal changes in diversity are usually referred to as "turnover", although the term may be applied to spatial changes as well (Wolda, 1988). From a broader perspective, it is clear from this study that diversity will increase as the similarity in species composition decreases.

This study demonstrates that increase or decrease in temperature may not have any impact on insect activity and diversity but cumulative temperature does. Among the abiotic factors (rainfall, temperature, relative humidity, wind speed, etc.), temperature is an important force to drive the insect population dynamics a reason as to why multiple regression analysis were undertaken to elucidate this confounding effect of temperature. Temperature might affect any stage of the insects' lifecycle and therefore limit distribution and abundance through the effects on survival, reproduction and development (Tauber and Tauber, 1981). Temperatures above the specific optimum range will lead to decreased growth rates, reduced fecundity and increased rates of mortality (Van Asch and Visser, 2007). Temperature thresholds for insect flight vary both among and within species, with season and also with region (Chambers *et al.,* 2013). Cumulative temperature and therefore climate change can cause major changes to the dynamics of insect individual species and to those communities in which they interact. Climate change is likely to involve a higher frequency of biotic disturbance. Depending on the dimension of disturbance, local to regional dynamics of insect populations and species composition will be strongly affected.

Although Wolda (1988) and Basset (1991) concurred that rainfall seasonality patterns in the tropical terrestrial ecosystems do present stronger influence on insect abundance than does temperature, the present study found cumulative temperature to be decreasing species richness and not abundance. In other words, the insect activity may be reduced by increasing temperatures of the globe- a concern in the context of climate change.

Thus, this study demonstrates that the temperature affects insect activity over long term than short term. Other parameters did not show any direct effect on diversity and abundance of insects. In other words, the insect activity may be reduced by increasing temperatures of the globe- a concern in the context of climate change. This effect however appears to be confounded when analyzed with other parameters.

Finally, these results suggest the importance of weather parameters stratification based on period when sampling insects is paramount to understanding the insect structure and composition and further recommend that conservation biologists should exercise caution when attempting to predict total species diversity of insects in ecosystems that are characterized by significant effects of seasonality.

4.14Body shape of insects:

If length and width of insects are independent of each other, i.e., if these two parameters evolve independently, then we should be able to find all possible combinations of lengths and widths. However, our analysis showed that the two are not independent and the width and length are strongly correlated (Table 31). The width increases linearly with the length at a rate of 0.3025 ($p<0.01$) suggesting that insects always have a highly rectangular body size- they are longer than their width. Thus, our study shows that the hymenoptera and flies are shaped as elongated insects while coleopteran are shaped towards squarish shape (Figure 45).

In insects however these linear relations between the length and width appears to have been shaped by the flight advantage. Because this relation seems to be different for different orders and related to their flight needs. For example, in Coleoptera and Hemiptera width increases with length at a higher rate 0.3475 and 0.3551 respectively than in the remaining three orders viz., Lepidotpera (0.2653), Hymenoptera (0.2623) and Diptera (0.235). In other words, with increase in length, the beetles and bugs seems to become more broad in their shape than bees, wasps and flies; the later become narrower and elongated in their body size (Figure 46).

These relations seem to be a feature shaped by the flight patterns that these different orders exhibit. Bees and wasps (Hymenoptera), flies and mosquitoes (Diptera)

