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STUDIES ON THE INSECT FAUNA DIVERSITY ATGULLELE BOTANICAL GARDEN IN WET, INTERMEDAITE AND DRY SEASONS

BY

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ABSTRACT: Gullele Botanic Garden contains diverse types of insects. The diversity, distribution, frequency, density, abundance and habitat association of these insects were investigated using 60 quadrants which is located at different habitat types and transect walk methods during the wet, intermediate and dry seasons. The mean comparisons of Gullele Botanic Garden showed that the presence of insects in large quantity both in wet seasons and natural habitats. From the total of 7593 insects collected, 64 families of insects in Gullele Botanic Garden were recorded. In all seasons more evenness and diversity of insects were observed in the natural forest habitat. On the other hand, the least evenness and diversity of insects were observed in artificial forest habitats in all seasons. In the dry season, the minimum insect diversity and evenness was recorded in all forest habitats of Gullele Botanic Garden. Based on jaccard's similarity index, the highest similarity was observed between grassland forest habitat and mixed forest habitats in Gullele Botanic Garden. On the other hand, the lowest similarity was observed between mixed forest habitat and artificial forest habitat. Natural forest habitat in Gullele Botanic Garden showed the highest Margalef’s Richness Index value. The result of ch-square analysis showed that the highest habitat association was recorded in grassland habitat in wet and dry seasons, and mixed forest habitat in intermediate season. T test and analysis of variance (Anova) results for insect diversity revealed the presence of significance difference (variation) between seasons in Gullele Botanic Garden. Abundance of food, species of vegetation, and stability of the habitats, animal grazing and human activities determined insect diversity at the study areas. Investment activities and human settlement inside had the most detrimental effect to the insect diversity in the garden. During data collection in Gullele Botanic Garden, carefully observation showed that insects had both positive and negative effects for humans, plants, animals and insects.

1. INTRODUTION

Insects belong to the class insecta and phylum arthropoda. They are the largest in the animal kingdom (Imms, 1973; Romoser, 1973; Fenemore and Prakash, 1995). The members of the phylum are characterized by a segmented body that are bearing varying members of paired and segmented appendages; bilateral symmetry; an exoskeleton that contain the nitrogenous polysaccharides, chitin that may be locally hardened and is periodically shed; and various internal features, such as an open circulatory system, malpigian tubules, and a system of ventilation tubules, the trachea and tracheoles, tagmosis (the grouping of segments into functional units, for example, head, thorax, and abdomen in insects), hemocoelic body cavity containing heart enclosed within a pericardium, nervous system comprising dorsal brain and ventral ganglionated nerve cord, muscles almost always striated, and epithelial tissue almost always non-ciliated (Gillott, 2005; Romoser, 1973). So insects are highly specialized groups of invertebrates (Nayar *et al*., 1992).

Insects are the earth's most abundant organisms. About half of the described species of living things and almost three quarters of all animals are insects (Daly *et al*., 1998). They are the dominant group of all animals on the earth to day. There are millions of kinds of insects, though we do not know exactly (or even approximately) how many there are. Some estimates imply that the species richness of insects is so great that, to near approximation, all organisms can be considered to be insect (Gullan and Cranston, 2000). Most of the unknown biological diversity of macro-organisms remaining to be discovered and described lies in the tropical regions of the world and consist primarily of insects. Those insects with Parasitoid lifestyles constitute a significant portion of insect diversity. However, estimates of the diversity of macroscopic organisms, such as insects, are nearly as variable and weakly supported as those of micro-organisms, with estimates of global insect species number ranging from as few as 4.8 million to over 30 million including other arthropods (Stireman *et al*., 2009). Gullan and Cranston (2000) also showed that estimation of species richness of insects varies from five million to as many as 80 million species.

Over half of the described organisms in the world are involved in plant-insect-parasitoid interaction, and these provide the basis for our understanding of fundamental issue in ecology and evolutionary biology. In fact, relationships between parasitoids, herbivorous insects, and their host plants are among the most productive system for understanding multi-trophic interaction (Pearson and Dyer, 2006; Miller and Dyer, 2009).

Insects now inhibit virtually all land surface of the globe except the extreme Polar Regions and the highest mountain peaks. Wherever they occur they tend to dominate the small fauna, being rivaled only by other group of arthropods, the mites, in some habitats. In body size most insects are one to ten mm in length. Some tiny insects are smaller than some protozoa, and some giant insects are larger than the smallest mammals (Daly *et al.*, 1998). Insect dominance applies to terrestrial and fresh water ecosystems (Gullan and Cranston, 2000).

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 availability, quality and quantity of suitable food is a primary one, but other factors such as light, access to undisturbed areas, proximity to other insects of the same species, are also useful. Fundamental to insect growth, however, are environmental factors of temperature, relative humidity and moisture content of food materials (Emana Getu, 2007; Child, 2007). The seasonal presence of insect species is synchronized with a seasonal presence of its food, if food availability varies seasonally (Wolda, 1978). Fogden (1972) finds that the seasonal cycles of caterpillars and Orthopteriod insects is well correlated with that of leaf production. He also finds that parasitic hymenoptera increase during the caterpillar season. When a combination of favorable factors leads to increased insect development there is a co-related increase in the damage to materials through eating, despoiling, burrowing and other activities (Child, 2007).

Insects have several functions in the ecosystem. For example, ants are abundant insects 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 their offspring, may increase the rate of soil nutrient cycling and reduce egg and larval populations of parasitic flies present in fresh dung of mammals. Many act 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 included change in forest habitats (Vinod and Sabu, 2007). Recently, insects, due to their small size, diversity and sensitivity to environmental stress have been considered as good indicators of habitat heterogeneity, ecosystem diversity and environmental stress (Rothery and Roy, 2001; Stefanscu *et al.*, 2003). Insects have been used as indicators of bio-diversity and endemism, prioritization for establishment of protected areas, bio-geographic relationships, bio-indicators of anthropogenic changes in the forest and water quality. The use of insects as bio-indicators or bio-diversity indicators can be grouped into three categories. These are environmental indicators, ecological indicators and biodiversity indicators (Schuster and Cano, 2006).

Basic aspect of insects in the Gullele Botanic Garden such as species richness, diversity, density and habitat association should be studied with regard to harmful or beneficial nature of insects within the Botanic Garden and their conservation purpose. Hence, the current study was initiated to know the diversity of insects in the stable ecosystems of Botanic Garden in different habitat.

2. OBJECTIVE OF THE STUDY

2.1. General objective

- The main objective of the project was to know insect diversity in Gullele Botanical Garden (GBG) at different habitats.

2.2. Specific objective

- To estimate the population sizes and composition of various insects
- To identify the major habitats of insect in Gullele Botanical Garden
- To evaluate the importance of insects in the Garden
- To collect, preserve and identify insects in to their proper order and family.

3. LITRATURE REVIEW

3.1. Insects and seasonal change

The major seasonal fluctuations occur in the insect fauna near the Equator in East Africa. Marked seasonal breeding occurs in many species of insects in tropical Africa (Dingle and Khamala, 1970). There is also some seasonality among forest insects with the highest occurring in wet seasons. This is due to an increase in rainfall, in the number of hours of overcast, and in the amount of green vegetation. The change in the appearance of the vegetation can in fact be quite dramatic even in areas with only a moderate dry season (Fogden, 1972). The seasonal breeding and biomass of insects increase dramatically during the long rains. The paper by Dingle and Khamala (1970) in tropical Africa deal with seasonal fluctuations in entire insect faunas caught in a Malaise trap and light trap. For example, the marked increases in abundance were noted in the single wet season in Sierra Leone and in the season of long rains in Uganda (Dingle and Khamala, 1970).

The amount of published research papers on wetland insect communities has grown steadily since the mid 1980s. One reason for this increase is that insect communities in small wetlands have proven to be useful systems for testing ecological paradigms (Batzer and Wissinger, 1996). Denlinger (1980) pointed out that seasonality is conspicuous in the life history of many organisms. 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. In areas with pronounced dry season, such as most of the Panama, the abundance of most insects in the season is relatively low. In areas with a very mild dry season, such as Sarkawak, insects decrease in abundance during the dry season (Fogden, 1972). So, the drying of the habitats could be considered a disturbance because it causes mortality that thereby decreases populations of organisms (Fontanarrosa *et al*., 2009).

The seasonal adaptations of insects to arctic conditions are especially instructive because more species of insects are found than other kinds of animals live in the arctic. Reduction in the fauna reflects the fact that only species with the requisite adaptations can survive in the north (Danks, 2004). According to Owen (1972) in the humid tropics of West Africa adult of many species of terrestrial insect occur in all month of the year, but with seasonal peaks of abundance that are associated with the alternation of wet and dry seasons. In savanna regions most species breed during the rainy season although some breed throughout the year and a few are restricted to the dry season. The rainy season insect breeding coincides with the greening of the vegetation and resultant increase in plant productivity. At a general level, there are various estimates of primary productivity and vegetation biomass in tropical savannas, but virtually nothing is known of the seasonal cycles of insect populations except for a few species of outstanding economic importance such as the desert locust (Dingle and Khamala, 1970).

The major change in the insect fauna of the Athi Plains came during the long rains beginning in late March. Numbers did increase somewhat in samples taken during the rains, but the most notable change occurs in the biomass which increased almost fourfold over the previous sample taken before the onset of the rains. There is thus an enormous increase in the food available for insectivorous birds following the onset of the long rains (Dingle and Khamala, 1970).

The research conducted by Dingle and Khamala (1970) in tropical Africa indicated some increase in insect numbers with the beginning of short rains. Without these, there is a size increase in the biomass over the dry season levels. However, the biomass still does not approach that present during the long rains. Owen (1972) noted essentially no changes in insect numbers during the September to December rains in Uganda and a marked increase in the April rains. An extreme dry season, such as occurs between June and early October in the Athi Plains, does not occur in Kampala.

Different rainforest sites, even in close proximity, may have highly variable insect populations due to slight differences in environmental factors or plant composition; and numbers may fluctuate greatly within one site, although this has not been thoroughly examined. Seasonal variability of arthropods can be extremely high, reflecting periodic food supplies or environmental changes such as rainfall (Denlinger, 1980).

In Britain the phytophage community of native deciduous oaks exhibits a regular seasonal pattern with chewing species peaking first, followed sequentially by peaks of sucking species, leaf miners and gall formers. These seasonal patterns can be related to the condition of the leaves. The young leaves are tender and relatively nutritious but, as the leaves age, they become tougher and less nutritious. These older leaves are barriers to chewing insects, but not to sucking insects, whose stylets pass directly into the phloem or xylem (Richard *et al.*, 2004).

