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Studies on Insect Diversity and Abundance in the Belette-Gera Forest, South Western Ethiopia

By

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School of Graduate Studies

This is to certify that the thesis prepared by Belay Beyene, titled: **“Studies on Insect Diversity and Abundance in the Belette-Gera Forest, South Western Ethiopia”**and submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Insect Sciences (Zoology) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

Studies on Insect Diversity and Abundance at Belette-Gera Forest, South Western Ethiopia

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Doctor of Philosophy in Biology (Insect Sciences)

Addis Ababa University, 2015/16

Abstract

Belette-Gera Forest is one of the Afromontane rain forests in south western Ethiopia. The diversity and abundance of insect communities within the forest are not studied and there is no documentation of the insect fauna of the forest.Iinsects is ecologically important and play valuable role in the ecosystem of Belette-Gera forest. This study identified insect species within the forest and assesssed thier diversity, abundance and distribution among habitats and seasons. Habitat distribution of insect fauna was catagorized into three habitats having different land uses/cover and varying degrees of disturbance; Natural forest habiat, Plantation forest habitat and Wetland habitat. Seasonal distribution of insect fauna was also studied in three seasons; long rain season, long dry season and short rain season. Insect species richness and abundance of insect communities of Belette-Gera forest was investigated along a line transect of 100m × 100m starting from the bottom of the valley to the top of the ridge with sample quadrats of 10m ×10m laid for sampling insects. A total of 1560 insect specimens from 14 orders and 120 families were collected from September 2013 to August 2015 using sweep net trap, beating cloth, pitfall trap and hand picking. Shannon-Wiener diversity index and Evenness were used to measure diversity and abundance of the insects at the family level. The highest insect diversity was observed in the order Coleoptera with Shannon diversity index, H' value of 1.77 and evenness, E value of 0.37. Dermaptera, Ephemeroptera, Mecoptera and Neuroptera were the raret insect orders. Similarly, diversity was measured in each habitat

using Shannon-Wiener species diversity index and Evenness. A total of 620 specimens (39.74 %) in the Natural forest habitat, 472 specimens (30.26 %) in the Wetland habitat and 468 specimens (30 %) in the Plantation forest habitat, were collected. These insects were used to determine the richness of the insect fauna in each habitat type. The highest insect diversity was observed in the Natural forest habitat with (Shannon's, H'= 2.36) and (Evenness, E = 0.49) followed by Plantation forest habitat (H'= 1.84; E = 0.38) and the lowest were recorded in the Wetland habitat (H'= 1.78; E= 0.37). In addition, the influence of season on the diversity and abundance of insects was computed for two different years (2013/2014 and 2014/2015). Shannon-Wiener species diversity index (H') and Evenness (E) were used to measure species diversity and abundance in each season. Paired sample T test was computed to determine the significant differences in insects collected in the rainy and dry seasons. Insect abundance and diversity were significantly different between seasons and in 2013/2014 the highest diversity was recorded in the long rain season with (H'value of 2.563; E value of 0.563). On the other hand, the lowest diversity was recorded during the short rain season (H' value of 1.234; E value of 0.271). Furthermore, in 2014/2015 the highest diversity was recorded in long rainy season with Shannon's H'value of 1.868 and with E value of 0.417. The lowest insect diversity was recorded from short rainy season with Shannon's H' value 1.57.

The diversity and abundance of insect communities varied with respect to habitat type and season. As a result, Wet land habitat, Plantation forest habitat and Natural forest habitat were varied in increasing order with respect to diversity and abundance of insect communities. In addition, Short rainy season, Long dry season and Long rainy season varied in increasing order with respect to of diversity and abundance in the study forest. The variation of insect species diversity and abundance in the habitat types and seasons were the result of

environmental variation (both biotic and abiotic factors), human interference; and the responce of insects to thesef actors influenced the diversity and abumdance of insect communities residing in these habitats in different seasons. Therefore, knowledge on the identity of insect species and factors which influence their diversity and abundance is important as baseline information for further study to assess the different aspects of the insect founa adapted in Belette-Gera forest.

Key words: Diversity, abundance, insects, habitat, season

DECLARATION

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of materials used for the thesis have been duly acknowledged.

Name: Belay Beyene Mekonnen Signature: ________________________

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DEDICATION

Dedicated to:

My sons Amir and Isak, for your sacrifice of time and endless love.

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Chapter 1 GENERAL INTRODUCTION

Biodiversity is among the issues of most human concern of this century and a lot of discussions are going on throughout the world on the conservation and sustainable use of the existing biodiversity. This is mainly due to the fact that the rapid alteration of the earth's environment may lead to a loss of stability of the ecosystems which will be detrimental to the survival of mankind in this universe (IGBP, 1990).

Insects have vital positions in food webs, dynamics of populations and communities. They act as herbivores, predators, decomposers, parasitoids and pollinators among others. Knowledge of insects is important for human survival. Certain insects can be detrimental to our health, domestic and wild animals, agriculture and horticulture (Gullan and Cranston, 2005). While there are others that are beneficial; over 1000 species of insects are being used as food somewhere in the world. Termites, crickets, grasshoppers, locusts, beetles, ants, bee brood and moth larvae are examples of insects that are used as food sources across the globe(Alan, 2009).Insects are high in protein, energy, and a number of minerals and vitamins and can form up to 5-10% of the annual animal protein consumption(Alan, 2009; Prins, 2014; FAO, 2014). Others directly benefit our society. For example, honey bees not only provide us with honey, but are also important pollinators performing a free service which if man had to do would cost several billion dollars annually. Some insects such as predatory beetles or parasitic wasps, control pests by keeping their population in check and are valuable entity for biological control of indigenous and invasive or exotic species (Alan, 2009; Gullan and Cranston, 2005).

Insects possess several characteristics that make them suitable for environmental monitoring. Because of they are the highest diversified animal, with small in body size, and have high reproductive capacity and also serve as a good indicator of environmental health (Weaver, 1995; New, 1998).

Furthermore, insects are useful for understanding general biological processes. Studies of hymenopterans insects such as ants and bees have helped us to understand the evolution and maintenance of social behaviors. Knowledge of general biological processes is important for the advancement of science as well as public and ecological sustainability.Because insects are so numerous they have an important impact on our environment and our lives (Gullan and Cranston, 2005; Mcgeoch, 1998; Weisser and Siemann, 2004).

Biodiversity deals with biological and geographical entities such as genes, chromosomes, species, families, and habitats or bio geographical regions. This means that in order to understand nature it is essential that we have to understand both distinction and description of these biological and bio geographical entities (Valk, 1999). Due to the reality of the rapid disappearance of species, this problem has come to be regarded as the worst situation that the earth's environment has had to face. Thus, species loss is related as being more serious than pollution and global warming (Wiggins *et al*., 1991).

Ecology looks at the interaction between organisms and their environment. An insect's environment may be described by physical factors such as temperature, wind, humidity, light, and biological factors such as the other members of the species, food sources, natural enemies, and competition (intra-specific and inter-specific computation). Although insects are highly adaptable, over the long term, it may be of paramount importance to have an understanding of how physical and biological factors relate to insect diversity, activity and abundance, as a contribution towards the maintenance of the environment to suit present insect diversity, and possibly prevent zoological extinction in a wider sense, despite developments (Schoonhoven *et al.,* 2005; Wiggins, 1983).

The insect biodiversity of Ethiopia is not well known. There have been a few studies conducted and documents have revealed there are 1225 arthropod species with 7 endemics in Ethiopia (CBD, 2009). There are 91 benthic and aquatic insect species recorded so far in Ethiopia (Mohammed Abdi *et al*., 2003). There is a huge knowledge gap on other components of the fauna owing to the absence of systematic surveys, especially for the insects where high diversity and endemism is expected from the array of diverse ecosystems in the country (CBD, 2009). Biodiversity should be conserved, to account for the unpredictability of the future, and to provide sustainability. As well as, serving as pollinators and crop protectors, insect biodiversity and populations are good indicators of ecosystem health and management. The main reason for using insects is because of their abundance, and biodiversity can be documented in continuous surveys (Hunter, 2001; Kosztarab and Schaefer, 1990).

Afromontane forests are among the most species-rich ecosystems on earth (Schmitt *et al*., 2010). They are under severe land-use pressure, because the same environmental conditions that foster high species diversity also render tropical montane forest areas suitable for agricultural uses (Schmitt *et al*., 2010). Deforestation in Afromontane areas has been generally associated with increased run-off and soil erosion leading to a decline in soil fertility. The Afromontane areas of eastern Africa, including the Ethiopian highlands, constitute vivid examples of tropical forest ecosystems that have exceptional species richness, high concentrations of endemic species, and which are under great human land-use pressure. These are, therefore, internationally recognized as the Eastern montane Biodiversity Hotspot (Schmitt *et al*., 2010). Much of the Ethiopian highlands would bear montane forests if untouched; hence remnants of these forests still occur in the central part of the country (Tamrat Bekele, 1993). Belette-Gera moist evergreen montane forest is one of the National Forest Priority Areas (NFPAs) Ethiopia which comprises economically and ecologically important plants. The edge of the forest, which is easily accessible by the people of the community, is planted to coffee. This is disturbing and reducing the size of the forest. The major threats observed in Belette-Gera forest were encroachment, coffee production and agricultural expansion (Kflay Gebrehiwot and Kitessa Hundera, 2014; Belay *et al*., 2013).

The study of the biodiversity of insects in Belette Gera forests specifically focuses on assessing the diversity and abundance of insect communities in reference to habitat heterogeneity effect and sessional distribution with in the forest. Because of, insects are important in the function of the forest ecosystem such as; nutrient recycle, soil decomposition, pollination, seed dispersal and population regulation of herbivore insects. Therefore, knowledge of the diversity and abundance of insect communities within the Belette-Gera forest will provide valuable information about the the insect founa of the forest. Inaddition, knowledge of diversity and abundance of insect in reference of habitat hetroginity will show the interaction of insect communities with the vegetation type and land cover of the forest. As aresult, the importance of insects for the survival of the forest ecosystem and attention should be given to conserve both the forest vegetation and insects. Farthermore, the seasonal distribution of insects with in the forest also important to identify insect groups and their seasonal aboundancy with in the forest will invite to study the seasonal variation of vegetation type and their relation with insect communities.

Objectives

General Objective

The overall objective of this study was to investigate insect diversity and abundance at Belette-Gera Forest and generating baseline information for further study.

Specific objectives

- To estimate the population sizes and composition of insects in Belette-Gera forest.
- To determine the seasonal cycles of insect populations.
- To determine the effect of habitat fragmentation on species diversity and abundance of insect communiuties.

Chapter 2 GENERAL LITERATURE REVIEW

2.1. Importance of Biodiversity

The term biodiversity has been defined as the variety and variability among living organisms and the ecological complexes in which they occur (Primack, 1998). Thus, biological diversity includes all species of plants, animals and micro-organisms and the ecosystems of which they are part. Usually biodiversity is considered at three levels: genetic diversity, species diversity and ecosystem diversity. Genetic diversity covers genetic variation, life history traits and population dynamics of organisms. The amount of genetic variation within species also determines its potential for subsequent evolutionary change. Consequently, genetic diversity ultimately arises at the molecular level and is the product of pleiotropic (the existence of genetic covariation among trait) and epistatic (trait variation restricted to a single trait) interactions (Flattand Kawecki, 2004). Therfore, it is a resource which cannot be replaced. Species and ecosystem diversity are dependent on the changes in the chemical and physical environment and human induced transformations of the earth's features (Hansen, 2006; Solbrig, 1991). In addition to this, there are also other aspects of diversity such as the functional diversity covering ecological processes (pollination, dispersal, etc.) and structural diversity covering distribution of diversity in space and time (vertical stratification in tropical forests, percentage of species, age structure of populations etc.) (Hansen, 2006).

All biodiversity in different parts of the earth are the products of several million years of evolution (Hansen, 2006; Wilson and Peter, 1992). The interaction of various species among themselves and with the environment has led to an increase in the diversity of species over years.

In addition to this, there are also various evolutionary pathways which produce a vast array of species and ecosystems. On the contrary, various catastrophes like drastic changes in climate have caused mass extinction of life on various parts of the globe (Hansen, 2006; Raup, 1988).

Over centuries in the past, human populations have relied exclusively on biodiversity for their livelihood. Like dyes, gum, incense, oils, resins, various fruits, nuts, honey and spices are obtained from the nature. Man has also learnt to cultivate and select varieties of crops and livestock breeds to meet diverse nutritional and social needs. With current developments in technology, we have been able to produce new plant varieties and animal breeds. Much of its success is attributed to the integration of indigenous knowledge and modern technological advancements (IAASTD, 2008)

Animal and microbial diversity are also important in the manufacture of various pharmaceutical products, as bio control agents against various pests and diseases, as material for advanced biological research and as indicators of environmental quality. However, much of the plant and animal genetic diversity are being lost at an alarming rate. Understanding and documenting the taxonomy of the flora and fauna and their interrelations within the ecosystem are very essential for the sustainable utilization of biodiversity to the advantage of mankind (Johnson, 1995).

2.2. Insect Biodiversity

This research work on insect species biodiversity is studied for many reasons. Insects are essential in the following roles within the forest ecosystem: nutrient recycling via leaf-litter and wood degradation, dispersal of fungi, dispersal of carrion and dung (Vinod and Sabu, 2007) and soil turn over; plant propagation, including pollination and seed dispersal; maintenance of plant community composition and structure via phytophagy, including seed feeding (Lowman, 2006); food for insectivorous vertebrates including, many birds, mammals, reptiles and fish; regulation of animal population, through transmissions of disease of large animals such as vectors of traipanasomiasis by tseste fly, and predation and parasitoidism to regulate the population of herbivore insects (Gullan and Cranston, 2000; Hill, 1997; Metcalf and Flint, 1979).

For example, ants are abundant insects, a large component of the insect community on ground in the forest ecosystems (Sakchoowong *et al*., 2008) and are considered important in ecosystem functioning. They have diverse ecological roles, including nutrient cycling, seed dispersal, and population regulation of other insects and constitute fractions of animal biomass in terrestrial ecosystems (Fergnani *et al*., 2008; Graham *et al*., 2004). Dung beetles have a variety of effects on the ecosystem. By burying dung and carrion as food for their offspring, dung beetles may increase the rate of soil nutrient cycling and reduce egg and larval populations of parasitic flies present in fresh dung of mammals (Vinod and Sabu, 2007).

In addition, insects make an enormous contribution to both tropical diversity and ecosystem functioning, and moths are one of the groups playing a central role in numerous ecosystem processes as prey, herbivores and pollinators (Hawes *et al*., 2009). Forest litter-inhabiting insects except ants are poorly understood because of their small sizes and cryptic habitats. However, they play an essential role in nutrient recycling and contribute valuable data to study of comparative biodiversity and conservation (Vinod and Sabu, 2007; Hill, 1997). Many acts as important secondary dispersal agents for seeds of several tree species defecated by fungivorous vertebrates, thus participating in the natural process of forest regeneration. In addition, they are good indicators of the impact of large herbivore and human in forest habitat changes (Vinod and Sabu, 2007).

Many insects are scavengers that feed on dead plants or on the living microbes that flourish in decaying matter. Insects that kill other insects are termed as entomophagous (Ehrlick *et al*., 1978) whereas gall forming insects are used for weed controlling Phytophagous by their feeding habit forming gall at the root of weed plants (Dennill, 1988). Predators and parasitoids constitute a large group of insects. They feed mostly on other insects. Predators belong to several orders: Hemiptera, Dictyoptera, Odonata, Dermaptera, Neuroptera, Coleoptera, Diptera and Hyminoptera. Most parasitoids belong to Hyminoptera and some Diptera (family Tachinidae). And also, devour other small invertebrates such as snails, millipedes, spiders and earthworms (Daly *et al*., 1998) and regulate animal population within the natural teristerial ecosystem.

However, most flowers are frequently visited by insects and partially dependent on them for seed-set. But, pollination of the most common plants is primarily by flies, but bumble bees are also important (Metcalf and Flint, 1979). Hill (1997) studied beneficial insects for the purpose of pollination, apiculture (honey bee), sericulture (moth), insect farming (butterflies) and natural control of pest consequently insects in natural food webs and insects as human food. Then, he found that the economic importance of insects for human livelihood.

Insect species introduced to new areas, whether naturally or by humans, can alter the receiving community.These invasive species are increasingly recognized for the economic and conservation problems they create through direct (competition, predation, herbivore, parasitism, hybridization, habitat alteration) and indirect effects on a community (Storz and Tschinkel, 2004).

Insects that feed on green plants (Phytophagous insects) attacks roots, trunks, stems, twigs, leaves, flowers, seeds, fruits, and sap in the vascular system. Insects either feed externally by chewing tissue or by sucking sap or cell contents, or they feed internally by boring into the plant tissues. The sucking insects especially Hemiptera are the only insects that are able to extract sap in quantity from the vascular system of plant. Insects feed on most other kinds of terrestrial animals. Mammals, birds, reptiles and amphibians are parasitized by blood sucking insects. Some parasites live on the host (biting and sucking lice, adult flea), burrow in its flesh, or inhabit the alimentary or respiratory tract (fly maggots) (Daly *et al*., 1998). Overall, Belette-Gera forest is one the remaining Afromontanea forest of Ethiopia which has recognition by the government. The diversity and abundance of the forest vegitations and management strategies are studied by different authers. However, from the above mentioned importance of insects for the existence of this forest ecosystem almost no or little knowledge about the diversity and abundance of insects in the Belette-Gera forest. Therefore, study the diversity and abundance of insects within the forest also equaly important from their contribution for the existence of Belette-Gera forest ecosystem. Thus, it is important to know their identities and numbers within the study forest.

2.2.1. Biotic factors affecting insect diversity

Much of the diversity of insects and plants in terrestrial ecosystems can be attributed to the extensive interactions between these two groups, both through herbivory and pollination (Kevan and Baker, 1983). Insects are the major herbivores in most terrestrial ecosystems, accounting for up to 80% of the total plant consumption in the system (Price, 1997). Insects are less efficient than vertebrates in assimilating plant material, but more efficient at converting assimilated material into body tissue (Slansky and Scriber, 1985). At the Savannah River Site, Odum *et al.* (1962) computed Orthoptera (grasshoppers, katydids and crickets) with sparrows and mice which contribute to the energy flow of the ecosystem found that the actual production by Orthoptera was 100 times greater than that of sparrows and 33 times greater than that of mice. This indicates that insects (here only one group of herbivorous insects) consume more energy in the system than vertebrates and make the most consumed energy to build their body tissue and more available energy to the secondary consumer. They are extremely important to the functioning of the community in energy flow within the ecosystem. Wiegert and Evans (1967) and Golley and Gentry (1964) found similar results as herbivore insects more efficient than vertebrate in Secondary productivity of terrestrial ecosystems. Similarly, the diversity and abundance of insects within Belette-Gera forest are directly or indirectly related with the diversity and abundance of vegetation. Thus, forest insects playing a major role in energy flow than vertebrate within the forest ecosystem due to insects are more efficient at converting assimilated material into body tissue than herbivore vertebrates.

2.2.1.1. Forest plant and insect interaction

Forest plant species diversity contributes to herbivore insect diversity specifically increased levels of nutrient.The putative role of Forest plant diversity in contributing to insect diversity has been discussed by a number of authors (Hunter and Price, 1992). Southwood (1988) suggested that variation in habitats (Forest plant communities) through time and space provides variation that supports multiple insect species. Siemann (1998) and Solar *et al*. (2005) demonstrated that changes in plant diversity alter not only herbivore diversity, but also insect predator and parasitoid diversity. There are also a number of direct mechanisms by which plants influence natural enemies, including volatiles released by attacked plants, the creation of structural refuges that shelter herbivores, structures such as trichomes that interfere with enemy foraging, and plant toxins that can be sequestered by herbivores as defenses against enemies (Perner *et al*., 2003; Price *et al.,* 1980). Thus, increased diversity and functional diversity of plant species increases the potential diversity of mechanisms by which plants can influence insect herbivores and their enemies (Perner *et al*., 2003; Siemann, 1998; Price *et al*., 1980).

Numerous studies in a wide variety of systems ranging from grasslands to forests have demonstrated that plant diversity contributes to insect diversity (Perner *et al.,* 2003; Siemann, 1998). Other factors also influence insect diversity. A path analysis (types of path model that are relevant to the analysis of selection) revealed that in diversity treatments the presence of legumes alfalfa increased insect composition (Perner *et al*., 2003). Insect abundance and functional group representation was also influenced by variation in species cover, plant biomass, soil nutrients and management regimes (Perner *et al*., 2005). Plant diversity can also be influenced by competition, stress tolerance, dispersal, facilitation, succession stage and environmental heterogeneity (Lundholm, 2009). Insects can strongly influence the abundance and richness of plant species during insect outbreaks, which can limit the fitness and abundance of certain plant species, outbreaks of chrysomelidaebeetles on goldenrod specie (Carson and Root, 2000). Even in non-outbreak scenarios insect herbivores have been shown to limit plant fitness and even small amounts of insect herbivory can limit tree fitness through feeding the growing tissue of the plant parts (Schoonhoven *et al*., 2005; Crawley, 1985). Insects clearly do not however decimate plant populations, and this is primarily due to the influence of herbivore enemies (Bernaysand Graham, 1988). 'Top down' theory suggests that the prevalence of herbivore enemies limits herbivore populations preventing them from consuming all plants. Several tests of 'top down' theory have demonstrated that herbivore enemies limit herbivore populations (Hunter, 2001), and plant adaptations such as volatiles may aid in top-down regulation (Howe and Jander, 2008).

Feedbacks between insect and plant diversity contribute to the diversity in both groups. Despite earlier debates over the quantification of relative top-down and bottom-up effects (Hassell *et al*., 1998), the current consensus is that both top-down and bottom-up effects influence ecosystems (Chapin *et al*., 2002). Feedback loops in ecological systems restrict the existence of unidirectional pathways (such as top-down or bottom-up effects on the tritrophic interactions) within ecological systems, because time can shift systems from top-down to bottom-up effects and vice versa, changing unidirectional pathways over time resulting in feedback loops (Hunter, 2001). The relative importance of top-down and bottom-up interactions also depends upon environmental heterogeneity such as water availability (Boyer *et al.,* 2003; Chase *et al*., 2000), light availability (Chase, 1996), nutrient availability (Denno *et al*., 2002) and spatial structure (Preszler and Boecklen, 1996). Thus, insect herbivores and their natural enemies affect plant diversity (through top-down mechanisms) whereas plant diversity affects the diversity of higher trophic levels (through bottom-up mechanisms) (Hunter, 2001; Walker and Jones, 2001; Hunter and Price, 1992). As far as these trophic relation concerned in natural teristrial ecosystem such as Belette-Gera forest the existing diversity and abundance of insect communities is a result of both top-down and bottom-up mechanisms.The trophic interaction of the forest vegetation and herbivor insect, predators, parasitoids community of the forest ecosystem remain stable and health due to both top-down and bottom-up effects in food-web.

2.2.1.2. Soil microorganism, forest plants and insect herbivours interactions

There are several possible mechanisms through which soil micro organism diversity could contribute to insect diversity. First, soil micro organisms could simply increase the diversity of plant species available to herbivores. Second, soil micro organisms could contribute to phenotypic variation within species by modifying plant size or quality (Bennett *et al*., 2006). Modifying plant defenses or growth rates would create a patchy distribution of plant phenotypes, and thus greater overall variation for insects to utilize. Finally, soil micro organisms could alter both plant inter and intra-species variation in traits that directly or indirectly affect herbivores and other insects resulting in greater insect diversity (Karban and Baldwin, 1997).

Interactions between root and shoot herbivores via their host plants have been shown to vary among habitats and systems (Masters *et al*., 1993). Root herbivory on *Sonchus oleraceus* benefits aboveground insect herbivores from a wide variety of classes (suckers, chewers, and miners) (Masters and Brown, 1997). Different fungal species and species have been shown to alter plant tolerance to herbivory (Bennett and Bever, 2007; Kula *et al*., 2005; Gange *et al*., 2002), constitutive levels of plant defense compounds (Gehring and Bennett, 2009; Gange, 2007; Gehring and Whitham, 2002), induced direct responses to herbivory (Bennett *et al*., 2009; Pozo and Azcon-Aguilar, 2007), and volatile release (Bezemer and Dam, 2005; Guerrieri *et al*., 2004; Gange *et al*., 2003). Root herbivores reduced aboveground Parasitoid and hyperparasitoid adult biomass (Soler *et al*., 2005) through changes in plant defense compounds or plant quality (Bezemer *et al*., 2005; Soler *et al*., 2005). A non-mutualistic fungal root endophyte (*Acremonium strictum*) has also been shown to reduce quantity, but increase the variety of volatiles emitted resulting in increased oviposition deposition by moths (Jallow *et al*., 2008). Root herbivores and nematodes, together and alone, have been shown to increase aphid and aphid parasitoid abundances, while only root herbivores influenced pollinator visitation in wild mustard by changes in plant structure or nutrients that alter the quality and volume of pollen and nectar production (Poveda *et al*., 2005). Belowground organisms can influence a wide variety of floral traits that are important mediators of pollinator attraction, including the number and size of flowers and nectar and pollen production (Barber *et al*., 2015).

Therefore, these ecological connections between above-and below ground communities, as well as the wider recognition that interactions among species in the soil can both influenced and be affected by aboveground organisms inscluding insects. And also, belowground micro organisms influence aboveground interactions of insect herbivory, predators and parasitoids through plant medeater consequently influence the diversity and abundance of insect community in natural teristerial ecosystem such as Belette-Gera forest.

Moreover, the direct interaction between plants and herbivores can be modified through variation in plant quality and quantity (Schoonhoven *et al*., 2005). Pathogens and mutualists alter growth and reproduction of host plants. Nematodes with or without a soil microbial community reduced aphid parasitoid mortality in grassland (Bezemer *et al*., 2005), while Black mustard root herbivores can change the quality of volatile releases in a way that results in a decrease in parasitoid oviposition on above ground herbivores (Soler *et al*., 2007). Decomposer bacteria and fungi release nutrients which can directly influence plant growth and reproduction. Thus, soil organisms can produce variation in the quantity and quality of plant tissues, the quantity and quality of plant tissues directly influence herbivore insects' growth and survival (Schoonhoven *et al*., 2005) and probably influence herbivore enemies through quality of volatile release or abundance and quality of prey items (Soler *et al*., 2007).This is well-studied for herbivores sharing the same shoot and also increasingly so for spatially separated species such as aboveground and belowground herbivores (Bezemer and van Dam, 2005).

Therefore, within the natural terristerial ecosystem the aboveground herbivore and belowgrownd herbivore which share the same host plant determine the diversity and abundance of insect herbivore and their parasitoide insects through host plant effct. Thus, the computiton of different groups which share tha same resourse no longer influenced but fluctuation population will occur due to the effect of the host plant. Similarly, within Belette-Gera forest the variation of diversity and abundance of insect community with place, time and the studied tax can be the result of such interaction and host plant effect.

Interactions among soil microbes or between soil microbes and larger soil fauna have been shown to produce a wide variety of responses in plants. For example, earthworms have been shown to alter foliar nitrogen (Newington *et al*., 2004), and combinations of earthworms and mycorrhizal fungi alter plant quality through changes in constitutive levels of plant defensive compounds (Bennett and Bever, 2007; Wurst *et al*., 2004). The distribution of litter has also been shown to influence plant defensive compounds (Wurst *et al*., 2004).

Mutualistic insects are also influenced by changes in soil communities. Pollinators are also probably influenced by changes in plant structure or nutrients that alter the quality and volume of pollen and nectar production (Gange and Smith, 2005; Wolfe *et al*., 2005). The elimination of mutualistic fungi changes plant community structure resulting in changes in the community of pollinators visiting plants (Cahill *et al*., 2008).

On the other hand, some recent research has focused on the influence of aboveground herbivores on belowground herbivores (Soler *et al*., 2007), primarily through induction of defenses in plant tissues (Bezemer *et al*., 2004; Hol *et al.,* 2004). In addition, foliar herbivory has been shown to influence negatively parasitoids of root herbivores (Soler *et al*., 2007). The majority of research in this area, however, has primarily been focused on how herbivores and herbivore enemies influence decomposer systems andmycorrhizal fungi (Bennett and Bever, 2007).

Invertebrate herbivores and their predators are most likely to influence soil communities indirectly through the abundance and variety (or quality) of litter (or organic matter) entering the soil system (Cebrian and Lartigue, 2004; Bardgett and Wardle, 2003). In grassland mesocosms, the addition of aphid herbivores alone benefited soil decomposer bacteria at the expense of decomposer fungi as well as herbivorous nematodes (Wardle *et al*., 2005) and microbe feeding nematodes (Wardle *et al*., 2004), but the addition of aphid enemies reversed these effects and benefited primary and tertiary consumers through changes in plant biomass and community composition (Wardle *et al*., 2005). Similarly, Dyer and Letourneau (2003) found that aboveground predators influenced decomposer faunal communities primarily through regulation of plant biomass. Siberian moth frass had effects on soil organisms lasting up to three years, while greenfall from Siberian moth herbivory had short-term effects on soil community activity (Krasnoshchekov and Bezkorovainaya, 2008; Krasnoshchekov *et al*., 2003).

Aboveground insects may also influence belowground communities through other direct and indirect pathways (Hunter, 2001). The quantity and quality of plant biomass have the strongest influence over soil detrital communities (Wardle *et al*., 2006). Aboveground invertebrate herbivory has also been shown to influence negatively root feeders (Masters and Brown, 1997).