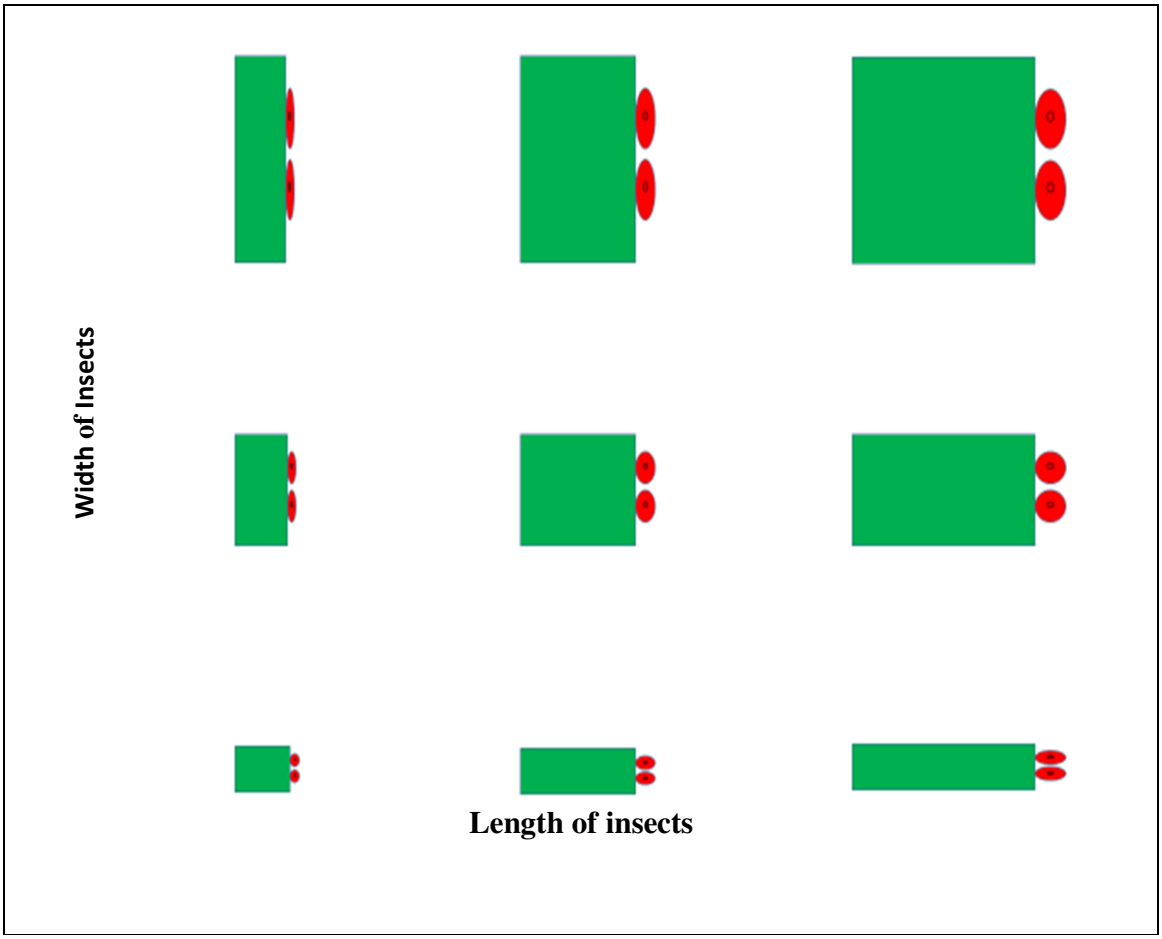

Figure 45. The expected shapes of insects when length and width evolve independently

and moths and butterflies (Lepidoptera), generally exhibit more agile flight patterns and fly longer distances than do beetles (Coleoptera) and bugs (Hemiptera).

While we do not have strong data to show that bees and wasps along with dipteran flies have a better flight range and agile flight patterns, this indeed is a very common observation. Clearly such flight features are facilitated by the more rectangular body size (Figure 46) as it reduces resistance during flights. Such relations between the different body sizes dimensions are also seen in the entire animal world for several reasons. For every type of animal there is a most convenient size, and a large change in size inevitably carries with it a change of form (Sabo *et al.,* 2002).

Body shape reflects species' evolution and mediates its role in the environment as it integrates gene expression, life style and structural morphology. Its comparative analysis may reveal insight on what shapes shape, being a useful approach when other evidence is lacking.

4.14.1. Body shape and weight relations:

Body weight, known to be related to the metabolic activity (Gillooly*et al.,*2001) is also known to be shaped as a function of size dimensions such as length (or height) and width (Sabo *et al.,* 2002 and Smock, 1980). Biomass is inarguably one of the more important variables in ecology, playing a central role in studies ranging from ecophysiology and community and food web regulation, to whole-ecosystem metabolism (Enquist and Niklas, 2001).

Ideally if the body can be assumed to be a cube, then the volume (V) of the body can be expected to be a cube power of any one of its dimensions such as length (L) such that $V= L^3$ and accordingly weight (W) can also be expected to increase as the cube (3) power of the length. In other words,

$$\mathbf{W = k * L^3}$$

Where k is the density or mass of the unit weight of the body that could be specific to each group of organisms. But this does not generally hold because the body volume does not increase as a cube (Figure 47). As argued in the previous section, all

insects are more like rectangular boxes than cubes and the width of the insects increases only by about 0.3 times the length. Consequently, their weight was found to increase by a factor of about 0.33 for all insects.

But the weight of bees and wasps appears to increase at a lower rate (power function = 2.58) than that of beetles (power function = 3.17), a relation that is perhaps shaped again by the flight requirements. Better flight is facilitated by lower body weights as it renders them low wing loading, and hence the insects that have adopted longer flights are better off with the smaller weights. This is also strengthened by the fact that Lepidopteran insectsthat have adopted a very agile flight pattern and longer flight ranges than the beetles have lower rates of increase in body weight with lengthas suggested by Bennett and Lenski (2007).

Another feature that could be adding to the weight of beetles could be the thicker fore wings compared to the members of Hymenoptera and Lepidoptera. It can also be argued that these two factors viz., the thickened fore wings of beetles and the flight agility of wasps and bees, could be features resulting from a trade off in the strategy adopted by the insects (See below).

4.14.2 Trade offs between flight and physical protection in insects:

Our results suggest that, in insects the requirement of flight agility and flight range appear to have shaped their body design and body weight. Insect groups that have evolved with long flight ranges and flight agility have sleek and longer bodies and also weigh relatively less. While the sleek body provides reduced resistance in flight, the light weight probably reduces their wing loading. Other groups of insects, such as beetles that have broader body shape and poor flight range seem to be heavier as they add relatively more weight with increase in length. Though the relatively heavier body of this later group could be attributed to the fact that they need to fly less, it is not clear whether their reduced flight is an adopted feature releasing them from the flight- based constraint on the body shape and size, or is a consequence of the fact that they have thickened fore wings. It is likely that the thickened forewings and increased flight ranges are the two competing strategies that insects adopt to enhance their survival.