Wickman *et al* (1983) defined diapauses as a means by which organisms survive unfavorable circumstance. It has been known for some time that many organisms enter periods of inactivity during winter or upon exposures to low temperatures (Bodine and Evans, 1992). This occurs particularly in temperate areas when environmental conditions become unsuitable such as in seasonal extremes of high or low temperature, or drought. Dormancy may occur in summer (aestivation) or in winter (hibernation), and may involve either quiescence or diapause (Wickman *et al.*, 1983).

Quiescence is halted or slowed development as a direct response to unfavorable conditions, with development resuming immediately favorable conditions return (Nayar *et al.*, 1992). In contrast, diapauses involves arrested development combined with adaptive physiological changes, with development recommencing not necessarily on return of suitable conditions, but only following particular physiological stimuli (Daly *et al.*,1998). Diapause at a fixed time regardless of varied environmental condition is termed obligatory. Univoltine insects often have obligatory diapauses to extend an essentially short life cycle to one full year (Nayar *et al.*, 1992). Diapauses that is optional is termed facultative (Sharma *et al.*, 1979) and this occurs widely in insects including many bi or multivoltine insects in which diapauses occur only in the generation that must survive the unfavorable conditions (Gullan and Cranston, 2000).

Major environmental cues that induce or terminate diapauses are photoperiod, temperature, food quality, moisture, PH and chemicals including oxygen, UREA and plant secondary compounds (Gullan and Cranston, 2000; Hazel and West, 1983).

3.2. Habitat heterogeneity of insects

The 'habitat heterogeneity hypothesis' is one of the cornerstones of ecology. It assumes that structurally complex habitats may provide more niches and diverse ways of exploiting the environmental resources and thus increase species diversity. In most habitats, plant communities determine the physical structure of the environment, and therefore, have a considerable influence on the distributions and interactions of animal species (Tew *et al*., 2004).

Insects can be found in rain-pool, forest grassland, desert, cultivated lands, urban areas, bodies of fresh and salt water and flying in the air. For example, many butterflies are localized or restricted to specific habitat types. It includes forests, savannahs and disturbed habitats (Sundufu and Dumbuya, 2008). Some species of insects are nearly ubiquitous among localities and abundant within each. The other species have very restricted localities and are less abundant where they occur (Williams, 1988). In other words, they occupy all major habitats within the limit of geography and physical environments. Specifically they are found in or on soil litter, in cave, in surface or underground water, immersed in decaying plant or animal matter, and on or the body of fungi, living plants, animals, and other insects (Daly *et al*., 1998; Gullan and Cranston, 2000).

Some insects penetrate the upper layer of soil by following natural crevices and entering mammal burrows themselves. Rocks and other cover objects provide shelters for the ground dwelling forms. Decaying logs (litters) are occupied by insects of many types, especially beetles (Coleoptera), acari (mites), termites (Isoptera) and ants (Formicidae) (Gullan and Cranston, 2000).

In the aquatic environment there is 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 (Daly *et al.*, 1998; Gullan and Cranston, 2000). 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 (Fontanarrosa *et al.*, 2009).

Insect architects are capable of building complex structures out of their secretions and bits of natural objects. Some construct about their bodies shelter of rolled leaves, plant debris, or carefully selected grains of sand. Many that have a resting pupal stage in their life history construct a special cocoon of silk or a chamber in soil or decayed wood. Shelters such as provide protection against desiccation, freezing, and reduce detection by enemies. Social ants, termites, and bees construct elaborate nests that permit some degree of control over temperature, humidity, and light, as well as provide protection against enemies (Daly *et al.*, 1998).

3.3. Species richness (diversity)

Insects are the earth's most diverse organisms, accounting for about half of the described species of living things and about three-quarters of all known animals, and it is estimated that more species of insects than known at present remain to be discovered (Wijesekara and Wijesinghe, 2003). Species richness is refers to the total number of species in a community (Kent and Coker, 1992; Krebs, 1999). The described species of insects are distributed unevenly amongst the highest taxonomic groupings (insect order) (New, 1996; Gullan and Cranston, 2000). Five order standout for their high species richness: the beetles (Coleoptera); butterflies and moths (Lepidopter); flies (Diptera); wasps, ants, and bees (Hymenoptera); the true bugs (Hemiptera). The beetles appear to be confirmed, as they comprise almost 40% of the described insects (more than 300,000 species). The Hymenoptera have nearly 250,000 species, with the Diptera, Lepidoptera and Hemiptera each having between 150,000 and 200,000 species. Of the remaining order of living insects, none exceeds the 2000 described species of the Orthoptera. Most of minor orders have hundreds to a few thousands of described species (Dermaptera and Blattodea) (Gullan and Cranston, 2000).

The tropical regions of the world generally have a richer store of biological diversity than other regions of the globe (Gadagkar *et al.,* 1990; New, 1996). Although it has been generally known that the degree of taxonomic diversity, i.e., species and higher taxa diversity, increases as latitude decreases, there are also numerous exceptions in specific groups of organisms. For example, based on previous studies, Plecoptera and Ephemeroptera are known to be more diverse in temperate streams, whereas many other insect groups such as riffle beetles are known to be more diverse in tropical streams (Hoang and Bae, 2006).

One of the few relatively undisputed generalizations in community ecology is a latitudinal gradient of increase in biological species richness and diversity from the temperate regions to the tropics. Apart from being something of a rule in community ecology this means that those of us who live in the tropics enjoy a biologically rich environment. Recent work suggests that the richness of the tropical insect fauna is beyond all earlier expectations, but insects are much more diverse in the southern temperature regions than Northern temperate regions (Gadagkar *et al.*, 1990; New, 1996). It is equally undisputed, however, that most tropical organisms are poorly studied and the little that we do know about any group of organisms comes largely from studies of temperate species (Gadagkar *et al.,* 1990).

Costa Rica is leading to an extraordinarily high biodiversity and it consists 4-5% of the world's biodiversity. This high biodiversity can be found not only in terrestrial, but also in marine and freshwater habitats, and among the latter, aquatic insects represent the most diverse group of organisms. Among the most diverse orders found in these habitats, are the Trichoptera, Diptera and Coleoptera (Springer, 2008).

3.4. Species abundance

Insects have the largest number of species in animal kingdom. There are between two and three times as many species of insects as all other animals combined. About 1.8 million species of living things are known on Earth. This includes > 1 million insect species, 250,000 species of higher plants and 69,000 species of fungi (Basset, 2001). Not only are insects numerous in species, at least 70, 000 (over one million species of insects) are already described in the world, but also they tend to occur in very large numbers in many kinds of habitats (Pfadt, 1962; New, 1996; Gullan and Cranston, 2000). Each acre of farmland may contain several hundred million insects and other arthropods. Insects have relatively short life cycle and produce large number of progeny per female (Pfadt, 1962; Morse *et al*., 1988). For example, the number of Indian butterflies amount to one fifth of the world butterfly species (Arun, 2003). In fact, there are more species of Diptera (flies) than there are vertebrates, and there are more Coloeptera (beetles and weevils) than invertebrate, other than insects. So a multitude of species has enabled insects to evolve a great diversity of habitats and to invade a wide range of habitats (Pfadt, 1962).

The abundance of insects is brought home particularly forcefully in the tropics where higher temperature and humidity's often lead to large population of spectacular, annoying or dangerous species (Lamp, 1974). In addition to these, the limited distribution and abundance of the species were due to inter-specific competition for food. Similarly, due to intra-specific competition for food, an ability to shrink in size and absence of predators, the populations of any specific species showed a restricted fluctuation in population number (Boddington and Mettrick, 1974). For example, more than 80 species of insects have been reported to attack rice in West Africa. The relative abundance and the severity of rice in insect species differ considerably in the various climatic zone and crop ecology (Alam, 1998).

3.5. Environmental factors

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 (for terrestrial species), heat (measured as temperature), or the presence of environmental signals (photoperiod). Two or more of the factors may interact to complicate interpretation of growth characteristics and patterns (Anu and Sabu, 2007; Gullan and Cranston, 2000).

Temperature: - Most insects are poikilothermic body (cold-blooded organisms) – their temperature varies more or less directly with environmental temperature (Petzoldt and Seaman, 1992) - and so heat is the force driving the rate of growth and development when food is not limiting. A rise in temperature, within the favorable range, will speed up the metabolism of an insect and consequently increase its rate of development. Each species and each stage in the life history may develop at its own rate in relation to temperature (Gullan and Cranston, 2000). Most insect pests in temperate climates have optimum development at temperatures between 20°C and 35°C. At temperatures below 15°C mating is limited, and movement such as flying becomes sluggish. Above 35°C some insects can cool themselves for short periods by evaporating water from their bodies, but in the longer term can die from desiccation. Some insects such as cockroaches, can acclimatize themselves to different temperature norms, but are then killed if subjected to other conditions (Child, 2007).

For example, winter cold can be a major cause of mortality for insects. Egg can survive lower temperature than active stages, but spring populations emerging from eggs have to undergo at least one and usually two full generation on the primary host plant before migrating to the secondary host plant. In theory the likelihood of death of an insect at low temperature increases with decreasing temperature or with increasing period of exposure at constant sub- zero temperature (Bale *et al*., 1988).

Ackonor (1988) explained that temperature has no apparent influence on the weight of hatchling desert locust. Study on insects which a wide geographical range frequently reveals that there are adaptations which allow such species to complete their life cycles over wide temperature ranges. As temperature decreases with increase in altitude, an insect that maintains itself over a wide altitude range may similar be expected to show adaptation to that allows the completion of the life history over a considerable temperature range (Coulson *et al.,* 1976). Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, population size, development, survival, and reproduction (Petzoldt and Seaman, 1992; Ward, 1992).

Humidity: - The high surface area: volume ratio of insects' means that loss of body water is a serious hazard in a terrestrial environment, especially a dry one. Low moisture content of the air can affect the physiology and thus the development, longevity and oviposition of many insects. Air holds more water vapor at high than at low temperature. The relative humidity (RH) at a particular temperature is the ratio of actual water vapors present to that necessary for saturation of the air at that temperature. At low relative humidity, development may be retarded, for example, in many pest of stored product, but at high relative humidity's or in saturated air (100% RH) insects or their eggs may be drown or be infected more readily by pathogens. The fact that, unfavorable humidity has serious implications for estimation of development time's weather calendar or physiological time is used (Gullan and Cranston, 2000).

Food: - Food is the most obvious and important biotic factor, and insects are involved in a wide spectrum of trophic relationships with other organisms, both living and dead. As the majority of insects feed on plant material in one form or another, they are key components in the flow of energy through the ecosystem (Gillott, 2005).