Herbivory by aphids, but not grasshoppers, has been shown to increase Collembola populations. These effects are mediated through the addition of carbon rich aphid honeydew to the soil surface and host-plant root reduction/changes in root shoot in response to aphid herbivory. Therefore, increases in the number of collembola may have been indirectly due to the presence of increased levels of dissolved organic carbon in the soil as a consequence of increased plant photosynthesis (Sinka *et al*., 2009).

All herbivores (both vertebrate and invertebrate) can directly influence soil nutrient inputs through excrement (frass). Frass inputs from canopy insect herbivores have been shown to influence soil invertebrates and alter nitrogen and carbon cycles, and variation in soil nitrogen has been shown to alter plant diversity (Reynolds *et al*., 2003), also alter insect diversity indirecticaly. Likewise, the present diversity and abunmdance of insects in a forest ecosystem is a result of soil communities'food webs and functions to a long-term and highly replicated manipulation of plant species richness. Therefore, conservation of the soil of a forest ecosystem is also conservation of the soil community, the vegetation and the insect community. Because, the contineous biological interaction (both directly and indirectly) that established ammong these group of organisms could contribute to build up the existing natural teristerial ecosystem such as Belette-Gera forest. Finally, dealing with the interaction among communities of the aboveground and belowground with respect to insect community is important inorder to study the species diversity and abundance of insec species within the forest ecosystem.

2.2.2. Habitat fragmentation and insect diversity

Habitat loss poses the greatest threat to the long term survival of species on earth. Habitat fragmentation (the reduction of continuous habitat into several smaller spatially isolated remnants), decreases area, increases edge effects, alters ecological processes and decreases connectivity (Debinski and Holt, 2000). Smaller, more isolated fragments are expected to retain fewer species than larger, less isolated patches. Decreases in species richness, in density and in species abundance, and alteration of interspecific interactions are some possible biotic effect of habitat loss and fragmentation recognized as the major causes of the current biodiversity crisis (Baguette, 2001; Saunders *et al.,* 1991).

Most imperiled species, however, face more than one threat, and it is difficult to disentangle proximate and ultimate causes of their decline or interactions between different threats and evaluate their relative importance (Gurevitch and Padilla, 2004). Land-use change is projected to have the largest global impact on biodiversity, followed by climate change, nitrogen deposition, species introductions and changing concentrations of atmospheric CO_2 (Sala *et al*., 2000).

A landscape which has high number of small patches and the inter-spatches distance of fragmentation in a land scape enhances the immigration flow to patches aggregately increasing population density (Arias*et al*., 2011; Grez *et al*., 2004), fragmentation decreased the rate of immigration to patches, resulting in lower population densities in more fragmented landscapes (Zi-hua *et al*., 2011). Insects are the most successful organisms present in almost on every vegetation all over the world. To fight for food and shelter they migrate from one crop to another crop, one cropping system to another cropping systems or one climatic environment to another totally different climatic conditions (Sutherst, 1991).

Landscape pattern and diversity also influence the landing of flying insects. Sometimes vegetative medium attract or rejects the aerial insect stock no doubt some what related to their landing behavior. Wheat crop proved very crucial to observe the rate of landing of some aerial insects (Ciss *et al*., 2013).

The composition and abundance of species likely to be sustained under alternative patterns of land cover within the habitat. To forecast changes in biodiversity, recent approaches combine species' habitat affiliations with alternative scenarios of change in land cover (Hughes *et al*., 2002). Some projections incorporate other information, such as species' area requirements and gap-crossing abilities (Pärt and Söderström, 1999). Such information is so limited, but, the studies undertaken so far typically base their analysis on a small number of vertebrate and plant species (usually 10 up to 30) and rarely insects; an exception is which incorporated general information on scarab beetles and euglossine bees (Kremen and Ricketts, 2000; Saunders *et al*., 1991).

However, changes in land use like intensification of agriculture, habitat fragmentation and invasion of alien species have led to the decline of species such as butterflies (Thomson, 2001; Dover *et al*., 1990), bees (Calabuig, 2000), and bumblebees (Kwak and Bergman, 1996). Several authors (Cox and Elmqvist, 2000; Kremen and Ricketts, 2000; Roubik, 2000) have expressed great concern for the consequence of pollinator fauna decline for wild plant and insect pollinated crops. Habitat loss poses the greatest threat to the long term survival of species on earth. Habitat fragmentation (the reduction of continuous habitat into several smaller spatially isolated remnants), decreases area, increases edge effects, alters ecological processes and decreases connectivity (Debinski and Holt, 2000).

There is, however, strong reason to expect a decline in diversity even with no further change in land cover, resulting from the slow, but entrained reduction in plant diversity as particular species (e.g., long-lived forest trees) fail to recruit sufficiently. In addition, microclimatic changes and other consequences of fragmentation can impact dynamics of insect communities of remnant forest fragments (Daily, 2001). Second, some insect taxa show species-area effects in native habitats (Daly *et al*., 1998). Similar situation were observed in Belette-Gera forest due to farm land need of the nearby community for growing coffe and also the forest wood for construction and fuel consumtion distruct the forest. As aresult, not only the losses of the forest vegetation but also the insect communities associated within the forest vegetation were distructed. Therefore, the degradation of the forest where continued with this rate the whole ecosystem will disappear with in short periode of time. So, cosservation effort should require on the diversity and ecological services rendered by different species.

Habitat fragmentation on insects has several implications for landscape management aimed at population survival. First, increasing similarity of habitat patches (i.e., homogenization of landscape) homogenizes species assemblages among habitat patches. In order to maintain diverse species assemblages in a landscape, it is important to maintain heterogeneity of habitat. Given the importance of movement to the spatial ecology of insects, it should be no surprise that the size and physical arrangement of habitat patches on landscape plays a fundamental role in determining the abundance and diversity of insects (Speight *et al*., 1999).

Over all, the major causes of deforestation and degradation of natural resources in the Belette-Gera forest are coffee production activities and encroachment into forest land to expand farm land and pasture. It is estimated that up to 49% of the accessible natural forest is under the influence of coffee production activities, among which collecting of naturally grown coffee beans has the least and the coffee plantations has the most impact on the natural forest. Coffee plantations in natural forest have reduced the forest density and species diversity. Age structure of the trees is limited to mature and old classes only, which eventually endangers their function as shade for coffee plantations" (Tamrat Bekele, 1993). Therefore, the degreadation of habitat fragmentation if extend with this reat the diversity and abundance of insect community will be affected. And also, study on management and conservation mechanisms should be required. Scince, diversity of insects are good indicaters of habitat fragmentation and loss of species diversity. Consquently, continuous study of the diversity and abundance of insects is important to conserve the forest environment.

2.2.3. Crowding effect and insect diversity

The idea of competition can also be associated into the concept of crowding, but competition may be inter or intra-species. Response of crowding for an individual and whole insect population can be positive and negative (Schoonhoven *et al.,* 2005; Southwood, 1966). It modifies its rate fecundity, growth and development, for instance, increase in population density may decrease their rate of increase. In case of social insects the queen boost up egg laying under uncrowed condition, but in over population its efficiency of egg-laying may slow down (Schoonhoven *et al*., 2005).

2.3. Abiotic Factors and Insect Abundance

Insect abundance and distribution are regulated by several abiotic factors and their interactions. Survival and thriving at extreme physical conditions require peculiar adaptations and plastic responses. Among abiotic factors, temperature and humidity stand out as the most important ones constraining abundance and distribution of insect. Furthermore, it is well documented that abiotic factors, especially temperature, regulate the ecology of insect communities (Pollard, 1988). The growth and development rates of insects are known to increase almost linearly with temperature till the optimum temperature (which varies with species type). Insect predators and parasitoids also become more active at higher temperatures (Finlay-Doney and Walter, 2012).

2.3.1. Temperature

In multi climatic factors particularly temperature can extend or reduce the life cycle of insects (Régnière *et al*., 2012). High thermal thresh hold influence the insects cycle stage, growth or some internal metabolic activities. For example, in case of *Helicoverpa armigera* egg period was observed to be 7.9 days at 28^{o}C, but extended to 10.4 days at 25^{o}C. Degree days for hatching are negatively correlated with rise in temperature from 10-27^{o}C. Generation time of *Leptocorisa acuta* was supposed to be increased 1-3 days with the raise to 3^{o}C (Emana Getu, 2007: Harrison *et al*., 2006; Heong *et al*., 1995).

Overall, reproduction, oviposition period and longevity of insect were reduced while preoviposition period was positively affected by an increase in temperature (Zhang *et al*., 2014; Finlay-Doney and Walter, 2012; Overgaard and Sorenson, 2008).The response of insects varies against a series of temperatures as 9-55^{o}C enhancing individual insect mortality. Insects flourish up to 10^{o}C, but below 6^{o}C mortality of certain insects like coleopterons species go up to > 99^{o}C after 9 months at 45% R.H. storage conditions. Many Psocopteran and Coleopterons species were dead almost 99% at 50°C within 2.5 h (Beckett, 2011).

In various insects species fecundity and survival are enhanced due to fluctuating regimes (FTR) - bin full contain cycles between both high and stressful low temperatures. Results also revealed that at larval stage body water (BWC) and lipids (BLC) do not change with reaction FTR and show long term fitness consequences (Boardman *et al*., 2013). Pine beetle flourish and disperse with better survival rate at warm winter as compared to lethal (-16°C) which reduce drastically. Aphids can produce 1-5 generation more with an increase a 2^{o}C in a temperature. In response to minute change in temperature also affect the pre-oviposition period, oviposition and survival of insects is strongly affected. *Nilapavata lugens* (Brown plant hopper) showed no effect on survival ability between 25-35^{o}C but reduced at 40^{o}C. In a similar way, female oviposition in higher rate at 35 and 40^{o}C as compared to 25 and 30^{o}C. In contrast to survival and oviposition, pre-oviposition period was decreased at higher temperatures (Yamamura and Kiritani, 1998).

On the other hand, cooling and freezing negatively affect the physiological, mechanical and behavioral of the various insects (Karl, *et al*., 2011; Overgaard and Sorenson, 2008). It can change the chemical ingredients and causing dehydration of the cells or maintaining body fluids keeping liquids below melting point (Sinclair *et al*., 2003). In some beetles (*Alphitobius diaperinus*) bear oxidative damage against cooled thermal stress, but antioxidant system is switched on to recover this cooled induce damage (Lalouette *et al*., 2011). Life cycle gene expression of yellow meal worm beetle (*Tenebrio molitor*) was observed under constant

(18±1^{o}C) and variable temperatures (mean = 18^{o}C and variance of 6.8°C). Insects were more cooling tolerant against variable thermal affect with maximum gene expression (Hsp 70) (Arias *et al*., 2011).

It was observed that *N. cincticeps* population fluctuate from 3-4 with change in thermal effect. Both of *N. cincticeps* and *C. suppressalis* greatly affect to global warming. Their population boost up due to winter temperature, significantly can be related the number of generation per year. In winter season death rate of adults of *Nezara viridula* and *Halyomorpha halys*was supposed to be decreased 15% by each increase of 1^{o}C temperature. On the other hand number of generation per year of *C. suppressalis* decrease after 2^{o}C warming. Degree day variation in sucking insect (mustard aphid) can alter its infestation. In a similar way in *Leptocorisa acuta* (rice ear head bug) increase or decrease in population is affected with each raise of 3^{o}C (Rejii and Chander, 2008).

2.3.2. Humidity

The physical environment major factors (temperature, light, humidity etc.) indirectly affect physiological reaction of insects by changing the rate of fecundity, growth and development rather than direct change in a specific physiological reaction (Karl *et al*., 2011; Overgaard and Sorenson, 2008; Fränzle, 2003). These factors can affect the mortality, fecundity, generation time, multiplication rate, sex ratio and somewhat mutation. For instance, with the range of temperature speed of development can be enhance but production of deformities and larval mortality will also increase (Chown, *et al*., 2011; Overgaard and Sorenson, 2008). Species richness and insect activity varies due to temperature and water availability. Certain receptors like thermo trips may act as primary integers, source of sensory information (such as environmental moisture and temperatures) which reacts to a wide range of stimuli. Sub elytra chamber and cuticular hydrocarbons in integument also play a vital role in water conservation and prevention during drought (Overgaard and Sorenson, 2008). Similarly, the variation of insect spectes diversity and abundance in Belette-Gera forest in wet and dry season is alo a result of variation in temperature and water availability.

2.3.3 Altitude

Altitude is one of the important factors that affect the distribution and abundance of insects on the surface of the earth (Kormondy, 1996). Air pressure, radiation, temperature and the humidity regime are functions of altitude. Therefore, altitude affects insect distribution and abundance indirectly by influencing these environmental factors. Bromham and Cardillo (2003) indicated the forest species of Papilionidae preferred the higher elevations while the open-forest species preferred the gaps at lower elevations. Narrow elevation gradients could sometimes influence some of the biological activities of the butterflies, like fecundity and opportunities to lay eggs (Uniyal, 2007). An Insect that maintains itself over a wide altitude range may similarly be expected to show adaptation that allows the completion of its life history over a considerable temperature range (Beckett, 2011). In general, changes in species and the numbers of individuals of insects in successive generations describe the population dynamics of most species.

2.4. Aquatic Environment and insect diversity

Although insects have been wildly successful in all terrestrial and freshwater habitats, few have been able to invade habitats characterized by high salinities or tidal influences (Merrit and Cummins 1996), both of which are typical of salt marshes. Although many explanations have been proposed for this phenomenon, no consensus has been reached. Two common explanations include inability to deal with the high osmoregulatory stress and competition with other invertebrates. Merrit and Cummins (1996) hypothesize that insects have not advanced past brackish areas because almost all aquatic insects are immature, but the associated adults are largely terrestrial and are unable to live in the open ocean.

Freshwaters are highly diverse and include ponds, lakes, springs, streams, rivers, wetlands, reservoirs, and ditches (Merrit and Cummins, 1996). Inland waters cover less than 1% of the Earth's surface yet harbor 10% of all known animal species, of which 60% is composed of aquatic insects. These diversity numbers more than 200,000 described species and thereby make up 80% of aquatic animal diversity (Balian, 2008; Mayhew, 2007). Aquatic insects spend one or more stages of their life cycles in the water, with the majority living in water as eggs and larvae and moving to terrestrial habitats as adults (Balian, 2008). They play important ecological roles in both aquatic and terrestrial realms as primary consumers, detritivores, predators, and pollinators. The ecology of many groups is well studied, owing to their roles as bioindicators or disease vectors, but freshwaters have been largely overlooked as a hotbed of diversification, despite their disproportionate contribution to global biodiversity (Mayhew, 2007). Likewise, in Belette-Gera forest among the collected adult insect species include insects which spend their lifecycle both aquatic and teristrial. Thus, adult insects are important in the forest ecosystem and build up diversity and abyndace of insect community of the study forest.

The transition to freshwaters demanded adaptation in mechanisms for thermoregulation, osmoregulation, respiration, feeding, and locomotion. Among the most notable characteristics of freshwaters are their daily and seasonal temperatures, which are more stable than air and soil temperatures (Merrit and Cummins, 1996).

In the aquatic environment, there are scavenging, phytophagous, and predatory insects, but few parasitoids (Laying eggs inside host and eventually killing the host) and true parasites. Some species able to skate about supported by the surface film, while others float in the film or swim for brief periods below the surface and return for air. Certain groups are adapted to remain beneath the surface indefinitely, obtaining their oxygen from water by means of gills. Of these, some are free swimming and living in temporary bodies of water, some crawl about on vegetation and the bottom, gravels, sand, or silt (Gullan and Cranston, 2000; Daly *et al*., 1998). Temporary aquatic environments are widespread in the world, and although there are considerable regional differences in their type and method of formation they have many physical, chemical and biological properties in common. These habitats impose rigorous conditions on the organisms living in them that must possess morphological, physiological and/or behavioral adaptations to survive (Daly *et al*., 1998).

Therefore, insect species diversity and abundance of insect community in Belette-Gera forest was assessed from collection of adult insects within the forest ecosystem.Therefore, some of adult insect specimens are found to be their immature stages spend in the aquatic environments of the forest. To mentionned, slowmoving streams, wet lands and temporary aquatic environments are the majer source of the diversity and abundance of those insects which addapte to live both aquatic and teristrial environment. Alerl over, the diversity and abundance of insect communities in this study includes adult insects which spend their life cycle both in acquatic and teristrial of the forest ecosystem by the collected methods uased in the study.

2.5. Insect Diversity and Seasonality

Insects biological system has a flexible characteristic which tuning itself to the ambient environment through behavioral, genetical or physiological and are among the major adaptations evolved during the course of organic evolution (Speight *et al*., 1999). These temporally recurring or resilient changes in the ecosystem processes are often referred to as seasonality. The seasonality studies in ecology focus on understanding the responses of ecosystem and its components to the cyclic changes in the environmental conditions, which are generally associated with the climate. These seasonal changes are predominant in invertebrates, especially insects, where an active system for regulating the body temperature is absent. Significant seasonality is exhibited by different taxa and communities of insects (Hunter, 2001).

Insects, being the most diverse among all groups of organisms, include diverse species adapted to various ecological conditions, which are reflected the temporal aspects of their life-cycles as well. The duration of the life cycles highly variable among different insects. In some Insects one generation takes whole year to complete (univoltine species), while in some others it takes less than a year and there are species with two (bivoltine species) or more (multivoltine species) generations per year. On the contrary, there are species which take longer than a year to complete their life cycle. For instance, the *Cicada septemdecien* takes 17 years to complete its life-cycle, which is the longest reported among insects (Mani, 1990).

Hence, for a complete understanding of the seasonal patterns of insect abundance in the wild studies should be continuous long-term monitoring of insect populations. Most of the long-term monitoring studies on insect populations other than butterflies are carried out using only the light trap method, and are mostly done in the temperate countries (Wolda, 1987). Similarly, in order to know the seasonal influence on the diversity and abundance of insects in Belette-Gera forest needs long-term study. And also, include various trap methods and with complit information on weatheral condition including the climate of the area.

There are many abiotic factors which influence of the living organisms. Among them, temperature is one of the most important abiotic factors (Pollard, 1988). Generally, the growth and development rates of insects are known to increase almost linearly with temperature till the optimum temperature. Insect predators and parasites also become more active at higher temperatures (Finlay-Doney and Walter, 2012). Temperature tolerances of insects vary much from species to species and temperature fluctuations often related directly with seasonality. Various authors have demonstrated the seasonality of insect groups, such as caterpillars (Casey, 1993), moths (Tobi*et al.*, 1992), collembolan (Argyropoulou *et al.*, 1994, Badejo and Straalen, 1993) and butterflies (Spitzer *et al.*, 1993). Most of the seasonality studies are done on the economically important insect pest species such as mosquitoes (Chadee, 1994), Cypress bark moth (Frankie and Koehler, 1971), Wire worms (Seal *et al.*, 1992) and Walnut husk fly (Kormondy, 1996).

Apart from its direct impact it also affects the organisms indirectly, by causing changes in many other environmental factors. Rainfall, humidity and light are the three other important factors closely associated with the seasonality of organisms. In the natural conditions these major factors often affect the abundance and diversity of organism indirectly (Janzen and Schoener, 1968). The rainfall, for instance could determine the seasonality of plants (Nummelin, 1996) and hence, that of the folivorous insects indirectly. Apart from the major environmental factors, the seasonality of animals is reported to be regulated by many other factors such as, composition of trees in forest (Wardle and Barker, 1997).

Distribution of rain is an important factor which controls the seasonal abundance of the insects (Pollard, 1988). The day length or photoperiod also has an important role in the insect seasonality (Annu and Sabu, 2007). Other factors illustrated as being responsible for insect seasonality are floral species diversity; diet (Gullan, 2000) and on the abundance and biology of vertebrate predators which depend on insects such as birds (Huffaker and Gutierrez, 1999). Overall, the combinations of the above described different factors are explained the phenomenon of insect seasonality.

2.6. Insect Biodiversity and Agricultural Practices

Agroecosystems include a large proportion of the world's biodiversity (Pimentel *et al*., 1992). For this reason, insects that inhabit agricultural land can be used as indicators of the disturbance associated with these environments. Insects are frequently used as bioindicator species for monitoring and detecting changes in the environment. By using bioindicators it is possible to assess the impact of human activities on the biota instead of examining the entire biota

(Spellerberg, 1993). Carabid beetles have been used as indicators in terms of how well they represent broader ecological responses to disturbances, since they are extremely sensitive to pH and humidity balance, as well as to toxic substances (agrochemicals). Changes in morphological characteristics of organisms have been used successfully as indicators of habitat quality and disturbance (Lagisz, 2008). Generally, small and winged carabids are present in more disturbed habitats, whereas large, apterous carabids are only present in non-disturbed areas. Environmental changes can cause changes in species numbers of indicator species, in abundance of individual species, or their physiological changes (Rainio and Niemelä, 2003). Increase or decrease of species number or abundance can be caused directly by changes in abiotic and/or biotic factors (Blake *et al*., 1996) or indirectly by changes of assemblages of other species (Haila *et al*., 1994).

2.6.1. Biological control of insect pests

Insects are also important as predators and parasitoids in ecosystems. In many cases, these predators and parasitoids may be the major factor controlling herbivorous insect populations (Östman *et al*., 2003; Dempster, 1983). However, the indirect evidence for such control comes from extensive use of predators and parasitoids in biological control efforts. An important ecosystem function that has been associated with biodiversity is biologica pest control. Here, the suppression of pest populations in crops by natural enemies provides environmental and economic benefits, because it may reduce yield loss without causing any negative environmental consequences that normally result from using chemical pesticides (Alan, 2009).

However, for a successful biological control, a good knowledge of the behavior and ecology of natural enemies and pest species is necessary: sometimes the introduction of an exotic organism has worse consequences than the pest itself. Parasitoids and predators of herbivores have evolved and function within a multitrophic context. Consequently, their physiology and behavior are affected by elements from other trophic levels, such as their herbivore victim (second trophic level) and its plant food (first trophic level) (Alan, 2009; Price *et al*., 1980). Natural enemies base their foraging decisions on information from these different trophic levels, and chemical information plays an important role. While communicating intraspecific ally through pheromones, herbivores are often much more conspicuous to their natural enemies that exploit these pheromones as kairomones in long-distance herbivore location (Roy and Weinberg, 2008). The introduction of a new organism in to a new environment can have a significant effect on species conservation, since it is in itself a form of contamination (Harmon *et al*., 2007; Elliott *et al*., 1996) and it is considered to be one of the major threats to native biodiversity (Wilcove *et al*., 1998).

2.6.2. Biodiversity and invasive species

The introduction of exotic natural enemies with the purpose of reducing pest populations below levels at which they can cause economic injury to crops has gained a special place in crop management and has been one of the contributing factors for the establishment of exotic species. Recently, the ladybird beetle, *Harmonia axyridis* (Pallas), has caused alarm in some countries. It is native to Asia, introduced several times into USA and more recently also to European countries, mainly for biological control of aphids (Roy and Weinberg, 2008). It is currently the commonest invasive coccinellid in the US and Canada (Harmon *et al*., 2007). However, the risks associated with invasive alien pests (e.g., widespread establishment dominate the new environment or ecological effect which is non targeted effect) are difficult to quantify, as they involve interactions between factors operating across a range of spatial and temporal scales, such as the population dynamics of an invader, environmental conditions in the invaded region and the status of potential dispersal pathways (Barney and Whitlow, 2008). Eventhogh, there is no documented or observed about invasive insect species within the study forest. At the same time, from their wide spread establishment or ecological effect and the ststus of potential dispersal pathways. Here, continuous study of the forest insect is important to control the risk associate with invasive alien insect pest

2.7. Biodiversity and Global Climate Change

Global climatic changes may also affect insect diversity and subsequently jeopardize the services provided by ecosystems, such as pollination of crops or pest control by predators. These changes affect not only the interactions between insects and plants, but also whole natural and agricultural ecosystems (Kannan and James, 2009; Kormondy, 1996). Even with some contrasting results, some studies indicate that current changes, especially the elevated concentrations of O_3 and CO_2 (IPCC, 2001), may affect the performance (e.g., growth and fecundity) and population dynamics of aphids. Aphids are a good model for studying the effects of environmental change, since they have short life cycles, several generations per year and high fecundity (Kannan and James, 2009; Dixon, 1985). Thus, phenological responses are likely to be widespread within all groups of insects especially at higher latitudes and elevations where temperatures are increasing due to climate changeand is predicted to increase more than in other parts of the world (Beckett, 2011).

Climate is an important determinant of geographic range for many species. Consequently, warming is expected to force species to shift their distributions by expanding into the new climatic areas and by disappearing from areas that have become climatically unsuitable (Hughes, 2000). Shifts in distributions will occur, in part, by range expansion at the cool, upper altitudinal and latitudinal limits, and by contractions at the warm, lower altitudinal and latitudinal limits of species' ranges. Numerous cases of recent distributional shifts have been recorded for a variety of taxa from around the world (Pounds *et al*., 2005).

2.8. Diversity Indices: Ways to Quantify Diversity

Most studies that examine species diversity focus on quantifying species richness. Species richness is simply the total number of species within a habitat or community. Species richness is the most commonly used measure of diversity because it is a straight forward measure and it is intuitive.

Species diversity is a measure of both the number of species (species richness) and the relative contribution of each of these species to the total number of individuals in a community. A diversity index is a mathematical measure of species diversity in a community. Diversity index provide important information about rarity and commonness of species in a community. The ability to quantify diversity in this way is an important tool for biologists trying to understand community structure. Biologists use the mathematics of information theory to make precise calculations about diversity. The commonly used indices include species richness, Shannon-Wiener, Evenness, Simpson's and Jaccard's Similarity diversity indices. These diversity indices include elements of richness and evenness in their calculations (Bruton *et al.,* 1992). These indices, along with indicator species, are commonly used for studies to examine diversity (Thompson, 2006).

The important of studing insect species diversity in an ecosystem: to conserve the available biodiversity, to account for the cheangeableness of the future, and to provide sustainability. As well as, serving as pollinators and crop protectors, insect biodiversity and populations are good indicators of ecosystem health and management. The main reason for using insects is because of their abundance, and biodiversity can be documented in continuous surveys.

Thus, the biodiversity of insects in Belette-Gera forests specifically focuses on assessing the diversity and abundance of insect communities in reference to habitat heterogeneity effect and sessional distribution with in the forest. Because of, insects are important in the function of the forest ecosystem such as; nutrient recycle, soil decomposition, pollination, seed dispersal and population regulation of herbivore insects.

Therefore, knowledge of the diversity and abundance of insect communities within the Belette-Gera forest will provide valuable information about the the insect founa of the forest. Inaddition, knowledge of diversity and abundance of insect in reference of habitat hetroginity will show the interaction of insect communities with the vegetation type and land cover of the forest. As as a result, the importance of insects for the survival of the forest ecosystem and attention should be given to conserve both the forest vegetation and insects. Farthermore, the seasonal distribution of insects with in the forest also important to identify insect groups and their seasonal aboundancy with in the forest will invite to study the seasonal variation of vegetation type and their relation with insect communities.

Shannon-Weiner Index and Evenness

One of the most commonly used diversity index is the Shannon-Wiener Index (H'). The Shannon-Wiener Index (H') takes both species richness and the percentage of species in a community into account to determine the uncertainty that an individual picked at random will be of a given species.

The Shannon index has been a popular diversity index in the ecological literature, where it is also known as Shannon's diversity index, the Shannon–Weaver index and the Shannon entropy. The measure was originally proposed by Claude Shannon to quantify the entropy (uncertainty or information content) in strings of text. The idea is that the more different letters there are, and the more equal their proportional abundances in the string of interest, the more difficult it is to correctly predict which letter will be the next one in the string. The Shannon entropy quantifies the uncertainty (entropy or degree of surprise) associated with this prediction. It is most often calculated as follows:

$$H' = -\sum_{i=1}^{S} pilnpi$$

where p_i is the proportion of characters belonging to the ith type of letter in the string of interest. In ecology, p_i is often the proportion of individuals belonging to the ith species in the dataset of interest. Then the Shannon entropy quantifies the uncertainty in predicting the species identity of an individual that is taken at random from the dataset.

Although the equation is here written with natural logarithms, the base of the logarithm used when calculating the Shannon entropy can be chosen freely. Shannon himself discussed logarithm bases 2, 10 and e, and these have since become the most popular bases in applications that use the Shannon entropy. Each log base corresponds to a different measurement unit, which have been called binary digits (bits), decimal digits (decits) and natural digits (nats) for the bases 2, 10 and *e*, respectively. Comparing Shannon entropy values that were originally calculated with different log bases requires converting them to the same log base: change from the base *a* to base *b* is obtained with multiplication by $\log_b a$.

It has been shown that the Shannon index is based on the weighted geometric mean of the proportional abundances of the types, and that it equals the logarithm of true diversity as calculated with $q = 1$.

$$H' = -\sum_{i=1}^{s} pi\ lnpi = -\sum_{i=1}^{S} lnpi^{pi}$$

This can also be written

$$H' = -(lnp1^{p1} + lnp2^{lnp2} + lnp3^{p3} + lnp4^{p4} + \cdots + lnpS^{pS})$$

which equals

$$H' = -\ lnp1^{p1} lnp2^{p2} lnp3^{p3} \ldots lnpS^{pS} = \ ln\left(\frac{1}{p1^{p1}\, p2^{[2}\, p3^{[p3} \ldots pS^{pS}!}\right) = \left(\frac{1}{\prod_{i=1}^{S} pi^{pi}}\right)$$

Since the sum of the p_i values equals unity by definition, the denominator equals the weighted geometric mean of the p_i values, with the p_i values themselves being used as the weights (exponents in the equation). The term within the parentheses hence equals true diversity ${}^{1}D$, and H' equals $\ln({}^{1}D)$.

