ASSESSING THE DIVERSITY OF INSECTS IN A QUARRY OPERATIONAL AREA IN THE ASHANTI REGION OF GHANA

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DECLARATION

With the exception of other scholarly reports which I have duly acknowledged, all experimental investigations and findings in this thesis were carried out and reported by me, and has not been presented in whole, or part, to any other institution for the award of another degree.

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ABSTRACT

Quarrying activities have negative impacts on invertebrate biodiversity and threaten local species through a variety of factors, such as habitat loss and pollution. Quarrying is a common practice in Ghana, but little is known about its impact on local insect diversity and abundance. In this study, the relationship between quarrying activities and insect communities at an active quarrying site, the Mowire quarry site in the Ashanti region of Ghana, was assessed. Transect counts, aerial netting, pitfalls, FIT, and Charaxes trapping have been employed to assess arthropod assemblages, particularly insects as surrogate arthropod communities. A total of 2,902 individual insects from 56 families and eleven orders were recorded at all transect points of the three zones. The quarry operational area habitat in the East Zone (EZ) supported a high abundance (N = 974) of insects and high species richness (S = 49), corresponding to a large diversity of flowering plants at this site, which is a food source for pollinators and herbivorous insects. The western zone of the quarry's operational area was not conducive to insect assemblage as the lowest abundance, diversity and richness occurred at the transect point (TP) 400 m, consistent with the low abundance of host plants as well as the amounts of dust settling in the western zone after each blast, as dust travels toward the zone. It is recommended that interventions to prevent the loss of biodiversity habitats in and around the quarry site must be focused on policies that ensure and enforce the establishment of a dust control mechanism system in the extractive industry.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Resource extraction through mining, logging and quarrying contributes to the economic lifeblood of several countries in sub-Saharan Africa. These activities represent an important source of income for the African continent and employ a significant number of people (White, 2013). Quarrying activities are an important source of income in the Mowire community and Afigya Kwabre district with an increasing demand for limestone which has led to the establishment of various sized quarrying companies in the district. Quarrying is a land use system and part of local heritage, extracting non-metallic rocks and aggregates from the land (Ukpong, 2012). This is usually done in the open pit method using rock drills, blasting dynamite and using other methods (Haseeb *et al*., 2018). Quarrying is a process by which rock is dug out of the earth and crushed to produce aggregate, which is then divided into portions ready for direct use or further processing, such as milling and coating with bitumen are required. Stripping involves removing topsoil and subsoil covering degradable material using a variety of equipment to strip, transport, and redeposit the subsoil (Bewiadzi *et al*., 2018).

Quarrying operations cause severe environmental impacts on invertebrate communities and negatively contribute to the destruction of habitats and the species they support. The quarry, whether small or large, is inherently polluting and produces enormous amounts of waste that have harmful effects on the environment (Lameed & Ayodele, 2010). The Mowire Quarry in Afigya

Kwabre District has improved significantly over the last fourteen years. Unfortunately, these operations cause significant environmental impacts. The extraction process usually depends on heavy machinery and explosives, both processes are usually associated with air pollution, noise pollution, biodiversity damage and habitat destruction (Lameed & Ayodele, 2010). Air pollution from quarry operations causes respiratory diseases, causes physical impacts on adjacent vegetation, such as obstructing and wounding their inner structures and abrasion of leaves, and chemical effects that can influence the long-term survival of invertebrates (Missanjo *et al*., 2015). The main environmental impact of quarrying is the destruction of vegetation, habitat disturbance, diversion and blockage of natural drainage systems (Sati, 2015), soil erosion and river silting, noise pollution and vibration, and dust pollution (Moeletsi & Tesfamichael, 2017). Quarry operations release dust that not only settles on soil, crops and trees but also the water surface for drinking and other household chores. (Yoon *et al*., 2006). Air pollution from quarrying is responsible for crop damage and crop loss and poses a risk to crop survival in quarrying areas (Lodhi *et al*., 2009).