It is a generally accepted fact that most species breed when the amount of food in nature is at its peak (Tov, 1974). The stability of food resources for herbivorous insects varies temporally and specially (Pfadt, 1962). For example, aging of leaves is a major determinant of food resources available to leaf eating insects. Many studies have shown that leaf- eating insects are restricted in their feeding to a certain-age class of leaves. Herbivorous insects that can utilize only part of their host plants are particularly vulnerable to fluctuation in the abundance of their resource (Larsson and Ohmart, 1988).

The quality of the food plant which affects the growth and survival of the insect may vary even within the same species of plant. For example, the water content of cotton affects the incidence of diapauses of cotton insects. Larvae of the European corn borer survive better on the upper part rather than the lower part of the corn plant. Some varieties of a given species of host plant are more suitable than others for development and survival of insects. In fact, the growing of the crop varieties least suitable for insects (resistant varieties) is one effective methods of discouraging infestation (Pfadt, 1962).

Larsson and Ohmart (1988) studied about the several reasons why food source may become limiting at certain point in time. At high population density, herbivore may use up all its food. A number of herbivores species utilizing the same resource (intra-specific competition) (Pfadt, 1962) may similarly cause depletion of food, although inter specific competition does not seem to be common among leaf eating insects (Larsson and Ohmart, 1988).

Photoperiod (light): - The development of insect is controlled by temperature as well as photoperiod. Insect reproductive diapauses is initiated by the photoperiod acting on both adult and pre-adult stage, the most sensitive being the third larvae instars within the cocoon and the pupa (Horobin, 1976). Insects have evolved mechanisms which utilize photoperiod for seasonal information. The photo phase sequence regulates diapauses, behavior, adult emergency and swarming, circadian rhythms and ecological adaptation. It has been shown that the major environmental factor influencing the onset and prevention of diapauses in most insect species is photoperiod. Photoperiod has also been shown to affect growth rate in some insects. In several species of Lepidopetrious larvae, growth is slower under shorter photoperiods, while in other species, the opposite effect was found (Goettel and Philogene, 1988).

Many insects, perhaps most, do not develop continuously all year round, but avoid some seasonally adverse conditions by resting period or migration. Summer dormancy (aestivation) and winter dormancy (hibernation) provide two examples of avoidance of seasonal extremes. Insects can be divided into long day and short day based on photoperiod. Most insects can be described as long day species, with growth and reproduction in summer, and with dormancy commencing with decreasing day length. Others show the reverse patterns, with short day (often autumn and spring) and summer aestivation (Gullan and Cranston, 2000). The most important factor is light; this factor limits growth, inhibit oviposition or retard development (Ismail *et al*, 1988).

Rainfall: - There is a positive relationship between arthropod abundance and rainfall (Tanaka and Tanaka, 1982). There is evidence that rainfall can directly influence arthropod abundance through physiological effects on reproduction, development, or activity. For example, rainfall is necessary for the initiation of breeding in Diptera, such as shadflies

(Chaniotis *et al*., 1971).

Evidence from other studies of tropical insects suggested that rainfall might directly cause within season variations of insect activity or development. Rainfall initiated the development of the mosquito larvae during the dry season in Colombia which required two to three weeks (Bates, 1945). Rainfall provides a direct seasonal cue for mating and may indirectly affect insect population by its effect on food availability (Tanaka and Tanaka, 1982). Janzen (1973) suggested that herbivorous insects may cease reproduction because of a lack of suitable food. Rainfall has been shown to initiate leaf growth in lowland Neotropical forest sites with a severe dry season. On the other hand, some insect groups are more evident during the dry season, when many tropical plants flower. Chaniotis *et al* (1971) stated that herbaceous insects such as Homoptera and Orthoptera may be responding to changes in vegetation affected by rainfall.

Wolda (1978) noted that even minor variations in rainfall can cause important variations in leaf production and a minor leaf flush within increasing insect populations two to three weeks later. Tanaka and Tanaka (1982) had also noted that at the onset of rainy season, new leaf growth was not evident until two to three weeks later. The response between rainfall and certain groups of arthropod on foliage was affected by rainfall patterns (Wolda, 1978). Therefore, it is clear that seasonal fluctuations in rainfall modify the physical environment and change resource availability for both plants and animals (Richards, 1952).

Williams (1964) suggested that seasonal distribution of many insect species maybe depend on rainfall. Denlinger (1980) in his studies of seasonal abundance of selected families of insects in Kenya stated that monitoring nine families of insects representing a diversity of life styles have been very informative. He reported that several families were consistently abundant at only one time of the year.

3.6. Interaction of insects with insects and other living things

Living components in the environment constitute the biotic factors affecting insects. These include natural enemies, pathogens, parasitoids and competitors (Tanada, 1966). The latter group includes individuals of the same species as well as individuals of other species. In *fact, competition among individuals of the same species is usually more intense because their requirements are almost identical* (Pfadt, 1962).

Many insect commonly have complex life cycles, and various interactions are possible among related species in the same habitat during different period of their life histories. Temporal segregation of activity among related species is often found and has been considered as a possible mechanism of coexistence. Thus, close examination of resource utilization patterns and interactions among related species in the same habitats at different stages in their life histories is necessary (Sota, 1985).

Men and insects share the same world. Therefore, there is a constant interaction between men and insects, the intensity of this interaction is contingent upon the size of human population and upon the number of insects both individuals and species levels (Chiang, 1971). Insects coexist with fresh water and terrestrial vertebrates throughout most of their evolutionary history. In the course of this long association, trophic relationships have evolved such that certain insects are parasitic on vertebrates and certain vertebrates are predator on insects (Daly *et al.*, 1998; Ehrlick *et al*, 1978). Ancient man not only used insects to satisfy his physical wants (such as food, leisure and pollination); he also brought them in to his rituals and made them symbols of worship (Pfadt, 1962). It is commonplace that insects are the chief competitors with man for the domination of his planet. Insects destroy mans growing crops, and defoliate his forests; they are responsible for the spreads of nearly all the great epidemic fevers of the tropics and sub-tropics, and for the infections of his live-stock with some of their most fatal diseases. The structural timbers of his buildings are weakened and destroyed by insect attack (termite); his household goods are ravaged by moth and beetles and heavy toll is levied on his stored reserves of food, spice and tobacco (Wigglesworth, 1976).

Insects kill or injure one or more invertebrate before completing their life cycle. Most of these carnivorous insects feed on other insects and are said to be Entomophagous (Connahs *et al.,* 2009). Snails, earth-worms, millipedes, mites and other terrestrial and fresh water invertebrates are also eaten by insects. The victims are called prey if killed directly**,** host if fed upon while still living. Entomophagous insects are divided into three major groups:

predators kill and consume more than one prey organisms to reach maturity; parasitoids require only one host to reach maturity, but ultimately kill the host; and parasites feed on one or more hosts, but do not normally kill the host (Daly *et al.*, 1998; Ehrlick *et al*, 1978). Lepidopteran larvae represent an important food source for a variety of predators, including ants, spiders, birds and small mammals, during summer in temperate forest of Northern America (Steward *et al*, 1988). The phonological relationships between predators (generally considered to be birds) are at least in part determined by the interaction among several properties of Batesian complexes (Waldbver and Laberge, 1985).

Herbivorous insects are insects that exhibit inter-specific competition (Crawley and Pattrasudhi, 1988). Roughly, nearly half of insect species are herbivores, feeding on live plants, which imply that, potentially, 456,000 species of herbivores might interact with 250,000 host plants. Evidently, the distribution of many insects and host plants do not coincide and many herbivore species only feed on a handful of different hosts, so that the total of species interactions between insects and plants must be much lower (Basset, 2001). Two long established notions lies behind this view; herbivores tend to be scarce in relation to their resources and because they are regulated by natural enemies. If resource limitation is common, then intra- specific competition must be involved (Crawley and Pattrasudhi, 1988).

Over half of the described organisms in the world are involved in plant-insect-parasitoid interactions (Miller and Dyer, 2009). About half of all living insect species are Phytophagous (Proche and Cowling, 2006) and exclusively plant- feeding Lepidoptera, Curculionidae (weevils), Chrysomelidae (leaf beetles) Agromyzidae (leaf mining flies) and Cynipidae (gall wasps) are very specious (Gullan and Cranston, 2000).

The two empires, herbivorous insects and plants, are united by intricate relationships. Animal life including that of insects cannot exist in the absence of green plant, which serves as primary source of energy-rich compounds for heterotrophic organisms (Schoonhoven *et al*., 1998). There are two very distinct types of association between insects and plants. Firstly many insects utilize plants as a source of food; there is usually no benefit to the plant from the insects feeding activities and the association is thus antagonistic one. Over geological time plants have evolved various mechanisms to protect themselves from such insects and from larger herbivorous. The second type of association is usually beneficial (Fenemore and Prakash, 1995). Connor (1988) stated that nutritional quality of plants has been implicated as a major factor in the dynamics of herbivorous insect populations remain at low abundance because of high larval mortality resulting from starvation while feeding on nutritionally in adequate plant material. He further suggested those insect outbreaks are caused by weather induced plant water stress that improves the nutritional quality of plant and hence increase early larval survival.

3.7. Importance of insect biodiversity

We should study insects for many reasons (Gullan and Cranston, 2000; Daly *et al*., 1998; Hill, 1997). Biodiversity of insects are important, whether viewed from ecological, economic, aesthetic or other perspectives (Wijesekara and Wijesinghe, 2003). Insects are essential in the following roles within the 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; maintenance of animal community structure, through transmissions of disease of large animals, and predation and parasitism of smaller ones (Metcalf and Flint, 1979; Hill, 1997; Gullan and Cranston, 2000).

Insects have several functions in the ecosystem. For example, ants are abundant insects, a large component of the arthropod community on ground in 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). Pselaphine beetles (Coleoptera: Staphylinidae: Pselaphinae) are cosmopolitan, species-rich, and yet poorly studied, particularly in the tropics (Hawes *et al*., 2009). Dung beetles have a variety of effects on the ecosystem. By burying dung and carrion as food 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).

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 arthropods 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 (Danks, 2004). 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 included change in forest habitats (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 entomophagous (Ehrlick *et al.,* 1978) where as gall forming insects are called weed controlling phytophagous (Dennill, 1988). Insect predators and parasitoids also devour other small invertebrates such as snails, millipedes, spiders and earthworm (Daly *et al*., 1998).

The flower most frequently visited by insects and partially dependent on them for seed-set. Pollinations of the most common plants are primarily by flies, but bumble bees are also important (Metcalf and Flint, 1979). Hill (1997) studied about beneficial insects for the purpose of pollination, apiculture (honey bee), sericulture (moth), insect farming (butterflies), natural control of pest, insects in natural food webs and insects as human food.