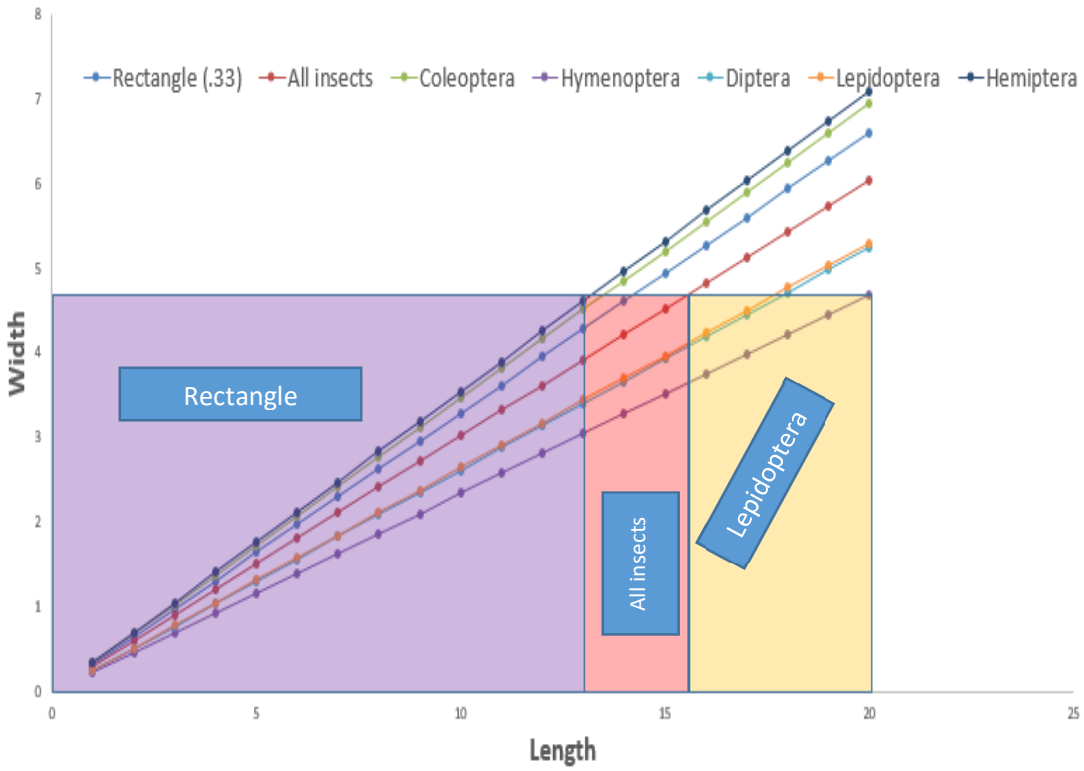

Figure 46. Length-width relationships of five major insect orders

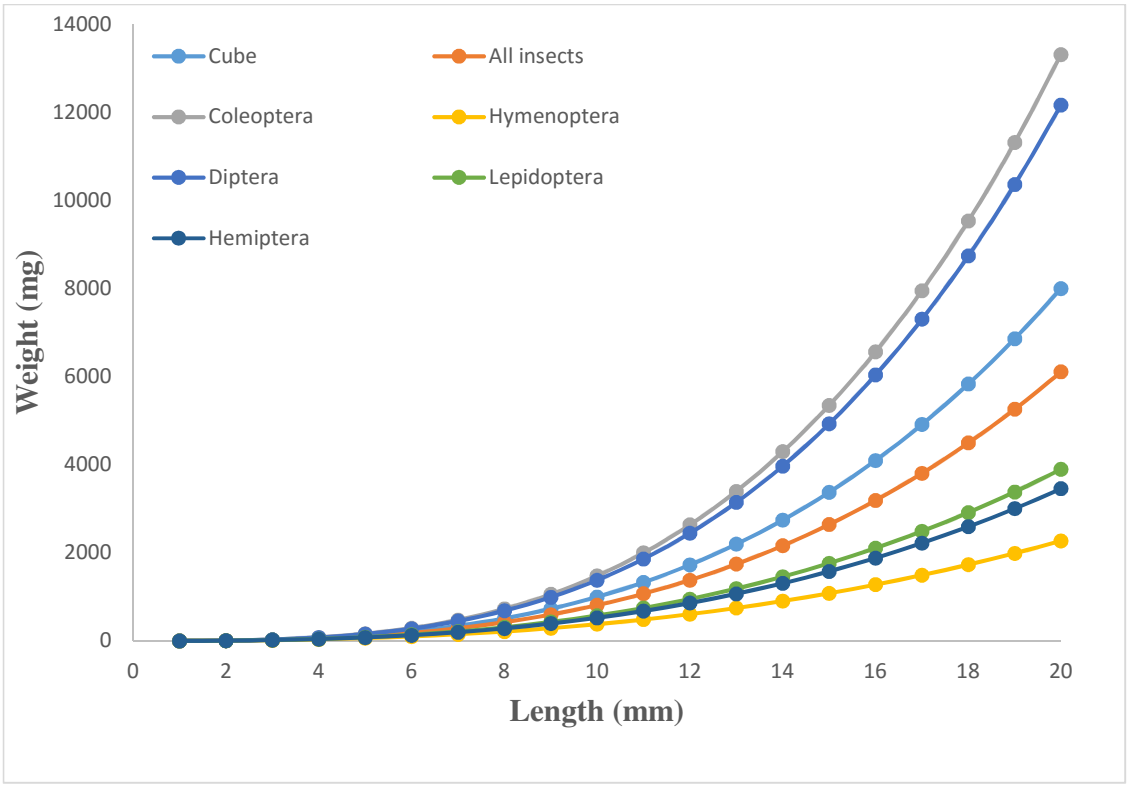

Figure 47. Comparisons of body size relationships of five major insect orders and a cube

Flight is needed for fetching food, to escape from predators and in certain cases even for enhanced mating. Insects that fetch their food with in a very short range of their parent generation and hence do not find a need for flying longer distances could save their resources on flight and convert them in to offspring production. However, such insects would be unable to use flight as a strategy to escape from the enemies (predators and parasites) and hence need to adopt alternate strategies to protect themselves. Forewings of insects cover almost the entire body and hence they are most immediate organs that could be shaped to enhance protection from enemies. Thickening of the forewings has in fact been suggested as one strategy of protection (Marquez *et al.,*2001).