Biodiversity refers to the variety of living species such as invertebrates, fish, mammals, plants, reptiles, birds, fungi and even microorganisms. Biodiversity conservation is vital as all species are interconnected and our lives in nature depend on this delicate balance (Grimm *et al*., 2008). Structure and species richness also have a strong impact on ecosystem functioning and stability (Flynn *et al*., 2009). The preservation of biodiversity has thus become one of the most important problems on the planet. Biological indicators are very sensitive organisms whose response to an environment provides more general information about environmental quality (Bazelet & Samways, 2011). Insect biodiversity tends to provide clearer results on the ecological consequences of human-induced disturbances (Husseini *et al*., 2019). In addition, the ecological

services provided by insects include nutrient recycling, decomposition, pollination and pest control, which form the basis of important biological interactions in forest ecosystems (Husseini *et al*., 2019). Studies on the conservation of biodiversity in ecosystems can provide information about the conservation of environmental resources and sustainable development. Arthropods occupy the broadest microhabitat and niche diversity and perform numerous ecological tasks than any other assemblage of animals (Maleque *et al*., 2009). Their excessive population sizes, reproductive potential, and short generation times allow them to be used to determine environmental stress. Arthropods are considered effective indicators of ecosystem functioning and are proposed for use in conservation planning (Maleque *et al*., 2006). Many researchers have used arthropods to assess habitat quality and measure habitat variation (Newbold *et al*., 2019). Arthropods are useful bio-indicators of human-caused environmental changes such as pollution, habitat loss and fragmentation, and early warning of ecological changes. Arthropods can more readily serve as useful markers of environmental change than vertebrates and crops (Zvereva & Kozlov, 2010).

Indicator species are easily regulated living organisms whose structures reproduce or predict the environmental scenario in which they find themselves (Siddig *et al*., 2016). Indicator species could be used to monitor ecological variability and offer warnings of upcoming ecological changes. Insects are mainly used as indicators of environmental degradation as well as bio-indicators of ecosystem well-being (Kyerematen *et al*., 2018). The widespread ecological importance of a variety of insects makes them useful for assessing disturbance or environmental impacts of various kinds through mortality assessments, sub lethal impacts, population changes and changes in community structure (Ode *et al*., 2016). Insects are important natural resources in the ecosystem

and important indicators in the management of ecosystems as effective pollinators and natural/biological pest control agents. Their general life cycles are well known and can therefore easily be linked to changes in the environment (Weisser & Siemann, 2008).

One such group of insects are the butterflies, which provide information about ecosystem health through the presence-absence of species and abundance, so we used them as bio indicators to monitor changes in habitat conditions in the environment (Weisser & Siemann, 2008). Butterflies have historically been used advantageously as bio indicators to study the health of forest ecology in natural, managed, and degraded ecosystems (Kyerematen *et al*., 2018). This is mainly because members of this group show diversity and relative sensitivity to environmental changes (Kobayashi *et al*., 2009). They are also closely intertwined with ecological systems as they are both major consumers (herbivores) and food source with a known taxonomy, life history traits, high reproductive rate and relatively small size (Nganso *et al*., 2012). The abundance and diversity of butterfly species in an ecosystem can be used as a bio-indicator to measure the health of that environment. For example, the diversity and abundance of butterfly species have been used to gain access to the impact of human activities on the landscape, to rapidly assess biodiversity, and to monitor degraded and managed ecosystems (Gandhi *et al*., 2017). This is because their presence, absence, diversity, and abundance are directly related to ecosystem changes (Roy *et al*., 2001). Insects play an important role in the ecosystem, assisting in nutrient recycling through leaf litter and wood degradation, transport and manure removal, and soil turnover. Through phytophagy, they play an important role in plant pollination and in maintaining the composition and structure of plant community. Insect species richness often improves with increasing vegetation, with the greatest diversity in mature trees (Milberg *et al*., 2016). Insects make excellent biological

indicators because of their short-lived life cycles, mobility, and sensitivity to environmental conditions. Insect predators are known to be more efficient than many chemicals at controlling economically harmful insects (Gariepy *et al*., 2007). Invertebrate population dynamics are therefore affected by changes in the environment (Marini *et al*., 2009).