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, but usually not killed. 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). Other parasites (e.g. mosquitoes) visit the host only to suck blood (Daly *et al*., 1998). Harmful insects such as medical pests, veterinary pests, household and stored product pests, agricultural pest and forestry pests are explained by Hill (1997).

4. MATERIALS AND METHOD

4.1. Descriptions of the study area

The flora of Ethiopia is estimated to include about 6000 species of higher plants with 10-12% endemism, but these are now in the verge of wanting forever due to deforestation, overgrazing, soil erosion, desertification and others (Sebsebe Demissew, 1988). There are diverse approaches to conserve threatened and endangered species, thus Botanic Gardens can play a crucial role in complementing in-situ conservation besides of its various roles such as recreation, education and research. Botanic Gardens assemble and maintain a diversity of plant species, in the open, in glasshouse and for reference and study, in herbaria (Birhanu Belay, 2009).

Location: - The Gullele Botanic Garden (GBG) is located at the north western part of Addis Ababa city administration. It belongs to the central plateau of Ethiopia, which shares its vegetation zone and climatic characteristics with adjacent part of Oromia National Regional state. The geographical co-ordinate of the garden lies between latitude 8^0 55' N and 9^0 $05^{'}$ N and longitudes 38^0 05' E and 39^0 05' E. The Botanical Garden covers a total area of 936 hectare, from this 736 is in Addis Ababa city administration where as the remaining 200 hectare is found in Oromia administrative region. It has two topographic landscapes units or physiographic features. The northern half is a plain land; the southern half is mountainous with the maximum elevations of 2960 m above sea level. The two perennial watercourses originate from this mountainous area and flow down to the town. The garden is also characterized by many smaller rivers which flow through the town seasonally (Ensermu Kelbessa, 2005).

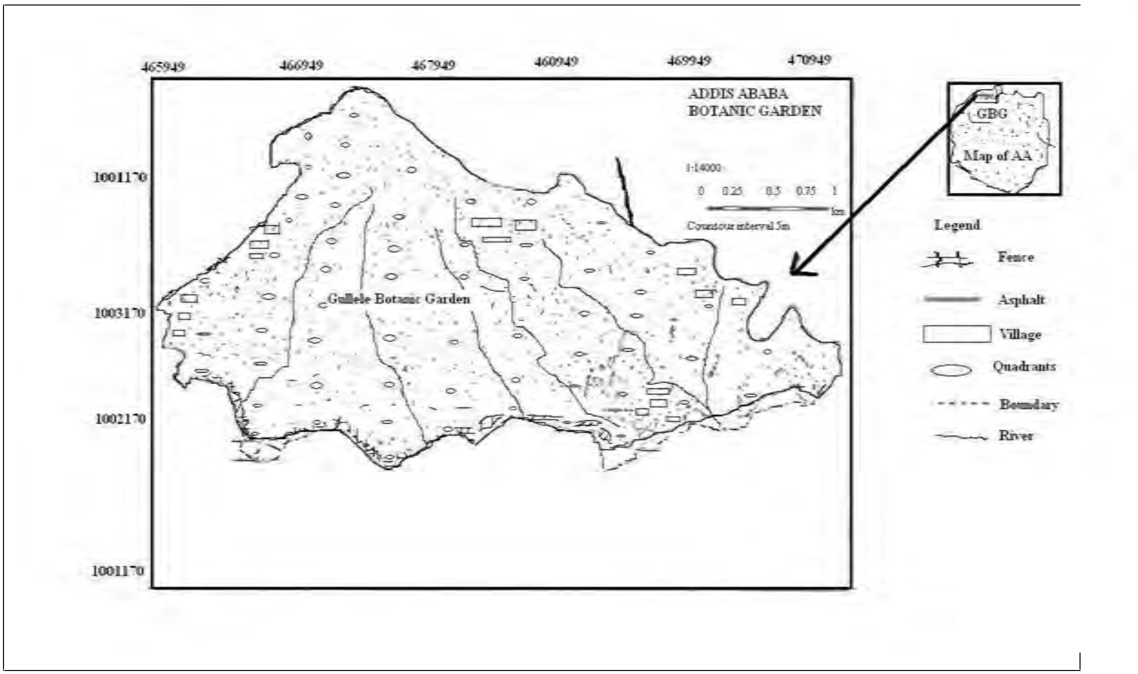

Figure 1. Map of the study area (Birhanu Belay, 2009).

4.2. Climate and vegetation (Flora)

Climate: - The rainfall and the temperature condition of the area were described based on the data collected from 1993-2006 by the Ethiopian Meteorological Service Agency (EMSA) from Entoto station. According to the data from EMSA, the result of the analysis showed that the mean annual temperature of the study area is about 13.4C^0. The range of mean monthly minimum and maximum temperatures of the study area is 7.5C^0 and 20.7C^0 in December and February, respectively. The mean annual minimum and maximum temperature is 8.4C^0 and 18.4C^0, respectively. The hottest month is February with maximum temperature of 20.7C^0, followed by March (20.2C^0) and May (20C^0) and the coldest month is December with minimum temperatures of 7.5C^0. The mean annual rainfall of the area is 1215.4 mm per year and is bimodal type. The mean monthly minimum and maximum rainfall is 16.6 mm (January) and 278 mm (August), respectively. The short rainy season extends from March to May and the long rainy season starts from July and extends to September, but unexpected showers may occur in all months of the year (Birhanu Belay, 2009).

Vegetation (Flora): - The Gullele Botanical Garden is mostly covered by *Eucalyptus globulus* tree species, but the land closer to the river banks and inaccessible areas are covered by more than 250 trees, shrubs, herbs, climbers, ferns and other plant species. From this there are also some endemic and endangered plant species. Some of the dominant indigenous woody species in the project site are *Juniperus procera*, *Hypericum revolution*, *Olinia rechetiana*, *Myrsine melanophleos*, *Myrsine africana* and *Erica araborea*.

4.3. Selection of the study site

Sampling sites from Gullele Botanic Garden were systematically selected (Birhanu Belay, 2009). The study area was divided into different sections based on the transect line. These techniques involved dividing the study site in to different habitat (Tamrat Aydagnhum, 2007; Tayyab *et al*., 2006; Tanaka and Tanaka 1982). The study area was divided into 10 transects, starting at the age of the road from the bottom (Sansuzi) to the upper (Fitesha of Gojam-ber). The distance between two successive transects and plots were 500 m and 300 m, respectively. The number of quadrats were 60 (10m by 10m) which cover a total area of 0.6 hectares. The quadrats are laid on different habitats, such as natural forests, artificial forests (entirely dominated by *eucalyptus* tree), grasslands, and mixed forests. Fifteen quadrats were laid on each habitat type and insect collection was done on each habitats.

4.4. Insect collection

The species diversity, composition, distribution, abundance, and habitat associations of Gullele Botanical Garden were investigated on systematically selected sampling units of each habitat type in the study area. The data were collected and recorded on notebook through a series of fieldworks from September to January by using quadrat method and conscious recording. The study was conducted 60 days in the wet, intermediate and dry season in 2009/10. The seasons were divided into wet, intermediate and dry seasons based on rainfall distribution of the study area. Slow moving insects, such as sedentary adult that may be incapable of flying or reluctant to fly, were collected using a wet finger, fine-hair brush, forceps, or an aspirator in their habitats. On the other hand, active and flying insects were collected using sweep net (with a 0.38 m diameter sweep net constructed of muslin with fine mesh at the tip). Samples of 4 sweeps were taken per quadrat, making a total of 240 sweeps per season sample. Each sweep represented a horizontal swing with an arc of approximately 135 degrees, 0.1-1 m above the ground. Investigators collected samples by sweeping street line transects within each quadrat. After each series of 4 sweeps, the contents of the net were emptied in to one litter killing bottle (jar) with chloroform or acetylene cyanide soaked sponge in it (Tanaka and Tanaka, 1982). The killing bottle (jar) was kept clean and insects were removed as soon as they die. Moth and butterflies were killed separately to avoid them contaminating other insects with their scales. The collected insects were taken to Addis Ababa University, Entomology Laboratory to be preserved, stored, sorted, counted and placed in to various taxa with the help of binocular microscope. All the insects were identified in to order level and then to the family level using identification key. Besides, the books, different drawings of insects, datasheet, specimens of insects in Addis Ababa University museums were used as a means of identifications tools. Finally the pined and preserved insects within wooden insect collection boxes were stored in the Entomology Laboratory.

4.5. Data analysis

- Insect diversity is related to the variety or number of species in a unit of environment. So the simplest measure of insect diversity is to use the number of species present (species richness).
- The Shannon-weaver index ($H^{'}$) is the most commonly used measure for diversity and it is defined as $H^{'} = -$ (pi) (lnpi), where pi is the proportion of i^{th} species in the total sample (pi= ni/N). A species with higher value of $H^{'}$ is more diverse than species with lower value of $H^{'}$. This indicates that, in a low diversity a community of one or two species will be more abundant than others, in diverse situation a few species cannot be very dominant. More number of species and greater evenness increases the diversity of insects (Afzan *et al*., 2006).
- Evenness (j), can be estimated by using the formula J=H/Hmax= lnS, where S is the number of families present. Evenness from calculation would be larger for large J value. This Means insect with larger J value has more even distribution (Price, 1976; Smith, 1992).

- Simpsons diversity index (D) is a measure of diversity and often used to quantify the diversity of insect habitats. It takes in to account the number of species present and the abundance of each species (D= 1- (Pi) ^{2}), where 1 is probability of picking two individual of the same species.

  - ü $(Pi)^2 = (Pi)(Pi)$
  - ü D is Simpsons' index of diversity
  - ü Pi is proportions of families in the sample (community)

- Insect order richness will be calculated by Margalef's richness index (MRI). Larger number indicates high diversity.

MRI= S-1/lnN, where S is the total number of organisms of a particular order and N is the total number of organisms of all individual.

SPSS computer software was used for chi-square analysis to test the association of insects and their habitats. Variation in abundance and distribution of insects in different habitats in the study area was computed by T-test and one way analysis of variance (ANOVA). Insect abundance, frequency, distribution and density were estimated by the following formulae.

- Family abundance (the ratio between total number of individuals of a family in all study plots and total number of sampling units in which the family observed),
- Frequency (the ratio of quad-rats of occurrence and total number of quad-rats studied). Families having a high frequency value are a widely distributed family through the study area; the same is not necessarily true for a high abundance value.

- Relative frequency (Rf) =frequency of species A*100/total frequency of all

  Distribution (the ratio between abundance and frequency) was computed to analyze the diversity of insects in the Garden
- Density of families (D), the number of that families /area sampled. It is closely related to abundance, but more important in estimating of the number of families.