Thus insects that forego the agility of flight, and hence the ability to escape from enemies by flying, may have to inevitably enhance their ability to resist enemies by developing protective forewings that are thick as in elytra of beetles. This thickening could also be a function of the extent of flight requirement that their food sources demand. In other words, flight agility (and range) and forewing thickening appear to be two competing strategies of adaptation. Insects with broader body shape, thickened forewing would compromise on flight and protect themselves from the predators whereas the light weighted, sleek bodied insects derive their advantage from the swiftness of escaping from the predators. All insects seem to be placed along this trade off line (Figure 48).

4.14.3 Diversity and body size distributions in insects

Diversity (number of species) of insects along different sizes (size distribution) reflects a range of issues: the way they utilize resources (Gillooly*etal.,* 2001; Enquist and Niklas, 2001; Root, 1973; Connor and McCoy, 1979) extent of competition among the species (Gaston *et al.,* 1997; Simberloff, 1976; Gaston and Blackburn, 2000) and the level of adaptation (Bennett and Lenski, 2007; Marquezet *al.,* 2001; Williams, 1964).

Size of insect is known to be highly positively skewed with a lot more of them having smaller body size and very few with large body size (Sabo *et al.,*2002; Smock, 1980; Gaston and Blackburn, 2000 and Schoener, 1980). In fact the extent of positive skew is shown to be so strong that some argue that the size distribution of insects shows a

log-normal distribution wherein number of species tend to show normal distribution when plotted against the log of the size (Gardezi and da Silva, 1999; Bakker and Kelt, 2000; Gaston and Blackburn, 2000; Hutchinson and MacArthur, 1959; May, 1978; Bonner, 1988 and May, 1988).However, some have argued that the distribution follows fractal relation where in the log of the number of species is plotted against the log of their size (Morse *et al.,* 1985). It has been argued that the fractal distribution of insect sizes is because the niche surfaces are fractal and hence the species occupying these niches are also expected to follow the trend. In fact, Morse *et al*. (1985) have shown that the vegetation structure is fractal and hence the arthropods size distribution may be expected to be fractal. As they argue ` if vegetation has a fractal structure, there is more usable space for smaller animals living on vegetation than for larger animals. Hence, there should be more individuals with a small body length than a large body length.' They also provide evidence to support this.

In the present study, the size distribution for length, width and for weight showed highly positively skewed distributions, though there were no indications of a strong fractal distribution. The highly positive skewness was seen for different orders as well though the extent of skewness differed among them. As (Brown and Nicoletto, 1991) suggested, differences in the shapes of the size distributions between orders may result from differences in the body plans and physiology. An implication of this study and argument by Morse *et al.* (1985), is that the diversity of body size of a taxonomic group depicts the range of niches they exploit. Accordingly, among the five orders, the order Hemiptera appeared to be exploiting the most diverse niches as it had the highest range size.

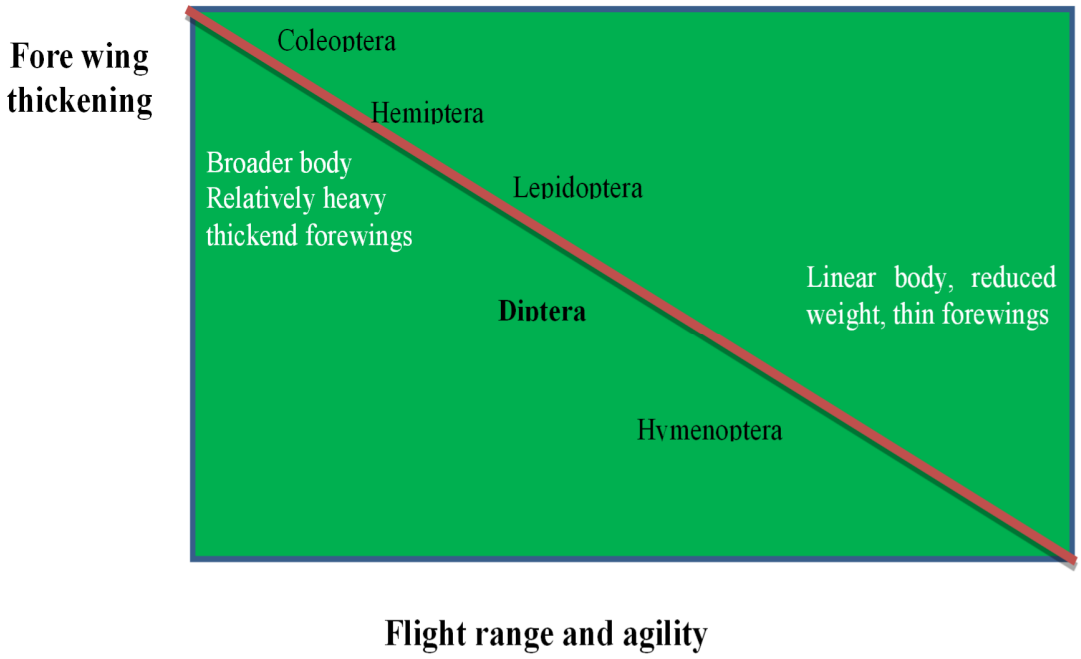

Figure 48. Relationship between fore wing thickening and flight agility in five most speciose orders

V SUMMARY

A study was conducted to assess temporal patterns of activity and diversity of insects attracted to light traps at Gandhi Krishi Vignana Kendra (GKVK) campus of the University of Agricultural Sciences, Bangalore. The study was conducted from 8th May, 2015 to 6th December, 2016 at the 'K' block and insects were collected once every 21 days. The summary of the study is given below.

A total of 209,098 individuals belonging to 764 morpho-species or Operational Taxonomic Units (OTUs), representing 101 families from 12 orders were collected through the two years of sampling. The Simpson's index of diversity computed for all insects was 0.97, the Shannon-Wiener index was 4.44and Avalanche index was 1.17.