1.2 Justification

Africa has a rich biodiversity of insects; however, few taxa have been comprehensively collected and studied in detail (Mokam *et al*., 2014). Studies on the conservation of biodiversity in ecosystems can provide data on the conservation of environmental resources and sustainable development. The extent of land degradation caused by quarrying in Ghana has raised questions as to whether or not the activity should continue (Nartey *et al*., 2012). Quarrying negatively contributes to habitat destruction and the species they support (Lameed & Ayodele, 2010). Even if habitats are not immediately removed by excavation, environmental impacts such as changes in ground or surface water cause certain habitats to dry out or become flooded, and insect species are hampered and harmed (Bewiadzi *et al*., 2018). Noise pollution can also significantly affect certain species, disrupting their effective reproduction. Landscape changes affect invertebrates more severely and faster than other taxa. Biodiversity is therefore being exploited much faster than ever before, with negative consequences for sustainable human livelihoods (Mittermeier *et al*., 2011). One of the major adverse environmental impacts of quarrying is the harm caused to biodiversity (Eta *et al*., 2019). In Ghana, increasing evidence suggests that the rate of environmental degradation has recently increased (Koranteng & Adu-Asare, 2018).

Indicator insects are particularly useful as more than half of all species are represented and their diversity allows an acceptably refined scale for assessing differences between habitats (da Rocha *et al*., 2010). The presence, diversity and abundance of many species are directly related to ecosystem changes, and butterflies have also been used for rapid assessments of natural habitats (Kyerematen *et al*., 2018). Ecosystem services provided by insects are fundamental to biodiversity and food security. For example (Fao, 2008) points out that the quantity and quality of pollination have multiple impacts on food security, biodiversity, ecosystem stability and resilience to climate change. As wild ecosystems are increasingly converted to human-dominated uses to meet imperative food security requirements, we must understand how to conserve the fundamental ecosystem functions that have supported tremendous biodiversity (Lunt *et al*., 2013). The problem of environmental pollution has become a major concern in developing countries and the impact of community exposure to this pollution is of concern (Lameed & Ayodele, 2010). This research aimed at assessing the relationship between quarry activity and insect diversity in the Mowire quarry concession.

1.3 Objectives

The main objective of this research was to assess the relationship between quarrying operations and the diversity of insects in an unprotected tropical forest site, with a focus on the diversity and abundance of insects as indicator species in quarry operational areas.

1.4 Specific Objectives

- To provide a comprehensive inventory of insect species over the sampling period, highlighting species richness and diversity in the quarry operational area.

- To determine the relationship between quarry operations and the relative diversity and abundance of key insect species at different sections of the quarry area using a radial transect approach.
- To use butterflies as indicator species to assess the relationship between quarry operations and insect diversity in the quarry operational area.
- To establish the effect of climate variations on insect diversity and abundance between the three zones in the quarry operational area.

CHAPTER TWO

LITERATURE REVIEW

2.0 Definition of Quarry

Quarrying is the process of extracting quarry resources, usually, rocks found on or below the land surface (Nene, 2011). The difference between mining and quarrying is that quarrying involves extracting non-metallic rocks and aggregates while mining involves excavating the site for mineral deposits. Some of the rocks mined are sandstone, limestone, perlite, marble, ironstone, slate, granite, rock salt and phosphate rock. The two main branches of the industry are natural stone and gravel quarrying. In the former, blocks or slabs of stone, such as marble, are extracted in various shapes and sizes for different purposes. In the crushed stone industry, granite, limestone, sandstone or basalt rock is mainly crushed for use as concrete aggregate or road stone. Quarrying is generally done using rock drilling, open pit methods, dynamite, blast and other techniques. The stone's suitability for quarrying depends on its quality, its ability to be transported cheaply and quickly to a large market, and its inclination and depth below the surface. Quarrying can generate noise and air pollution through operations such as drilling, screening, blasting, sand conveying, manufacturing of sandstone and open-cast quarrying.