- Relative density (RD) =density of family A*100/total density of all families
- The similarity of insects in different habitats were determined by:

  Jaccard's index (Cj) = j / (a+b-j)

  Where, j = the number of families found in both sites

  a = the number of families in site A

  b = the number of families in site B.
- The Jaccard's Index is equal to zero for two sites that are completely dissimilar. One indicates that two sites are completely similar.

5. RESULTS

5.1. Comparison of mean number of insect per seasons and habitats

A total of 7593 insects were collected in which wet season was more populated season with mean number of (245) than intermediate season (198) and dry season (95). These differed from one another (Figure 2). Natural forest habitat is the most susceptible host for insects with mean number of (151), but mixed forest habitat, grassland habitat and artificial forest habitat are relatively less susceptible for insects with means of (137), (135) and (116) insects, respectively. So, insect population significantly differs in all habitats except between grassland and mixed forest habitats (Figure 3).

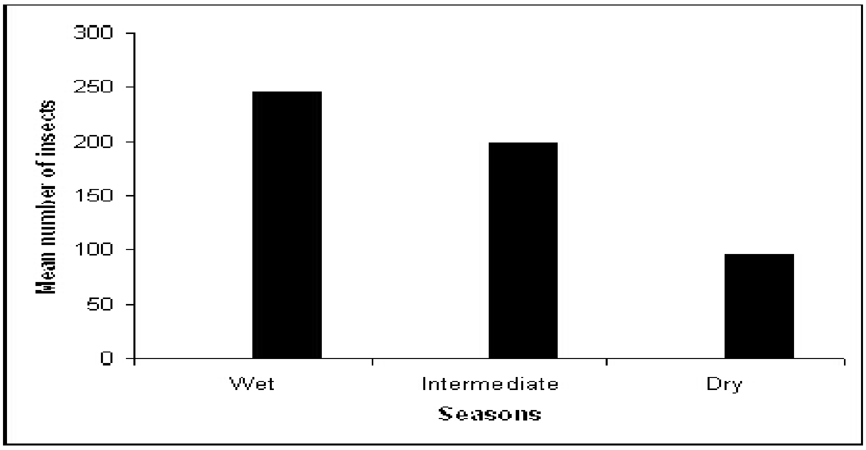

Figure 2. Mean number of insect per seasons

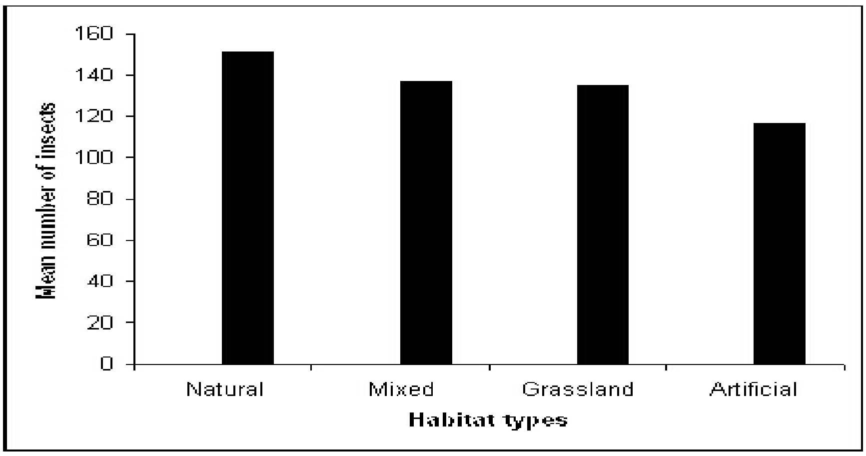

Figure 3. Mean number of insect per habitats

5.2. Insect composition in Gullele Botanic Garden

Table 1 shows the percentage compositions of insects in Gullele Botanic Garden. From the total of 7593 (Appendix 3) insects species collected, 14 orders were identified in Gullele Botanic Garden. Insects in the Order Hymenoptera are the most dominant (2251 (29.6%)) followed by order Isoptera which contain (1599 (21%)), order Diptera (1474 (19.4%)), order Orthoptera (1422 (18.7%)), order Coleopteran (274 (3.6%)), order Hemiptera (270 (3.5%))… and the smallest one is order Raphidioptera (1 (0.01%)).

Table 1. The percentage composition of insects by order in Gullele Botanic Garden

Order	Number of individuals	Percentage composition
Isoptera	1599	21.0
Hymenopter	2251	29.6
Diptera	1474	19.4
Orthoptera	1422	18.7
Hemiptera	270	3.5
Lepidoptera	151	2.00
Odonata	24	0.3
Diplura	35	0.5
Blattodea	20	0.3
Mantodea	7	0.09
Coleoptera	274	3.6
Thysanura	2	0.03
Raphidioptera	1	0.01
Neuroptera	2	0.03

From the totals of 64 insect families collected (Table 2), insects both in Diptera and Coleoptera orders contained the largest number of families 12 (18.8 %). The second position of the family numbers was also occupied by Hymenoptera 10 (15.6%). The third, fourth and fifth positions were occupied by Lepidoptera, Hemiptera and Orthoptera with numbers and percentages of 7 (10.9%), 6 (9.4%) and 5 (7.8%), respectively. The sixth position was held by Isoptera, Odonata, Blattodea and Diplura with similar number and percentage of 2 (3.12%). The least number of families were also occupied by Thysanura, Raphidioptera and Neuroptera with similar number and percentage of 1 (1.6%).

Table 2. Number and percentage of insect families examined in each insect order during the study

order	**Number of families**	**Percentage composition**
Isoptera	2	3.12
Hymenoptera	10	15.6
Diptera	12	18.8
Orthoptera	5	7.8
Hemiptera	6	9.4
Lepidoptera	7	10.9
Odonata	2	3.12
Diplura	2	3.12
Blattodea	2	3.12
Mantodea	1	1.6
Coleoptera	12	18.8
Thysanura	1	1.6
Raphidioptera	1	1.6
Neuroptera	1	1.6

5.3. Frequency, abundance, distribution and density of insects in Gullele Botanic Garden

Appendix 1 and appendix 2 show the frequency, abundance, distribution, percentage composition and density of insects in Gullele Botanic Garden. From a total of 7593 insects collected, 64 insect families were identified in Gullele Botanic Garden which belongs to 14 orders. Family Formicidae is the most dominant, frequently occurring and distributed family with 2149 (28.3%) individuals followed by family Acrididae having 1388 (18.3%) individuals, family Rhinotermitidae 945 (12.45%), family Mucidae 450 (10.71%), family Termitidae 654 (8.61%), family Calliphoridae 400 (5.27%), family Sarcophagidae *303* (3.99%), Reduviidae 246 (3.24%), and family Anthomyiidae 208 (2.74%). On the other hand, the smallest families were Scarabaeidae, Halictidae, Coelopidae, Myrmeleontidae, Coreidae, Micromalthidae, Hutilidae and scotlytidae with number and percent compositions of 2 (0.026%) and Raphidiidae and Tingidae with number and percent composition of 1 (0.013%).

Appendix 1 shows the insect families, such as Formicidae, Acrididae, Nymphalidae, Mucidae, Rhinotermitidae, Termitidae, Calliphoridae and Sphingidae had the highest values of frequency, abundance, distribution and density in the study area. So, they were the most dominant, frequently occurring and distributed family in Gullele Botanic Garden. On the other hand, Scarabaedae, Halictidae, Coelopidae, Myrmeleontidae, Raphidiidae, Coreidae, Tingidae, Tiphiidae, Mutilidae and Neriidae had the least values of frequency, abundance, distribution and density in the study area. So, they were the smallest dominant, frequently occurring and distributed family in Gullele Botanic Garden.

5.4. Diversity of insects in Gullele Botanic Garden at different habitats

Insect diversity in Gullele Botanic Garden is shown in Table 3. The highest diversity of insects in Gullele Botanic Garden was observed in the natural forest (Appendix 4A) in the three wet seasons. The second and the third more diversity of insects were also found at mixed forest habitat (Appendix 4C) and grassland forest habitats (Appendix 4B) of the garden in the three seasons, respectively. On the other hand, artificial forest habitat (Appendix 4D) holds the least diversity in all seasons of Gullele Botanic Garden. The highest homogeneity or pattern of distribution of species in relation to other species in a sampled per unit area were observed in wet season at natural habitat. The least homogeneity or pattern of distribution of species was also found in dry season at artificial habitat. Totally the most even distribution of insects in the three seasons was that of the natural forest habitat. Simpsons diversity index (D) shows that the presence of highest and least diversity of insect habitats at natural forest habitat in wet season and artificial forest habitat in dry season, respectively.

Table 3. Insect diversity in Gullele Botanic Garden in different seasons and habitats

Seasons	Habitat type	Number of individuals	H'	H'/Hmax	D
Wet season	Natural	971	1.88	0.45	0.92
	Grass land	885	1.75	0.42	0.77
	Mixed	864	1.76	0.41	0.75
	Artificial	708	1.58	0.38	0.68
Intermediate	Natural	761	1.76	0.41	0.75
	Grass land	734	1.69	0.40	0.71
	Mixed	718	1.71	0.40	0.71
	Artificial	556	1.56	0.37	0.66
Dry season	Natural	376	1.64	0.39	0.80
	Grass land	339	1.56	0.37	0.66
	Mixed	332	1.60	0.38	0.68
	Artificial	286	1.41	0.34	0.61

Note: - H'= Shannon Wiener Index of diversity

H'/H max = Evenness.

D = Simpson's diversity index

5.5. Similarity and difference in insects' species richness at Gullele Botanic Garden

Similarity and difference in distribution of insects in Gullele Botanic Garden is shown in Table 4. In the three seasons the most similar habitats of Gullele Botanic Garden were grassland forest habitat and mixed forest habitat, whereas the most difference habitats were found between mixed forest habitat and artificial forest habitats. On the other hand, the second, the third, the fourth and the fifth rank similarity of insect distribution in Gullele Botanic Garden was occupied by natural forest habitat and mixed forest habitat, natural forest habitat and grassland forest habitat, natural forest habitat and artificial forest habitat and grassland forest habitat and artificial forest habitats, respectively.

Table 4. Similarity and differences in distribution of insects in Gullele Botanic Garden

	jaccard's similarity index			
comparison (a*b)	**j**	**a**	**b**	**j/(a+b-j)**
Natural*Grassland	26	48	39	0.426
Natural*Mixed	24	48	32	0.429
Natural*Artificial	12	48	15	0.235
Grassland*Mixed	28	39	32	0.651
Grassland*Artificial	8	39	15	0.174
Mixed*Artificial	6	32	15	0.146

High values indicate high similarity in distribution of insects.