The number of species of the five most speciose orders collected at GKVK (Coleoptera, Hemiptera, Hymenoptera, Lepidoptera and Diptera) were compared with those expected on the basis of their proportions at the national and at the global level. Order Coleoptera was found to be over represented at GKVK while Lepidoptera, Diptera and Hymenoptera were under represented. It is not clear if these results reflect the actual differences between the insects of GKVK and the total insect profile or they reflect the biasness of the light traps in attracting only nocturnal insects.

Coleoptera emerged a major insect order in the present study owing to its high species richness (348) compared to other orders. Four other orders viz., Hemiptera, Lepidoptera, Diptera and Hymenoptera were the next most speciose groups. Simpson's and Shannon-Wiener indices also showed that order Coleoptera to be the most diverse at GKVK while the order Mantodea is the least diverse group.

Insect diversity and abundance exhibited clear temporal patterns through the two-year study. Insects were abundant and also diverse during summer and post rainy season but decreased during winter and rainy seasons. In fact, all the five speciose orders showed similar trend through the study period. The application of circular statistics where the data is plotted on a 360° module, helped in effectively elucidatingthe temporal patterns of species richness and abundance. Circular statistics revealed that total insect activity and species richness behaved similarly along seasons. Thus it would be good to

replace the traditional 'linear-based' statistics with circular statistics for the analysis of the temporal data.

Effect of weather parameters on the insect activity was analyzed by correlational and multiple regression analysis. Among the parameters studied, cumulative temperature for three weeks was found to negatively affect the diversity, but not the abundance.

Our results also showed that the Coleoptera is a good indicator of the total insect diversity perhaps because it is the most predominant component (47.3 %) of the collections made in our study. Further diversity of this group was also correlated with the diversity of Hemiptera and Lepidoptera.

Body width showed linear increase with the length of the insects; but the rate of increase was very less (0.3025). This linear relation was true for different orders also though the strength varied; Coleoptera and Hemiptera had higher slopes (0.3475 and 0.3551 respectively) than Lepidotpera (0.2653), Hymenoptera (0.2623) and Diptera (0.235). Thus, with increase in length, the beetles and bugs seems to become broader in their shape than those of Diptera and Hymenoptera and Lepidoptera. This may have been shaped by the increased flight agility and flight range of the later compared to beetles and bugs. The weight of the beetles and bugs also increased at a higher rate with their length than in the other orders probably because the former have thickened forewings. We argue that the most linear shape of the body with less weight of bees, flies and butterflies and relatively broader body shape with more body weight of beetles and bugs represents a tradeoff strategy in insects: they are perhaps shaped to be good fliers as in bees, wasps, and flies to escape from the predators or are selected to have thick forewing to protect against the predators as in beetles and bugs.

This work was an attempt to assess the diversity measures of biological heterogeneity using insects attracted to light at Gandhi Krishi Vignana Kendra (GKVK) campus of the University of Agricultural Sciences, Bangalore. Study recommends that light traps may be used for addressing broad ecological questions but may not beeffective to estimate the total insect diversity. It is hoped that such work may lead to the development of standard monitoring procedures which could be of value in assessing the long term ecological stability of an ecosystem.

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Mysore J. Agric. Sci., 51 (1): 79-84, 2017 **Research Paper**

Temporal Patterns of Insect Diversity in Bengaluru - A Study Using Light Traps

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ABSTRACT

Studied the temporal pattern of all insects attracted to light trap from May 2015 to December 2016 at GKVK, Campus was studied. The results indicated that, both the abundance and richness of insects is high during summer seasons than winter and rainy seasons. Assessed the effect of temperature, relative humidity and rainfall on the species richness and abundance was studied through correlations and multiple regression analysis. Three kinds of analysis were attempted: impact of these parameters on (a) the day of sampling, (b) cumulated over the period of three days, and (c) cumulated over three weeks. Correlation studies indicated that the rainfall and relative humidity over three days before sampling affected the insect diversity significantly and the total insect activity (as reflected by abundance) was affected only by rainfall over three days before sampling. Temperature did not appear to impact on the insect activity and diversity. However, multiple regression analysis showed that temperature cumulated over three week period negatively impacted the species richness and diversity though the abundance was not affected. The temperature on the day of sampling or cumulated over three day period did not have any direct impact. Thus, the study demonstrates that the temperature affect insect activity over long term than short term. Other parameters did not show any direct effect on diversity and abundance of insects. In other words, the insect activity may be reduced by increasing temperatures of the globe- a concern in the context of climate change. This effect however appears to be confounded when analyzed with other parameters.

ASSESSING diversity is central to ecology and conservation. Different methods can be used to assess insect diversity: Sweep netting, light trap, pit fall trap, hand picking etc. Light traps capture highly diverse orders of insects like Coleoptera, Hemiptera, Lepidoptera, Diptera, Hymenoptera etc. Efforts to conserve or manage insect communities require some knowledge of the total number of species present, within habitat patches and, perhaps, the relative degree of species turnover among habitats or regions (New, 1999).

Insect activity is important because the movement of insects is associated with various ecological services ranging from pollination (Johnson, 1996), pest control (Johnson, 1992) to seed dispersal (Bond, 1994), but also spread of disease (Epstein *et al*., 1998) and predation of economically important crops (Ward and Masters, 2007; Sana and Samways, 2015). While, many arthropod species depend on plants for food and are influenced by vegetation structure (Scherber *et al*., 2014), their activity is also influenced by different abiotic factors like rainfall, altitude, temperature or wind (Addo-Bediako *et al*., 2000; Briers *et al*., 2003 and Rahbek, 2005). This can result in seasonal peaks in abundance and species richness. The abiotic environment often varies along altitudinal gradients, with consequences for composition and activity of arthropod assemblages. Insects often show specific annual activity patterns frequently linked to phenology often triggered by photoperiod in combination with temperature and humidity (Van Asch and Visser, 2007) causing high insect activity in some seasons than others. In this paper, an attempt has been made to test the impact of temparature on insect species richness.