When all types in the dataset of interest are equally common, all p_i values equal $1 / S$, and the Shannon index hence takes the value $\ln(S)$. The more unequal the abundances of the types, the larger the weighted geometric mean of the p_i values, and the smaller the corresponding Shannon entropy. If practically all abundance is concentrated to one type, and the other types are very rare (even if there are many of them), Shannon entropy approaches zero. When there is only one type in the dataset, Shannon entropy exactly equals zero (there is no uncertainty in predicting the type of the next randomly chosen entity).

Shannon-Wiener Index denoted by $H' = -\sum_{i=1}^{s} pi\ lnpi$

p_i = proportion of total sample represented by species *i*

Divide # of individuals of species *i* by total number of samples

S = number of species, = species richness

$H_{max=}\ ln\ (S)$Maximum diversity possible

$E\ = Evenness = H' / H_{max}$

Simpson's Index (D) is a measure of dominance therefore, (1-D) measures species diversity.

It gives the probability that any two individuals drawn at random from an infinitely large community belong to different species.

Simpson’s Index is expressed as:

$$D = \frac{\Sigma\ ni\ (ni-1)}{N\ (N-1)}$$

Where,

N = total number of individuals encountered in the site

ni = number of individuals of i^{th} species

It is less sensitive to species richness and heavily weighted towards the most abundant species

Measurement of species richness

Species richness is the number of species at a site, which is the simplest and most useful measure of species diversity. It is calculated as:

$$\text{Margalef's index } (R) = (S - 1)/\ln N$$

Where,

S = total number of species

N = total number of individuals in the sample

ln = natural logarithm

So how these indicesused were during your study and what information did you expect from each that would help answer the study objectives?

Chapter 3 GENERAL MATERIALS AND METHODS

3.1 Description of the Study Site

Belette forest is part of Belette Gera National Forest Priority Area. The forest is located in Shebbe Sombo district of Jimma Zone and Oromiya National Regional State, southwestern Ethiopia. It is found along Jimma Bonga main road 45 km away from Jimma town and 375 km away from Addis Ababa to the south west. Geographically, it is found between 7°30' N and 7°45' N and 36°15'E (Belette Gera PFMP, 2006) and elevation ranging between 1300 and 3000 m.a.s.l. (Cheng *et al*., 1998).

Figure 1: Map of the study area.

The forest reserve is categorized into Gera and Belette Branch. The total forest area of Belette branch is about 25,597.94 ha. (Belette Gera PFMP, 2006).

3.1.1. Vegetation and ecology

Belette Forest is one of the remaining mountain rainforests in South-western Ethiopia. The Ethiopian government designated the area part of 'Belette-Gera Forest Priority Area' in 1994. Belette Forest is managed with multiple objectives, including contributing to soil, water and biodiversity conservation and protecting and developing sustainable use of the forest (Mohammed Abdi *et al*., 2003). It consists of a mixed deciduous native forest and recently established plantation forests, and covers an area of 18,324 ha (JICA, 1998). A number of tree, shrub and climber species dominate the mixed deciduous forest. The dominant tree species include *Ilexmitis* (L.). Radelkofer, *Syzygium guineense* (Willd.) D.C., *Verpis daniellii* (Pichi.Serm.) *Koko waro* and *Allophylus abyssinicus* (Hochst.), Radlkofer. There is also a considerable amount of trees of *Macaranga capensis* (Ball.) Sim and *Croton macrostachyus* Del. Dominant climbers include *Hippocratea getzei* (Loes). And *Rubus apetalus* (Poir) and dominant shrubs were *Maytenus arbutifolia* (Hochst. Ex A.Rich.) Wilczek and *Dracaena afromontana* (Mildbr).

The native forest consists of plants that have a C_3 photosynthetic pathway or Calvin cycle (Farquhar, Ehleringer and Hubick, 1989). The plantation part of the forest has an area of 918.7 ha, and is mainly composed of *Eucalyptus saligna*, *E. grandis* (Hill ex Maiden), *E. citriodora, Cupressus lusitanica* (Miller), and the pine *Pinus patula* (Schiede and Deppe) (JICA, 1998). The plantations have been established as even-aged monocultures. The area of the current plantation forests under *C. lusitanica* and *P. patula* was deforested around 1928 and the area was also use as farmland local cmmunity for crop production, mainly maize, until it was set aside in 1981 and afforested in 1983 as part of the government afforestation program. The area under *E. grandis* (Hill ex Maiden) was also deforested at about the same period, but it was first used for pasture before being converted to cropping in 1963, and was finally afforested in 1983 under the national program (Cheng *et al*., 1998). The aim of this afforestation program was to create a buffer zone around the native forest in order to divert pressure away from it. As in most parts of Ethiopia, the farming system practiced on the cleared land was characterized by small households and traditional, rain-fed cropping, usually neither limed nor fertilized. Soils of the study area are largely volcanic in origin and relatively fertile and the dominant soil types are nitosols (Bridges *et al*., 1998). Tertiary volcanic and related volcano-clastic sediments underlie the area (Mohammed Abdi *et al.,* 2003; Murphy, 1968).

3.1.2. Fauna

Several animal species are known to inhabit the montane forest ecosystem of south west forest of Ethiopia (including Belette-Gera Forest) although intensive scientific investigations were lacking in the past. Larger mammals living in this ecosystem include Lion, Leopard, Black Leopard, Serval Cat, Black Common Jackal, Wild Dog, Wild Cat, Bush Pig, Giant Forest Hog, Warthog, Bush Bug, Colobus Monkey, Olive Babbon, Grey Duicker and Bush Babby among others. Although complete inventory is lacking about avean fauna of Belette-Gera forest some of the montane moist forest ecosystem is recognized to be important bird areas of Ethiopia (EWNHS, 1996).

3.1.3. Climate

The mean annual rainfall of the area is between 1800 mm and 2300 mm with maximum rainfall between the months of June and September. The mean annual temperature of the area is between 15^{o}C and 22^{o}C (Briggs and Blatt, 2009).

3.2. Selection of Sampling Site

Insect diversity assessments within the study area were conducted using line transects by categorizing the forest into three sections: wetland habitat, plantation habitat with exotic tree species and natural forest habitat. The starting point of all line transects were lso located randomly in each stand. And also, all sample plots were located at least 50 m from forest edges/road to avoid edge effect. In addition, the sample linetransects was laid down along a distance of 50m from each other where no collection made. There was 12 line transects that were also laid down in each study site.Therefore, all linetransects were made and labeled N1-N12 (Plate 2) for Natural forest habitat, as A1-A12 (Plate 3) for Plantation forest habitat and W1-W12 (Plate 4) for wetland habitat with a piece of iron sheet material and were posted on the tree before data collection were began. Thus, the minimum distance between sites was 900m (between Plantation forest habitat and Natural forest habitat) and the maximum distance was 4km (between Plantation forest habitat and wetland forest habitat. Natural forest habitat was also found between the two habitats.

Each linetransects contained 100 quadrates (a gird of 10m x10m) and were needed to sample 17 quadrates in order to calculate reliable abundance estimates. Samplings begun at some point from which randomely choosen line transect and quadrate with in that line transect and was sampled that quadrate and every 6th quadrate until accumulate a sufficiently robust sample of 17 quadrates. The times spent for sampling was three days in each habitat in order to collect insects from three linetransects.

All naturally found insects were collected from the systematically established quadrates along each transect. Species which were readily identifiable were recorded in the field. For species which were difficult to identify in the field a specimen was preserved in70% ethanol solution in a vial. All collected samples were labeled (site name, plot number, date and method of collection). Identification and counting of collected specimens were done at Addis Ababa University Entomology laboratory.

Plate 3.1: Natural Forest Habitat type of Belette-Gera Forest

Plate 3.2: Plantation Forest Habitat type of Belette-Gera Forest

Plate 3.3: Wet land Habitat type of Belette-Gera Forest

3.3. Data Collection

Collection was done randomly using sweep nets, screen trap, hand picking and pitfall traps. Sampling was done from September, 2013 to August, 2015 every two months. Therefore, insect collection was done randomly using sweep nets, screen trap, hand picking and pitfall traps. These methods could be used to compare insect communities in different habitats or across different habitats or across different seasons and can also be used for long term monitoring of changes in tropical habitats (Stork, 1988).

3.3.1. Sampling methods

Sweep net: This method was employed to collect insects from vegetation (Plate 3.5). The net used in systematic sweeping off the ground level vegetation was made of thick cotton cloth and it had a diameter of 30 cm at the mouth with 60 cm length.

Each linetransects was divided into 100 quadrates out of which six were chosen for the study. The entire ground level vegetation was considered for sampling following Gradagkar *et al*. (1990) procedure. Likewise, collections were carried out in the early hours of the day between 9:00 am and 11:00 am.The collected insects were transferred into polythene bags containing a cotton wad dipped in chloroform. After being killed insects were preserved in 70% alcohol in a vial.

Pl

Plate 3.4: Insect collecting activities using a Sweep net

Beating net collection: The beating net method as shown in plate 6 was used to collect insects' droppingfrom the vegetation by shaking. The beating cloth measuring 1.2 m by 2m was made of thick cotton cloth. The beating net collection method was carried out after dividing each plot into 100 quadrates from which only 6 were randomly selected for the study following Gradagkar et al., (1990) procedure. Within 6 quadrates 3 plants with approximately 3 m height were chosen. The beating net collection was also done between 10:00 am and 12:00 noon as the action of insectsassociated with vegetation rich during this time. The collected insects were killed and preserved similarto those of the sweep net collection.

Plate 3.5. Insect collection activities using beating net in the plantation forest habitat

Pitfall traps: The pitfall trap consisting of a 2.5 liter plastic jar with an opening of 9 cm in diameter, were buried at ground level and were protected from rain by a plastic plate of about 30 cm diameter supported on a tripod stand about 15 cm above the ground. One pitfall trap was placed in each of the five randomly chosen quadrates. Each jar contained 25 ml of 0.05% methyl parathion. The traps were set up between 1500 and 1700 hrs and the caught insects were collected the next morning. Insects trapped in the jar were preserved in 70% alcohol.

Plate 3.5: Collection of insects using the pitfall traps method in the Natural forest study site

Hand picking: Insects like leaf-miners (Diptera), bark inhabiting beetles, insects living under stones and leaf litters (Coleoptera) were collected by hand picking using flexible forceps to prevent damage of the insect bodies.

Plate 3.6: Hand picking of insect in the natural forest study site

Debarking: using a debarked, Knife, wood chisel or, the operative materials was reached the required states of root or part of the wood (bark, trunk, branches, and stump) when needed to collecte insects from live or dead woods during collection was made. The resulting materials were collected in a plastic tray or a beating sheet for immediate observation. Individual insects were captured using flexible forceps. The collected specimen transfer in to a vile preserved in 70% alcohol.

Plate 3.7: Insect collection by debarking at natural forest study site

3.3.3. Preservation for taxonomic study

The collected insect specimens were pinned with entomological pins, using spreding board to arrenge the wings for taxonomy, after mounting the collection date and other details on a paper lable were attached to the specimen.

3.3.4. Taxonomic keys for identification

Morphological identification of insects was done using binocular microscope, Dichotomous key pictorial key, as far as possible species levels. The collected insect specimens were identified using binocular microscope and identification key at the family, genus and species level with the help of available literatures such as Borror *et al.* (1992), Borror *et al.* (1989) and Carcasson (1975). Besides, books, different drawings of insects, datasheet, specimens of insects in Addis Ababa University museums were used as a means of identifications tools. When identifying and describing insect taxon, morphological characteristics were used to separate species.

Online Insect Identification: West Virginia University Extension [Online]. Available at: http://www.wvu.edu/~agexten/ipm/identify/insectid.htm (verified 17 March 2015), online key to insect orders [Online]. Available at: http://www.kendall-bioresearch.co.uk/key.htm (verified 17 March 2015], Insect Identification Laboratory at Virginia Tech [Online]. Available at: http://www.idlab.ento.vt.edu/ (verified 17 March 2015).

Identification of specimens was done in Biology department ins ect science research laboratory Addis Ababa University. Some of the specimens were identified by counter checking with the existing specimens in the laboratory.

3.4. Data Analysis

Different diversity indices were calculated, of which the widely used Shannon diversity indices were the most important, as it is widely accepted that all species at a site, within and across systematic groups, equally contribute to its biodiversity (Ganeshaiah *et al*., 1997).

3.4.1. Measurement of diversity

For the measurement of diversity Shannon – Wiener diversity index (Shannon, 1948) was used.

Shannon-Wiener Index denoted by H′ = $-\sum_{i=1}^{s} pi\ lnpi$

p$_i$ = proportion of total sample represented by species *i*

Divide # of individuals of species *i* by total number of samples

S = number of species, = species richness

$H_{max=} ln\ (S)$ Maximum diversity possible

$E\ = Evenness = H^{'} / H_{max}$

To calculate H', determine the proportions of each species in the study community, pi, and the 1n~ of each pi. Next, multiply each pi times lnpi and sum the results for all species from species I to species s, where s = the number of species in the community,

A species with higher value of H′ is more diverse than species with lower value of H'. Its advantage is relatively easy to calculate and sensitive to actual site differences. Evenness (E) is an index that makes the H′values comparable between communities or habitats by controlling for the number of species found within the communities. For a given number of species in a community, the highest H′ (H'max) would be represented as:

H'max = lnS (where S = total number of species).

So, when H′ (actual estimate of the community) is divided by H'max, you get the Evenness.

$E = H'/H'max$

E can range from close to 0, where most species are rare and just a few are abundant, to 1, where the potential evenness between species (H'max) is equal to that which will be observed (H'). This Means insect with larger E value has more even distribution (Smith, 1992).

3.4.2. Persentage composition (Persentage)

Patterns of Persentage of species determine the percentage composition of diversity. In this study, the percentage composition of each order, families and individual insects in the study forest were determined by calculating with the following formula:

$$\text{Percentage} = \frac{ni \times 100}{N}$$

Where,

ni = number of insects in the 'i' th family, and

N = the total number of insects in all the families collected in each study year, habitat and season.

To evaluate insect species compositional similarity or variation among habitats, Sorensen's similarity index was used. Sorensen's index (Pielou, 1969) is expressed as:

$$SI = [a / a + b + c] * 100$$

Where,

a = number of species present in both Sites under consideration

b = number of species present in Habitat 1 but absent in Habitat 2

c = number of species present in Habitat 2 but absent in Habitat 1

3.4.4. Measures of species abundance – density, frequency, dominance, and importance

Several standard measures of absolute and relative abundance were used to assess the contribution of each species to a community (Barbour *et al*., 1999). These measures include **density,** the number of individuals within a chosen area (e.g., per m^2, for hectare); **relative density**, the density of one species as a percentage of total density; **frequency**, the percentage of total quadrates or points that contains at least one individual of a given species; **relative frequency**, the frequency of one species as a percentage of total frequency; **dominance,** the total basal area of a given species per unit area within the community; **relative dominance**, the dominance of one species as a percentage of total dominance; and **importance**, expressed as the relative contribution of a species to the entire community expressed as a combination of relative density, relative frequency, and relative dominance.

Insect density, Dominance, frequency and Importance were computed using the following formulas (Brower *et al.,* 1998).

Relative Density = (Individuals of a species/Total individual of all species) × 100

Density = (Relative density of a species/100) × Total density of all species

Dominance = Density of a species × Average dominance value for a species

Relative Dominance = (Dominance for a species/Total dominance for all species) × 100

Frequency = (Number of points at which species occurs/Total number of points sampled)

Relative frequency = (Frequency of a species/Total frequency values for all species) × 100

Importance Value = (Relative density + Relative dominance + Relative frequency + y)/3

Chapter 4 STUDY ON THE DIVERSITY AND ABUNDANCE OF INSECT SPECIES AT BELETTE-GERA FOREST

4.1 Introduction

Insects have been around for more than 400 million years and it could be argued that they are the most successful and enduring life form that has ever arisen on this planet (Samways, 2005). Insects are abundant and ubiquitous. The distributions of insect are from the poles to the equator, from the surface of the sea to the highest peaks and from deserts to rain forests (Chapin, 2002). Diverse as well as abundant, insects comprise roughly half of the Earth's one and a half million known species (Samways, 2005). There are many more species than those to which we have given names and past estimates have been as high as 100 million (Gadagkar *et al*., 1990). The majority view nowadays is that we share the planet with somewhere between 5-15 million species, of which insects will be a sizeable proportion (Gadagkar *et al*., 1990).

Insects are so important to the continued working of the global ecosystems that, as long as the well-being of insects is safeguarded, the Earth should remain habitable for humans (Samways, 2005). Such as; herbivores, predators, parasitoids and as a food source for countless species, insects are fundamental in all terrestrial and aquatic food chains. Put simply, without insects, global ecosystems would disintegrate. Insects pollinate more than a quarter of a million species of flowering plant. Even from a purely anthropocentric view, without pollinators we would lose one third of all the food we eat (Losey and Vaughan, 2006). In addition, insects recycle nutrients, enrich soils and dispose of carcasses and dung (Samways, 2005). And also, insects provide us with silk, honey, waxes, medicines and dyes. We use them to control pests (mostly other insects) and weeds. Consequently, Insects have been revealed as sacred, celebrated in art and literature and eaten as human food (Losey and Vaughan, 2006).

On the other hand, insects are also important for the damage they can do. On average, one fifth of all crops grown around the world are eaten by insects (Elliott *et al*., 1996). They carry a large number of plant, animal and human diseases (New, 1998).

Biodiversity is one of the important cornerstones of sustainable development and represents the biological wealth of a given nation. Species richness provides an extremely useful measurement of diversity where a complete catalogue of species in the community is obtained (Magurran, 1988). Many groups of insects were recognized today. Insects are unique in their own way and have an important ecological role for survival of life on Earth. Great insect diversity is indeed an intrinsic part of the Earth's ecosystem (Samways, 1994).

Belette-Gera Natural Forest has been chosen for the study because of the less knowledge of diversity and abundance of insect communities in the forest.

Objectives

- To determine the diversity of insect community in Belette- Gera Forest.
- To evaluate species diversity and abundance of insect communities in the forest.

4.2. Materials and Methods

This study was conducted at the Belette-Gera forest from September 2013 until August 2015. Samples of insects were collected from three sampling sites that is, Natural forest site, Plantation forest site and wetland site.The sampling, and insect collection methods wer used as outlined in chapter 3.

4.2.1 Methods of data analysis

In this chapter species richness was computed as the total number of insect species encountered in each year. In addition both Shanon-Wiener Diversity index (H') and Evenness (E) were computed for each study year.The formula and the detaiel were used as out lined in chapter 3. Furthermore, paired *t*-test was used in order to know the variations of Shanon-Wiener Diversity index (H') and Evenness (E) value with the study years are statistically different or not.

4.3. Results

4.3.1. Diversity and abundance of insects in different study years at Belette-Gera forest

There were 810 individuals from 13 orders and 95 families were collected and identified in 2013/2014 (Table 4.1). On the other hand, 750 individuals from 11 orders and 88 families were collected and identified in 2014/2015 (Table 4.3). Insect collected in 2013/2014 had the richest species interms of numbers of families 95 insect families and the highest diversity and abundance than 2014/2015, with Shannon's H′value 1.99 and Evenness (E value) of 0.45, while the lowest

Shannon's H′ value and E values are 1.06 and 0.24, respectively in 2014/2015 (Table 4.4). Moreover, the variation of the diversity index (H′) and Evenness (E value) with the study years is shown Appendix 2, the value of diversity index H′ was significantly different with the study years at t = -9.007, df = 21 $P < 0.001$. And also, the value of Evenness (E value) was significantly different with the study years at t = -12.993, df = 21 $P < 0.001$.

The Percentage of insect individuals collected in 2013/2014 with in orders is shown in Table 4.1. Thus, order Coleoptera had contained the largest insect numbers of 231and 28.52%, followed by Hymenoptera, Hemiptera, Orthoptera, Dipteral, Blattodea, Lepidoptera, Isoptera and Odonata with156 (19.26%), 130 (16.05%), 93 (11.48%), 53 (6.3%), 47 (5.8%),40 (4.94%), 39 (4.81%) and 10 (1.23%) respectively.The least numbers of individual and percentage were recorded from Neuroptera, Ephemeroptera, Mecoptera and Dermaptera insect orders.

Table 4.1: Numbers and percentages of insect in different orders and families in 2013 /2014

Order	No. of insects	Percentage of individual insect composition	No. of Families	Percentage family composition
Coleoptera	231	28.52	17	17.9
Hymenoptera	156	19.26	16	16.84
Hemiptera	130	16.05	19	20
Orthoptera	93	11.48	8	8.42
Diptera	51	6.3	14	14.74
Blattodea	47	5.8	4	4.21
Lepidoptera	40	4.94	5	5.26
Isoptera	39	4.81	1	1.05
Odonata	10	1.23	5	5.26
Neuroptera	7	0.86	3	3.16
Mecoptera	3	0.37	1	1.05
Ephemeroptera	2	0.25	1	1.05
Dermaptera	1	0.12	1	1.05
Total	810	100	95	100

As far as species richness interms of number of families was concerned, order Hemiptera had the largest numbers of insect families consisting of 19 families (20%) followed by the order Coleoptera, Hymenoptera, Diptera, Orthoptera Lepidoptera, Odonata Blattodea, and Neuroptera, Mecoptera, Ephemeroptera and Dermaptera (Table 4.1).

The diversity index and Evenness of insects collected from Belette-Gera forest in 2013/2014 is shown inTable 4.1. The Shannon-Wiener Diversity index (H′) and Evenness (E) was the highest for the order Coleoptera with Shannon's H′ value of 1.00, while the lowest Shannon's H′ value of 0.01 was recorded from the insect orders Neuroptera, Mecoptera, Ephemeroptera and Dermaptera.

Evenness (E value) was highest for the order Coleoptera with E value of 0.22. On the ortherhand, the lowest E value of 0.00 was recorded from the insect orders Dermaptera and Mecoptera.

Table 4.2: Species richness, Diversity index and Evenness of the insect community in 2013/2014 (pooled data)

Order	Diversity Index (H')	Evenness (E)
Coleoptera	1	0.22
Hemiptera	0.65	0.14
Hymenoptera	0.63	0.14
Orthoptera	0.5	0.11
Diptera	0.32	0.07
Lepidoptera	0.2	0.04
Blattodea	0.23	0.03
Isoptera	0.15	0.03
Neuroptera	0.05	0.01
Mecoptera	0.02	0.01
Odonata	0.03	0.01
Ephemeroptera	0.02	0.00
Dermaptera	0.01	0.00

From a total of 750 insect specimens collected in the study area in 2014/2015 is shown in Table 4.3. The order Hemiptera had the largest insect numbers consisting of 225 insects (30%) followed by the order Coleoptera, Hymenoptera, Orthoptera, Lepidoptera, Isoptera, Blattodea, Diptera and Odonata. The least number of insect was recorded from the order Neuroptera.

Table 4.3: Numbers and percentages of insect in different orders and families in 2014/2015

Order	# of Insects	Percent composition of insects	Number of family	Percent composition of families
Hemiptera	225	30	19	21.59
Coleoptera	175	23.33	17	19.32
Hymenoptera	138	18.4	11	12.5
Orthoptera	51	6.8	11	12.5
Lepidoptera	46	6.13	5	5.68
Isoptera	40	5.33	1	1.14
Blattodea	28	3.73	3	3.41
Diptera	15	2	10	11.36
Odonata	15	2	5	5.68
Mantodea	11	1.47	4	4.51
Neuroptera	6	0.8	1	1.14
Total	750	100	88	100

From total of 88 insect families collected the order Hemiptera had the largest number of insect families (species richness) consisting of 19 families (21.59%) followed by the order Coleoptera, Orthoptera, Hymenoptera, Diptera, Odonata, Lepidoptera, Mantodea and Blattodea (Table 4.3).The least numbers of families (species richness) were recorded from Isoptera and Neuroptera insect orders.

The diversity index and Evenness of insects collected from Belette-Gera forest in 2014/2015 is shown in Table 4.4. The Shannon–Wiener diversity index (H′) and Evenness (E) were the highest for the order Hemiptera with Shannon's H′ value of 1.06. The lowest Shannon's H′ value of 0.04 was recorded from the insect ordered Neuroptera. Evenness (E value) was highest for the order Hemiptera with E value of 0.24, while the lowest E value of 0.01 was recorded from the insect order Neuroptera.

Table 4.4: Species richness, Diversity index and Evenness of the insect community in 2014/2015 (pooled data)

Order	Diversity index (')	Evenness (E)
Hemiptera	1.06	0.24
Coleoptera	0.89	0.2
Hymenoptera	0.54	0.12
Orthoptera	0.32	0.07
Odonata	0.24	0.05
Lepidoptera	0.24	0.05
Blattodea	0.16	0.04
Isoptera	0.16	0.04
Diptera	0.12	0.03
Mantodea	0.08	0.02
Neuroptera	0.04	0.01

4.3.2. Species richness, Diversity and abundance of insects in Belette-Gera Forest

A total of 1560 individual insects were collected using four collection methods (Arial sweep net, Screen trap, Pitfall trap and Hand picking method), (Appendix 1). The collected individual insects were from 14 Orders and 120 families (Table 4.5). They are Order Blattodea, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Isoptera, Lepidoptera, Neuroptera, Mantodea, Ephemeroptera, Odonata, Orthoptera, Mecoptera and Lepidoptera. From 1560 collected specimens 143 were identified to the family level, 996 were identified to the genus level and 471 were identified to the species level (Appendix 1).