Note: j = the number of families found in both sites

a = the number of families in site A

b = the number of families in site B.

Table 5 shows that the Margalef´s richness index (MRI) values of insects in various habitats of Gullele Botanic Garden. Order Isoptera was equally distributed throughout all habitats of Gullele Botanic Garden with MRI values of 0.14. Hymenoptera were also observed in all habitats with MRI value of 0.78 in natural forest habitat, 0.52 in mixed forest habitat, 0.39 in grassland forest habitat and 0.13 in artificial forest habitats. The order Diptera and Coleoptera were collected in all habitats with the MRI value of (1.23, 0.96, 0.82 and 0.41) and (1.25, 0.89, 0.71 and 0.36) in natural, mixed, grassland and artificial forest habitats, respectively. The orders Lepidoptera, Orthoptera, Hemiptera were recorded in all habitats except artificial habitat. Order Odonata, Diplura and Blattodea were found only both natural and mixed forest habitats in small amount of MRI value. MRI value (0.00) in the Table 5 indicated that the least abundant and distributed insects.

Table 5. Margalef´s richness index of insects in various habitats in Gullele Botanic Garden.

	Habitat types			
Insect order	**natural**	**mixed**	**grassland**	**artificial**
Isoptera	0.14	0.14	0.14	0.14
Hymenoptera	0.78	0.52	0.39	0.13
Diptera	1.23	0.96	0.82	0.41
Orthoptera	0.41	0.55	0.41	0.00
Hemiptera	0.54	0.36	0.36	0.00
Lepidoptera	0.60	0.40	0.20	0.00
Odonata	0.31	0.31	0.00	0.00
Diplura	0.28	0.28	0.00	0.00
Blattodea	0.33	0.33	0.00	0.00
Mantodea	0.00	0.00	0.00	0.00
Neuroptera	0.00	0.00	0.00	0.00
Coleoptera	1.25	0.89	0.71	0.36
Raphidioptera	0.00	0.00	0.00	0.00
Thysanura	0.00	0.00	0.00	0.00

High values indicate high richness of insects

5.6. Habitat associations of insects in Gulele Botanic Garden.

Habitat association of insects in Gullele Botanic Garden is shown in Table 6. Wet season result of Gullele Botanic Garden indicated high significance difference showing the existence of interaction between insects and the vegetation use. The total habitat association value of the wet season was x^2 =421.07, $P < 0.002$. In this season the highest habitat association was obtained in the Grassland habitat. Significance difference between the insects and habitat usage x^2 =355.77, $P < 0.011$ was obtained in intermediate season in Gullele Botanic Garden. Mixed forest was the preferred habitat in this season. In dry seasons of the garden, high significance difference was observed with x^2 = 462 and $P < 0.0001$ values. Grassland vegetation was preferred by insects in this season.

Table 6. Habitat association of insects in Gullele Botanic Garden.

		Habitat types			
Season		natural	grassland	mixed	artificial
Wet season	Chi-square	98	137.07	90.8	95.2
	df	59	54	54	51
	Probability Value	0.001	0.000	0.001	0.000
Intermediate	Chi-square	72.4	80.97	111.7	90.7
	df	45	48	46	45
	Probability Value	0.01	0.001	0.000	0.000
Dry season	Chi-square	120	132.7	105.2	104.1
	df	48	32	39	39
	Probability Value	0.000	0.000	0.000	0.0001

T-test result of the comparison of Gullele Botanic Garden wet and dry seasons insect abundance difference was significant with $t = 23.97$ and $p < 0.002$ values. The comparison result of intermediate season with both wet and dry seasons abundance variation in Gullele Botanic Garden were also significant with $t = 18.05$ and $p < 0.0001$, $t=14.96$ and $p= 0.001$ values, respectively.

Analysis of variance (one way Anova) showed that the seasonal variations of insects. There were significance differences in the number of insects in each season; at $F=43.87$ and $p< 0.0001$ (one way ANOVA, Tukey test). The multiple competitions test (Post Hoc Test) also showed that the presence of the highest significance mean differences between wet season and dry season, and intermediate season and dry season. On the other hand, it stated that the wet season had less significance means difference with intermediate season.

6. DISCUSSION

In all season of Gullele Botanic Garden, fluctuations of insect diversity, abundance and evenness were observed in all habitats due to the presence or absence of stability and availability of larval food, the effect of environmental factors and the quantity and quality of food. 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) (Anu and Sabu, 2007; Gullan and Cranston, 2000).

Tov (1974) accepted that most species breed when the amount of food in nature is at its peak. The stability of food resources for herbivorous insects varies temporally and specially. For example, aging of leaves is a major determinant of food resources available to leaf eating insects. Many studies have shown that leaf-eating insects are restricted in their feeding to a certain-age class of leaves (Larsson and Ohmart, 1988). The young leaves are tender and relatively nutritious, but as the leaves age, they become tougher and less nutritious. These older leaves are barriers to chewing insects, but not to sucking insects, whose stylets pass directly into the phloem or xylem (Richard *et al*., 2004). Herbivorous insects that can utilize only part of their host plants are particularly vulnerable to fluctuation in the abundance of their resource (Larsson and Ohmart, 1988).

Seasonality is conspicuous in the life history of many organisms (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 lowland 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). The seasonal breeding and biomass of insects increase dramatically during the long rains (Dingle and Khamala, 1970). So, insect abundance is closely limited with rain fall and it provides a direct seasonal cue for mating and reproducing insects in Africa. In addition to this, rainfall may indirectly affect insect populations by its effect on food availability (Tanaka and Tanaka, 1982).

Droughts were causes for malnutrition and mortality for insect species. Distinct seasonal peaks of abundance were observed among most insect families. However, the time of peak activity differed among the various insect families, thus implying that one particular season is not universally unsatisfactory for all major insect groups. The conspicuous absence of selected insect groups at certain times of the year suggests that many tropical insects have developed strategies for escape during particular seasons (Denlinger, 1980). These are dormancy occurs in summer (aestivation) or in winter (hibernation), and may involve either quiescence or diapauses. This occurs particularly in temperate areas when environmental conditions become unsuitable such as in seasonal extremes of high or low temperature, or drought (Wickman *et al.*, 1983).

Restricted periods of abundance may be dictated by periodic food supply and as well as advantage in predator avoidance and enhancement of mating success. Seasonal occurrence of species in a particular area could be achieved by coordinating periods of dormancy and development with appropriate environmental signals such as photoperiod, temperature and food quality. Chemical change in host plant provide triggers for larval diapauses in the Lepidoptera stem borer and provide cue for adult diapauses termination in desert locust. Seasonal changes in temperature are important for other tropical species, high temperatures induce egg diapauses in the locust, and low temperature triggers pupal diapauses in flesh flies (Denlinger, 1980).

In the wet season of Gullele Botanic Garden high diversity and evenness of insects were observed in all forest habitats due to stability and easy availability of larval food. The seasonal changes in abundance and diversity in Gullele Botanic Garden are similar to results from other studies conducted in the tropics where wet and dry seasons alternate. Tanaka and Tanaka (1982) stated that each of the major arthropod groups was most abundance during the wet season and least abundant during the dry season. Several study of tropical insect seasonality have suggested as wet-season increases in insect number are primarily caused by increased precipitation. The precipitation has, therefore, initiated enormous amount of grass in habitats. This is as a result of increased phytophagous insects (Tamrat Aydagnhum, 2007).

Comparable fluctuations in abundance of tropical insect within seasons have also been found in studies where samples were regularly taken throughout the wet and dry seasons. The arthropod abundance for each collecting site was significantly correlated with rain fall patterns. There is evidence that rainfall can directly influence arthropod abundance through physiological effect on reproduction, development, or activity. For example rainfall is necessary for initiation of breeding in Diptera, such as sand flies and mosquitoes and the emergence of the adult dung beetle is initiated by rainfall. Rainfall may indirectly affect insect populations by its effect on food availability (Tanaka and Tanaka, 1982). Janzen (1983) suggested that the peak abundance of dung beetles were observed during the first half of rainy season.

Both in intermediate and dry seasons of Gullele Botanic Garden; the diversity, abundance and evenness of insects were decreased slowly in all forest habitats. Especially in the dry season, all forest habitats had shown decrement in diversity of insect. The reason for the decrement might be man-made activities in these habitats. During the intermediate seasons, the insect habitats were subjected to repeated disturbances by local people activities and animal grazing (Appendix 4). The grasses under the newly planted seedlings were cleared which highly minimized the diversity of phytophagous insects. This idea was well-supported by Tamrat Aydagnhum (2007).

Almost all the food plants exhibit a seasonal cycle of growth and some of them are not available at all in the dry season (Denlinger, 1980). Janzen (1968) find in dry season that differences between areas in the abundance of insects are due to differences in the productions of leaves and shoots. Leaf production seems to be rather strongly related with rain fall. Wolda (1978) showed that major leaf flush occurs at the beginning of the rainy season and very little production during the latter part of rainy season and during the dry season. Old leaves fall mainly during the dry season, especially in January and February. During dry season, old leaves often have toxin, are tough, and the best defense of all, have low contents of usable nutrient. So, it is not suitable to insect survival, growth and development.

Tanaka and Tanaka (1982) showed that in areas with a severe dry season, insect and spider number are lowest during the dry season while peak densities occur in early to mid-wet season. The major problems that insects face during the dry season is the maintenance of water balance. Wolda (1977) noted that rainfall during the dry season initiated the activity and development of aestivation of Homopteran nymphs. Factors such as moisture and nutrition influence the rate of growth and development. Janzen (1973) suggested that herbivorous insects may cease reproduction in dry season because of lack of suitable food. Insects that live in dry environment and eat nutritionally deficient food require longer time to maturing and the adult life of insects is devoted to mating and reproduction.

The life cycle of insects are synchronized on a long term or seasonal basis (Daly *et al*., 1998). Wickman *et al* (1983) stated that insects survived annual periods of winter cold, drought, summer heat, or food shortage by entering a state of dormancy. As in other small terrestrial organisms, the surface area of insect's body is relatively large, so the risk of desiccation is always great in warm and dry seasons. Insects avoid unfavorable hot or dry environments by seeking cooler, shady places or moist crevices. Insects usually die if their water content falls below about 20 percent (Daly *et al*., 1998). Shortages of food in dry season elongate the generation time of insects (Gullan and Cranston, 2000).

The grassland forest habitats in Gullele Botanic Garden at all seasons were dominated by phytophagous Orthoptera order. This is due to less exposure of the grassland forest habitat to cattle grazing. Grass is the most preferable food source for Orthoptera in this habitat. This idea is more or less similar with the study of insect diversity by Tamrat Aydagnhum (2007).