i. Drilling/Slotting and Wedging: According to (Ndubuisi, 2018) two of the oldest quarrying methods are slot cutting and drilling and reaming. A channel milling machine cuts a channel in the rock using multiple chisel-edged cutter bars that cut with a chopping motion. In drilling and reaming, a drilling tool first drills numerous holes in an aligned pattern. The broach then chisels and hacks the web between the drill holes and frees the block. Both channel cutting and drilling and reaming are slow and the cutting tool needs to be sharpened frequently. Channeling and wedging is a quarry practice in which channeling machines are used to cut long, narrow channels

in the rock deep enough to insert wedges. The rock is then split through the fracture. The quarry channeling and wedge method is used extensively in the quarrying of marble, sandstone, limestone and other softer rocks, but is unsuccessful in granite and other hard rocks.

ii. Rock Blasting and Cutting: Some minerals, such as sand, gravel, clay, and coal, can be extracted by using an excavator shovel directly on the mineral. Other materials such as sandstone and limestone must be broken up by blasting or ripping before they can be excavated. Blasting can also occur when the overburdened rock is too strong to be excavated directly with a shovel. Blasting usually involves breaking the rock into pieces suitable for crushing. An explosive charge is detonated in a bullet hole and within a short period, a rapid discharge of energy takes place, causing an enormous increase in pressure and temperature. Most of the energy released is used to break rock, but a significant percentage is wasted. This wasted energy is dissipated in the form of noise, dust, heat and noxious gases along with the creation of several environmental impacts. Quarry blocks are then transported down the hills by bulldozers or caterpillars. There are three main environmental impacts at this stage. These are:

i. **Ground vibration –** caused by seismic waves travelling through the ground.

ii. **Overpressure –** caused by pressure waves travelling through the air.

iii. **Fly rocks** – individual rock fragments being thrown long distances from the site by the force of the explosion.

iii. Crushing and Grading (Sieving/Screening): Rock crushing is performed to produce relatively small pieces of rock suitable for crushing into gravel-sized particles. The crushing plant includes a vibrating feeder, jaw crusher, impact crusher or cone crusher, vibrating screen, belt conveyor and central electrical control. The large materials are smoothly and gradually transferred by a vibrating feeder through a hopper for primary crushing into the jaw crusher. After the first

crushing, the material is transferred to an impact crusher or a cone crusher by a belt conveyor for secondary crushing. The crushed material is then transferred to a vibrating screen for separation. After crushing comes screening. When the stones are broken down into smaller sizes, screens are used to separate them into equally sized heaps. Some screens are larger, allowing larger stones to pass through. The smaller screens only let the small stones through. Stones may be crushed and sifted many times before being heaped with other stones of the same size. Screened stone is known as aggregate.

iv. Conveyance or Transfer: As the rock passes through the crushers, it is moved through the processing plant on conveyor belts. For stones to move from one place to another in a facility, they are transported on long, continuously moving conveyor belts.

v. Loading and Transport: Crawlers and bulldozers use their shovels to load quarry products into transport trucks for various destinations. When loading products into trucks, the wind blows dust away and dust emission increases with height.