Table 4.5: Orders and Families of Insect Communities at Belette-Gera Forest

Order	Family	# of Insect	pi	lnpi	pilnpi
Coleoptera	Anthribidae	8	0.005128	-5.273	-0.02704
	Buperstidae	6	0.003846	-5.56068	-0.02139
	Carabidae	18	0.011538	-4.46207	-0.05149
	Cerambycidae	26	0.016667	-4.09434	-0.06824
	Chrysomelidae	74	0.047436	-3.04838	-0.1446
	Cleridae	16	0.010256	-4.57985	-0.04697
	Coccinellidae	68	0.04359	-3.13293	-0.13656
	Curcculionidae	24	0.015385	-4.17439	-0.06422
	Erotylidae	1	0.000641	-7.35244	-0.00471
	Glateridae	1	0.000641	-7.35244	-0.00471
	Lagriidae	1	0.000641	-7.35244	-0.00471

Table continued

	Lucanidae	1	0.000641	-7.35244	-0.00471
	Lycidae	5	0.003205	-5.743	-0.01841
	Lygaeidae	1	0.000641	-7.35244	-0.00471
	Meloidae	26	0.016667	-4.09434	-0.06824
	Oryzaephilus	1	0.000641	-7.35244	-0.00471
	Scarabaeidae	54	0.034615	-3.36346	-0.11643
	Silphidae	1	0.000641	-7.35244	-0.00471
	Staphylinidae	38	0.024359	-3.71485	-0.09049
	Tenbrionidae	30	0.019231	-3.95124	-0.07599
	Trongidae	1	0.000641	-7.35244	-0.00471
Hemiptera	Alydidae	1	0.000641	-7.35244	-0.00471
	Aphididae	2	0.001282	-6.65929	-0.00854
	Blissidae	24	0.015385	-4.17439	-0.06422
	Cercopidae	2	0.001282	-6.65929	-0.00854
	Cicadellidae	7	0.004487	-5.40653	-0.02426
	Cicadidae	2	0.001282	-6.65929	-0.00854
	Coreidae	10	0.00641	-5.04986	-0.03237
	Cydinidae	2	0.001282	-6.65929	-0.00854
	Fulgoridae	1	0.000641	-7.35244	-0.00471
	Leptopodidae	3	0.001923	-6.25383	-0.01203
	Lygaeidae	35	0.022436	-3.79709	-0.08519
	Pentatomidae	34	0.021795	-3.82608	-0.08339

Table continued

	Phymatidae	1	0.000641	-7.35244	-0.00471
	Psyllidae	90	0.057692	-2.85263	-0.16457
	Pyrrhocoridae	40	0.025641	-3.66356	-0.09394
	Reduvidae	55	0.035256	-3.34511	-0.11794
	Rhopalidae	19	0.012179	-4.408	-0.05369
	Scutelleridae	3	0.001923	-6.25383	-0.01203
	Tiginidae	6	0.003846	-5.56068	-0.02139
	Naucoridae	1	0.000641	-7.35244	-0.00471
	Membracidae	4	0.002564	-5.96615	-0.0153
	Saldidae	1	0.000641	-7.35244	-0.00471
	Thyreoridae	3	0.001923	-6.25383	-0.01203
	Dictyopharidae	1	0.000641	-7.35244	-0.00471
	Largidae	3	0.001923	-6.25383	-0.01203
	Issidae	3	0.001923	-6.25383	-0.01203
Hymenoptera	Agaonidae	11	0.007051	-4.95455	-0.03494
	Anthophoridae	4	0.002564	-5.96615	-0.0153
	Apidae	9	0.005769	-5.15522	-0.02974
	Bracconidae	10	0.00641	-5.04986	-0.03237
	Bradyphoridae	3	0.001923	-6.25383	-0.01203
	Eumenidae	5	0.003205	-5.743	-0.01841
	Formicidae	192	0.123077	-2.09495	-0.25784
	Gucharistidae	4	0.002564	-5.96615	-0.0153

Table continued

	Megachilidae	1	0.000641	-7.35244	-0.00471
	Pteromallidae	12	0.007692	-4.86753	-0.03744
	Siricidae	1	0.000641	-7.35244	-0.00471
	Sphecidae	4	0.002564	-5.96615	-0.0153
	Tenthredinidae	1	0.000641	-7.35244	-0.00471
	Tiphiidae	1	0.000641	-7.35244	-0.00471
	Ichnomenidae	15	0.009615	-4.64439	-0.04466
	Vespidae	16	0.010256	-4.57985	-0.04697
	Assillidae	1	0.000641	-7.35244	-0.00471
	Pompillidae	2	0.001282	-6.65929	-0.00854
	Chalicidae	2	0.001282	-6.65929	-0.00854
Diptera	Empididae	1	0.000641	-7.35244	-0.00471
	Ephydridae	4	0.002564	-5.96615	-0.0153
	Nemestrinidae	3	0.001923	-6.25383	-0.01203
	Mydidae	1	0.000641	-7.35244	-0.00471
	Phoridae	1	0.000641	-7.35244	-0.00471
	Pyrgomorphidae	1	0.000641	-7.35244	-0.00471
	Sarcophagidae	3	0.001923	-6.25383	-0.01203
	Scarabidae	1	0.000641	-7.35244	-0.00471
	Tachinidae	4	0.002564	-5.96615	-0.0153
	Syrphidae	9	0.005769	-5.15522	-0.02974
	Tephritidae	3	0.001923	-6.25383	-0.01203

Table continued

	Muscidae	17	0.010897	-4.51923	-0.04925
	Bombylidae	4	0.002564	-5.96615	-0.0153
	Assilidae	8	0.005128	-5.273	-0.02704
	Calliphoridae	3	0.001923	-6.25383	-0.01203
	Anthomyiidae	6	0.003846	-5.56068	-0.02139
Blattodea	Blaberidae	5	0.003205	-5.743	-0.01841
	Blatellidae	33	0.021154	-3.85593	-0.08157
	Polyphagidae	3	0.001923	-6.25383	-0.01203
	Blattidae	34	0.021795	-3.82608	-0.08339
Lepidoptera	Hesperidae	3	0.001923	-6.25383	-0.01203
	Lycaenidae	10	0.00641	-5.04986	-0.03237
	Nymphalidae	55	0.035256	-3.34511	-0.11794
	Pamilionidae	14	0.008974	-4.71338	-0.0423
	Pieridae	4	0.002564	-5.96615	-0.0153
Orthoptera	Heteronemiidae	1	0.000641	-7.35244	-0.00471
	Hetrodes	1	0.000641	-7.35244	-0.00471
	Mogoplistidae	4	0.002564	-5.96615	-0.0153
	Pamphagidae	2	0.001282	-6.65929	-0.00854
	Penumoridae	1	0.000641	-7.35244	-0.00471
	Shizoductyilidae	2	0.001282	-6.65929	-0.00854
	Tridactylidae	1	0.000641	-7.35244	-0.00471
	Acrididae	40	0.025641	-3.66356	-0.09394

Table continued

	Bradyporidae	17	0.010897	-4.51923	-0.04925
	Gryllacarididae	24	0.015385	-4.17439	-0.06422
	Gryllidae	27	0.017308	-4.0566	-0.07021
	Pyrgomorphidae	17	0.010897	-4.51923	-0.04925
	Tettigonidae	7	0.004487	-5.40653	-0.02426
Odonata	Aeshnidae	4	0.002564	-5.96615	-0.0153
	Chorocyphidae	3	0.001923	-6.25383	-0.01203
	Cowngrionidae	7	0.004487	-5.40653	-0.02426
	Hemistigma	3	0.001923	-6.25383	-0.01203
	Libelludae	8	0.005128	-5.273	-0.02704
Neuroptera	Myrmeleontidae	3	0.001923	-6.25383	-0.01203
	Chrysopidae	9	0.005769	-5.15522	-0.02974
	Mantispidae	1	0.000641	-7.35244	-0.00471
Mantodea	Hymenopodidae	4	0.002564	-5.96615	-0.0153
	Thespidae	6	0.003846	-5.56068	-0.02139
	Mantidae	4	0.002564	-5.96615	-0.0153
	Sibyllidae	1	0.000641	-7.35244	-0.00471
Mecoptera	Bittacidae	3	0.001923	-6.25383	-0.01203
Dermaptera	Labiduridae	1	0.000641	-7.35244	-0.00471
Ephemeroptera	Leptophelebiidae	2	0.001282	-6.65929	-0.00854
Isoptera	Termitidae	79	0.050641	-2.98299	-0.15106
Total		1560			-3.88034

Shannon-Wiener diversity index (H′)	**H'**	**3.88**
Evenness (E)	**E**	**0.81**
Species richness (# of families)	**S**	**120**

The Shannon's H′ value of 3.88 and Evenness (E value) of 0.81 were recorded from the diversity and abundance of insect communities in Natural forest habitat (Table 4.5), and also the speciesr richness interms of number of insect families was 120. Therefore, the insect families were well diversified consequently most of them were equaly distributed with in it.

The percentage of individual insects within orders is shown in Table 4.6 , order Coleoptera had the largest numbers of individuals consisting of 404 insects (25.9%) followed by Hemiptera, Hymenoptera, Orthoptera, Lepidoptera, Isoptera, Blattodea, Diptera and Odonata 294, 144, 86, 79, 75, 66, 25, 15, 13, 3 and 2 insects, respectively. Conversely, the least insect number was recorded from insect order Dermaptera.

Table 4.6: Numbers and percentages of insect in different orders and families in Belette-Gera forest

Order	Number of insects	Percent composition of individual insect	Number of families	Percent Composition of families
Coleoptera	404	25.9	22	18.33
Hemiptera	353	22.63	26	21.67
Hymenoptera	294	18.85	19	15.83
Orthoptera	144	9.23	13	10.83
Lepidoptera	86	5.51	5	4.17
Isoptera	79	5.06	1	0.83
Blattodea	75	4.81	4	3.33
Diptera	66	4.23	15	12.5
Odonata	25	1.6	5	4.17
Mantodea	15	0.96	4	3.33
Neuroptera	13	0.83	3	2.5
Mecoptera	3	0.19	1	0.83
Ephemeroptera	2	0.13	1	0.83
Dermaptera	1	0.06	1	0.83
Total	1560	100	120	100

Out of 120 insect families collected the order Hemiptera had the largest number of insect families (species richness) consisting of 26 families (21.67%) followed by the order Coleoptera, Hymenoptera, Diptera and Orthoptera which had 22, 19, 15 and 13 insect families, respectively whie, the least number of families were recorded from Ephemeroptera, Dermaptera, Isoptera and Mecoptera insect orders (Table 4.6).

The diversity index and Evenness of insects collected from Belette-Gera forest is shown in Table 4.7. And also, the Shannon-Wiener diversity Index (H') was the highest for the order Coleoptera with Shannon's H′value of 1.77. On the contrary, the lowest Shannon's H′value of 0.01were recorded from Dermaptera, Mecoptera and Ephemeroptera insect orders. Similarly, Evenness (E value) of 0.37 was the highest for the order Coleoptera. To the opposit, the lowest E values of 0.00 were recorded from Neuroptera, Dermaptera, Mecoptera and Ephemeroptera insect orders.

Table 4.7: Species richness, Diversity index and Evenness of the insect community at the Belette-Gera Forest (Pooled data)

Order	Diversity index H'	Evenness (E)
Coleoptera	1.77	0.37
Hemiptera	1.49	0.31
Hymenoptera	1.19	0.25
Orthoptera	0.62	0.13
Lepidoptera	0.4	0.08
Blattodea	0.32	0.07
Isoptera	0.32	0.07
Diptera	0.3	0.06
Odonata	0.12	0.02
Mantodea	0.07	0.01
Neuroptera	0.05	0
Ephemeroptera	0.01	0
Dermaptera	0.01	0
Mecoptera	0.01	0

4.4.3. Measure of species abundance frequency, dominance, density and importance of insects

Abundance of insect communities in the study forest was calculated based on area method (Brower *et al*., 1998) in order to know the frequency, density, dominance and important value of a family. Table 4.8 showed the frequency, density, dominance and important value of insects in Belette-Gera Forest. A total of 1560 collected individuals from 14 orders and 120 families were identified (Table 4.8). Family Formicidae was the most dominant insect family with 192 individual insects (12.31%). Among 120 insect families 31 of them were the least occurred (0.06%), (Table 4.8).

Dominance value expresses a given family (species) occupied with in a community per unit area From the result Dominance value is shown in Table 4.8, Family Formicidae had the highest per unit area in the forest with dominance value of 0.105/m^2. On the other hand, among 120 families 40 families were recorded with the least Dominance value of 0.001/m^2, (Table 4.8).

Consequently, the most frequently occurring and highest dominant families in the forest were Formicidae 0.028 and 0.028 m^2. To the contrary, out of 120 families 55 were recorded the least frequently occurring and the least dominance value 0.001 and 0.001 m^2 (Table 4.8). Then, the highest importance value was recorded in family Formicidae (0.0798). Nevertheless, out of 120 families 31 of them were recorded the least important value with important value of 0.001 (Table 4.8).

Table 4.7: Abundance, Density, Frequency, Dominance and Important value of insect families in Belette-Gera Forest

Order	Family	NI	D	RD	Do	F	RF	RD	Imp
Coleoptera	Anthribidae	8	0.004	0.005	0.003	0.003	0.007	0.007	0.0062
	Buperstidae	6	0.003	0.004	0.003	0.003	0.006	0.006	0.005
	Carabidae	18	0.01	0.012	0.008	0.008	0.016	0.016	0.0143
	Cerambycidae	26	0.014	0.017	0.009	0.009	0.019	0.019	0.0182
	Chrysomelidae	74	0.040	0.047	0.026	0.026	0.053	0.053	0.0508
	Anthicidae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Cleridae	16	0.009	0.010	0.008	0.008	0.016	0.016	0.0138
	Coccinellidae	68	0.037	0.044	0.022	0.022	0.045	0.045	0.0443
	Curcculionidae	24	0.013	0.015	0.009	0.009	0.018	0.018	0.0170
	Erotylidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Glateridae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Lagriidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Lucanidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Lycidae	5	0.003	0.003	0.003	0.003	0.006	0.006	0.0048
	Lygaeidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Meloidae	26	0.014	0.017	0.010	0.01	0.021	0.021	0.0198
	Oryzaephilus	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Scarabaeidae	54	0.029	0.035	0.017	0.017	0.036	0.036	0.0354
	Silphidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Table continued

	Staphylinidae	38	0.021	0.024	0.014	0.014	0.028	0.028	0.0267
	Tenbrionidae	30	0.016	0.019	0.011	0.011	0.023	0.023	0.0221
	Trogidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Hemiptera	Alydidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Aphididae	2	0.001	0.001	0.001	0.001	0.001	0.001	0.0012
	Blissidae	24	0.013	0.015	0.005	0.005	0.010	0.01	0.0118
	Cercopidae	2	0.001	0.001	0.001	0.001	0.002	0.002	0.0019
	Cicadellidae	7	0.004	0.004	0.002	0.002	0.004	0.004	0.0045
	Cicadidae	2	0.001	0.001	0.001	0.001	0.001	0.001	0.0012
	Coreidae	10	0.005	0.001	0.005	0.005	0.011	0.011	0.0096
	Cydinidae	2	0.001	0.001	0.001	0.001	0.002	0.002	0.0019
	Fulgoridae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Leptopodidae	3	0.002	0.002	0.001	0.001	0.002	0.002	0.0021
	Lygaeidae	35	0.019	0.022	0.014	0.014	0.029	0.029	0.0268
	Pentatomidae	34	0.019	0.022	0.011	0.011	0.022	0.022	0.0222
	Phymatidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Psyllidae	90	0.049	0.058	0.02	0.02	0.040	0.040	0.0460
	Pyrrhocoridae	40	0.022	0.026	0.012	0.011	0.022	0.022	0.0234
	Reduvidae	55	0.03	0.035	0.015	0.015	0.030	0.030	0.0319
	Rhopalidae	19	0.010	0.012	0.005	0.005	0.010	0.010	0.0108
	Scutelleridae	3	0.002	0.002	0.001	0.001	0.001	0.001	0.0014
	Tiginidae	6	0.003	0.004	0.003	0.003	0.007	0.007	0.0058

Table continued

	Naucoridae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Membracidae	4	0.002	0.003	0.001	0.001	0.002	0.002	0.0023
	Saldidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Thyreoridae	3	0.002	0.002	0.001	0.001	0.001	0.001	0.0014
	Dictyopharidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Largidae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Issidae	3	0.002	0.002	0.001	0.001	0.001	0.001	0.0014
Hymenoptera	Agaonidae	11	0.006	0.007	0.002	0.002	0.004	0.004	0.0053
	Anthophoridae	4	0.002	0.003	0.001	0.001	0.002	0.002	0.0023
	Apidae	9	0.005	0.006	0.004	0.004	0.009	0.009	0.0079
	Bracconidae	10	0.005	0.001	0.002	0.002	0.004	0.004	0.0051
	Cicindelinae	3	0.002	0.002	0.001	0.001	0.001	0.001	0.0014
	Eumenidae	5	0.003	0.003	0.001	0.001	0.002	0.002	0.0026
	Formicidae	192	0.105	0.123	0.028	0.028	0.058	0.058	0.0798
	Gucharistidae	4	0.002	0.003	0.001	0.001	0.002	0.002	0.0023
	Megachilidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Pteromallidae	12	0.007	0.008	0.001	0.001	0.002	0.002	0.0041
	Siricidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Sphecidae	4	0.002	0.003	0.001	0.001	0.002	0.002	0.002
	Tenthredinidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Tiphiidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Ichnomenidae	15	0.008	0.01	0.003	0.003	0.007	0.007	0.0077

Table continued

	Vespidae	16	0.009	0.010	0.003	0.003	0.007	0.007	0.0079
	Cicadidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Pompillidae	2	0.001	0.001	0.001	0.001	0.001	0.001	0.0012
	Chalicidae	2	0.001	0.001	0.001	0.001	0.001	0.001	0.0012
Diptera	Empididae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Ephydridae	4	0.002	0.003	0.001	0.001	0.002	0.002	0.0023
	Mydidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Phoridae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Nemestrinidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Sarcophagidae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Sciaridae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Tachinidae	4	0.002	0.003	0.002	0.002	0.004	0.004	0.0038
	Syrphidae	9	0.005	0.006	0.004	0.004	0.008	0.008	0.0071
	Tephritidae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Muscidae	17	0.009	0.011	0.005	0.005	0.011	0.011	0.0111
	Bombylidae	4	0.002	0.003	0.002	0.002	0.004	0.004	0.0038
	Assilidae	8	0.004	0.005	0.002	0.002	0.004	0.004	0.0047
	Calliphoridae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Anthomyiidae	6	0.003	0.004	0.003	0.003	0.006	0.006	0.0050
Blattodea	Blaberidae	5	0.003	0.003	0.002	0.002	0.004	0.004	0.0040
	Blatellidae	33	0.018	0.021	0.010	0.010	0.021	0.021	0.0212
	Polyphagidae	3	0.002	0.002	0.001	0.001	0.002	0.002	0.0021

Table continued

	Blattidae	34	0.019	0.022	0.011	0.011	0.022	0.022	0.0222
Lepidoptera	Hesperidae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Lycaenidae	10	0.005	0.001	0.001	0.005	0.011	0.011	0.0096
	Nymphalidae	55	0.03	0.035	0.026	0.026	0.053	0.053	0.0468
	Papilionidae	14	0.008	0.01	0.007	0.007	0.013	0.013	0.0119
	Pieridae	4	0.002	0.003	0.002	0.002	0.004	0.004	0.0038
Orthoptera	Heteronemiidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Hetrodes	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Mogoplistidae	4	0.002	0.003	0.002	0.002	0.003	0.003	0.0031
	Pamphagidae	2	0.001	0.001	0.001	0.001	0.001	0.001	0.0012
	Penumoridae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Shizoductyilidae	2	0.001	0.001	0.001	0.001	0.002	0.002	0.0019
	Tridactylidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Acrididae	40	0.022	0.026	0.011	0.011	0.023	0.023	0.0242
	Bradyporidae	17	0.009	0.011	0.005	0.005	0.010	0.010	0.0103
	Gryllacarididae	24	0.013	0.015	0.009	0.009	0.019	0.019	0.0178
	Gryllidae	27	0.015	0.017	0.009	0.009	0.018	0.018	0.0177
	Pyrgomorphidae	17	0.009	0.011	0.005	0.005	0.010	0.010	0.0103
	Tettigonidae	7	0.004	0.004	0.003	0.003	0.007	0.007	0.006
Odonata	Aeshnidae	4	0.002	0.003	0.002	0.002	0.003	0.003	0.0031
	Chorocyphidae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Coenagrionidae	7	0.004	0.004	0.003	0.003	0.007	0.007	0.006

Table continued

	Hemistigma	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
	Libelludae	8	0.004	0.005	0.003	0.003	0.007	0.007	0.0062
Isoptera	Termitidae	79	0.043	0.051	0.015	0.015	0.031	0.031	0.0377
Neuroptera	Chrysomella	3	0.002	0.002	0.001	0.001	0.002	0.002	0.0021
	Chrysopidae	9	0.005	0.006	0.004	0.004	0.008	0.008	0.0071
	Mantispidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Mantodea	Hymenopodidae	4	0.002	0.003	0.002	0.002	0.003	0.003	0.0031
	Thespidae	6	0.003	0.004	0.003	0.003	0.006	0.006	0.0050
	Mantidae	4	0.002	0.002	0.002	0.002	0.004	0.004	0.0038
	Sibyllidae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Mecoptera	Bittacidae	3	0.002	0.002	0.002	0.002	0.003	0.003	0.0029
Dermaptra	Labiduridae	1	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Ephemeroptera	Leptophelebiidae	2	0.001	0.001	0.001	0.001	0.001	0.001	0.0012
		1560			0.487	0.487			

NI = Number of individual, D = Density, RD = Relative density, Do = Dominance, F = Frequency, RF = Relative Frequency, RD = Relative Density and IMP = Important Value

4.5. Discussion

In order to know the diversity of insect species in a particular forest ecosystem, species richness provides an extremely useful measurement of diversity where a complete catalogue of species in the community is obtained (Magurran, 1988). Accordingly, many groups of insects were recognized in the study from Belette-Gera forest, for example, Order Blattodea, Coleoptera, Dermaptera, Diptera, Hemiptera, Hymenoptera, Isoptera, Lepidoptera, Mantodea, Neuroptera, Odonata, Orthoptera, and Ephemeroptera. They are unique in their own way and have an important ecological role for survival of life in the forest.

The insect family Formicidea was the most frequently occurring and the highest dominant familes in the forest. Thus, insect species which belong to this family might have different mode of adaptation within the study forest, which is why frequently observed in the study forest ecosystem.

Farther more, Formicidae, Chrysomelidae, Nymphalidae, Psyllidae, Coccinellidae, Termittidae, Scarabidae, Reduvidae, Lygaeidae and Staphylinidae insect families were the first ten families recorded with the highest importance value in the forest ecosystem. This can be due to their ability to navigate across all trophic levels and participated in the provision of services to the forest ecosystems. To mentioned, nutrient recycling, seed dispersal and pollinating, as insect predators and parasitoids, serve as food for other organisms etc. So that, they are important in ecosystem functioning.

The above idea was also supported by different outers. Insects have several functions in the ecosystem. For example, ants are abundant insects, a large component of the insect community on ground in forest ecosystems and provide service in seed dispersa, pollinating, nutrient recycling, controlling herbivores insects, insect predators and parasitoids (Sakchoowong*et al*., 2008) and are considered important in ecosystem functioning. They have diverse ecological roles, including nutrient cycling, seed dispersal, and population regulation of other insects and constitute fractions of animal biomass in terrestrial ecosystems (Fergnani *et al*., 2008; Graham *et al*., 2004). Some species of Staphylinidae (Coleoptera) are cosmopolitan; species-rich particularly in the tropics (Hawes *et al*., 2009). Chrysomelidae, Coccinellidae, Scarabidae and Staphylinidae are insect families which belong to Coleoptera. These families are important in decomposition, nutrient cycling, pollination, seed dispersal and control of other animal populations (Davis *et al*., 2001; Costa, 2000), which contribute to keep the stability insect fauna and and the vegetation within Belette-Gera forest ecosystem. That is why the above mentioned insect families were recorded the highest important value within the forest ecosystem.

Results of this study demonstrated that Belette-Gera Forest has high diversity and abundance of insect fauna. The highest insect species richness and diversity in the forest could be as a result of higher diversity of plant species. A number of trees, shrubs and climber species dominate the mixed deciduous forest. The dominant tree species include *Ilex mitis* (L.). Radelkofer, *Syzygium guineense* (Willd.) D. C., *Verpis daniellii* (Pichi.Serm.) Kokowaro and *Allophylus abyssinicus* (Hochst.), Radlkofer. There is also a considerable amount of trees of *Macaranga capensis* (Ball.) Sim and *Croton macrostachyus* Del. Dominant climbers include *Hippocratea getzei* (Loes). And *Rubus apetalu*s (Poir) and dominant shrubs are *Maytenus arbutifolia* (Hochst. Ex A. Rich.) Wilczek and *Dracaena afro montana* (Mildbr) (Kiflay Gebrehiwot and Kitesa Hundera, 2014Ehleringer and Hubick, 1989). Because of the diverse nature of indigenous plant species in protected forests, insects of different mode of foraging behaveours are more attracted to the diversified plant species for the forging purpose. Consequently, the diversity and abundance of insect community could be increased (FAO, 2001). In addition, large patches of forest plant usually provide higher heterogeneity and thereby support different insect communities (Ricklefs and Lovette, 1999).

The majority of insects found in this forest belonged to the order Coleoptera (25%). This is because the Families of Chrysomelidae, Scarabidae, Staphylinidae and Tenbrionidae occurred most of the time in this study. The success of the group is due, mainly, to the presence of hardened fore wings, the ability to consume a wide variety of materials and holometabolia (Costa, 2000; Daly *et al*., 1998), characteristics that have enabled the conquest of different environments during their evolution. Insects of this order are important in decomposition, nutrient cycling, pollination, seed dispersal and control of other animal populations (Davis *et al*., 2001; Costa, 2000). In addition, order Coleoptera was the most diversified order with Shannon's H′ value of 1.77 and with Evenness (E value) of 0.37. Because of most of the families of this order are rich individuals distributed equally within the community than the rest of the orders.

The National forest has diverse topography, vegetative features and climate with splendid natural settings which directly affect the diversity and occurrence of insect species. These willcomprise various list of food and suitable climatic conditions, and may also include shelter from disturbance and natural enemies that provide suitable environment for the coexistence of insect species (Uniyal and Mathur, 1998).

There were a decline of numbers of individual insect, number of insect orders and numbers of insect families during 2014/2015 study year than 2013. On 2013/2014 Coleoptera possessed the largest insect numbers of 231 insects (28.52%), and the highest diversified insect order with Shannon's H′ value of 1.00 and E value of 0.1. On the other hand, order Hemiptera had the largest numbers of insect families consisting of 19 families (20%).

However, in 2014/2015 insect order Hemiptera possessed the largest insect number of 225 insects (30%) and also it had the largest insect families consisting of 19 families (21.59%). Moreover, it was the highest abundantly and diversified order with Shannon's H′value of 1.06 and Evenness (E value) of 0.24. On the other hand, the declines of insect numbers were observed in Coleoptera and Hymenoptera insect orders.

One possible explanation for a positive relationship between food plant and insect species richness is that, a greater number of plant species could potentially provide more niches for the coexistence of insect species. Therefore, there might be insect species of this group physiologically and beheaveraly respond posetvely towards the biotic and abiotic factors of the forest which, encourage the growth and development insects that belong to insect order Hemiptera than the remaining insect orders was observed in the study forest in 2014/2015.

Not only fluctuations of insect population were observed in Coleoptera, Hymenoptera and Hemiptera insect orders, but also remarkable decreasing were shown in other insect orders in 2014/2015. There were less number of insect individuals and insect families in Blattodea and Diptera insect orders, whereas insect orders Lepidoptera and Isoptera were recorded less number of individuals in 2014/2015 than 2013/2014 but, numbers of insect families remain constant in both study years. On the contrary, increasing both numbers of individuals and families were observed in order Orthoptera and Odonata. Therefore, the diversity and abundance of insect species in a particular area might be fluctuating due to different biotic and abiotic factors in different collection years.

In addition, in 2014/2015 there were global climatic changes were observed. Eventhough, the risk was not that mach as observed North Eastern and Eastern part of the Ethioia the slight climitic change that happened in the study area to some extent were influenced the forest vegitation and also herbivory insects.This could be the reason for the declining of diversity and abundance of insect communities were recorded in the last study year.

Numerous studies share the above mentioned environmental variation both biotic and abiotic factors observed in different years affect the diversity and abundance of insects. Schoonhoven *et al*. (2005), suggested that both plants inter and intra-species variation in traits that directly or indirectly affect herbivores and other insects resulting in greater insect diversity. The direct interaction between plants and herbivores can be modified through variation in plant quality and quantity. The increasing and decreasing of insect populations in a wide variety of systems ranging from grasslands to forests have demonstrated that plant diversity contributes to insect diversity (Perner *et al*., 2003; Crisp *et al*., 1998; Siemann, 1998; Southwood*et al*., 1979). Increased diversity and⁄or functional diversity of plant species can be increases the potential diversity mechanisms by which plants can influence insect herbivores and their enemies (Perner *et al*., 2003; Siemann, 1998; Price *et al*., 1980).

In Belette-Gera forest among the four collection methods used in the study about 43.91%, insects which belong to different orders, were collected directly from different shrubs in the forest through screen trap. In this case most of the collected insects were attached to the understory forest vegetation. Therefore, the forest plant diversity might be important foraging area for herbivore insects. In addition, the diversified vegetation of the forest might encourage the potential of insect diversity; by providing shelter, oviposition site, food resource and hiding from their enemies.

Moreover, much of the diversity of insects and plants in terrestrial ecosystems can be attributed to the extensive interactions between these two groups, both through herbivory (Ehrlich and Raven, 1964) and pollination (Kevan and Baker, 1983). Insects are the major herbivores in most terrestrial ecosystems, accounting for up to 80% of the total plant consumption in the system (Price, 1997) and they are extremely important to the functioning of the community (Slansky and Scriber, 1985; Wiegert and Evans, 1967;).

In this study the diversity and abundance of order Diptera were very low. Only 66 individuals of insect specimens from the order Diptera were collected throughout the study. This is 4.23% of the total collection. From a total of 66 individual insects 15 insect families were identified and which is 12.5 % of the total families. Therefore, most of the insect species of this family can be canopy level dwelers, as most of the insect species which belong to deptera are adapted to the canopy of the forest. Or, some other unkown factors that need a scientific study about the less distribution of family Diptera with in Belette-Gera forest ecosystem.

Overall, Belette-Gera forest has a good diversity and abundance of insect community. Their diversity is due to the presence of diversified plant species with in the forest. And also, the diversity and abundance of insect communitiies were varying between the study years. Consequently, insect species which were diversified and abundantly found within the forest are important in ecosystem functioning.

Chapter 5 THE INFLUENCE HABITAT DIFFERENCES ON THE DIVERSITY AND ABUNDANCE OF INSECT SPECIES INBELETTE- GERA FOREST

5.1. Introduction

Elucidation of the factors that control species diversity and community composition in local habitats is essential for protecting biodiversity in small habitats. Many relevant studies have been conducted such as the ratio of habitat edge to interior (Radelof *et al*., 2000), the isolation of habitat fragments, particularly regarding the development of efficient monitoring methods and conservation practices (Rosenzweig, 1995). Some studies have suggested that environmental heterogeneity (Kruess and Tscharntke, 2002) and ecosystem size and patch diversity (Haddad *et al*., 2001) all are crucial factors determining diversity and community structure in local habitats. In addition, species richness is believed first to increase, and then to decrease according to the productivity of an ecosystem, thereby producing a hump-shaped relationship (Rosenzweig, 1995). These findings are important when predicting community composition.

The factors that determine local community structures in natural systems are complicated by the range of processes and interactions occurring across trophic guilds (Chapin *et al*., 2002). To understand the conservation of a whole community within an ecosystem, these interactions must be considered. However, previous empirical and theoretical studies have mainly focused on restricted numbers of organism groups, in order to reduce the complexity of the relationships with biotic and abiotic factors, and also to simplify interpretation of the results (Price, 1997).

Similarities among different community assemblages at the same location may facilitate ecological understanding and yield new insights, by highlighting similarities and differences regarding the way in which different assemblages respond to the environment (Perner *et al*., 2005).

Work on the effect of habitat fragmentation on insects has several implications for landscape management aimed at population survival. First, increasing similarity of habitat patches (i.e., homogenization of landscape) homogenizes species assemblages among habitat patches (Debinski and Holt, 2000).