MATERIAL AND METHODS

Study area

Gandhi Krishi Vignana Kendra (GKVK) campus of the University of Agricultural Sciences, Bengaluru, Karnataka State, India which is located about 15 kms north of Bangalore City. Geographically, the place is located at 12°58' latitude North and 77°35' longitude East. The centre is at an altitude of 930 meters above sea level. The annual rainfall ranges from 679.1 mm to 888.9 mm.

GKVK falls under the Eastern Dry Agro-climatic zone of Karnataka. Sampling site was 'K' block situated near ZARS, GKVK, Bengaluru and located

at 13°081' longitude North and 77° 571' East at an altitude of 930 meters above mean sea level.

Data collection

Sampling method : Insects were collected using a light trap. The source of light used was a mercury vapour lamp of 165 Watts (Philips). Light traps were run once every 21 days from 8-05-2015 to 6-12-2016 period. Insects attracted to light were collected in a container placed at the bottom of the trap provided with an insecticide as the killing agent.

Processing of collections : All collected specimens were air dried and processed. Larger specimens were easily separated and smaller ones sorted under a stereo-zoom microscope. All insects were further sorted into different morpho-types

Identification of specimens : Each morpho-type was then verified for uniformity based on the external morphology and assigned an Operational Taxonomic Units (OTU). As a consequence, each morpho-type was in principle, represented as a taxonomic species. Assistance from Agricultural Entomology Department was sought to identify OTUs according to their taxonomic positions. Identified morpho-types were classified into their respective families and orders and their numbers counted. All the specimens were stored in packets labeled with sampling date, OTU and species count for further examination.

Results and Discussion

Insect species composition

Samples taken through use of a Mercury vapour lamp light trap at 21 day interval period from 5th May 2015 to 6th December 2016 at GKVK yielded a total of 209,098 individuals (Fig. 1) belonging to 764 morpho-species (Fig. 2), representing 103 families.

Pattern of insect species richness and abundance

Sampled data on species richness and abundance was analyzed at various levels in relation to seasons. Patterns of both abundance and richness of insects was found to be higher during summer seasons than winter and rainy seasons (Fig. 3). The abundance and

Fig. 1: Proportional distribution of insects attracted to mercury vapour lamp light traps at GKVK, Bengaluru from 8th May, 2015 to 6th December, 2016 (Table I).

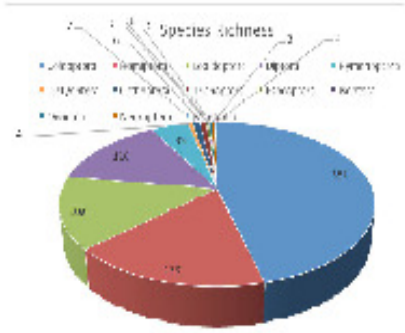

Fig. 2: Proportional distribution of insect species attracted to mercury vapour lamp light traps at GKVK, Bengaluru from 8th May, 2015 to 6th December, 2016 (Table I).

species richness data could not be easily understood when plotted linearly (Fig. 3). This necessitated the study to explore analysis on a circular distribution (Fig. 4) and (Fig. 5), correlation (Table II) and regression (Table III) in an effort to delineate any variations that may exist.

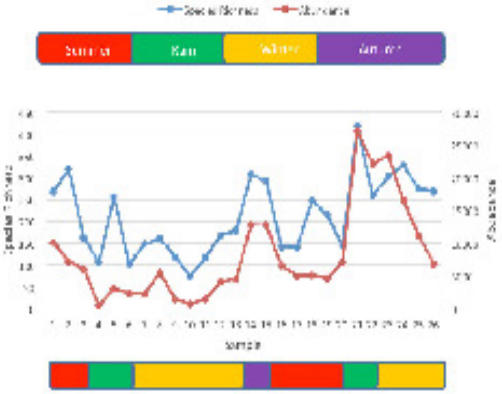

Fig. 3: Relative diversity of species richness and individuals' collected from 8th May, 2015 to 6th December, 2016 using mercury vapour light trap at GKVK, Bengaluru (Table I).

Number of Observations	5474
Mean Vector (μ)	250.233°
Length of Mean Vector (r)	0.178
Rayleigh Test (p)	< 1E-12
Watson's U^2 Test (Uniform, U^2)	12.605
Watson's U^2 Test (p)	< 0.005

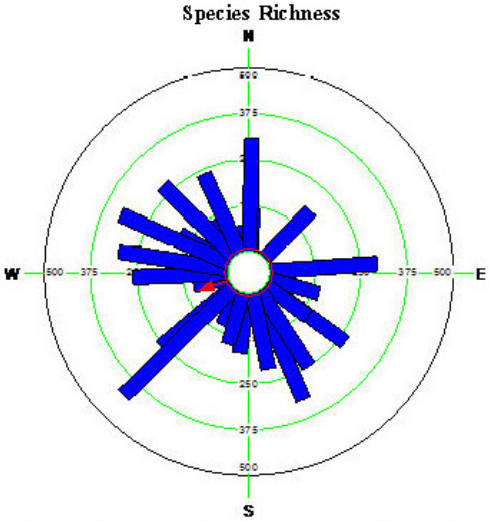

Fig.4: Circular bar graph of insect species and the relative azimuth, 'α', collected in catches attracted to mercury vapour lamp light traps at GKVK, Bengaluru from 8th May, 2015 to 6th December, 2016. Circular bars indicate the number of insect species caught in corresponding days of sampling conside-ring the bimodal distribution plotted at modulo 360° (Table I).