Dust kicked up by vehicles driving on roads can account for 33% of air pollution and dust from construction sites. Road dust is a significant source of pollution that contributes to the generation and release of particulate matter into the atmosphere (Holmes & Harbottle, 2001). Dust on plant leaves can trigger leaf injury and impair photosynthesis, respiration, and transpiration, leading to reduced performance (Tozsin *et al.*, 2015). Air pollution from quarrying activities comes from high levels of particulate matter in the air, black smoke, noise and vibration from blasting (Maponga & Munyanduri, 2001). Dust can also originate from air filter units or stacks, transport trucks, conveyor belts and transfer points (Nene, 2011). It is carried by moving air when there is sufficient energy in the airflow and is removed by gravitational settling (sedimentation), leaching

in rain, or wetting and by impact with surfaces. Settled dust can be re-suspended when conditions permit, either by wind blowing off the bare surface or by disturbances such as vehicle movement.

The social importance of quarrying in Ghana.

The shift from environmental management and modernization to purely economic gain is designed to make people understand and accept the new rule of economic growth, which includes expanding educational facilities and improving environmental quality while considering alternative costs of natural resources (fauna and flora) that would be affected (Mabogunje, 1980). The need to develop the natural resources (quarry) at the Monwire Quarry site will lead to economic growth and technological advances, but this has been sought at the expense of the environment (social cost), to improve the quality of materials and human resources (social responsibility) in relation to employment opportunities, road construction and other raw materials that can be extracted from quarries. The reason for many environmental problems related to resource extraction, as in the case of the quarry, could be due to a lack of environmental considerations in the design and construction of the large-scale project (Oyaigheviven, 1998). As such, projects are typically planned and undertaken to meet the social and economic needs of the organization without considering the needs and aspirations of the people directly affected. During mining, materials such as sand, clay, gravel, and red earth devastate useful agricultural land and affect other biodiversity (flora and fauna) resources native and endemic to the area. Depending on the relative toxicity of the material, leakage from the disturbed mineral extraction or quarry site into groundwater could pose a serious health hazard to both humans and other animals (either domestic or wild) in the vicinity of the quarry. Perhaps the most significant impact of a mining project is its impact on water quality and water resource availability within the project area. Key questions are whether surface and groundwater supplies remain fit for human consumption and whether surface

water quality in the project area remains adequate to support native aquatic and terrestrial life. The possibility of soil and sediment eroding into surface waters and deteriorating surface water quality is also a serious problem. Because of the large area of land disturbed by quarry operations and the large amounts of earthen materials exposed at sites, erosion can be a major problem at hard rock mining sites. Consequently, erosion control must be considered from the start of operations to the completion of reclamation. Erosion can result in significant loading of sediments (and any entrained chemical pollutants) in nearby waters, particularly during severe storm events and periods of heavy snowmelt.

Environmental impact of quarry operations

The nature of the mining processes has potentially negative environmental impacts both during mining operations and years after the mine is closed. These impacts have led to most of the world's nations enacting regulations to mitigate the negative effects of mining. Some of the environmental disturbances caused by quarries are directly caused by technical activities during the quarrying and processing of aggregates. The most obvious engineering impact of quarrying is a change in geomorphology and land-use conversion with associated change in the visual scene (Gale and Groat, 2001). These severe impacts can include habitat loss, noise, dust, vibration, chemical spills, erosion, sedimentation and mine site degradation. Some of the effects are short-lived and most are easy to predict and easy to observe. Most engineering impacts can be controlled, mitigated, maintained at tolerable levels and confined to the immediate environment by adopting responsible operational practices using available engineering techniques and technology.

2.1 Insect ecology

Arthropods represent a significant part of the Earth's biodiversity and form an important element in the conservation of species. The short generation periods of most arthropods are ideal for tracking year-to-year changes. Arthropods occupy the widest range of microhabitats and niches and play more environmental functions in the ecosystem. Arthropods are useful ecological indicators because of their great diversity and abundance, ease of collection, and rapid response to environmental changes (Sousa *et al*., 2019). Insects have colonized the earth with great success and can be found in almost every available habitat. They have also proven to be extremely adaptable to changing conditions, much faster than other organisms. This allows them to thrive in conditions that have led to the extinction of many other animals or plants (Van Wyk *et al*., 2019). Insects assist in nutrient recycling through leaf litter and wood decomposition, transportation and dung disposal, and land degradation. In most terrestrial environments, insects are the dominant herbivores (Van Wyk *et al*., 2019).