In order to maintain diverse species assemblages in a landscape, it is important to maintain heterogeneity of habitat. Given the importance of movement to the spatial ecology of insects, it should be no surprise that the size and physical arrangement of habitat patches on landscape plays a fundamental role in determining the abundance and diversity of insects (Gibbs and Stanton, 2001). Because every habitat type has specific structural characteristics and assume that various habitat types contain differential insect communities. In addition no study had been carried out with in the forest to ascertain the impact of habitat fragmentation, modification, and loss, on the composition and diversity of the insect populations (Golden and Crist, 2000).

There fore, the hypothesis of the study was habitat fragmentations in Belette-Gera forest have effect on insect species diversity and abundance. Consequently, this study was a step in that direction. It was conducted with a view to providing a comprehensive understanding on the effect of habitat fragmentation on insect populations in the forest and to establish a baseline upon which further monitoring and studies could be based.

Objectives

The objectives of the study were to:

- To identify the insect species in the identified habitats,
- To determine and compare the diversity of insect species among the different fragments and ascertain the level of similarity or otherwise of insect species assemblages between each pair of the fragmented habitat

5.2. Materials and Methods

5.2.1 Description the study habitat

Considering Belette-Gera Forest the study defined three habitat types. These habitats were easily categorized as Natural Forest Habitat, Plantation Forest Habitat and Wet land Habitat in order to test the influence of habitat difference on the diversity and abundance of insect species. The distance between Natural forest habitat and Plantation forest habitat was about 900 m. And also, the main road from Jimma to Mizan town was accrossed them. Whereas, the wetland habitat was far away from the above mentioned habitats about 4km on the way to Jimma town Moreover, the fragmented sites were also chosen to reflect varying land use/land cover types (dominant vegetation) and degrees of disturbance.

5.2.2. Data collection

The sampling and insect collection methods were used as outlined in chapter 3.

5.2.3. Methods of data analysis

In this chapter species richness was computed as the total number of insect species encountered in each habitat. In addition both Shannon –Wiener Diversity index and Evenness (E) were computed for each study habitat. Then, Sorenes index were used to compare species similarity between habitats. And also, the details were given in section 3:4. Consequently, And also, paired *t*-test was used in order to know the variations of Shanon-Wiener Diversity index (H') and Evenness (E) value with habitat type are statically different or not.

5.3. Results

5.3.1. Species richness and abundance of insects in natural forest habitat

A total of 620 individual insects from 12 orders and 85 families were collected in two years is shown in Table 5.1. Order Hemiptera had the largest insect individuals consisting of 151 insects (24.35 %) followed by Coleoptera, Hymenoptera, Lepidoptera, Orthoptera, Isoptera Blattodea, Mantodea, Neuroptera, Odonata and Isoptera. On the otherhand, the least number of individual insects was recorded from the order Mecoptera.

Table 5.1: Orders and families of insect communities at natural forest habitat

Order	Family	# of insects	Pi	lnpi	pilnpi
Blattodea	Blatellidae	13	0.020968	-3.86477	-0.08104
	Blattidae	17	0.027419	-3.59651	-0.09861
	Polyphagidae	3	0.004839	-5.33111	-0.0258
	Blaberidae	1	0.001613	-6.42972	-0.01037
Coleoptera	Anthribidae	8	0.012903	-4.35028	-0.05613
	Buperstidae	1	0.001613	-6.42972	-0.01037
	Carabidae	8	0.012903	-4.35028	-0.05613
	Cerambycidae	8	0.012903	-4.35028	-0.05613
	Chrysomelidae	20	0.032258	-3.43399	-0.11077
	Anthicidae	3	0.004839	-5.33111	-0.0258
	Cleridae	9	0.014516	-4.23249	-0.06144
	Coccinellidae	33	0.053226	-2.93321	-0.15612
	Curcculionidae	15	0.024194	-3.72167	-0.09004
	Glateridae	1	0.001613	-6.42972	-0.01037
	Lagriidae	1	0.001613	-6.42972	-0.01037
	Lycidae	5	0.008065	-4.82028	-0.03887
	Lygaeidae	1	0.001613	-6.42972	-0.01037
	Meloidae	3	0.004839	-5.33111	-0.0258
	Trogidae	1	0.001613	-6.42972	-0.01037
	Scarabaeidae	13	0.020968	-3.86477	-0.08104

Table continued

	Staphylinidae	10	0.016129	-4.12713	-0.06657
	Tenbrionidae	10	0.016129	-4.12713	-0.06657
Diptera	Anthomyiidae	3	0.004839	-5.33111	-0.0258
	Asilidae	1	0.001613	-6.42972	-0.01037
	Nemestrinidae	1	0.001613	-6.42972	-0.01037
	Phoridae	1	0.001613	-6.42972	-0.01037
	Ephydridae	4	0.006452	-5.04343	-0.03254
	Calliphoridae	2	0.003226	-5.73657	-0.01851
	Tephritidae	1	0.001613	-6.42972	-0.01037
	Muscidae	8	0.012903	-4.35028	-0.05613
	Syrphidae	4	0.006452	-5.04343	-0.03254
Hemiptera	Reduvidae	35	0.056452	-2.87437	-0.16226
	Pyrrhocoridae	4	0.006452	-5.04343	-0.03254
	Psyllidae	56	0.090323	-2.40437	-0.21717
	Pentatomidae	13	0.020968	-3.86477	-0.08104
	Lygaeidae	7	0.01129	-4.48381	-0.05062
	Membracidae	3	0.004839	-5.33111	-0.0258
	Naucoridae	1	0.001613	-6.42972	-0.01037
	Phymatidae	1	0.001613	-6.42972	-0.01037
	Leptopodidae	3	0.004839	-5.33111	-0.0258
	Coreidae	4	0.006452	-5.04343	-0.03254
	Blissidae	14	0.022581	-3.79066	-0.0856

Table continued

	Issidae	2	0.003226	-5.73657	-0.01851
	Largidae	2	0.003226	-5.73657	-0.01851
	Alydidae	1	0.001613	-6.42972	-0.01037
	Dictyopharidae	1	0.001613	-6.42972	-0.01037
	Cercopidae	1	0.001613	-6.42972	-0.01037
	Cixiidae	1	0.001613	-6.42972	-0.01037
	Fulgoridae	1	0.001613	-6.42972	-0.01037
	Tiginidae	1	0.001613	-6.42972	-0.01037
	Tenthredinidae	1	0.001613	-6.42972	-0.01037
Hymenoptera	Eumenidae	3	0.004839	-5.33111	-0.0258
	Asilidae	1	0.001613	-6.42972	-0.01037
	Siricidae	1	0.001613	-6.42972	-0.01037
	Agaonidae	9	0.014516	-4.23249	-0.06144
	Tiphiidae	1	0.001613	-6.42972	-0.01037
	Formicidae	58	0.093548	-2.36928	-0.22164
	Vespidae	9	0.014516	-4.23249	-0.06144
	Apidae	2	0.003226	-5.73657	-0.01851
	Bracconidae	2	0.003226	-5.73657	-0.01851
	Ichneumonidae	6	0.009677	-4.63796	-0.04488
	Pteromalidae	5	0.008065	-4.82028	-0.03887
	Sphecidae	3	0.004839	-5.33111	-0.0258
Isoptera	Termitidae	39	0.062903	-2.76616	-0.174

Table continued

Lepidoptera	Hesperiidae	3	0.004839	-5.33111	-0.0258
	Lycaenidae	5	0.008065	-4.82028	-0.03887
	Nymphalidae	31	0.05	-2.99573	-0.14979
	Papilionidae	9	0.014516	-4.23249	-0.06144
	Pieridae	2	0.003226	-5.73657	-0.01851
Mantodea	Hymenopodidae	1	0.001613	-6.42972	-0.01037
	Thespidae	4	0.006452	-5.04343	-0.03254
	Mantidae	4	0.006452	-5.04343	-0.03254
Mecoptera	Bittacidae	2	0.003226	-5.73657	-0.01851
Neuroptera	Chrysopidae	8	0.012903	-4.35028	-0.05613
Odonata	Aeshnidae	1	0.001613	-6.42972	-0.01037
	Chlorocyphidae	1	0.001613	-6.42972	-0.01037
	Gomphidae	2	0.003226	-5.73657	-0.01851
	Libellulidae	3	0.004839	-5.33111	-0.0258
Orthoptera	Acrididae	6	0.009677	-4.63796	-0.04488
	Bradyporidae	2	0.003226	-5.73657	-0.01851
	Gryllacarididae	16	0.025806	-3.65713	-0.09438
	Gryllidae	13	0.020968	-3.86477	-0.08104
	Penumoridae	1	0.001613	-6.42972	-0.01037
	Pyrgomorphidae	2	0.003226	-5.73657	-0.01851
	Tettigoniidae	4	0.006452	-5.04343	-0.03254
Total		620			-3.7415

Shannon-Wienr diversity index (H′)	**3.74**
Evenness (E)	**0.84**
Speciess richness (# of families)	**85**

The Shannon's H′ value of 3.74 and Evenness (E value) of 0.84 were recorded from the diversity and abundance of insect communities in Natural forest habitat (Table 5.1), and also the species richness interms of number of families 85 insect families was recorded Therefore, the insect families were well diversified consequently most of them were equaly distributed with in it.

Numbers of families and Persentage among orders is shown Table 5.2, order Hemiptera had the largest numbers of insect families (species richness) consisting of 19 families (22.35%) followed by Coleoptera, Hymenoptera, Diptera, Orthoptera, Lepidoptera, Odonata, Blattodea, Mantodea and Neuroptera The least number of insect families was recorded from the order Mecoptera and Isoptera.

Table 5.2: Numbers and percentages of insects in different orders and families from the natural forest habitat

Order	# of Insects	Percent composition	Number of families	Percent composition
Hemiptera	151	24.35	19	22.35
Coleoptera	150	24.19	18	21.18
Hymenoptera	101	16.29	12	14.12
Lepidoptera	50	8.06	5	5.88
Orthoptera	44	7.1	7	8.24
Isoptera	39	6.29	1	1.18
Blattodea	34	5.48	4	4.71
Diptera	25	4.03	9	10.59
Mantodea	9	1.45	3	3.53
Neuroptera	8	1.29	2	2.35
Odonata	7	1.13	4	4.71
Mecoptera	2	0.32	1	1.18
Total	620	100	85	100

From the result of Shannon–Wiener diversity index (H′) and Evenness (E) (Table 5.3), the highest Shannon–Wiener diversity index (H') was recorded for the order Coleoptera with Shannon's H′ value of 1.22 followed by Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Blattodea, Diptera, Isoptera, Mantodea, Odonata and Neuroptera insect orders with . The lowest Shannon's H′ value of 0.02 was recorded from order Mecoptera. (Table 5.3).

From the result of Evenness (E) (Table 5.3), the highest was recorded for the order Coleoptera with E value of 0.27 followed by Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Blattodea, Diptera, Isoptera, Mantodea, Odonata and Neuroptera insect orders.On the contrary, the lowest was recorded from order Mecoptera with E value of nill.

Table 5.3: Species richness, Diversity Index (H') and Evenness (E) of species diversity of Natural Forest Habitat (pooled data)

Order	Diversity Index (H')	Evenness (E)
Coleoptera	1.22	0.27
Hemiptera	0.92	0.21
Hymenoptera	0.77	0.17
Lepidoptera	0.4	0.09
Orthoptera	0.34	0.08
Blattodea	0.22	0.05
Diptera	0.22	0.05
Isoptera	0.17	0.04
Mantodea	0.08	0.02
Odonata	0.07	0.02
Neuroptera	0.06	0.01
Mecoptera	0.02	0

5.3.2. Species richness and abundance of wetland habitat

The result of the study at wetland habitat yielded 472 insects from 13 insect orders belonging to 61 families in the two years study (Table 5.4). Out of the 13 insect orders Coleoptera was the dominant insect order in possessing148 insects (31.36%) followed by Hymenoptera, Hemiptera, Blattodea, Orthoptera, Isoptera, Lepidoptera, Odonata, Diptera, Ephemeroptera and Neuroptera. To the opposite, the least 1 insect was recorded from theinsect order Mecoptera (Table 5.4).

Table 5.4: Orders and families of insect communities at wetland habitat

Order	Family	# of Insects	Pi	lnpi	Pilnpi
Blattodea	Blatellidae	12	0.025424	-3.67207	-0.09336
	Blattidae	15	0.03178	-3.44893	-0.10961
	Buperstidae	2	0.004237	-5.46383	-0.02315
Coleoptera	Carabidae	6	0.012712	-4.36522	-0.05549
	Cerambycidae	6	0.012712	-4.36522	-0.05549
	Chrysomelidae	24	0.050847	-2.97893	-0.15147
	Cleridae	5	0.010593	-4.54754	-0.04817
	Coccinellidae	25	0.052966	-2.9381	-0.15562
	Curcculionidae	1	0.002119	-6.15698	-0.01304
	Lucanidae	1	0.002119	-6.15698	-0.01304

Table continued

	Meloidae	6	0.012712	-4.36522	-0.05549
	Oryzaephilus	1	0.002119	-6.15698	-0.01304
	Scarabaeidae	36	0.076271	-2.57346	-0.19628
	Staphylinidae	23	0.048729	-3.02148	-0.14723
	Tenbrionidae	12	0.025424	-3.67207	-0.09336
Diptera	Anthomyiidae	2	0.004237	-5.46383	-0.02315
	Asilidae	3	0.006356	-5.05837	-0.03215
	Tachinidae	1	0.002119	-6.15698	-0.01304
	Bombyliidae	3	0.006356	-5.05837	-0.03215
	Muscidae	1	0.002119	-6.15698	-0.01304
Hemiptera	Reduvidae	9	0.019068	-3.95975	-0.0755
	Pyrrhocoridae	14	0.029661	-3.51792	-0.10435
	Pentatomidae	20	0.042373	-3.16125	-0.13395
	Lygaeidae	15	0.03178	-3.44893	-0.10961
	Thyrecoridae	2	0.004237	-5.46383	-0.02315
	Scutelleridae	2	0.004237	-5.46383	-0.02315
	Saldidae	1	0.002119	-6.15698	-0.01304
	Coreidae	3	0.006356	-5.05837	-0.03215
	Cicadellidae	5	0.010593	-4.54754	-0.04817
	Blissidae	5	0.010593	-4.54754	-0.04817
	Cydnidae	1	0.002119	-6.15698	-0.01304
Hemiptera	Cixiidae	2	0.004237	-5.46383	-0.02315

Table continued

	Largidae	1	0.002119	-6.15698	-0.01304
	Eumenidae	2	0.004237	-5.46383	-0.02315
	Megachilidae	1	0.002119	-6.15698	-0.01304
Hymenoptera	Anthophoridae	2	0.004237	-5.46383	-0.02315
	Formicidae	79	0.167373	-1.78753	-0.29918
	Apidae	4	0.008475	-4.77068	-0.04043
	Bracconidae	5	0.010593	-4.54754	-0.04817
	Ichneumonidae	5	0.010593	-4.54754	-0.04817
	Pteromalidae	7	0.014831	-4.21107	-0.06245
	Sphecidae	1	0.002119	-6.15698	-0.01304
Lepidoptera	Lycaenidae	4	0.008475	-4.77068	-0.04043
	Nymphalidae	6	0.012712	-4.36522	-0.05549
	Papilionidae	2	0.004237	-5.46383	-0.02315
	Pieridae	1	0.002119	-6.15698	-0.01304
Odonata	Aeshnidae	1	0.002119	-6.15698	-0.01304
	Chlorocyphidae	1	0.002119	-6.15698	-0.01304
	Coenagrionidae	7	0.014831	-4.21107	-0.06245
	Libellulidae	4	0.008475	-4.77068	-0.04043
Orthoptera	Acrididae	29	0.061441	-2.78968	-0.1714
	Gryllacarididae	1	0.002119	-6.15698	-0.01304
	Gryllidae	11	0.023305	-3.75908	-0.08761
	Heteronemiidae	1	0.002119	-6.15698	-0.01304

Table continued

	Mogoplistidae	1	0.002119	-6.15698	-0.01304
	Pyrgomorphidae	11	0.023305	-3.75908	-0.08761
Ephemeroptera	Leptophlebiidae	2	0.004237	-5.46383	-0.02315
Isoptera	Termitidae	14	0.029661	-3.51792	-0.10435
Mantodea	Hymenopodidae	2	0.004237	-5.46383	-0.02315
Mecoptera	Bittacidae	1	0.002119	-6.15698	-0.01304
Neuroptera	Chrysopidae	2	0.004237	-5.46383	-0.02315
Total		**472**			**-3.40237**
Shannon-Wienr diversity index (H′)					**3.4**
Evenness (E)					**0.83**
Species rechiness (# of families)					**61**

The Shannon's H′ value of 3.4 and Evenness (E value) of 0.83 were recorded from the diversity and abundance of insect communities in wetland forest habitat (Table 5.4), and also the species richness interms of families 61 insect families was recordede Inaddition, the insect families were well diversified and also most of them were equaly distributed with in wetland habitat.

As far as numbers of families (species richness) and percentage among orders was concerned insect orders Hemiptera and Coleoptera had with similar largest numbers of insect families (species richness) consisting of 13 families each (21.31%) (Table 5.5) followed by Hymenoptera, Orthoptera, Diptera, Odonata, Lepidoptera and Blattodea 9, 6, 5, 4, 4 and 2 insect families, respectively. The least was1family were recorded from the orders Ephemeroptera, Neuroptera, Mecoptera and Isoptera.

Table 5.5: Numbers and percentages of insects in different orders and families from wetland habitat (pooled data)

Order	Individual	Pecent (%)	Families	Composition (%)
Coleoptera	148	31.36	13	21.31
Hymenoptera	106	22.46	9	14.75
Hemiptera	80	16.99	13	21.31
Orthoptera	54	11.44	6	9.84
Blattodea	27	5.72	2	3.28
Isoptera	14	2.97	1	1.64
Odonata	13	2.75	4	6.56
Lepidoptera	13	2.75	4	6.56
Diptera	10	2.19	5	8.2
Neuroptera	2	0.42	1	1.64
Mantodea	2	0.42	1	1.64
Ephemeroptera	2	0.42	1	1.64
Mecoptera	1	0.21	1	1.64
Total	472	100	61	100

From the result of Shannon–Wiener diversity and Evenness (Table 5.6), highest Shannon – Wiener diversity index was recorded from order Coleoptera with Shannon's H′ value 1.35 followed by Hymenoptera, Hemiptera, Orthoptera, Blattodea, Lepidoptera, Isoptera; Odonata and Diptera. The least H′ value of 0.02 was recorded from order Neuroptera, Mantodea and Ephemeroptera.

From the result of Evenness (E) (Table 5.6), highest diversified order was Coleoptera with E value of 0.33 followed by Hymenoptera, Hemiptera, Orthoptera, Blattodea, Lepidoptera, Isoptera and Odonata insect orders.To the contrary the lowest were recorded from the insect orders Neuroptera, Mantodea and Ephemeroptera with E value of 0.33.

Table 5.6: Species richness, Diversity Index (H') and Evenness (E) of orders at wetland habitat (pooled data)

Order	Diversity Index (H')	Evenness (E)
Coleoptera	1.35	0.33
Hymenoptera	0.86	0.21
Hemiptera	0.77	0.19
Orthoptera	0.45	0.11
Blattodea	0.22	0.05
Lepidoptera	0.15	0.04
Isoptera	0.14	0.03
Odonata	0.13	0.03
Diptera	0.12	0.03
Neuroptera	0.02	0.01
Mantodea	0.02	0.01
Ephemeroptera	0.02	0.01

5.4.3. Insect species richness and abundance of insects in plantation forest habitat

In the Plantation forest habitat 468 insect specimens collected from 12 insect orders belonging into 83 families (Table 5.6). Out of 12 insect orders order Hemiptera had the largest insect number consisting of 123 insects (26.12%) (Table 5.6) followed by Coleoptera, Hymenoptera, Orthoptera, Diptera, Isoptera, Lepidoptera, Blattodea, Odonata, Nuroptera and Mantodea. The least was one insect recorded from insect order Dermaptera.

Table 5.7: Orders and families of insect communities at plantation forest habitat

Order	Family	# of Insects	Pi	Lnpi	pilnpi
Blattodea	Blatellidae	8	0.017094	-4.06903	-0.06956
	Blaberidae	4	0.008547	-4.76217	-0.0407
	Blattidae	2	0.004274	-5.45532	-0.02331
Coleoptera	Buperstidae	3	0.00641	-5.04986	-0.03237
	Carabidae	3	0.00641	-5.04986	-0.03237
	Cerambycidae	13	0.027778	-3.58352	-0.09954
	Chrysomelidae	29	0.061966	-2.78117	-0.17234
	Cleridae	2	0.004274	-5.45532	-0.02331
	Coccinellidae	10	0.021368	-3.84588	-0.08218
	Curcculionidae	8	0.017094	-4.06903	-0.06956
	Erotylidae	1	0.002137	-6.14847	-0.01314
	Meloidae	17	0.036325	-3.31525	-0.12043
	Silphidae	1	0.002137	-6.14847	-0.01314
	Scarabaeidae	6	0.012821	-4.35671	-0.05586
	Staphylinidae	5	0.010684	-4.53903	-0.04849
	Tenbrionidae	8	0.017094	-4.06903	-0.06956
Dermaptra	Labiduridae	1	0.002137	-6.14847	-0.01314
Diptera	Anthomyiidae	1	0.002137	-6.14847	-0.01314
	Asilidae	1	0.002137	-6.14847	-0.01314

Table continued

	Mydidae	1	0.002137	-6.14847	-0.01314
	Empididae	1	0.002137	-6.14847	-0.01314
	Tachinidae	3	0.00641	-5.04986	-0.03237
	Nemestrinidae	2	0.004274	-5.45532	-0.02331
	Sarcophagidae	3	0.00641	-5.04986	-0.03237
	Sciaridae	1	0.002137	-6.14847	-0.01314
	Bombyliidae	1	0.002137	-6.14847	-0.01314
	Tephritidae	2	0.004274	-5.45532	-0.02331
	Muscidae	9	0.019231	-3.95124	-0.07599
	Syrphidae	5	0.010684	-4.53903	-0.04849
Hemiptera	Reduvidae	11	0.023504	-3.75057	-0.08815
	Pyrrhocoridae	22	0.047009	-3.05743	-0.14373
	Psyllidae	32	0.068376	-2.68273	-0.18343
	Pentatomidae	1	0.002137	-6.14847	-0.01314
	Lygaeidae	13	0.027778	-3.58352	-0.09954
	Membracidae	1	0.002137	-6.14847	-0.01314
	Rhopalidae	19	0.040598	-3.20403	-0.13008
	Scutelleridae	1	0.002137	-6.14847	-0.01314
	Coreidae	3	0.00641	-5.04986	-0.03237
	Cicadellidae	2	0.004274	-5.45532	-0.02331
	Blissidae	5	0.010684	-4.53903	-0.04849
	Issidae	1	0.002137	-6.14847	-0.01314

Table continued

	Aphididae	3	0.00641	-5.04986	-0.03237
	Cicadidae	2	0.004274	-5.45532	-0.02331
	Cercopidae	1	0.002137	-6.14847	-0.01314
	Cydnidae	1	0.002137	-6.14847	-0.01314
	Tiginidae	5	0.010684	-4.53903	-0.04849
Hymenoptera	Pompilidae	2	0.004274	-5.45532	-0.02331
	Bradyporidae	3	0.00641	-5.04986	-0.03237
	Chalcidae	2	0.004274	-5.45532	-0.02331
	Gucharitidae	4	0.008547	-4.76217	-0.0407
	Anthophoridae	2	0.004274	-5.45532	-0.02331
	Agaonidae	2	0.004274	-5.45532	-0.02331
	Formicidae	54	0.115385	-2.15948	-0.24917
	Vespidae	7	0.014957	-4.20256	-0.06286
	Apidae	3	0.00641	-5.04986	-0.03237
	Bracconidae	3	0.00641	-5.04986	-0.03237
	Ichneumonidae	4	0.008547	-4.76217	-0.0407
Isoptera	Termitidae	26	0.055556	-2.89037	-0.16058
Lepidoptera	Lycaenidae	1	0.002137	-6.14847	-0.01314
	Nymphalidae	18	0.038462	-3.2581	-0.12531
	Papilionidae	3	0.00641	-5.04986	-0.03237
	Pieridae	1	0.002137	-6.14847	-0.01314
Mantodea	Thespidae	2	0.004274	-5.45532	-0.02331

Table continued

	Sibyllidae	1	0.002137	-6.14847	-0.01314
	Hymenopodidae	1	0.002137	-6.14847	-0.01314
Neuroptera	Chrysopidae	2	0.004274	-5.45532	-0.02331
	Mantispidae	1	0.002137	-6.14847	-0.01314
Odonata	Aeshnidae	2	0.004274	-5.45532	-0.02331
	Chlorocyphidae	1	0.002137	-6.14847	-0.01314
	Gomphidae	1	0.002137	-6.14847	-0.01314
	Libellulidae	1	0.002137	-6.14847	-0.01314
Orthoptera	Acrididae	5	0.010684	-4.53903	-0.04849
	Bradyporidae	15	0.032051	-3.44042	-0.11027
	Gryllacarididae	7	0.014957	-4.20256	-0.06286
	Gryllidae	3	0.00641	-5.04986	-0.03237
	Shizoductylidae	2	0.004274	-5.45532	-0.02331
	Mogoplistidae	3	0.00641	-5.04986	-0.03237
	Hetrodes	1	0.002137	-6.14847	-0.01314
	Pamphagidae	2	0.004274	-5.45532	-0.02331
	Tridactylidae	1	0.002137	-6.14847	-0.01314
	Pyrgomorphidae	4	0.008547	-4.76217	-0.0407
	Tettigoniidae	3	0.00641	-5.04986	-0.03237
	Pyrgomorphidae	1	0.002137	-6.14847	-0.01314
Total		**468**			-3.74835
Shannon-Wienr diversity index (H′)					**3.75**

Evenness (E)	**0.84**
Species richiness	**83**

The Shannon's H′ value of 3.75 and Evenness (E value) of 0.84 were recorded from the diversity and abundance of insect communities in plantation forest habitat (Table 5.6), and also the species richness interms of number of families, 83 insect families was recorded. Therefore, the insect families were well diversified consequently most of them were equaly distributed with in the habitat.

The Numbers and percentages of insect of families (species richness) in each insect order is shown in (Table 5.7), insect order Hemiptera had the largest insect number consisting of 17 insects (20.48 %) followed by Diptera, Coleoptera, Orthoptera, Hymenoptera, Odonata, Lepidoptera, Mantodea, Blattodea and Neuroptera. The least was 1 recorded from insect order Dermaptera.

Table 5.8: Numbers and percentages of insects in different orders and families from plantation forest habitat (pooled data)

Order	Individual	%	Families	Composition (%)
Hemiptera	123	26.28	17	20.48
Coleoptera	106	22.65	13	15.66
Hymenoptera	86	18.38	11	13.25
Orthoptera	46	9.83	11	13.25
Diptera	31	6.62	13	15.66
Isoptera	26	5.56	1	1.2
Lepidoptera	23	4.91	4	4.82
Blattodea	14	2.99	3	3.61
Odonata	5	1.07	4	4.82
Mantodea	4	0.85	3	3.61
Neuroptera	3	0.64	2	2.41
Dermaptera	1	0.21	1	1.2
Total	468	100	83	100

From the result of Shannon-Wiener diversity Index (H') and Evenness (E) (Table 5.8), the highest Shannon- Wiener diversity Index were recorded by the order Hemiptera with-Shannon's H′value of 1.05 followed by Coleoptera, Hymenoptera, Orthoptera and Diptera Lepidoptera, Isoptera, Blattodea, Odonata, Mantodea and Neuroptera The least was recorded from insect order Dermaptera with H′ value of 0.01. As far as, Evenness (E) was concerned the highest evenly diversified order with in the habitat was Hemiptera with Evenness (E value) of 0.24 (Table 5.8) followed by Coleoptera, Hymenoptera, Orthoptera, Diptera , Lepidoptera, Isoptera, Blattodea, Odonata, Mantodea and Neuroptera insect orders. The least were recorded from the order Dermaptera with E value of 0.00.

Table 5.9: Species richness, Diversity Index (H') and Evenness (E) at plantation forest habitat (Pooled data)

Order	Diversity Index (H')	Evenness (E)
Hemiptera	1.05	0.24
Coleoptera	0.83	0.19
Hymenoptera	0.77	0.17
Orthoptera	0.48	0.11
Diptera	0.33	0.07
Lepidoptera	0.25	0.05
Isoptera	0.16	0.04
Blattodea	0.13	0.03
Odonata	0.06	0.01
Mantodea	0.05	0.01
Neuroptera	0.04	0.01
Dermaptera	0.01	0

5.3.4. Evaluation of insect species compositional similarity and/or variation among study sites

Sorensen's similarity indices were calculated to evaluate the similarity of insect species for the different habitats as shown in (Table 5.9). The level of similarity between each pair habitats in terms of their insect species composition was generally not low (above 40%). The highest variation of insect families was observed between plantation forest habitat and wetland habitat with (58.16%), followed by Natural forest habitat and wetland habitat having insect families variation of (57.29%) while the least insect families variation was observed between Natural forest habitat and plantation forest habitat with (53.15%) variation were observed from the result of Sorensens similarity index.