Number of Observations	2124
Mean Vector (μ)	257.065°
Length of Mean Vector (r)	0.197
Rayleigh Test (p)	< 1E-12
Watson's U^2 Test (p)	< 0.005
95% Confidence Interval (-/+) for μ	248.385° 265.744°
99% Confidence Interval (-/+) for μ	245.659° 268.471°

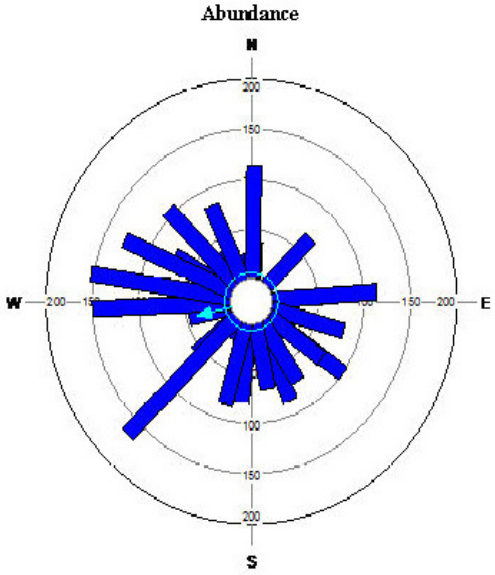

Fig.5: Circular bar graph of insects and the relative azimuth, 'α', collected in catches attracted to mercury vapour lamp light traps at GKVK, Bengaluru from 8th May, 2015 to 6th December, 2016. Circular bars indicate the number of insects caught in corresponding days of sampling considering the bimodal distribution plotted at modulo 360° (Table I).

Correlation analysis

The Pearson product moment correlation coefficient was used to determine the relationship among temperature, relative humidity, rainfall, Simpson's and Shannon-Wiener indices of diversity, species richness and abundance. The results of the correlational analysis as presented in Table II shows that significant correlations were observed between species richness and rainfall ($n=26$; $r=0.34$, $p<0.05$), abundance and rainfall ($n=26$; $r=0.34$, $p<0.05$), species richness and relative humidity ($n=26$; $r=0.355$, $p<0.05$) and abundance and relative humidity ($n=26$; $r=0.355$, $p<0.05$) over three days before sampling. Temperature did not appear to have any impact on the insect activity and diversity. However, results from multiple regression analysis indicate otherwise (Table II).

Multiple regression analysis

We used a multiple linear regression to analyze the relationships between species richness, abundance of insects, Simpson's index of diversity, Shannon-Wiener index of diversity and climate variables. Although correlation studies indicated temperature to have no impact on insect diversity (Table II), multiple regression analysis (Table III) showed that temperature cumulated over three week period was reducing the species richness and diversity and not abundance.

This study demonstrates that temperature on the day of sampling may not have any impact on insect activity and diversity but cumulative temperature does. Among the abiotic factors (rainfall, temperature, relative humidity, wind speed, etc.), temperature is an important force to drive the insect population dynamics a reason as to why multiple regression analysis were undertaken to elucidate this confounding effect of

TABLE I

Circular statistical measures of species richness and abundance of insects collected from 8th May, 2015 to 6th December, 2016 using mercury vapour lamp light trap at GKVK, Bengaluru

Basic statistics	Species richness	Abundance
Number of observations (N)	5474	2124
Mean vector (μ)	250.233°	257.065°
Length of mean vector (r)	0.178	0.197
Concentration	0.362	0.401
Circular standard deviation	106.471°	103.342°
Standard error of mean	3.054°	4.427°
Rayleigh test (Z)	173.225	82.097
Rayleigh test (p)	p<0.001	p<0.001
Watson's U^2 test (Uniform, U^2)	12.605	5.907
Watson's U^2 test (p)	p<0.005	p<0.005

TABLE II

Relationship between species richness, abundance, simpson index of diversity, shannon index and meteorological variables

Parameters	Species richness	Abundance	Simpson index of diversity	Shannon index of diversity
Temperature 21days before sampling	0.0646	-0.0054	0.0791	0.0530
Temperature three days before sampling	0.1446	0.0594	0.0936	0.0989
Temperature attime of sampling	0.2130	0.1666	0.0833	0.0656
Relative humidity 21days before sampling	-0.2702	-0.0329	-0.1502	-0.1805
Relative humidity three days before sampling	-0.3551*	-0.2173*	-0.2510	-0.2232
Relative humidity at day of sampling	-0.0694	-0.0278	-0.0450	0.0109
Rainfall 21days before sampling	0.0769*	-0.0008*	0.1041	0.1214
Rainfall three days before sampling	-0.3397	-0.3399	0.1869	0.1350
Rainfall at day of sampling	-0.1005	0.0038	-0.2405	-0.1502

*Correction is significant at p=0.05 level.