In all seasons of Gullele Botanic Garden, artificial forest habitat was evident to have the least diversity of insects. Artificial forest of the study area was highly exposed to fuel wood collection which affected insect diversity (Appendix 4). But, the local people collected fuel wood in the form of shed leaves from the ground which had minimal effect on flying insects (Tamrat Aydagnhum, 2007). Insect prefer undisturbed, stable habitats. Quality and distribution of food are also crucial factors. All the artificial forest habitats were entirely dominated by *eucalyptus globulus* species. So these plants might suppress the growth and development of insects. Pfadt (1962) suggested that the monoculture system with one crop dominating large area responsible for some of insect problem. Some varieties of a given species of host plant are more suitable than others for development and survival of insects, but not the others. In fact, the growing of the crop varieties least suitable for insects (resistant varieties) is one effective methods of discouraging infestation.

The most similar habitats in all seasons of Gullele Botanic Garden were mixed forest habitat and grassland forest habitat. The abundance, diversity and evenness of mixed forest habitat in all seasons were more or less similar to grassland forest habitat. The reason might be the presence of grass in both habitats and certain flower-visiting insects might have dominated these habitats. This idea was well-supported by Owen and Chanter (1972). The most different habitats in all seasons of Gullele Botanic Garden were also observed between mixed forest habitat and artificial forest habitat. Plant diversity and structure affect the viability of many species of terrestrial invertebrate populations (Warren *et al*., 1997). *Insects vary in the flexibility of in their feeding habits. They Are Polyphagous, Olgophagous, or Monophagous if they feed on many, a few, or a single species of plant or animal, respectively* (Pfadt, 1962).

Diversity of insects in an area depends primarily on the availability of mixed plant species, which constitute their major food resources. Heterogeneity of the habitat is the main reason for species richness in Gullele Botanic Garden. Tew *et al* (2004) assumes that structurally complex habitats may provide more niches and diverse ways of exploiting the environmental resources and thus increase species diversity. In most habitats, plant communities determine the physical structure of the environment, and therefore, have a considerable influence on the distributions and interactions of animal species. Each habitat has a specific set of micro-environment suitable for a species (Sreekumar and Balakrishanan, 2001a as cited in Tamrat aydagnhum, 2007). In grassland vegetation, most habitat specific insects had to be phytophagous insects which made them suitable in utilizing the grass nutrition. Some insects might not be habitat specific at all. Such general occurrence would help them to have a wider distribution and to maintain larger population size. Many of such kinds of non-specific insects are polyphagous which would help them to live in all habitats and in different elevation gradients (Sreekumar and Balakrishanan, 2001b as cited in Tamrat Aydagnhum, 2007).

Generally, rainfall, human activities, environmental factors and food played great roles in the distribution, density, abundance and habitat association of insects in Gullele Botanic Garden.

During data collection in Gullele Botanic Garden, carefully observation showed that insects had both positive (Appendix 6) and negative (Appendix 5) effects for humans, plants, animals and insects. Insects can increase soil fertility (Appendix 6) by digging the ground and with their waste materials. Insects have several functions in the ecosystem. For example, ants are abundant insects, a large component of the arthropod community on ground in forest ecosystems (Sakchoowong *et al*., 2008) and are considered important in ecosystem functioning. They have diverse ecological roles, including nutrient cycling (Graham *et al*., 2004; Fergnani *et al*., 2008). By burying dung and carrion as food to their offspring, dung beetles may also increase the rate of soil nutrient cycling (Vinod and Sabu, 2007).

On the other hand, insects in the Gullele Botanic Garden can facilitate the process of cross pollination, for plants which had no capability of self pollination (Appendix 6E). Moths are one of the groups playing a central role in numerous ecosystem processes as pollinators (Hawes *et al*., 2009). The flower most frequently visited by insects and partially dependent on them for seed-set. Pollinations of the most common plants are primarily by flies, but bumble bees are also important (Metcalf and Flint, 1979). Hill (1997) studied about beneficial insects for the purpose of pollination, apiculture (honey bee), sericulture (moth), and insect farming (butterflies). Daly *et al* (1998) stated that flies are common visitors to flowers, which provide the only food for adults of some families (e.g.Bombyliidae, Conopidae, Acroceridae, and Apioceridae). However few Diptera have engaged in the intimate type of symbiotic relationship displayed by the angiosperm plants and hymenoptera, and flies appear to be of sporadic important in pollination.

The feeding relationships of insects were different in different living habitats. Some insects were predators (mantids) the others were also prey. So this feeding relationship created a constant balance of insect populations in the Botanic Garden. The carnivorous insects feed on other insects and are said to be Entomophagous (Connahs *et al.*, 2009). Snails, earth-worms, millipedes, mites and other terrestrial and fresh water invertebrates are also eaten by insects. The victims are called prey if killed directly, host if fed upon while still living. Entomophagous insects are divided into three major groups: predators, parasitoids and parasites (Daly *et al*., 1998; Ehrlick, 1978). Lepidoptera larvae represent an important food source for a variety of predators, including ants, spiders, birds and small mammals (Steward *et al*., 1988).

Some of the insects which found in the Garden showed the environmental cleanness of the Garden. Species of butterflies and bees were the most indicators of environmental cleanness. Insects have been used as indicators of bio-diversity and endemism, prioritization for establishment of protected areas, bio-geographic relationships and bio-indicators of anthropogenic changes in the forest and water quality (Schuster and Cano, 2006). Insects are good indicators of the impact of large herbivore and human included change in forest habitats (Vinod and Sabu, 2007).

Honey bee produces wild honey and wax which are very important for human food and other purposes (Appendix 5A-D). African bee is the superior forager and gives high yields of honey. The bee collects nectar and pollen (and water) as their foodstuffs and any excess to their daily requirement is stored in the cells for later use. Honey’s main commercial use is for sweet a wide variety of foods (Hill, 1997). Honey is produced from natural hole in a cliff. The Egyptian used the honey as food and the wax for making candles, medicines and other purposes (Pfadt, 1962).

On the other hand insects had negative advantage for both human and animal species. Some species of insects, such as bees, wasp, ant and termite had a pain full stung for both human and animal species. The African bee is native to east Africa and it is responsible for many cases of unprovoked attack on people and (sometimes livestock): people have been stung to death (Hill, 1997). Most of the phytophagous (herbivorous) insects were the major cause for plant drying by feeding both the external and internal parts of the plant (Appendix 6F). Some species of the insects also decreased the quality of external appearance of plant by the process of eating, defecation and laying their eggs on the parts of the plants. 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 (Daly *et al*., 1998).

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. CONCLUSIONS

- The presence of 64 families in Gullele Botanic Garden revealed the importance of these areas as good habitats for the insects.
- Out of the total insect families, Formicidae and Acrididae had the highest frequency, where as Raphidiidae and Tingidae had the least frequency in the Garden.
- The Highest diversity and evenness of insects were found in natural forest habitats in Gullele Botanic Garden. This was due to less exposure of these habitats to humans and animals' activity and availability of food. In natural forest habitat, most insects were Polyphagous which would help them to live in all habitats and in different elevation gradients.
- On the other hand, less diversity and evenness of insects in Gullele Botanic Garden was observed in artificial forest habitats. The reasons were the intensive interference of both human and animal, and the absence of food (plant diversity) in the area. These areas are only dominated by Monophagous insects. These habitats are also exposed to animal grazing and deforestation at the highest rate. This is because of fuel wood collection and most importantly the escalation of investment activities in the forest.
- Based on jaccard's similarity index, grassland forest habitat and mixed forest habitat showed highest similarity in all seasons. The reason behind the similarity was the presence of grass in these sites which is the main food stuff of Phytophagous insects.
- The result of chi-square analysis showed that the most preferred habitat in Gullele Botanic Garden was the grassland forest habitats both in wet and dry season. Most of the associated insects in these habitats are herbivores that mainly depend on the grass as food source.
- The most diverse, abundant and density of insects were observed in wet

season. This is due to the availability, quality and quantity of food. There is evidence that rainfall can directly and indirectly influence arthropod abundance through physiological effect on reproduction, development, or activity.

- In the dry season of the garden, on the other hand, there was the least diverse, abundant and density of insects. The insects were spending their time moving and searching for food in all habitats. The availability, quality and quantity of food also decreased and this leads to insect mortality and different resting stages such as, diapauses, migration, aestivation and hibernation.
- Totally the study area, on the other hand, has an appreciable diversity of insects. But, it would have very big loss of diversity of insects. The diversity use of plants like firewood, construction coupled with medicinal use resulted an over exploitation by increase pressure on the plants species and may lead to loss of plants and insects from Gulellele Botanic Garden. Even if the garden helps as a means of generating income for those having low daily income, on the other hand, the Garden is highly disturbed by leaf collectors. If the present disturbances and investment activities continues at this rate, most insect families will totally be endangered.
- During data collection in Gullele Botanic Garden, carefully observation of the study area showed that insects had both positive and negative effects for humans, plants, animals and insects.

7.2. RECOMMENDATIONS

- Generally the results of the study in Gullele Botanic Garden initiated to develop the following recommendations.
- In the study area, the most diverse insects were located in natural forests habitat, which are highly protected to human activities and animal grazing. So, to keeping up the diversity, all habitats in the garden should

be well protected from high human and animal interferences.

- Different insects have different habitat association. Therefore the different vegetation types should be protected from being devastated.
- This study is identified 64 families of insects in Gullele Botanic Garden at all habitats. This does not mean that these families are the only ones in the study areas. This study did not include the smallest sized, immature stage and nocturnal insects. So, further, study should be conducted to fill the gap.
- All Gullele Botanic Garden habitats are rich in other vertebrate species such as mammals, amphibians, reptiles, birds and invertebrates like nematodes and other arthropods.
- On the other hand, these habitats have also got appreciable diversity of plants. Therefore, a multidisciplinary approach is needed to conserve this biota. Generally the well conservations of plants increase the diversity of insects because plants are the main source of food for insects. To solve this problem the government should form network system with different concerned governmental, non-governmental and the local people. By raising awareness for the local people via public education and participation is the best solution of utilizing and improving the trend and the knowledge of the local people for conservation.
- As any organism, insects distribute themselves in areas of suitable climatic conditions, when sufficient food for survival and reproduction is available. Critical action should be taken to stabilize disturbed habitats especially in the artificial forest study area.

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9. APPENDICES

Appendix 1- Frequency, Abundance, Density and Distribution of insects in Gullele Botanic Garden (NI=number of individual, A=abundance, F= frequency, Di=distribution, RF=relative frequency, D=density, RD=relative density).