Table 5.10: Orensen's similarity indices for the different habitat type

Collective methods	NFH	PFH	WLH
NFH	*	46.85	
PFH		*	41.84
WLH	42.71		*

NFH = Natural Forest habitat, PFH = Plantation Forest habitat and WLH = Wetland habitat

* = -----

5.4.5. Comparison of species composition among habitats

The insect species encountered in the three habitats are shown in Tables 5.1, 5.4, and 5.6, for Natural forest habitat, plantation forest habitat and wetland habitat respectively. The highest number of species was found in the Natural forest habitat followed by wetland habitat and plantation forest habitat 620, 472 and 468 respectively, (Table 5.10). The diversity of the three habitats was computed using Shannon-Wiener diversity Index (H') and Evenness (E) (Table 5.10), highest diversity was recorded in Natural forest habitat with Shannon's H′ value of 2.36. The second position was also occupied by plantation forest habitat with Shannon's value H′ of 1.84.The least Shannon-Wiener diversity Index (H') was recorded from the wetland habitat with Shannon's H′ value of 1.78.

Equitability of species composition among habitat was also computed with Evenness (E), the highest Evenness (E) was recorded by Natural forest habitat with E value of 0.49 followed by plantation forest habitat with E value of 0.38 whereas the least was recorded from wetland habitat with E value of 0.37.

Moreover, the variation of the diversity index H′ and Evenness (E) value with the study years is shown Appendix 3; the value of diversity index H′ was significantly different with the study years at $t = -10.726$, df = 35 $P < 0.001$. On the other hand, the variation of Evenness index (E) value was significantly different with season at $t = -13.834$, df = 35 $P < 0.001$.

Table 5.11: Shannon-Wiener Index (H') and Evenness (E) among the three habitats

Habitat	No. Families	Total individual	Percentage	Shannon-Wiener Index (H')	Evenness (E)
PFH	83	468	30.00	1.84	0.38
NFH	95	620	39.74	2.36	0.49
WLH	61	472	30.26	1.78	0.37
Total	239	1560	100		

PFH = Plantation Forest Habitat, NFH= Natural Forest Habitat and WLH,= Wetland Habitat

5.4 Discussion

Insects are the most successful organisms present in almost on every where in the world. To fight for food and shelter they migrate from one climatic environment to another totally different climatic condition, one crop to another crop or one cropping system to another cropping system (Sutherst, 1991).

The National forest has diverse vegetation and habitats. The vegetation's diversity and richness indirectly affect insect species diversity and abundance. The structure of vegetation between the different habitats could be affecting the existing of insect diversity (Abdullah and Sina, 2009).

Belette–Gera Forest is divided into three habitats based on vegetation structures. The Natural forest habitat mostly dominated by different indigenous trees, shrubs, climbers and restriction of human induced activities. The dominant tree species include *Il*ex *mitis* (L.) Radelk, *Syzygium guineense* (Willd.) DC., *Verpis daniellii* (Pichi.Serm.) *Koko waro* and *Allophylus abyssinicus* (Hochst.) Radlkofer. There is also a considerable amount of trees of *Macaranga capensis* (Ball.) *Sim* and *Croton macrostachyus* Del. Dominant climbers include *Hippocratea getzei* Loes. And *Rubus apetalus* Poir, and dominant shrubs are *Maytenus arbutifolia* (Hochst. Ex A.Rich.) *Wilczek*and *Dracaena afromontana* Mildbr (Kflay Gebrehiwot and Kitessa Hundera, 2014).

On the other hand, plantation forest habitats consist of indigenous shrubs, climbers and dominated by equal aged *Euqualiptes* sps., which are purposely established for commercial purpose. Commercial forestry involves road-cutting through forests and the harvesting of trees that are important as timber production and electric poles. As a result, during harvesting of trees many of the insects live on the tree wer died or migreat to the near by habitat due to disturbance and road-cutting through forests were also resalted for disturbance of insect communities with in this habitat.

In addition, wetland habitat dominated by grasses, sparsely shrubs and indigenous trees also found at edge of the forest. This habitat was exploited with community for agriculture by dreaing the water and also many of the catles of the community were used this habita as a grazing purpose. In addition, unlike the above mentioned habitat less attention was given for this area by government and local administration to conserve and protect this habitat. Scince, this habitat was part of Belette-Gera forest and the water resource of the habitat play valueable role on keeping humidity of the environment. Therefore, the above mentioned problems of the wetland habitat can contribute as a reason that the lowest diversity and abundance of insect species was recorded in wet land habitat. And the least numbers of families were recorded compared to the other habitats. However, 13 insect orders which were the largest recorded in wetland and insect order Ephemeroptera only was collected from this habitat.

This study also indicated that insect species diversity and abundance are significantly different among habitats. The highest abundance and diversity of insects in Natural forest habitat could be as a result of higher diversity of plant species, restriction of human induced activities, and fragment area than the other habitats studied. Similar phenomenon has been reported in other study by Chima *et al*. (2013) when study insect species diversity in fragmented habitat of the University area of Port Harcourt Nigeria among the studied fragment habitats the highest insect species richness and diversity was reported in the Biodiversity Conservation Area in which higher diversity of plant species, restriction of human induced activities.

Moreover, insect species in protected forests are found abundant because of their protection from human induced activities. Because of the diverse nature of plant species in protected forests, insects which have different mode feeding adaptation are more likely attracted to the diverse plant species for the forging purpose. Consequently, minimized the intra-copmutition among insects within their habitat which, could result in richness and abundance (FAO, 2001), large patches provide usually higher heterogeneity and thereby support different communities (Ricklefs and Lovette, 1999).

In addition, the relationship between the species richness of the insect herbivore community and the abundance of the tree species is commonly cited as one of the definitive indications of the relationship between resource availability and species richness (Kennedy and Southwood, 1984). Similarly, there were different vegetation covers among the habitat. So that, as the abundance of vegetation species composition increased the resourse availability to support the diverse insect community were also increases. This situation could be the different numbers of insect families and abundance insect community were observed among the habitats.

Belette-Gera Natural Forest has diverse topography, vegetative features and climate with splendid natural settings which directly affect the diversity and occurrence of insect species. These needs will comprise, at the very least, food and suitable climatic conditions, and may also include shelter from disturbance and natural enemies (Uniyal and Mathur, 1998).

Decreases in species richness, in density and in species abundance, and alteration of inter specific interactions are some possible biotic effect of habitat loss and fragmentation recognized as the major causes of the current biodiversity crisis (Baguette, 2001; Saunders *et al*., 1991). The relative importance of top-down and bottom-up interactions also depends upon environmental heterogeneity factors such as water availability (Boyer *et al*., 2003; Chase *et al*., 2000), light availability (Richards and Coley, 2007), nutrient availability (Denno *et al*., 2002) and spatial structure (Gripenberg and Roslin, 2007). Insect abundance and functional group representation also influenced by variation in species cover, plant biomass, soil nutrients and management regimes (Perner *et al*., 2005).

Southwood (1988) suggested that variation in habitats (forest plant communities) through time and space provides variation that supports multiple species. Changes in plant diversity alter not only herbivore diversity, but also insect predator and parasitoid diversity (Siemann, 1998). Thus, increased diversity and functional diversity of plant species increases the potential diversity of mechanisms by which plants can influence insect herbivores and their enemies (Perner *et al*., 2003; Siemann, 1998; Price *et al*., 1980).

As far as species composition among the habitats of Belette-Gera forest was concerned the highest variation was observed between plantation forest habitat and wetland habitat (58.16 %). Wet land habitat about 4 km far away from the natural forest habitat and plantation forest habitat, such distance might influence the movement of insect species with the other habitats. The least variation was recorded between plantation forest habitat and natural forest habitat (53.29%). The distance between them was 900 m gap. Therefore, the Natural forest habitat and plantation forest habitats were not far away as wetland habitat consequently the narrowness of the gap between fragments enhance the flow of insects between them. Then, these could be one of the reasons where the least variation of species composition was observed between Natural forest habitat and plantation forest habitat.

Similar phenomenon has been reported in other studies such as Zi-hua *et al*. (2011), who work on the effects of habitat loss and fragmentation on species loss and colonization of insect assemblages such as; ladybug beetles and aphids communities in experimental alfalfa landscapes. They suggested that fragmentation decreased the rate of immigration to patches, resulting in lower population densities in more fragmented landscapes.

In addition, a landscape which has high number of small patches and the inter-spatches distance of fragmentation in a land scape enhances the immigration of insects flowing to patches aggregately increasing their population density (Arias *et al*., 2011; Grez *et al*., 2004). On the other hand habitat fragmentation (the reduction of continuous habitat into several smaller spatially isolated remnants), decreases area, increases edge effects, alters ecological processes and decreases connectivity (Debinski and Holt, 2000).

On the contrary, Yaacobi *et al.* (2007) in their study compared species diversities of plants, Tenebrionid beetles and Carabid beetles in a highly fragmented Mediterranean scrub landscape. From their results they suggest that fragmentation has no consistent or significant effect on species diversity. Similarly, Tscharntke *et al*. (2002) investigate from their study; small grassland fragments showed higher species diversities of butterflies, legume-feeding herbivores and of rape-pollen beetles and their parasitoids than did those same groups in larger grassland fragments.Therefore, their suggestions about the effect of habitat fragmenmtation on insect diversity were disagreed with the result of this study and suggested that fragmentation does not have a negative effect on species diversity.

Chapter 6 THE INFLUENCE OF SEASONAL DIFFERENCES ON THE DIVERSITY AND ABUNDANCE OF INSECT SPECIES AT BELETTE-GERA FOREST

6.1. Introduction

Insects are abundant organisms in all terrestrial ecosystems, playing a key role in the ecosystem, and affecting the primary and secondary production, energy flow and nutrient cycling. Insects can act as decomposers, herbivores, pollinators, seed dispersers, predators, parasitoids and ecosystem engineers as well as prey for a variety of vertebrates and other invertebrates. The exact role of insect species or their functional groups in terrestrial ecosystems will depend on populations' numerical oscillations and intensity of foraging activity and reproduction. These activities will, in turn, be associated with seasonality and climatic conditions in ecosystems (Wolda, 1992, 1987).

Seasonal climatic conditions can exert a strong influence on insect abundance and activity. In ecosystems with clear distinction between rainy and dry seasons, climatic variables are known to be good predictors of population behavior (Wolda, 1987; Janzen, 1973). However, insect responses to climate are not uniform and may vary according to habitat characteristics and the studied taxa (; Wolda, 1987; Levings and Windsor, 1985; Janzen and Schoener 1968). Some insect species may present a strong synchrony with climatic patterns, such as temperature and rainfall, while some species present various peaks in abundance throughout the year or may even show preferences for the dry season (Wolda, 1987).

In general, changes in species and the numbers of individuals of insects in successive generations describe the population dynamics of most species. For some species, population density remains constant over time, whereas others show variation. This is due to a number of factors including climate, natural enemies and the quality and distribution of natural resources. These factors affect basic population parameters such as birth, death and migration rates through both density-dependent and density-independent processes (Emana Getu, 2007; Richards and Coley, 2007; Boyer *et al*., 2003).

There are gently distinct dry and rainy seasons in the area. The short rainy season begins at the end of March and lasts until the end of April. The short dry season occurs for about a month in May and the long rainy season starts in the beginning of June and lasts until the middle of November. The long dry season starts in the middle of November and ends at the end of March (Yoshimasa, 2014). The average annual maximum and minimum temperatures are 26ºC and 10ºC, respectively. Average annual precipitation over 21 years from 1987 to 2008 was 1700 mm. (Briggs and Blatt, 2009).

The main objectives of the present study were to investigate the influence of seasonal variables on insect species diversity and abundance.

Objectives the study

- To determine seasonal diversity and abundance of insect communities in 2013/2014 and 2014/2015.

- To determine species composition across seasons in 2013/ 2014 and 2014/ 2015.

6.2. Materials and Methods

6.2.1. Data collection

The sampling and insect collection methods were used as sketched in chapter 3.

6.2.2. Methods of data analysis

In this chapter species richness was computed as the total number of insect species encountered in each year of the season. In addition both Shanon-Wiener diversity index (H') and Evenness (E) were computed for each year of the study season. And also, the details were given in section 3:4. Farther more, paired *t*-test was used in order to know the variations of Shanon-Wiener diversity index (H') and Evenness (E) value with season are statically different or not.

6.3. Results

6.3.1. The seasonal patterns of insect communities in Belette-Gera forest

A total of 247 insects from 10 orders and 54 families were collected in long dry season (Table 6.1). Family Coccinelidae had the highest number of insects consisting of 38 insects (15.38%). The least was 1 insect (0.04%) which were recorded from the families Tenbrionidae, Cleridae, Carabidae, Buperstidae, Empididae, Alydidae, Blissidae, Coreidae, Tiginidae, Cydinidae, Tenthredinidae, Ichneumonidae, Megachilidae, Eumenidae, Lycaenidae, Chrysopidae and Tettigoniidae.

Table 6.1: Numbers and percentages of insect in different orders and families from long dry season in 2013/2014

Order	Family	# of Insects	Percent composition	pi	lnpi	pilnpi
Blattodea	Blatellidae	3	1.21	0.012146	-4.41078	-0.05357
	Blattidae	3	1.21	0.012146	-4.41078	-0.05357
	Blaberidae	3	1.21	0.012146	-4.41078	-0.05357
Coleoptera	Coccinellidae	38	15.38	0.153846	-1.8718	-0.28797
	Chrysomelidae	15	6.07	0.060729	-2.80134	-0.17012
	Staphylinidae	14	5.67	0.05668	-2.87033	-0.16269
	Scarabaeidae	5	2.02	0.020243	-3.89995	-0.07895
	Anthribidae	3	1.21	0.012146	-4.41078	-0.05357
	Meloidae	3	1.21	0.012146	-4.41078	-0.05357
	Curcculionidae	2	0.81	0.008097	-4.81624	-0.039
	Cerambycidae	2	0.81	0.008097	-4.81624	-0.039
	Tenbrionidae	1	0.4	0.004049	-5.50939	-0.02231
	Cleridae	1	0.4	0.004049	-5.50939	-0.02231
	Carabidae	1	0.4	0.004049	-5.50939	-0.02231
	Buperstidae	1	0.4	0.004049	-5.50939	-0.02231

Table continued

Diptera	Ephydridae	4	1.62	0.016194	-4.12309	-0.06677
	Syrphidae	3	1.21	0.012146	-4.41078	-0.05357
	Calliphoridae	2	0.81	0.008097	-4.81624	-0.039
	Assillidae	2	0.81	0.008097	-4.81624	-0.039
	Empididae	1	0.4	0.004049	-5.50939	-0.02231
Hemiptera	Psyllidae	24	9.72	0.097166	-2.33133	-0.22653
	Reduvidae	8	3.24	0.032389	-3.42995	-0.11109
	Pyrrhocoridae	5	2.02	0.020243	-3.89995	-0.07895
	Pyrrhocoridae	3	1.21	0.012146	-4.41078	-0.05357
	Lygaeidae	2	0.81	0.008097	-4.81624	-0.039
	Cicadellidae	2	0.81	0.008097	-4.81624	-0.039
	Alydidae	1	0.4	0.004049	-5.50939	-0.02231
	Blissidae	1	0.4	0.004049	-5.50939	-0.02231
	Coreidae	1	0.4	0.004049	-5.50939	-0.02231
	Tiginidae	1	0.4	0.004049	-5.50939	-0.02231
	Cydinidae	1	0.4	0.004049	-5.50939	-0.02231
Hymenoptera	Formicidae	20	8.1	0.080972	-2.51366	-0.20353
	Pteromallidae	4	1.62	0.016194	-4.12309	-0.06677
	Apidae	3	1.21	0.012146	-4.41078	-0.05357
	Bracconidae	3	1.21	0.012146	-4.41078	-0.05357
	Sphecidae	2	0.81	0.008097	-4.81624	-0.039
	Cicadidae	2	0.81	0.008097	-4.81624	-0.039

Table continued

	Anthophoridae	2	0.81	0.008097	-4.81624	-0.039
	Tenthredinidae	1	0.4	0.004049	-5.50939	-0.02231
	Ichneumonidae	1	0.4	0.004049	-5.50939	-0.02231
	Megachilidae	1	0.4	0.004049	-5.50939	-0.02231
	Eumenidae	1	0.4	0.004049	-5.50939	-0.02231
Isoptera	Termitidae	8	3.24	0.032389	-3.42995	-0.11109
Lepidoptera	Nymphalidae	8	3.24	0.032389	-3.42995	-0.11109
	Papilionidae	3	1.21	0.012146	-4.41078	-0.05357
	Lycaenidae	1	0.4	0.004049	-5.50939	-0.02231
Neuroptera	Myrmeleontidae	2	0.81	0.008097	-4.81624	-0.039
	Chrysopidae	1	0.4	0.004049	-5.50939	-0.02231
Orthoptera	Bradyporidae	16	6.48	0.064777	-2.7368	-0.17728
	Acrididae	4	1.62	0.016194	-4.12309	-0.06677
	Gryllacaridida	3	1.21	0.012146	-4.41078	-0.05357
	Pamphagidae	2	0.81	0.008097	-4.81624	-0.039
	Gryllidae	2	0.81	0.008097	-4.81624	-0.039
	Tettigoniidae	1	0.4	0.004049	-5.50939	-0.02231
Total		**247**				-3.35606
Shannon-Wienr diversity index (H′)						**3.36**
Evenness (E)						**0.84**
Species richness						**54**

The.Shannon's H′ value of 3.36 and Evenness (E) value of 0.84 were recorded the diversity and abundance of insect communities from the long rain season (Table 6.1), and also the species richness intermas of number of families, 54 insect families was recorded Therefore, the insect families were well diversified consequently most of them were equaly distributed with in this season.

Diversity index (H') and Evenness (E) from long dry season is shown in Table 6.2, order Coleoptera had the highest number of insects with 86 and the least number of insects was 3 recorded from order Neuroptera (Table 6.2). From the total of 54 families collected order Coleoptera and Hymenoptera had the largest number of insect families (species richness) consisting of 12 families. The least was one insect family was recorded from order Neuroptera (Table 6.2).

Table 6.2: Species richness, Diversity index (H') and Evenness (E) from long dry season in 2013/2015 (pooled data)

Order	No. of Families	No. of Insects	H'	E
Coleoptera	12	86	0.424	0.093
Hymenoptera	12	43	0.258	0.057
Hemiptera	10	46	0.253	0.056
Orthoptera	6	28	0.163	0.036
Diptera	5	12	0.085	0.019
Lepidoptera	3	12	0.075	0.016
Isoptera	1	8	0.046	0.01
Blattodea	3	9	0.042	0.009
Neuroptera	2	3	0.023	0.005
Total	54	247		

The diversity index and Evenness of insects collected from long dry season in 2013/2014 is shown in Table 6.2, the highest insect diversification was noted in the order Coleoptera with Shannon's H′ value of 0.424. The lowest H′value of 0.023 was recorded from order Neuroptera.The highest homogeneity or pattern of distribution of species was for the order Coleoptera with E value of 0.093. The lowest E value of 0.005 was recorded from order Neuroptera what does this mean. Describe it to enrich your results.

Table 6.3: Numbers and percentage of insect in different orders and families in the long rain season of 2013/2014

Order	Family	# of Insects	Percentage composition	Pi	lnpi	pilnpi
Blattodea	Blattidae	18	4.84	0.048387	-3.02852	-0.14654
	Blatellidae	7	1.88	0.018817	-3.97298	-0.07476
	Polyphagidae	1	0.27	0.002688	-5.91889	-0.01591
	Blaberidae	1	0.27	0.002688	-5.91889	-0.01591
Coleoptera	Scarabaeidae	17	4.57	0.045699	-3.08568	-0.14101
	Cerambycidae	15	4.03	0.040323	-3.21084	-0.12947
	Carabidae	13	3.49	0.034946	-3.35394	-0.11721
	Chrysomelidae	10	2.67	0.026882	-3.61631	-0.09721
	Tenbrionidae	8	2.15	0.021505	-3.83945	-0.08257
	Cleridae	6	1.61	0.016129	-4.12713	-0.06657
	Coccinellidae	6	1.61	0.016129	-4.12713	-0.06657
	Staphylinidae	5	1.34	0.013441	-4.30946	-0.05792
	Scarabidae	5	1.34	0.013441	-4.30946	-0.05792
	Lycidae	4	1.08	0.010753	-4.5326	-0.04874
	Meloidae	3	0.81	0.008065	-4.82028	-0.03887
	Curcculionidae	3	0.81	0.008065	-4.82028	-0.03887
	Lagriidae	1	0.27	0.002688	-5.91889	-0.01591
	Buperstidae	1	0.27	0.002688	-5.91889	-0.01591

Table continued

	Trogidae	1	0.27	0.002688	-5.91889	-0.01591
Diptera	Anthribidae	1	0.27	0.002688	-5.91889	-0.01591
	Silphidae	1	0.27	0.002688	-5.91889	-0.01591
	Erotylidae	1	0.27	0.002688	-5.91889	-0.01591
	Muscidae	8	2.15	0.021505	-3.83945	-0.08257
	Syrphidae	6	1.61	0.016129	-4.12713	-0.06657
	Tachinidae	3	0.81	0.008065	-4.82028	-0.03887
	Tephritidae	2	0.54	0.005376	-5.22575	-0.0281
	Assillidae	2	0.54	0.005376	-5.22575	-0.0281
	Nemestrinidae	2	0.54	0.005376	-5.22575	-0.0281
	Phoridae	1	0.27	0.002688	-5.91889	-0.01591
	Sarcophagidae	1	0.27	0.002688	-5.91889	-0.01591
	Bombyliidae	1	0.27	0.002688	-5.91889	-0.01591
	Calliphoridae	1	0.27	0.002688	-5.91889	-0.01591
	Anthomyiidae	1	0.27	0.002688	-5.91889	-0.01591
Ephemeropter	Leptophelebiidae	2	0.54	0.005376	-5.22575	-0.0281
Hemiptera	Pentatomidae	8	2.15	0.021505	-3.83945	-0.08257
	Lygaeidae	7	1.88	0.018817	-3.97298	-0.07476
	Pyrrhocoridae	5	1.34	0.013441	-4.30946	-0.05792
	Reduvidae	5	1.34	0.013441	-4.30946	-0.05792
	Coreidae	3	0.81	0.008065	-4.82028	-0.03887
	Scutelleridae	3	0.81	0.008065	-4.82028	-0.03887

Table continued

	Psyllidae	3	0.8	0.008065	-4.82028	-0.03887
	Tiginidae	2	0.54	0.005376	-5.22575	-0.0281
Hymenoptera	Aphididae	2	0.54	0.005376	-5.22575	-0.0281
	Fulgoridae	1	0.27	0.002688	-5.91889	-0.01591
	Blissidae	1	0.27	0.002688	-5.91889	-0.01591
	Cercopidae	1	0.27	0.002688	-5.91889	-0.01591
	Formicidae	49	13.17	0.13172	-2.02707	-0.26701
	Vespidae	8	2.15	0.021505	-3.83945	-0.08257
	Gucharistidae	4	1.08	0.010753	-4.5326	-0.04874
	Apidae	3	0.81	0.008065	-4.82028	-0.03887
	Anthophoridae	2	0.54	0.005376	-5.22575	-0.0281
	Agaonidae	2	0.54	0.005376	-5.22575	-0.0281
	Tiphiidae	1	0.27	0.002688	-5.91889	-0.01591
Isoptera	Termitidae	27	7.26	0.072581	-2.62306	-0.19038
Lepidoptera	Nymphalidae	15	4.03	0.040323	-3.21084	-0.12947
	Papilionidae	2	0.54	0.005376	-5.22575	-0.0281
	Lycaenidae	1	0.27	0.002688	-5.91889	-0.01591
	Hesperiidae	1	0.27	0.002688	-5.91889	-0.01591
Mecoptera	Bittacidae	3	0.81	0.008065	-4.82028	-0.03887
	Chrysopidae	2	0.54	0.005376	-5.22575	-0.0281
Neuroptera	Myrmeleontidae	1	0.27	0.002688	-5.91889	-0.01591
	Mantispidae	1	0.27	0.002688	-5.91889	-0.01591

	Table continued					
Odonata	Libellulidae	3	0.81	0.008065	-4.82028	-0.03887
	Coenagrionidae	3	0.81	0.008065	-4.82028	-0.03887
	Hemistigma	2	0.53	0.005376	-5.22575	-0.0281
	Chlorocyphidae	1	0.27	0.002688	-5.91889	-0.01591
	Aeshnidae	1	0.27	0.002688	-5.91889	-0.01591
Orthoptera	Gryllidae	15	4.03	0.040323	-3.21084	-0.12947
	Pyrgomorphidae	9	2.42	0.024194	-3.72167	-0.09004
	Acrididae	8	2.15	0.021505	-3.83945	-0.08257
	Gryllacaridida	5	1.34	0.013441	-4.30946	-0.05792
	Tettigoniidae	2	0.54	0.005376	-5.22575	-0.0281
	Bradyporidae	1	0.27	0.002688	-5.91889	-0.01591
	Hetrodes	1	0.27	0.002688	-5.91889	-0.01591
Total		**372**				-3.71062
Shannon-Wienr diversity index (H′)						**3.71**
Evenness (E)						**0.86**
Speciess richness						**54**

The.Shannon's H′ value of 3.71 and Evenness (E value) of 0.86 were recorded the diversity and abundance of insect communities from the long rain season (Table 6.3), and also Therefore, the insect families were well diversified consequently there was not that mach domination of a single family over the rest of insect families within this season. In addition, Family Formicidae had the largest number of individuals consisting of 49 insects (13.17%). Unlikely, the least one insect

(0.27%) was recorded from the insect families Polyphagidae, Blaberidae, Lagriidae, Buperstidae, Torgidae, Tenbrionidae, Cleridae, Carabidae, Buperstidae, Empididae, Alydidae, Blissidae, Coreidae, Tiginidae, Phoridae, Sarcophagidae, Bombyliidae, Calliphoridae, Anthomyiidae, Fulgoridae, Blissidae, Cercopidae, Tiphiidae, Lycaenidae, Hesperiidae, Chrysomela, Mantispidae, Chlorocyphidae, Aeshnidae, Bradyphoridand Hetrodes (Table 6.3).

Table 6.4: Species richness**,** Diversity index (H') and Evenness (E) of insect orders from long rain season in 2013/2014 (pooled data)

Order	No. of Families	No. of insects	H'	E
Coleoptera	18	101	0.572	0.126
Hymenoptera	7	69	0.3	0.066
Hemiptera	12	41	0.266	0.058
Orthoptera	7	41	0.232	0.051
Diptera	11	28	0.189	0.042
Blattodea	4	27	0.142	0.031
Isoptera	1	27	0.113	0.025
Lepidoptera	4	19	0.105	0.023
Odonata	5	10	0.072	0.016
Neuroptera	3	4	0.031	0.007
Mecoptera	1	3	0.021	0.005
Ephemeroptera	1	2	0.015	0.003
Total	74	372		

Among 12 insect orders collected from long rainy season in 2013/2014 order Coleoptera recorded the largest number of individuals consisting of 101 insects. The least was two insects which wererecorded from the order Ephemeroptera. From the total of 74 insect families collected the order Coleoptera had the largest number of insect families consisting of 18 families. The least was one family which was recorded from the orders Ephemeroptera and Isoptera (Table 6.4).

The diversity index and Evenness of insects collected from long rain season in 2013/2014 is shown in (Table 6.4). The highest Shannon's H′value of 0.572 was recorded from the order Coleoptera. The lowest H′ value of 0.015 was recorded from order Ephemeroptera. The highest homogeneity or pattern of distribution of species was for the order Coleoptera with Evenness (E value) of 0.126. The lowest E value of 0.003 was recorded from the order Ephemeroptera. Therfore, order Coleoptera was the most diversified and abundantly found insect order in long rain season. While order Ephemeroptera was the lowest diversified and abundantly found insec order in long rain season.