TABLE III

Multiple regression analysis of species richness, abundance, Simpson index of diversity, Shannon index and meteorological variables

Dependent variable:	Species richness	Meteorological variables	Coeff.	Std.err.	t	p	R^2
N:	26	Constant	1065.4	604.51	1.7625	0.097082	
Multiple R:	0.66293	Temperature 21days before sampling	-28.236	24.413	-1.1566	2.64E-01	0.0041733
Multiple R2:	0.43947	Temperature three days before sampling	9.2672	27.923	0.33189	0.74428	0.020912
Multiple R2 adj.:	0.12418	Temp Temperature at time of sampling	8.2816	18.738	0.44197	0.66443	0.045384
		Relative humidity 21days before sampling	-2.5738	6.4756	-0.39746	0.69628	0.073059
ANOVA		Relative humidity three days before sampling	-12.307	7.1959	-1.7102	0.10654	0.12611
F:	1.3938	Relative humidity at day of sampling	5.8647	5.5978	1.0477	0.31036	0.00483
df1, df2:	9, 16	Rainfall 21days before sampling	12.668	7.8563	1.6125	0.12641	0.0059153
p:	2.69E-01	Rainfall three days before sampling	-4.5722	7.0732	-0.6464	0.52718	0.11546
		Rainfall at day of sampling	-0.83162	1.4551	-0.5715	0.5756	0.010112
Dependent variable	Abundance		Coeff.	Std.err.	t	p	R^2
N:	26	Constant	-3801.9	5497.7	-0.069155	0.94572	
Multiple R:	0.55533	Temperature 21days before sampling	261.97	2220.2	0.11799	0.90754	2.95E-05
Multiple R2:	0.30839	Temperature three days before sampling	-1920.7	2539.4	-0.75637	0.46042	0.0035395
Multiple R2 adj.:	-0.080644	Temperature at time of sampling	1991.9	1704.1	1.1689	0.25958	0.027785
		Relative humidity 21days before sampling	698.17	588.92	1.1855	0.25313	0.0010887
ANOVA		Relative humidity three days before sampling	-967.36	654.44	-1.4782	0.15878	0.047222
F:	0.79271	Relative humidity at day of sampling	329.07	509.1	0.64638	0.5272	0.00077803
df1, df2:	9, 16	Rainfall 21days before sampling	194.49	714.49	0.27221	0.78895	6.59E-07
p:	0.62781	Rainfall three days before sampling	-762.07	643.28	-1.1847	0.25345	0.11556
		Rainfall at day of sampling	-61.851	132.34	-0.46737	0.64653	1.49E-05
Dependent variable	Shannon		Coeff.	Std.err.	t	p	R^2
N:	26	Constant	10.421	2.9917	3.4832	0.0030704	
Multiple R:	0.67648	Temperature 21days before sampling	-0.27339	0.12082	-2.2628	3.79E-02	0.0028139
Multiple R2:	0.45763	Temperature three days before sampling	0.24785	0.13819	1.7935	0.091806	0.0097946

(contd....)

TABLE III (Contd.)

Dependent variable:	Species richness	Meteorological variables	Coeff.	Std.err.	t	p	R^2
Multiple R2 adj.:	0.15255	Temperature at time of sampling	-0.11444	0.092736	-1.234	0.23501	0.0043054
		Relative humidity 21days before sampling	-0.019196	0.032048	-0.59898	0.55757	0.032588
ANOVA		Relative humidity three days before sampling	-0.082373	0.035613	-2.313	0.034355	0.049824
F:	1.5	Relative humidity at day of sampling	0.049395	0.027704	1.7829	0.093576	0.00011892
df1, df2:	9, 16	Rainfall 21days before sampling	0.039748	0.038881	1.0223	0.32185	0.014743
p:	2.30E-01	Rainfall three days before sampling	0.079275	0.035006	2.2646	0.037777	0.018236
		Rainfall at day of sampling	-7.92E-03	7.20E-03	-1.1003	0.28746	2.26E-02
Dependent variable:	Simpson	Meteorological variables	Coeff.	Std.err.	t	p	R^2
N:	26	Constant	1.335	0.21973	6.0754	1.61E-05	
Multiple R:	0.68519	Temperature 21days before sampling	-0.015727	0.0088738	-1.7723	0.095378	0.006265
Multiple R2:	0.46948	Temperature three days before sampling	0.013301	0.01015	1.3105	0.20853	0.008765
Multiple R2 adj.:	0.17107	Temperature at time of sampling	-0.0062662	0.0068111	-0.92	0.37124	0.0069503
		Relative humidity 21days before sampling	0.00080279	0.0023538	0.34106	0.7375	0.022565
ANOVA		Relative humidity three days before sampling	-0.0074454	0.0026157	-2.8465	0.011666	0.063008
F:	1.5733	Relative humidity at day of sampling	0.0037194	0.0020348	1.8279	0.086266	0.0020275
df1, df2:	9, 16	Rainfall 21days before sampling	0.001668	0.0028557	0.5841	0.5673	0.01084
p:	0.20557	Rainfall three days before sampling	0.0060641	0.0025711	2.3586	0.031397	0.034954
		Rainfall at day of sampling	-0.00093018	0.00052893	-1.7586	0.097754	0.057853

temperature. Temperature might affect any stage of the insects' lifecycle and therefore limit distribution and abundance through the effects on survival, reproduction and development (Tauber and Tauber, 1981). Temperatures above the specific optimum range will lead to decreased growth rates, reduced fecundity and increased rates of mortality (Van Asch and Visser, 2007). Temperature thresholds for insect flight vary both among and within species, with season and also with region (Chambers *et al.*, 2013). Cumulative temperature and therefore climate change can cause major changes to the dynamics of insect individual species and to those communities in which they interact. Climate change is likely to involve a higher frequency of biotic disturbance. Depending on the dimension of disturbance, local to regional dynamics of insect populations and species composition may be affected. Thus our study demonstrates that the temperature affected insect activity over long term than short term. Other parameters did not show any direct effect on diversity and abundance of insects. In other words, the insect activity may be reduced by increasing temperatures of the globe- a concern in the context of climate change. This effect however appears to be confounded when analyzed with other parameters.

The results suggest the importance of weather parameters and stratification based on period when sampling insects is paramount to understanding the insect structure and composition and further recommend that conservation biologists should exercise caution when attempting to predict total species diversity of insects in ecosystems that are characterized by significant effects of seasonality.

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