Family name	**NI**	**A**	**F**	**Di**	**RF**	**D**	**RD**
Carabidae	41	0.68	0.2	3.4	1.9	68	0.54
Scarabaeidae	2	0.033	0.017	1.94	0.16	3.33	0.03
Coccinellidae	88	1.47	0.25	5.88	2.4	146.7	1.2
Histeridae	4	0.067	0.033	2.03	0.32	6.7	0.05
Amphizoidae	50	0.83	0.22	3.77	2.1	83.3	0.66
Lycidae	36	0.6	0.27	2.22	2.6	60	0.48
Trogossitidae	31	0.52	0.2	2.6	1.9	51.7	0.4
Pitinidae	4	0.067	0.033	2.03	0.32	6.7	0.056
Tenebriodae	3	0.05	0.033	1.52	0.32	5	0.04
Aeshnidae	14	0.23	0.1	2.3	0.96	23.3	0.18
Calopterygidae	10	0.167	0.067	1	0.64	16.7	0.14
Gryllidae	3	0.05	0.033	1.52	0.32	5	0.04
Acrididae	1388	23.13	0.83	27.87	7.9	2313	18.5
Tettigoniidae	12	0.2	0.067	2.99	0.64	20	0.16
Gryllotalpidae	9	0.15	0.067	2.24	0.64	15	0.12
Stenopelmatidae*	6	0.1	0.05	2	0.48	10	0.08
Pieridae	10	0.167	0.13	1.28	1.14	16.7	0.14
Papilionidae	12	0.2	0.15	1.33	1.4	20	0.16
Lycaenidae	6	0.1	0.067	0.167	0.64	10	0.08
Nymphalidae	60	1	0.75	1.33	7.2	100	0.8
Sphingidae	45	0.75	0.53	1.42	5	75	0.6
Micropteryidae	7	0.117	0.083	1.41	0.79	11.7	0.1
Hepilidae	11	0.18	0.13	1.38	1.2	18.3	0.14
Pompilidae	13	0.22	0.1	2.2	0.96	21.7	0.17
Apidae	63	1.05	0.47	2.23	4.5	105	0.83
Scoliidae	3	0.05	0.033	1.52	0.32	5	0.04

Table 3 continued

Formicidae	2149	35.82	0.88	40.71	8.4	3531	28
Stephanidae	6	0.1	0.067	1.49	64	10	0.08
Halictidae	2	0.033	0.017	1.94	0.16	3.33	0.03
Tipulidae	13	0.22	0.05	4.4	0.48	21.7	0.17
Tachinidae	4	0.067	0.033	2.03	0.32	6.7	0.06
Asilidae	17	0.28	0.067	4.18	0.64	28.3	0.2
Syphidae	31	0.52	0.05	10.4	0.48	51.7	0.1
Hippoboscidae	29	0.48	0.05	9.6	0.48	48.3	0.4
Mucidae	450	7.5	0.7	10.71	6.7	750	6
Coelopidae	2	0.033	0.017	1.94	0.16	3.33	0.03
Bombyliidae	20	0.33	0.05	6.6	0.48	33.3	0.3
Japygidae	16	0.27	0.033	8.18	0.32	26.7	0.022
Projapygidae	19	0.32	0.067	4.78	0.64	31.7	0.25
Myrmeleontidae	2	0.033	0.017	1.44	0.16	3.33	0.03
Lepismatidae	2	0.033	0.05	0.66	0.48	3.33	0.03
Blattidae	8	0.13	0.033	3.94	0.32	13.3	0.01
Blattellidae	12	0.2	0.05	4	0.48	20	0.16
Mantidae	7	0.117	0.067	2.54	0.64	11.7	0.096
Raphidiidae*	1	0.017	0.017	1	0.16	1.7	0.016
Coreidae*	2	0.033	0.017	1.94	0.16	3.33	0.03
Pentatomidae	4	0.067	0.033	2.03	0.32	6.7	0.06
Gerridae	3	0.05	0.033	1.52	0.32	5	0.04
Aradidae	15	0.25	0.067	3.73	0.64	25	0.2
Reduviidae	246	4.1	0.27	15.19	2.6	410	3.3
Heloridae	4	0.067	0.05	1.34	0.48	6.7	0.06
Tingidae	1	0.017	0.017	1	0.16	1.7	0.016
Chrysomelidae	15	0.25	0.1	2.5	0.96	25	0.2
Micromalthidae	2	0.033	0.033	1	0.32	3.33	0.03
Scolytidae	2	0.033	0.033	1	0.32	3.33	0.03
Gasteruptiidae	9	0.15	0.05	3	0.48	15	0.12
Tiphiidae	3	0.05	0.017	2.94	0.16	5	0.04
Mutillidae	2	0.033	0.017	1.94	0.16	3.33	0.03
Neriidae	3	0.05	0.017	2.94	0.16	5	0.04
Calliphoridae	400	6.67	0.53	12.58	5	667	5.3
Sarcophagidae	303	5.05	0.45	11.22	4.3	505	4
Anthomyiidae	208	3.47	0.37	9.38	3.5	347	2.8
Termitidae	654	10.9	0.53	20.57	5	1090	8.7
Rhinotermitidae	945	15.75	0.6	26.25	5.7	1575	12.6

*=Damaged family

Appendix 2- The percentage composition of insect families and their order in Gullele Botanic Garden

Family name	Number of individual	Order name	Percentage composition
Carabidae	41	Coleoptera	0.54
Scarabaeidae	2	Coleoptera	0.026
Coccinellidae	88	Coleoptera	1.56
Histeridae	4	Coleoptera	0.053
Amphizoidae	50	Coleoptera	0.66
Lycidae	36	Coleoptera	0.47
Trogossitidae	31	Coleoptera	0.41
Pitinidae	4	Coleoptera	0.053
Tenebriodae	3	Coleoptera	0.039
Aeshnidae	14	Odonata	0.18
Calopterygidae	10	Odonata	0.13
Gryllidae	3	Orthoptra	0.039
Acrididae	1388	Orthoptra	18.3
Tettigoniidae	12	Orthoptra	0.16
Gryllotalpidae	9	Orthoptra	0.12
Stenopelmatidae	6	Orthoptra	0.08
Pieridae	10	Lepidopetera	0.13
Papilionidae	12	Lepidopetera	0.16
Lycaenidae	6	Lepidopetera	0.079
Nymphalidae	60	Lepidopetera	0.79
Sphingidae	45	Lepidopetera	0.59
Micropteryidae	7	Lepidopetera	0.09
Hepilidae	11	Lepidopetera	0.14
Pompilidae	13	Hymenoptera	0.17
Apidae	63	Hymenoptera	0.83
Scoliidae	3	Hymenoptera	0.039

Formicidae	2149	Hymenoptera	28.3
Stephanidae	6	Hymenoptera	0.08
Halictidae	2	Hymenoptera	0.026
Tipulidae	13	Diptera	0.17
Tachinidae	4	Diptera	0.053
Asilidae	17	Diptera	0.22
Syphidae	31	Diptera	0.4
Hippoboscidae	29	Diptera	0.38
Mucidae	450	Diptera	5.93
Coelopidae	2	Diptera	0.026
Bombyliidae	20	Diptera	0.26
Japygidae	16	Diplura	0.21
Projapygidae	19	Diplura	0.25
Myrmeleontidae	2	Neuroptera	0.026
Lepismatidae	2	Thysanura	0.026
Blattidae	8	Blattodea	0.10
Blattellidae	12	Blattodea	0.16
Mantidae	7	Mantodea	0.092
Raphidiidae	1	Raphidioptera	0.013
Coreidae	2	Hemiptera	0.026
Pentatomidae	4	Hemiptera	0.053
Gerridae	3	Hemiptera	0.039
Aradidae	15	Hemiptera	0.21
Reduviidae	246	Hemiptera	3.24
Heloridae	4	Hemiptera	0.053
Tingidae	1	Hemiptera	0.013
Chrysomelidae	15	Coleoptera	0.21
Micromalthidae	2	Coleoptera	0.026
Scolytidae	2	Coleoptera	0.026
Gasteruptiidae	9	Hymenoptera	0.12
Tiphiidae	3	Hymenoptera	0.039
Mutillidae	2	Hymenoptera	0.026
Neriidae	3	Diptera	0.039
Calliphoridae	400	Diptera	5.27
Sarcophagidae	303	Diptera	3.99
Anthomyiidae	208	Diptera	2.74
Termitidae	654	Isoptera	8.61
Rhinotermitidae	945	Isoptera	12.45

Appendix 3-Total number of insects in each habitats and seasons (WS=wet season, IS= intermediate season, DS=dry season).

Insect order	Natural forest habitats			Grassland forest habitats			Mixed forest habitats			Artificial forest habitats			Total
	WS	IS	DS	WS	IS	DS	WS	IS	DS	WS	IS	DS	
Isoptera	215	192	63	120	149	72	163	164	100	167	130	64	1599
Hymenoptera	240	280	108	292	252	99	263	204	65	212	171	65	2251
Diptera	213	118	87	168	135	54	128	144	70	161	112	84	1474
Orthoptera	193	111	64	217	141	69	190	100	52	132	101	52	1422
Hemiptera	41	5	15	50	1	7	77	46	11	11	5	1	270
Lepidoptera	17	17	9	10	21	8	14	17	10	6	14	8	151
Odonata	1	0	1	4	4	2	2	2	2	1	2	3	24
Diplura	4	2	1	1	3	2	2	4	2	3	10	0	35
Blattodea	11	0	0	1	2	5	0	0	0	1	0	0	20
Mantodea	0	0	0	0	1	0	1	2	2	0	1	0	7
Neuroptera	0	0	0	0	0	0	2		0	0	0	0	2
Coleoptera	36	36	28	22	25	20	22	34	18	14	10	9	274
Total	971	761	376	885	734	338	864	717	332	708	556	286	7593

Appendix 4- Different habitats of the study area (A=natural forest habitat, B=grassland forest habitat, C=mixed forest habitat and D=artificial forest habitat)

A

B

C

D

Appendix 5- The major Cause of destructors of plant and insect diversity in the study area (A=deforestation by human activity, B=animal grazing, C=Woman are collecting leaves and D=women are carrying wood)

A

B

C

D

Appendix 6- Importance of insects for plants, animals and insects (A=wild honey, B=modern bee hive, C= traditional bee hive, D=fertile soil by insect and E=flower, pollinator insects and F= plants damaged by insects)

A

B

C

D

E

F

Appendix 7- The representative insect families observed and identified in Gullele Botanic Garden in all seasons and habitats

Declaration

I, the undersigned, declare that this thesis is my work and that all source of materials used for the thesis have been duly acknowledged.

Fasil Adugna Kindie…………………………….… ……………………….

Signature Date

This thesis has been submitted for examination with my approval as university advisor.

Emana Getu………………………… …………………………………

Signature Date