Table 6.5: Numbers and percentages of insect in different orders and families from short rain season in 2013/2014

Order	Family	# of Insects	Persentage composition	pi	lnpi	pilnpi
Blattodea	Blatellidae	8	4.21	0.042105	-3.16758	-0.13337
	Blattidae	2	1.05	0.010526	-4.55388	-0.04794
	Blaberidae	1	0.53	0.005263	-5.24702	-0.02762
Coleoptera	Chrysomelidae	18	9.47	0.094737	-2.35665	-0.22326
	Coccinellidae	9	4.74	0.047368	-3.0498	-0.14446
	Scarabidae	6	3.16	0.031579	-3.45526	-0.10911
	Tenbrionidae	4	2.11	0.021053	-3.86073	-0.08128
	Cerambycidae	2	1.05	0.010526	-4.55388	-0.04794
	Cleridae	2	1.05	0.010526	-4.55388	-0.04794
	Anthribidae	1	0.53	0.005263	-5.24702	-0.02762
	Curcculionidae	1	0.53	0.005263	-5.24702	-0.02762
	Staphylinidae	1	0.53	0.005263	-5.24702	-0.02762
Dermaptra	Labiduridae	1	0.53	0.005263	-5.24702	-0.02762
Diptera	Anthomyiidae	4	2.11	0.021053	-3.86073	-0.08128
	Muscidae	4	2.11	0.021053	-3.86073	-0.08128
	Bombyliidae	2	1.05	0.010526	-4.55388	-0.04794
	Mydidae	1	0.53	0.005263	-5.24702	-0.02762
Hemiptera	Psyllidae	18	9.47	0.094737	-2.35665	-0.22326

Table continued

	Cicadellidae	5	2.63	0.026316	-3.63759	-0.09573
	Reduvidae	4	2.11	0.021053	-3.86073	-0.08128
	Pyrrhocoridae	3	1.58	0.015789	-4.14841	-0.0655
	Blissidae	1	0.53	0.005263	-5.24702	-0.02762
	Lygaeidae	1	0.53	0.005263	-5.24702	-0.02762
	Cercopidae	1	0.53	0.005263	-5.24702	-0.02762
	Pentatomidae	1	0.53	0.005263	-5.24702	-0.02762
	Phymatidae	1	0.53	0.005263	-5.24702	-0.02762
	Leptopodidae	1	0.53	0.005263	-5.24702	-0.02762
	Rhopalidae	1	0.53	0.005263	-5.24702	-0.02762
Hymenoptera	Formicidae	28	14.74	0.147368	-1.91482	-0.28218
	Pteromalidae	6	3.16	0.031579	-3.45526	-0.10911
	Ichneumonidae	4	2.11	0.021053	-3.86073	-0.08128
	Eumenidae	3	1.58	0.015789	-4.14841	-0.0655
	Bracconidae	2	1.05	0.010526	-4.55388	-0.04794
	Siricidae	1	0.53	0.005263	-5.24702	-0.02762
	Apidae	1	0.53	0.005263	-5.24702	-0.02762
	Sphecidae	1	0.53	0.005263	-5.24702	-0.02762
Isoptera	Termitidae	4	2.11	0.021053	-3.86073	-0.08128
Lepidoptera	Nymphalidae	5	2.63	0.026316	-3.63759	-0.09573
	Lycaenidae	2	1.05	0.010526	-4.55388	-0.04794
	Hesperiidae	1	0.53	0.005263	-5.24702	-0.02762

	Pieridae	1	0.53	0.005263	-5.24702	-0.02762
Orthoptera	Acrididae	15	7.89	0.078947	-2.53897	-0.20045
	Gryllacaridida	6	3.16	0.031579	-3.45526	-0.10911
	Pyrgomorphidae	4	2.11	0.021053	-3.86073	-0.08128
	Bradyporidae	2	1.05	0.010526	-4.55388	-0.04794
Total		**190**				-3.25837
Shannon-Wienr diversity index (H′)						**3.26**
Evenness (E)						**0.86**
Species richiness						**74**

The.Shannon's H′ value of 3.26 and Evenness (E value) of 0.86 were recorded from the short rain season (Table 6.5). Hence, the insect families were well diversified and also there was not that mach domination of a single family over the rest of insect families within this season. And also, Family Formicidae had the largest number of individuals consisting of 28 insects (14.74%). On the contrary, the least was one insect (0.53%) which was recorded from families, Blaberidae, Anthribidae, Curcculionidae, Staphylinidae, Mydidae, Blissidae, Lygaeidae, Cercopidae, Pentatomidae, Phymatidae, Leptopodidae, Rhopalidae, Siricidae, Apidae, Sphecidae, Hesperiidae and Pieridae (Table 6.4).

Table 6.6: Species richness, Diversity index (H') and Evenness (E) from short rain season in 2013/2014 (pooled data)

Order	No. of Families	No. of Insects	H'	E
Coleoptera	9	44	0.252	0.055
Hymenoptera	8	46	0.239	0.052
Hemiptera	11	37	0.221	0.049
Orthoptera	4	27	0.151	0.033
Diptera	4	11	0.076	0.017
Blattodea	3	11	0.069	0.015
Lepidoptera	4	9	0.063	0.014
Isoptera	1	4	0.026	0.006
Dermaptera	1	1	0.008	0.002
Total	45	190		

Among nine orders collected in short rain season order Hymenoptera had the largest number of individuals consisting of 46 insects. The least number of individual was 1 insect which was recorded from order Dermaptera (Table 6.6). From the total of 45 insect families collected from short rain season in 2013/2014 order Hemiptera had the largest insect families (species richness) consisting of 11 insect families. The least number of families was one insect family which was recorded from the orders Isoptera and Dermaptera.

The diversity index and Evenness of insects collected from short rain season in 2013/2014 (Table 6.6). The result of Shannon's-Wiener diversity index (H') was the highest for the order

Coleoptera with Shannon's H′value of 0.252. The lowest H′value of 0.008 was recorded from the order Dermaptera. And the highest homogeneity or pattern of distribution of species was for the order Coleoptera with E value of 0.055. The lowest E value of 0.002 was recorded from order Dermaptera. Therefore, order Coleoptera was the highest diversified and abundantly found in short rain season in 2013/2014. While, order Dermaptera was the lowest diversified and abundant insect order in short rain season in 2013/2014

Table 6.7: Numbers and percentages of insects in different orders and families from long dry season in 2014/2015

Order	Family	# of Insects	Percent composition	pi	lnpi	pilnpi
Blattodea	Blattidae	2	0.78	0.007752	-4.85981	-0.03767
	Blatellidae	1	0.39	0.003876	-5.55296	-0.02152
	Scarabidae	18	6.98	0.069767	-2.66259	-0.18576
	Meloidae	13	5.04	0.050388	-2.98801	-0.15056
	Chrysomelidae	12	4.65	0.046512	-3.06805	-0.1427
	Coccinellidae	9	3.49	0.034884	-3.35574	-0.11706
	Curcculionidae	5	1.94	0.01938	-3.94352	-0.07642
	Staphylinidae	4	1.55	0.015504	-4.16667	-0.0646
	Cerambycidae	3	1.16	0.011628	-4.45435	-0.05179
Coleoptera	Anthribidae	3	1.16	0.011628	-4.45435	-0.05179
	Buperstidae	3	1.16	0.011628	-4.45435	-0.05179

Table continued

	Tenbrionidae	3	1.16	0.011628	-4.45435	-0.05179
	Cicindelinae	2	0.78	0.007752	-4.85981	-0.03767
	Cleridae	1	0.39	0.003876	-5.55296	-0.02152
	Glateridae	1	0.39	0.003876	-5.55296	-0.02152
	Carabidae	1	0.39	0.003876	-5.55296	-0.02152
	Oryzaephilus	1	0.39	0.003876	-5.55296	-0.02152
Diptera	Muscidae	2	0.78	0.007752	-4.85981	-0.03767
	Nemestrinidae	1	0.39	0.003876	-5.55296	-0.02152
	Anthomyiidae	1	0.39	0.003876	-5.55296	-0.02152
	Asilidae	1	0.39	0.003876	-5.55296	-0.02152
	Sciaridae	1	0.39	0.003876	-5.55296	-0.02152
	Tachinidae	1	0.39	0.003876	-5.55296	-0.02152
	Tephritidae	1	0.39	0.003876	-5.55296	-0.02152
Hemiptera	Lygaeidae	17	6.59	0.065891	-2.71975	-0.17921
	Rhopalidae	17	6.59	0.065891	-2.71975	-0.17921
	Psyllidae	14	5.43	0.054264	-2.9139	-0.15812
	Pyrrhocoridae	13	5.04	0.050388	-2.98801	-0.15056
	Reduvidae	5	1.94	0.01938	-3.94352	-0.07642
	Membracidae	3	1.16	0.011628	-4.45435	-0.05179
	Pentatomidae	3	1.16	0.011628	-4.45435	-0.05179
	Leptopodidae	2	0.78	0.007752	-4.85981	-0.03767
	Coreidae	2	0.78	0.007752	-4.85981	-0.03767

Table continued

	Thespidae	2	0.78	0.007752	-4.85981	-0.03767
	Thyrecoridaeo	2	0.78	0.007752	-4.85981	-0.03767
	Dictyopharidae	1	0.39	0.003876	-5.55296	-0.02152
	Cixiidae	1	0.39	0.003876	-5.55296	-0.02152
	Tiginidae	1	0.39	0.003876	-5.55296	-0.02152
	Formicidae	52	20.16	0.20155	-1.60172	-0.32283
	Ichneumonidae	3	1.16	0.011628	-4.45435	-0.05179
Hymenoptera	Vespidae	1	0.39	0.003876	-5.55296	-0.02152
	Sphycidae	1	0.39	0.003876	-5.55296	-0.02152
	Bracconidae	1	0.39	0.003876	-5.55296	-0.02152
Isoptera	Termitidae	10	3.88	0.03876	-3.25037	-0.12598
Lepidoptera	Papilionidae	3	1.16	0.011628	-4.45435	-0.05179
	Nymphalidae	1	0.39	0.003876	-5.55296	-0.02152
Mantodea	Mantidae	2	0.78	0.007752	-4.85981	-0.03767
Neuroptera	Chrysopidae	6	2.33	0.023256	-3.7612	-0.08747
	Gryllacaridida	2	0.78	0.007752	-4.85981	-0.03767
	Pyrgomorphidae	1	0.39	0.003876	-5.55296	-0.02152
Orthoptera	Shizoductyilidae	1	0.39	0.003876	-5.55296	-0.02152
	Heteronemiidae	1	0.39	0.003876	-5.55296	-0.02152
Total		**258**				-3.22217
Shannon-Wienr diversity index (H′)						**3.22**
Evenness (E)						**0.91**

Speciess richness	**52**

The.Shannon’s H′ value of 3.22 and Evenness (E value) of 0.91 were recorded from the long dry season (Table 6.7). So that, the insect families were well diversified consequently there was no that mach domination of a single family over the rest of insect families within this season. Therefore, family Formicidae had the largest number of individuals consisting of 52 insects (20.16 %). To the oppsite, the least number of individual was 1 insect (0.39%) which was recorded from the families Blatellidae, Cleridae, Glateridae, Oryzaephilus, Carabidae, Nemestrinidae, Anthomyiidae, Assillidae, Sciaridae, Tachinidae, Tephritidae, Dictyopharidae, Cixiidae, Tiginidae, Vespidae, Sphycidae, Bracconidae, Nymphalidae, Pyrgomorphidae, Shizoductyilidae and Heteronemiidae (Table 6.7).

Table 6.8: Species richness, Diversity index (H') and Evenness (E) of different orders from long dry season in 2014/2015 (pooled data)

Order	No. of families	No. of insects	H'	E
Hemiptera	14	83	0.483	0.108
Coleoptera	15	79	0.479	0.107
Hymenoptera	5	58	0.233	0.052
Diptera	7	8	0.069	0.015
Isoptera	1	10	0.058	0.013
Orthoptera	4	5	0.042	0.009
Neuroptera	1	6	0.039	0.009
Lepidoptera	2	4	0.031	0.007
Blattodea	2	3	0.025	0.006
Mantodea	1	2	0.016	0.004
Total	52	258		

Among 10 insect orders collected in long dry season the order Hemiptera was recorded the largest number of individuals consisting of 83 insects. The least number of individuals was 2 insects had recorded from order Mantodea (Table 6.8). From the total of 52 insect families collected from in long dry season season in 2014/2015 insect order Hemiptera had the largest insect families (Species richness) consisting of 11 insect families. The least number of families was 1 insect family which was recorded from the orders Isoptera, Dermaptera and Mantodea.

The diversity index and Evenness of insects collected from long dry season in 2014/2015 (Table 6.8). The highest diversity with Shannon's H′ value of 0.483 was recorded from the insect order Hemiptera. The lowest H′of value 0.016 was recorded from the order Mantodea. The highest homogeneity or pattern of distribution of species was for the order Hemiptera with E value of 0.055. The lowest E value of 0.004 was recorded from the order Mantodea.

Table 6.9: Numbers and percentages of insect in different orders and families from long rain season in 2014/2015

Order	Family	# of Insects	Percent composition	pi	lnpi	pilnpi
Blattodea	Blattidae	7	2.65	0.026515	-3.63004	-0.09625
	Blatellidae	4	1.52	0.015152	-4.18965	-0.06348
	Chrysomelidae	11	4.17	0.041667	-3.17805	-0.13242
	Tenbrionidae	11	4.17	0.041667	-3.17805	-0.13242
	Curcculionidae	9	3.41	0.034091	-3.37872	-0.11518
	Coccinellidae	4	1.52	0.015152	-4.18965	-0.06348
	Staphylinidae	4	1.52	0.015152	-4.18965	-0.06348
	Cerambycidae	4	1.52	0.015152	-4.18965	-0.06348
	Cleridae	3	1.14	0.011364	-4.47734	-0.05088
Coleoptera	Lygaeidae	2	0.76	0.007576	-4.8828	-0.03699
	Meloidae	1	0.38	0.003788	-5.57595	-0.02112
	Buperstidae	1	0.38	0.003788	-5.57595	-0.02112

Table continued

	Lucanidae	1	0.38	0.003788	-5.57595	-0.02112
	Scarabaeidae	1	0.38	0.003788	-5.57595	-0.02112
	Sarcophagidae	1	0.38	0.003788	-5.57595	-0.02112
Diptera	Bombyliidae	1	0.38	0.003788	-5.57595	-0.02112
	Muscidae	1	0.38	0.003788	-5.57595	-0.02112
	Reduvidae	25	9.47	0.094697	-2.35707	-0.22321
	Psyllidae	17	6.44	0.064394	-2.74274	-0.17662
	Pentatomidae	15	5.68	0.056818	-2.8679	-0.16295
Hemiptera	Blissidae	8	3.03	0.030303	-3.49651	-0.10595
	Pyrrhocoridae	7	2.65	0.026515	-3.63004	-0.09625
	Largidae	2	0.76	0.007576	-4.8828	-0.03699
	Naucoridae	2	0.76	0.007576	-4.8828	-0.03699
	Coreidae	2	0.76	0.007576	-4.8828	-0.03699
	Lygaeidae	2	0.76	0.007576	-4.8828	-0.03699
	Tiginidae	1	0.38	0.003788	-5.57595	-0.02112
	Membracidae	1	0.38	0.003788	-5.57595	-0.02112
	Cydnidae	1	0.38	0.003788	-5.57595	-0.02112
Hymenoptera	Formicidae	20	7.58	0.075758	-2.58022	-0.19547
	Pteromalidae	2	0.76	0.007576	-4.8828	-0.03699
	Pompilidae	2	0.76	0.007576	-4.8828	-0.03699
	Chalcidae	2	0.76	0.007576	-4.8828	-0.03699
	Bracconidae	2	0.76	0.007576	-4.8828	-0.03699

Table continued

	Cicindelinae	1	0.38	0.003788	-5.57595	-0.02112
	Vespidae	1	0.38	0.003788	-5.57595	-0.02112
	Apidae	1	0.38	0.003788	-5.57595	-0.02112
	Eumenidae	1	0.38	0.003788	-5.57595	-0.02112
Isoptera	Termitidae	4	1.52	0.015152	-4.18965	-0.06348
	Nymphalidae	23	8.71	0.087121	-2.44045	-0.21262
	Lycaenidae	5	1.89	0.018939	-3.96651	-0.07512
Lepidoptera	Papilionidae	4	1.52	0.015152	-4.18965	-0.06348
	Pieridae	3	1.14	0.011364	-4.47734	-0.05088
	Hesperiidae	1	0.38	0.003788	-5.57595	-0.02112
	Thespidae	3	1.14	0.011364	-4.47734	-0.05088
Mantodea	Hymenopodidae	1	0.38	0.003788	-5.57595	-0.02112
	Libellulidae	5	1.89	0.018939	-3.96651	-0.07512
	Coenagrionidae	4	1.51	0.015152	-4.18965	-0.06348
Odonata	Aeshnidae	3	1.14	0.011364	-4.47734	-0.05088
	Chlorocyphidae	2	0.76	0.007576	-4.8828	-0.03699
	Acrididae	8	3.03	0.030303	-3.49651	-0.10595
	Gryllidae	6	2.27	0.022727	-3.78419	-0.086
	Gryllacaridida	3	1.14	0.011364	-4.47734	-0.05088
	Tettigoniidae	3	1.14	0.011364	-4.47734	-0.05088
Orthoptera	Pyrgomorphidae	2	0.76	0.007576	-4.8828	-0.03699
	Penumoridae	1	0.38	0.003788	-5.57595	-0.02112

Table continued

Shizoductyilidae	1	0.38	0.003788	-5.57595	-0.02112
Mogoplistidae	1	0.38	0.003788	-5.57595	-0.02112
Total	**264**				**-3.54937**
Shannon-Wienr diversity index (H′)					**3.55**
Evenness (E)					**0.87**
Speciess richness					**58**

The.Shannon's H′ value of 3.55 and Evenness (E value) of 0.87 were recorded from the long rain season (Table 6.9). Therefore, the insect families were well diversified consequently there was no that mach domination of a single family over the rest of insect families within this season. In addition, family Reduvidae had the largest number of individuals consisting of 25 insects (9.47 %), while the least number of individuals was1insect (0.39%) which was recorded from the insect families Meloidae, Buperstidae, Lucanidae, Scarabidae, Sarcophagidae, Bombyliidae, Muscidae, Tiginidae, Membracidae, Cydinidae, Cicindelinae, Vespidae, Apidae, Eumenidae, Hesperiidae, Hymenopodidae, Penumoridae, Shizoductyilidae and Mogoplistidae (Table 6.9)..

Table **6.10**: Species richness, Diversity Index (H') and Evenness (E) of different orders from long rain season in 2014/2015

Order	Family	Individual	H'	E
Hemiptera	12	83	0.459	0.103
Coleoptera	12	52	0.334	0.075
Lepidoptera	5	36	0.199	0.044
Hymenoptera	9	32	0.195	0.044
Orthoptera	8	25	0.173	0.039
Odonata	4	14	0.099	0.022
Blattodea	2	11	0.071	0.016
Mantodea	2	4	0.031	0.007
Isoptera	1	4	0.028	0.006
Diptera	3	3	0.026	0.006
Total	58	264		

Among ten orders collected in long rain season the order Hemiptera had the largest number of individual insects consisting of 83 insects. The least number was 3 insects which were recorded from the order Mantodea. From the total of 58 insect families collected from short rain season in 2014/2015 the order Hemiptera had the largest insect families consisting of 11 families. The least number was 1 family which was recorded from the order Isoptera (Table 6.10).

The diversity index and Evenness of insects collected from long rain season in 2014/2015 (Table 6.10). The highest Shannon's H′ value of 0.459 was recorded from the order Hemiptera. The lowest H′value of 0.026 was recorded from the order Diptera. The highest homogeneity or pattern of distribution of species was for the order Hemiptera with E value of 0.103. The lowest E value of 0.006 was recorded from the order Diptera.

Table 6.11: Numbers and percentages of insects in different orders and families from short rain season in 2014/2015

Order	Family	# of Insects	Percentage composition	pi	lnpi	pilnpi
Blattodea	Blatellidae	10	4.37	0.043668	-3.13114	-0.13673
	Blattidae	2	0.87	0.008734	-4.74057	-0.0414
	Polyphagidae	2	0.87	0.008734	-4.74057	-0.0414
Coleoptera	Chrysomelidae	8	3.49	0.034934	-3.35428	-0.11718
	Staphylinidae	7	3.06	0.030568	-3.48781	-0.10661
	Meloidae	6	2.62	0.026201	-3.64196	-0.09542
	Tenbrionidae	5	2.18	0.021834	-3.82428	-0.0835
	Scarabaeidae	5	2.18	0.021834	-3.82428	-0.0835
	Curcculionidae	4	1.75	0.017467	-4.04743	-0.0707
	Carabidae	3	1.31	0.0131	-4.33511	-0.05679
	Cleridae	3	1.31	0.0131	-4.33511	-0.05679
	Coccinellidae	2	0.87	0.008734	-4.74057	-0.0414

Table continued

	Cerambycidae	1	0.44	0.004367	-5.43372	-0.02373
	Lycidae	1	0.44	0.004367	-5.43372	-0.02373
Diptera	Muscidae	2	0.87	0.008734	-4.74057	-0.0414
	Sarcophagidae	1	0.44	0.004367	-5.43372	-0.02373
Hemiptera	Blissidae	13	5.68	0.056769	-2.86877	-0.16286
	Psyllidae	12	5.2	0.052402	-2.94882	-0.15452
	Reduvidae	8	3.49	0.034934	-3.35428	-0.11718
	Pentatomidae	7	3.06	0.030568	-3.48781	-0.10661
	Lygaeidae	4	1.75	0.017467	-4.04743	-0.0707
	Pyrrhocoridae	4	1.75	0.017467	-4.04743	-0.0707
	Issidae	3	1.31	0.0131	-4.33511	-0.05679
	Coreidae	2	0.87	0.008734	-4.74057	-0.0414
	Cixiidae	2	0.87	0.008734	-4.74057	-0.0414
	Largidae	1	0.44	0.004367	-5.43372	-0.02373
	Rhopalidae	1	0.44	0.004367	-5.43372	-0.02373
	Tiginidae	1	0.44	0.004367	-5.43372	-0.02373
	Saldidae	1	0.44	0.004367	-5.43372	-0.02373
Hymenoptera	Formicidae	25	10.92	0.10917	-2.21485	-0.2418
	Agaonidae	9	3.93	0.039301	-3.2365	-0.1272
	Ichneumonidae	7	3.06	0.030568	-3.48781	-0.10661
	Vespidae	6	2.62	0.026201	-3.64196	-0.09542
	Bracconidae	2	0.87	0.008734	-4.74057	-0.0414

Table continued

	Apidae	1	0.44	0.004367	-5.43372	-0.02373
Isoptera	Termitidae	26	11.35	0.113537	-2.17563	-0.24701
Lepidoptera	Nymphalidae	3	1.31	0.0131	-4.33511	-0.05679
	Papilionidae	2	0.87	0.008734	-4.74057	-0.0414
	Lycaenidae	1	0.44	0.004367	-5.43372	-0.02373
Mantodea	Hymenopodidae	2	0.87	0.008734	-4.74057	-0.0414
	Sibyllidae	1	0.44	0.004367	-5.43372	-0.02373
Odonata	Hemistigma	1	0.44	0.004367	-5.43372	-0.02373
Orthoptera	Gryllacaridida	5	2.18	0.021834	-3.82428	-0.0835
	Acrididae	5	2.18	0.021834	-3.82428	-0.0835
	Gryllidae	4	1.75	0.017467	-4.04743	-0.0707
	Mogoplistidae	3	1.31	0.0131	-4.33511	-0.05679
	Pyrgomorphidae	2	0.87	0.008734	-4.74057	-0.0414
	Bradyporidae	1	0.44	0.004367	-5.43372	-0.02373
	Tettigoniidae	1	0.44	0.004367	-5.43372	-0.02373
	Tridactylidae	1	0.44	0.004367	-5.43372	-0.02373
Total		**229**				-3.46213
Shannon-Wienr diversity index (H′)						**3.46**
Evenness (E)						**0.88**
Speciess richness						**50**

The.Shannon’s H′ value of 3.46 and E value of 0.88 were recorded from the short rain season (Table 6.11). Therefore, the insect families were well diversified consequently there was not that mach domination of a single family over the rest of insect families within this season. In addition, And also, family Termitidae had the largest number of individual insects consisting of 26 insects (11.36 %), while, the least number was 1 insect (0.44%) which was recorded from the insect families Cerambycidae, Lycidae, Sarcophagidae, Apidae, Lycaenidae, Sibyllidae, Hemistigma, Bradyporidae, Tettigoniidae and Tridactylidae (Table 6.11) .

Table 6.12: Species richness, Diversity index (H') and Evenness (E) of different insect orders from short rain season in 2014/2015 (pooled data)

Order	No. of Families	No. of Insects	H'	E
Hemiptera	13	59	0.373	0.083
Coleoptera	11	45	0.303	0.068
Hymenoptera	6	50	0.273	0.061
Orthoptera	8	22	0.159	0.036
Isoptera	1	26	0.116	0.026
Blattodea	3	14	0.089	0.02
Lepidoptera	3	6	0.047	0.01
Diptera	2	3	0.025	0.006
Mantodea	2	3	0.025	0.001
Odonata	1	1	0.001	0
	50	229		

Among ten orders collected in short rain season order Hemiptera had the largest number of individual insects consisting of 59 insects. The least number was 1insect which was recorded from the order Odonata. From the total of 50 insect families collected from short rain season in 2014/2015 order Hemiptera had the largest insect families (Species richness) consisting of 13 families. The least number was 1 family which was recorded from the order Odonata (Table 6.12).

The diversity index and Evenness of insects collected from short rain season in 2014/2015 (Table 6.12). Shannon's–Wiener diversity index (H') was the highest for the order Hemiptera with Shannon's H′ value of 0.373. The lowest H′ value of 0.001 was recorded from the order Odonata. The highest homogeneity or pattern of distribution of species was for the order Hemiptera with E value of 0.083. The lowest E value of 0.00 was recorded from the order Odonata.

6.3.2. The seasonality of insect communities in the Belette-Gera Forest

The seasonality of insect community was computed with respect to collected year therefor, from the result of Shannon-Wiener diversity index (H'), in 2013/2014 (Table 6.13), the highest seasonal diversity of insect community was recorded in long rain season with Shannon's H′value of 2.563 and followed by long dry season with Shannon's H′value of 1.601. The least Shannon's H′ value of 1.234 was recorded from short rainy season.

From the result of Evenness (E) in 2013/2014 (Table 6.13) the highest homogeneity or pattern of distribution of species was recorded in long rain season with E value of 0.563 and followed by long dry season with Evenness (E) value of 0.352. The lowest E value of 0.271 was recorded from short rain season.

As far as numbers of insect families (Species richness) were concerned the highest numbers of insect families were recorded during the long rainy season consisting of 74 families. The least numbers of insect families (Species richness) consisting of 54 families was recorded from short rain season (Table 6.13).

Farther more, the variation of the diversity index H′ and Evenness E value with the study years is shown Appendix 4; the value of diversity index H′ was significantly different with season at $t = -11.329$, df = 30 and $P < 0.001$. On the other hand, the variation of Evenness index E value was significantly different with season at $t = -12.364$, df = 30 and $P < 0.001$.

Table 6.13: Seasonal Divsersity Index, Abundance (H') and Evenness (E) of species diversity from Belette-Gera Forest

Year	Season	No. individual	No. Family	Percentage	H'	E
2013/2014	long dry season	247	54	30.53	1.601	0.352
	Long rainy season	372	74	45.98	2.563	0.563
	short rainy season	190	45	23.49	1.234	0.271
	Total	809				
2014/2015	long dry season	258	51	34.35	1.73	0.386
	long rainy season	264	55	35.15	1.868	0.417
	short rainy season	229	50	30.49	1.57	0.351
	Total	751				

From the result of Shannon-Wiener diversity index (H'), in 2014/2015 (Table 6.13), the highest diversity of insect was recorded from long rainy season with Shannon's H′ value of 1.868. The lowest H′ value of 1.57 was recorded from short rainy season.

The result of Evenness (E), in 2014/2015 (Table 6.13), the highest homogeneity or pattern of distribution of species was recorded in long rainy with E value of 0.417. The lowest E value of 0.00 was recorded from short rainy season.

As far as numbers of insect families (Species richness) were concerned long rainy season had the largest number of insect families consisting of 55 families. The least number of insect families (Species richness) was recorded from short rainy season 50 families.

6.4. Discussion

There were four remarable found in the study area; namely short dry season, long dry season, long rainy season and short rainy season in the study area. The current study covered three of them (long dry season, short rainy season and long rainy season).

Insects occur in different ecological niches of Belette-Gera forests. They may be permanent residents or only transient visitors. They are either harmful or beneficial, and play an important role in the ecology of the forest ecosystems. Most insect species inhabited in Belett-Gera forest are only temporal visitors, and they do visit many other habitats. As a result, the insects provide a linkage between the study forest and other environments (Balasubramanian *et al*., 2005). Therefore, it is important to study the influence of season on insect's diversity and abundance in the study forest.

The diversity index H′ value was significantly different with season at $t = -11.329$, df = 30 and $P < 0.001$. Inaddition, Evenness E value was significantly different with season at $t = -12.364$, df = 30 and $P < 0.001$.

Furthermore, the diversity and abundance of insect families were analysed with respect to seasons of in two different study years 2013/2014 and 2014/2015. Therefore, the diversity and abundance of insect families were shown seasonal variation in the study area. The insect families; Formicidae, Termitidae, Blattidae, Scarabidae, Cerambycidae, Nymphalidae, Gryllidae, Chrysomelidae and Carabidae were the most populated insect families collected from long rain season in 2013/2014. In addition, insect families of Coccinellidae, Psyllidae, Formicidae, Bradyporidae, Chrysomelidae and Staphylinidae were the most populated insect families collected from long dry season. Insect families of Formicidae, Chrysomelidae, Psyllidae and Acrididae were also the most populated insect families in short rain season.

On the other hand, insect families of Formicidae, Scarabidae, Lygaeidae, Rhopalidae, Psyllidae, Pyrrhocoridae, Meloidae, Chrysomelidae and Termitidae were the most populated insect families from long dry season in 2014/2015. Insect families of Reduvidae, Formicidae, Nymphalidae, Psyllidae, Pentatomidae, Chrysomelidae andTenbrionidae were the most populated insect families of long rain season. Insect families of Formicidae, Termitidae, Blissidae, Psyllidae and Blatellidae were the most populated insect families of short rain season. These show different families were responding to the seasonal variation in different ways either declining their number or increasing their numbers. The different populations of insect groups within different seasons might be the environmental factors such as temperature, humidity, rain etc and their condition which are observed in different seasons in Belette-Gera forest. Therefore, these seasonal effects could be directly or indirectly influence insects on their biology due to the presence or absence of stability and availability of resources; such as oviposition, resting, overwintering sites and the quantity and quality of food on the diversity and distributions of insect communities with in the study forest. This result is in agreement with different ideas of people. The rate of manner of insect development or growth may depend up on a number of biotic and abiotic factors (Emana Getu, 2007). These include, the type and amount of food, the amount of moisture, temperature, or the presence of environmental signals (photoperiod) (Emana Getu, 2007; Gullan and Cranston, 2000). Among these, the amount of food, moisture and temperature were probably agreed with the suggestion of the present study. Seasonality is noticeable in the life history of many insects (Denlinger, 1980).

The major seasonal fluctuations occur in the insect fauna near the Equator in East Africa. Marked seasonal breeding also occurs in many species of insects in tropical Africa (Dingle and Khamala, 1970). Davis (1945) also showed that tropical insects undergo seasonal change in abundance at least for those part of the tropics where wet and dry seasons alternate. There is also some seasonality among forest insects with the highest occurring in species of wet forests. This is due to an increase in rainfall, in the number of hours of overcast, and in the amount of green vegetation (Fogden, 1972). Similarly, in this study the diversity and abundance of insect communities were varried among seasons and the highest variation was observed in long rain season. Consequently, in the long rain season is where the amount of rainfall increase and also the diversity and abundance of insect species was recorded the highest. In addition, Belette-Gera forest was belong to the moist tropical forest and wet dry seasons within the forest alternate and also variations of insect abundance and diversity were observed among seasons.

The diversity and abundance of the collected insect community in the study area were shown seasonal variation. Because of, the sesonal factors observed in different seasons influence on the growth and development of insect communities within the study forest. Insect order Coleoptera possessed the highest diversity and abundance in all seasons of 2013/2014. The highest numbers of insect families (Species richness) were collected from the order Coleoptera and insects which are belong to different insect families of the order Coleoptera might be positively responding to wards seasonal factors which encourage for growth and developments of insects of this order than the rest of insect orders in 2013/2014. On the other hand, insect order Hemiptera was recorded the highest diversity and abundance in all seasons of 2014/2015.

Similarly insect order Hemiptera were possessed the highest numbers of insect families (Species richness) in the study year. This can be insects which belong to the different insect families of order Hemiptera respond positively towards the seasonal factors which were observed in different seasons. As aresult, encourage growth and development of insect families of this order than the remaining collected insect orders in 2014/2015 within the study forest. Therefore, from the result one can conclude that, diversity and abundance of insect communities' respond to seasonal variation were varied among the year due to several biotic and abiotic factors. In other words, these factors limit or encourage the growth of different insect groups (taxa). In addition, seasonal climatic conditions can exert a strong influence on insect abundance and activity. Different ideas of authors in the field of insect ecology support this suggestion.Therefore, in ecosystems with clear distinction between rainy and dry seasons; climatic variables are known to be good predictors of population behavior (Wolda, 1987; Janzen 1973). However, insect responses to climate are not uniform and may vary according to their biology and physiological characteristic and the studied taxa (Wolda, 1987; Janzen and Schoener, 1968).

There is a great diversity of studies included that goes across several insect taxa and ecosystems reflecting the magnitude of the effects of the physical environment on insect populations (Tanaka and Tanaka, 1982; Dingle and Khamala, 1970). The effect of temperature fluctuations on the rate of development of insects has been well studied in the past. Moreover, Temperature fluctuations often seasonality directly and also temperature tolerance vary from species to species. Insect predators and parasitoids also become more active at higher temperatures (Boyer *et al*., 2003). The variations in the diurnal surface temperatures affect the distribution and abundance of Alpine grasshoppers (Coxwell and Bock, 1995). Furthermore, the temperature and humidity have been established as the major factors regulating the insect abundance and seasonality in many of the studies (Beckett, 2011; Overgaard and Sorenson, 2008; Rejii and Chander, 2008).

Apart from its direct impact of temperature, it also affects the organisms indirectly, by causing changes in many other environmental factors such as; rainfall, humidity and light are the three other important factors closely associated with the seasonality of insects. Consequently, in the natural conditions these major factors often affect the abundance and diversity of insects indirectly (Janzen and Schoener, 1968). The rainfall, for instance could determine the seasonality of plants (Tanaka and Tanaka, 1982) and hence, that of the folivorous insects will be affect indirectly. Also, distribution of rain is an environmental factor which controls the seasonal abundance of the insects (Pollard, 1988).

In the case of springtails, the soil humidity played only a minor role in their seasonality, while was the life history phenomena that decided the patterns of seasonal fluctuations in the soil and litter collembolans were the major factors in their sesonality (Badejo and Straalen, 1993).

Apart from the major environmental factors, the seasonality of insects is also reported to be regulated with many other factors such as, composition of trees in the forest (floral species diversity), diet, shade, predation by natural enemies (Anu and Sabu, 2007; Gullan and Cranston 2000; Daly *et al*., 1998).

In most cases a combination of different factors described above only can explain the phenomenon of insect seasonality. On the other hand, there have been studies describing the effect of insect population abundance on the abundance and biology of vertebrate predators which depend on insects such as birds (Huffaker and Gutierrez, 1999).

There were two seasonal declines of insect diversity and abundance was observed in Belette-Gera forest. These are in long dry season and short rain season of both study years. On the other hand, the highest diversity and abundance of insects were recorded in long rain season. These can be the amount of rain fall directly influence on the growth of the vegetation in the study forest which provide enough food resources for phytophagous insects, pollinators and their natural enemies, also provide as shade, oviposition sites etc.

This phenomenon was related with the study of different aothurs. The seasonal breeding and biomass of insects increase dramatically during the long rains season (Dingle and Khamala, 1970). Therefore, insect abundance is closely limited by rainfall and it provides a direct seasonal clue for mating and reproducing insects in Africa including Ethiopia such as Belette-Gera national forest which is one of the tropical moist forests. In addition to this, rainfall may indirectly affect insect populations by its effect on food availability (Tanaka and Tanaka, 1982).

In general, species diversity increases with environmental complexity or heterogeneity. However, an aspect of environmental structure important to one group of organisms may not have a positive influence on another group. Hence, ecologicsl studies are very important inorder to know something about the ecological requirements of insect species and to predict how environmental structures influence the diversity and abundance of insects in given place and time. In other words, it is important to knowing something about their niches (Losey and Vaughan, 2006). Overall, these ecological requirements can be resulted due to seasonal factors such as variation in temperature, rain fall, humidity etc. in to which the diversity and abundance of insects affected in space and time. And also, affect the fuctional diversity of insect species within the forest ecosystem.

Chapter 7 GENERAL CONCLUSIONS AND RECOMMENDATIONS

Belette-Gera Forest has also good diversity and abundance of insect communities observed from the understory forest collected and analysis data. The study identified 14 insect orders and 120 insect families with in Belette-Gera forest. Hence, among the collected insect orders; order Coleoptera, Hemiptera, Hyminoptera, Lepidoptera and Orthoptera are the first five diversified and abundantly found insect orders within the forest. Therefore, insects of these orders are important in decomposition, nutrient cycling, pollination, seed dispersal and control of other animal populations within Belette-Gera forest ecosystem.

Habitat fragmentation was influenced the diversity and abundance of insect community with in the study forest. As a result, the highest diversity and abundance of insect community was recorded in Natural forest habitat. Unlikly, the lowest diversity and abundance of insect community was observed in wetland habitat.

The highest insect species diversity and abundance was obseved in the Natural forest habitat due to some level of protection and diversified indigenous forests with in the habitat. This underscores the importance of the site for insect species conservation and calls for better protection and management. Therefore, as unprotecting continues a good species compositional similarity between each pair of the fragments will decrease as a result of fragmentation and land use changes.

In the wet land habitat the least insect diversity was observed mainly due to human interferences for grazing and farming by draining the marsh land. Similarly, plantation forest habitat also exploits the forest mainly for the purpose of fuel consumption, for construction and as asource of income by the nearby communities.

Here the government in charge of the wetland habitat area and plantation forest habitats should take some measure to avoid from distracting these habitats by local farmers for agriculture and fuel consumptions. In addition the lowest insect diversity observed in the monoculture plantation underscores the need for diverse plant communities if diversity in insect communities must be achieved.

Seasonal flactuation of insect diversity and abundance were observed in Bellete-Gera forest. The highest diversity and abundance of insect community was noted in long rain season. On the otherhand, the lowest diversity and abundance was recorded in short rain season. Therefore, long rain season is a suitable season that encouraged the growth and development of insect communities that adapted with in the study forest.

From this study, the National forest is still considered to have a diverse and numerous insect fauna. And also, knowledge of forest insect biodiversity is one of the important cornerstones of sustainable development and represents the biological wealth of a given nation. However, the results which were being presented in this research might be the first comprehensive list of insects in Belette-Gera National forest. Hopefully, there should be further research study needed on the insect biodiversity and taxonomy.

- Especially by including different collection methods that do not cover in this study such as light trap, bait trap, in order to determine diversity and abundance of insect communities in the area.

- Therefore, research work should require on the diversity and distribution of insect community at canopy level in order to get reliable information about insect fauna of Belette-Gera national forest.

- Finally, insect biodiversity and populations are good indicators of ecosystem health and management. Therefore, continuous study should be required to meet the needs of understanding and conserving biodiversity.

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APPENDICES

Appendix 1: List of insects' species of Belette-Gera National Forest between September, 2013 and August, 2015

Order	Family	Genus	Species	NFH	AFH	WLH	# of insects
Blattodea	Blatellidae	Blatella	Unknown	13	8	12	33
		Blepharodera	Unknown	0	2	0	2
		Derocolymma	Unknown	0	1	0	1
		Deropeltis	Unknown	7	2	5	14
		Periplantea	Unknown	2	0	0	2
		Perisphaeria	Unknown	0	1	0	1
		Pseudoderopeltis	Unknown	7	0	10	17
	Polyphagidae	Tivia	Unknown	3	0	0	3
	Blaberidae	Unknown	Unknown	1	0	0	1
	Blattidae	Unknown	Unknown	1	0	0	1
Coleoptera	Anthribidae	Chirotenon	Unknown	8	0	0	8
	Buperstidae	Acmaeodera	Unknown	1	3	2	6
	Carabidae	Thermophilum	Unknown	1	2	0	3
		Graphipterus	Lineolatus	2	0	0	2
		Graphipterus	Unknown	0	1	0	1

Table continued

	Craspedophorus	Unknown	0	0	3	3
	Anthia	maxillosa	3	0	0	3
	Tefflus	Unknown	1	0	0	1
	Caminara	Unknown	0	0	3	3
	Cicinedela	Unknown	1	0	0	1
Cerambycidae	Anubis	Natalense	0	2	0	2
	Tragocephala	formosa	5	1	1	7
	Ceroplesis	thunbergi	0	2	0	2
	Philematium	Unknown	1	0	0	1
	Phoracantha	Unknown	0	2	0	2
	Chrotyse	Unkown	0	1	0	1
	Anubis	natalense	1	0	0	1
	Platycorynus	dejeani	0	0	4	4
	Phoracantha	Unknown	0	1	0	1
	Promeces	longipes	1	1	0	2
	Promeces	longipes	0	3	0	3
	Sonchia unknon	Unknown	0	0	1	1
Chrysomelidae	Aspidimorpha	Unknown	0	4	0	4
	Chrysolina	clarkia	1	1	1	3
	Cryptocephalus	decemnotatus	0	2	2	4
	Diabrotica	Unknown	7	11	2	20
	Lema	Unknown	1	0	0	1

Table continued

	Megaleruca	Unknown	1	0	0	1
	Monolepta	bioculata	4	3	2	9
	Unknown	Unknown	0	0	1	1
	Platycorynus	Unknown	1	0	0	1
	Sonchia	sternalis	4	4	1	9
	Unknown	Unknown	1	0	15	16
	Phylloterta	Unknown	0	4	0	4
Anthicidae	Unknown	Unknown	1	0	0	1
	Unknown	Unknown	1	0	0	1
	Unknown	Unknown	1	0	0	1
Cleridae	Dalsira	Unknown	1	0	0	1
	Exkorynetes	analis	7	1	2	10
	Tenerus	variabilis	1	0	0	1
	Phloeocopus	ferreti	0	1	3	4
Coccinellidae	Cheilomene	lanta	0	0	2	2
	Denopia	Unknown	1	0	0	1
	Epilachina	infirma	9	5	1	15
	Epilachina	paykulli	5	2	1	8
	Epilachina	dregei	4	2	1	7
	Exochomus	flavipes	7	1	13	21
	Harmonia	vigintiduomaculata	1	0	0	1
	Exochomus	Unknown	5	0	6	11

Table continued

	Henosepilachina	bifasciata	1	0	1	2
Curcculionidae	Brachycerus	Unknown	0	4	0	4
	Brachycerus	ornatus	0	2	0	2
	Curculio	hessei	1	0	0	1
	Hypolixus	Unknown	0	1	0	1
	Protostrophus	Unknow	7	0	0	7
	Sciobius	Unknown	1	0	0	1
	Timola	Unknown	6	1	0	7
	Unknown	Unknown	0	0	1	1
Erotylidae	Unknown	Unknown	0	1	0	1
Glateridae	Cardiotarsus	Unknown	1	0	0	1
Lagriidae	Unknown	Unknown	1	0	0	1
Lucanidae	Unknown	Unknown	0	0	1	1
Lycidae	Lycus	Unknown	1	0	0	1
	Cladophorus	marshlli	4	0	0	4
Lygaeidae	Unknown	Unknown	1	0	0	1
Meloidae	Decapotoma	lunata	0	2	0	2
	Epicauta	Unknown	1	0	0	1
	Lydomorphus	bisignatus	0	9	0	9
	Lytta	nitidula	2	2	1	5
	Mylobris	burmeisteri	0	4	3	7
	Synhoria	Hottentota	0	0	1	1

Table continued

	Unknown	Unknown	0	0	1	1
Silphidae	Unknown	Unknown	0	1	0	1
Oryzaephilus	Unknown	Unknown	0	0	1	1
Trogidae	Omorgus	Unknown	1	0	0	1
Scarabaeidae	Anisonyx	ditus	2	0	0	2
	Aphodius	Unknown	0	1	7	8
	Circellium	Unknown	0	0	1	1
	Diplognatha	Unknown	1	0	0	1
	Kheper	Unknown	2	1	6	9
	Kheper	nigroaeneus	2	1	4	7
	Mausoleopsis	amabilis	1	0	0	1
	Pachycnema	marginella	0	1	0	1
	Porphyronota	Unknown	1	0	0	1
	Scarabaeus	rugosus	0	0	2	2
	Schizonycha	Unknown	0	1	0	1
	Unknown	Unknown	2	1	14	17
	Cyclus	Unknown	1	0	0	1
	Diline transectaxis	Unknown	1	0	0	1
	Phyllophaga	Unknown	0	0	2	2
Staphylinidae	Dolicaon	Unknown	3	1	3	7
	Paederinae	Pallipas	6	3	19	28

Table continued

		Zyras	Unknown	1	1	1	3
	Tenbrionidae	Asthenochirus	Unknown	1	0	0	1
		Eleodes	Unknown	0	0	2	2
		Himatismus	Unknown	3	4	2	9
		Lagria	Unknown	2	0	0	2
		Metallonotus	Unknown	1	3	1	5
		Psammodes	Unknown	1	0	6	7
		Unknown	Unknown	2	1	1	4
Diptera	Anthomyiidae	Anthomyia	Unknown	0	1	2	3
		Fucellia	capensis	3	0	0	3
	Asilidae	Alcimus	tristrigatus	0	1	0	1
		Lasiocnemis	lugens	0	0	2	2
		Leptogaster	Unknown	0	0	1	1
		Unknown	Unknown	1	0	0	1
	Mydidae	Cephalocera	Unknown	0	1	0	1
	Empididae	Coptophlebia	Unknown	0	1	0	1
	Tachinidae	Dejeania	Unknown	0	2	1	3
	Nemestrinidae	Prosoeca	Unknown	1	2	0	3
	Sarcophagidae	Saecophaga	pachtyli	0	2	0	2
		Saecophaga	Unknown	0	1	0	1
	Phoridae	Unknown	Unknown	1	0	0	1
	Ephydridae	Unknown	Unknown	4	0	0	4

Table continued

	Calliphoridae	Unknown	Unknown	2	0	0	2
	Tachinidae	Unknown	Unknown	0	1	0	1
	Sciaridae	Unknown	Unknown	0	1	0	1
	Bombyliidae	Bombomyia	discoidae	0	0	2	2
		Archytes	Unknown	0	1	1	2
	Tephritidae	Ceratitis	rosa	1	2	0	3
	Muscidae	Lispe	Unknown	0	1	0	1
		Musca	domestica	5	8	1	14
		Stomoxys	calcitranus	3	0	0	3
	Syrphidae	Allograpta	fuscotibialis	0	1	0	1
		Asarkina	unknown	1	3	0	4
		Eristolis	taeniops	0	1	0	1
		Phytomia	Unknown	1	0	0	1
		Unknown	Unknown	2	0	0	2
Hemiptera	Reduvidae	Glymmatophoa	Unknown	4	5	2	11
		Pantoleistes	princeps	1	1	0	2
		Phanoctonus	Unkown	28	0	0	28
		Reduvius	karsalus	0	2	0	2
		Reduvius	Unknown	1	3	0	4
		Threocorid	Unknown	0	0	7	7
		Zelus	Unknown	1	0	0	1
	Pyrrhocoridae	Cenaeus	carnifex	0	7	6	13

Table continued

	Dysdercus	nigrofasciatus	2	3	3	8
	Scantius	forsteri	2	12	5	19
Psyllidae	Retroacizzia	mopanei	32	21	0	53
	Retroacizzia	Unknown	24	11	0	35
Pentatomidae	Bagrada	Unknown	0	1	0	1
	Coenomorpha	Unknown	1	0	0	1
	Coridius	nubilis	2	0	0	2
	Dalsira	costalis	7	0	0	7
	Nezara	Unknown	0	0	1	1
	Pangaeus	Unknown	0	0	1	1
	Scutellaridae	Unknown	0	0	1	1
	Veterna	Unknown	3	0	4	7
	Unknown	Unknown	0	0	13	13
Lygaeidae	Dieuches	Unknown	2	7	2	11
	Lygus	Unknown	0	1	0	1
	Oncopeltus	famelicus	2	4	13	19
	Pachygronatha	lineata	3	1	0	4
Membracidae	Anchon	nodicornis	0	1	0	1
	Centrotus	Unknown	3	0	0	3
Thyrecoridae	Conimelaena	Unknown	0	0	2	2
Scutelleridae	Graptocoris	aulicus	0	0	2	2
	Sphaerocoris	Unknown	0	1	0	1

Table continued

Rhopalidae	Jadera	Unknown	0	19	0	19
Saldidae	Saldula	Unknown	0	0	1	1
Naucoridae	Unknown	Unknown	1	0	0	1
Phymatidae	Unknown	Unknown	1	0	0	1
Leptopodidae	Unknown	Unknown	3	0	0	3
Coreidae	Acanthocoris	Unknown	1	0	0	1
	Anoplocnemis	Unknown	0	1	0	1
	Carlisis	wahlbergi	0	1	0	1
	Cletus	Unknown	1	1	0	2
	Homoeocerus	Unknown	1	0	0	1
	Leptoglossus	membranaceus	0	0	1	1
	Petalocnemis	Unknown	0	0	2	2
	Unknown	Unknown	1	0	0	1
Cicadellidae	Poecilocarda	cosmopobita	0	2	4	6
	Unknown	Unknown	0	0	1	1
Blissidae	Blissus	Unknown	14	4	5	23
	Unknown	Unknown	0	1	0	1
Issidae	Gamergomorphus	Unknown	2	1	0	3
Cydnidae	Geocnethus	Unknown	0	0	1	1
Cixiidae	Inxwala	Unknown	0	0	2	2
Largidae	Largus	Unknown	0	0	1	1
Largidae	Lygaeus	Unknown	2	0	0	2

Table continued

	Aphididae	Macrosiphon	Unknown	0	3	0	3
	Alydidae	Nariscus	Unknown	1	0	0	1
	Dictyopharidae	Putala	Unknown	1	0	0	1
	Cercopidae	Rhinaulax	Unknown	1	0	0	1
	Cicadidae	Stagira	Unknown	0	2	0	2
	Cixiidae	Unknown	Unknown	1	0	0	1
	Fulgoridae	Unknown	Unknown	1	0	0	1
	Cercopidae	Unknown	Unknown	0	1	0	1
	Cydnidae	Unknown	Unknown	0	1	0	1
	Tiginidae	Plerochila	australis	1	5	0	6
Hymenoptera	Tenthredinidae	Arge	Unknown	1	0	0	1
	Pompilidae	Cyphononyx	optimus	0	2	0	2
	Bradyporidae	Hetrodes	Unknown	0	3	0	3
	Eumenidae	Delta	aethiopicus	1	0	2	3
	Chalcidae	Hockeria	Unknown	0	2	0	2
	Megachilidae	Megachile	Unknown	0	0	1	1
	Eumenidae	Parachilus	Capensis	2	0	0	2
	Gucharitidae	Pteromalus	Unknown	0	4	0	4
	Anthophoridae	Xylocopa	caffra	0	2	2	4
	Asilidae	Unknown	Unknown	1	0	0	1
	Siricidae	Unknown	Unknown	1	0	0	1
	Agaonidae	Unknown	Unknown	9	2	0	11

Table continued

Tiphiidae	Unknown	Unknown	1	0	0	1
Formicidae	Camponotus	Unknown	4	27	37	68
	Crematogaster	Unknown	1	0	0	1
	Dorylus	Unknown	0	6	0	6
	Lignepithema	Unknown	20	0	0	20
	Messor	Unknown	9	0	0	9
	Myrmicaria	Unknown	2	5	8	15
	Oecophylla	Unknown	2	0	0	2
	Paratrechina	Unknown	0	4	8	12
	Pogonymyrmex	Unknown	0	0	8	8
	Polyrhachis	Unknown	6	3	0	9
	Solenopsis	Unknown	2	8	8	18
	Stereblognathus	Unknown	8	0	4	12
	Tetraponera	Unknown	3	1	0	4
	Unknown	Unknown	1	0	6	7
Vespidae	Belangoster	Unknown	4	2	0	6
	Belangoster	dubia	5	4	0	9
	Vespula	Unknown	0	1	0	1
Apidae	Apis	Unknown	0	3	0	3
	Apis	mellifera	2	0	3	5
	Meliponula	Unknown	0	0	1	1
Bracconidae	Apanteles	Acraea	0	1	0	1

Table continued

		Archibracon	servillei	1	0	4	5
		Charops	Unknown	1	2	0	3
		Unknown	Unknown	0	0	1	1
	Ichneumonidae	Enicospilus	Unknown	0	3	0	3
		Gabunia	Unknown	3	1	0	4
		Theronia	Unknown	3	0	1	4
		Ichneumon	Unknown	0	0	4	4
	Pteromalidae	Pteromalus	Unknown	5	0	0	5
		Trichilogaster	Unknown	0	0	7	7
	Sphecidae	Podalonia	Unknown	2	0	0	2
		Sceliphron	Unknown	0	0	1	1
		Chalybion	Unknown	1	0	0	1
Isoptera	Termitidae	Macrotermes	Unknown	29	8	4	41
		Amitermes	Unknown	6	0	6	12
		Unknown	Unknown	0	0	4	4
		Microcerotermes	Unknown	4	18	0	22
Lepidoptera	Hesperiidae	Unknown	Unknown	3	0	0	3
	Lycaenidae	Azanus	jesous	0	0	2	2
		Lolalus	silas	1	0	0	1
		Myrina	Unknown	1	0	0	1
		Ornipholidotes	Unknown	2	1	1	4
		Ornipholidotes	Peucetia	1	0	1	2

Table continued

	Nymphalidae	Acraea	Unknown	7	5	2	14
		Acraea	natalica	5	2	1	8
		Aeropetes	tulbaghia	1	2	0	3
		Amauris	Unknown	6	0	0	6
		Bicyclus	Unknown	4	2	0	6
		Danaus	Unknown	2	1	0	3
		Hyalites	eponina	2	2	1	5
		Hyalites	esebria	2	3	1	6
		Junonia	Unknown	2	1	1	4
	Papilionidae	Papilio	demodocus	2	1	1	4
		Graphium	colona	1	0	0	1
		Papilio	Unknown	6	2	1	9
	Pieridae	Pieris	Unknown	0	0	1	1
		Colotis	auxo	1	0	0	1
		Eurema	Unknown	1	1	0	2
Mantodea	Hymenopodidae	Galinthias	Unknown	1	0	2	3
	Thespidae	Hoplocoryphella	Unknown	3	2	0	5
	Mantidae	Mantispa	Unknown	3	0	0	3
		Unknown	Unknown	1	0	0	1
	Sibyllidae	Sibylla	Unknown	0	1	0	1
	Thespidae	Unknown	Unknown	1	0	0	1
	Hymenopodidae	Galinthias	amoena	0	1	0	1

Table continued

Neuroptera	Chrysopidae	Chrysemosa	Unknown	7	0	0	7
		Chrysopara	Unknown	0	0	2	2
	Chrysomelidae	Ankylopteryx	Unknown	1	2	0	3
	Mantispidae	Unknown	Unknown	0	1	0	1
Odonata	Aeshnidae	Anax	Unknown	1	2	1	4
	Chlorocyphidae	Unknown	Unknown	1	1	1	3
	Coenagrionidae	Pseudagrion	Unknown	0	0	4	4
		Pseudagrion	sublacteum	0	0	3	3
	Gomphidae	Uknown	Unknown	2	1	0	3
	Libellulidae	Pantala	flavescers	3	1	0	4
		Orthetrum	Julia	0	0	4	4
Orthoptera	Acrididae	Abisares	Unknown	0	1	0	1
		Acanthacris	ruficornis	0	0	1	1
		Acrotylus	Unknown	0	0	26	26
		Euprepoenemis	Unknown	0	0	2	2
		Leptocris	Unknown	0	1	0	1
		Locusta	Unknown	0	3	0	3
		Locustana	Unknown	6	0	0	6
	Bradyporidae	Acanthoproctus	armiventris	2	0	0	2
		Hetrodes	pupus	0	6	0	6
		Hetrodes	Unknown	0	9	0	9
	Gryllacarididae	Eremus	Unknown	0	1	0	1

Table continued

	Gryllacaris	Unknown	11	3	1	15
	Plagryllcus	Unknown	0	3	0	3
	Protostrophus	Unknown	1	0	0	1
	Unknown	Unknown	4	0	0	4
Gryllidae	Gryllus	Unknown	8	1	2	11
	Acanthogryllus	Unknown	0	0	2	2
	Acanthogryllus	fortipes	0	0	3	3
	Platygryllus	Unknown	2	1	4	7
	Oecanthus	Unknown	3	1	0	4
Penumoridae	Bullacris	Unknown	1	0	0	1
Heteronemiidae	Carausiies	Unknown	0	0	1	1
Mogoplistidae	Mogoplistes	Unknown	0	1	1	2
	Unknown	Unknown	0	2	0	2
Hetrodes	Unknown	Unknown	0	1	0	1
Pamphagidae	Unknown	Unknown	0	2	0	2
Shizoductylidae	Unknown	Unknown	0	1	0	1
	Cenaeus	Unknown	0	1	0	1
Pyrgomorphidae	Unknown	Unknown	0	1	0	1
	Phymatus	morbillosus	0	2	4	6
	Tophronota	Unknown	2	2	7	11
Tridactylidae	Unknown	Unknown	0	1	0	1
Tettigoniidae	Eurycorpha	Unknown	1	0	0	1

Table continued

		Conocephalus	caudalis	3	2	0	5
		Zabalius	Unknown	0	1	0	1
Dermaptra	Labiduridae	Euborellia	Unknown	0	1	0	1
Ephemeroptera	Leptophlebiidae	Unknown	Unknown	0	0	2	2
Mecoptera	Bittacidae	Unknown	Unknown	2	0	1	3
Total				620	468	472	1560

NHF = Natural Forest Habitat, PFH = Plantation Forest Habitat and WLH = Wetland Forest Habitat

Appendix 2: *t*-test for significance difference of the value of diversity index (H′) and Evenness (E) with study years

Paired Samples Test										
		Paired Differences					t	df	Sig. (2-tailed)	
		Mean	Std. Deviat	Std. Error I	95% Confidence Interval of the Difference					
					Lower	Upper				
Pair 1	Diversity ir	-1.15318	0.60053	0.12803	-1.41944	-0.88692	-9.007	21	0	
Pair 2	Evenness i	-1.42364	0.51393	0.10957	-1.6515	-1.19577	-12.993	21	0	

Appendix 3: *t*-test for significance difference of the value of diversity index (H′) and Evenness (E) with habitat type

Paired Samples Test										
		Paired Differences					t	df	Sig. (2-tailed)	
		Mean	Std. Deviat	Std. Error I	95% Confidence Interval of the Difference					
					Lower	Upper				
Pair 1	Shannon D	-1.64167	0.91836	0.15306	-1.9524	-1.33094	-10.726	35	0	
Pair 2	Shannon E	-1.91694	0.8314	0.13857	-2.19825	-1.63564	-13.834	35	0	

Appendix 4: *t*-test for significance difference of the value of diversity index (H′) and Evenness (E) with habitat type

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-taile
		Mean	Std. Deviat	Std. Error I	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Diversity ir	-1.78587	0.8777	0.15764	-2.10781	-1.46393	-11.329	30	0
Pair 2	Evinness ir	-1.90239	0.85669	0.15387	-2.21662	-1.58815	-12.364	30	0