Using insects as bio indicators is a useful way to assess environmental changes (Lee *et al*., 2010). Butterflies have been widely used as bio indicators due to their high diversity, as well as their well-known taxonomy and life cycle (Lee, *et al*., 2014). Among insects, butterflies can be considered one of the best groups to study human disturbance and other forest management practices due to their sensitivity to environmental changes (UeharaPrado & Freitas, 2009). Likewise, butterflies respond quickly to environmental changes because of their short generation, good mobility, and specific habitat preferences (New *et al*., 1995). Butterfly communities are greatly affected by vegetation changes, as most butterfly larvae have strong associations with host plants, and adults also require a specific selection of nectar plants (Kwon *et al*., 2013). Butterflies are considered a useful group of insects in environmental monitoring and assessment due to their sensitivity to

anthropogenic disturbances (Nyafwono *et al*., 2014). Butterfly diversity and abundance can track changes in plant diversity and forest structure resulting from various disturbance regimes such as logging, agriculture, and quarrying.

Butterflies are the best known group of insects, taxonomically well-known and ecologically diverse (Nyafwono *et al*., 2014). Butterflies have been used as indicator species in many studies to predict changes in the environment (Thomson *et al*., 2007). Butterfly species richness can change due to changes in plant composition and density, light intensity, and humidity, making them good indicators for predicting environmental change (Osei, 2016). The order Coleoptera represents approximately 20% of total arthropod diversity and plays a role in soil maintenance, other invertebrate population regulation and energy flow, and also contributes to the chemistry and physical soil formation (Carlton & Robison, 1998). Beetle species (Coleoptera: Scarabaeidae) have a high potential as environmental indicators in forest areas or agricultural crops (Davis, 2000). Members of the beetle family Carabidae are important predators and are also used as biological control agents, for biological monitoring of oil, herbicide, insecticide and radioactive phosphorus pollution. Ants reliably exhibit strong ecosystem succession patterns, and their functional diversity and composition are related to practices and disturbances in property management, including forest management (Andersen & Sparling, 1997).

2.2 Biodiversity of insects

Biodiversity is the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems (De Laat, 2010). A topic of enormous concern is the importance of biodiversity for the conservation of ecological development (Reiss *et al*., 2009). The loss of certain species can lead to changes in important

ecological processes with potential consequences for the overall functioning of an ecosystem. Biodiversity includes species richness and species uniformity (Bartolom *et al*., 2000). The goal of biological surveillance programs is to predict or assess changes in habitat structure, function and composition in response to natural and anthropogenic factors (Marshall *et al*., 2002). An important aspect of biodiversity can be the conservation and preservation of biological ecosystems to meet as yet unforeseen needs.

Biodiversity encompasses much more than the variety of animal and plant species, habitats, ecosystems and landscapes through which our biosphere is described and viewed (Spenceley, 2015). Biodiversity includes genetic diversity, species richness and ecosystem diversity and assumes that these are interdependent (Groombridge *et al*., 2002) and are quantified by taxonomic inventories within specific areas (Fox *et al*., 2000). Competition for resources forces the evolution of new species as well as co-evolution among those already existing. Species that are endangered or unable to compete with others may disappear while others may take their place. The number of different species within a geographical area depends on migration and adaptation to environmental conditions and how they in turn change the environment (Groves *et al*., 2002). Biodiversity is therefore being exploited much faster than ever before, with negative consequences for a sustainable human livelihood (Mittermeier *et al*., 2011). Biodiversity is in crisis and facing a decline that could eventually lead to mass extinctions in the very near future (Spenceley, 2015). As local populations become extinct or lose viability, intraspecific variation is also reduced.

One of the biggest negative impacts of quarrying on the environment is the damage to biodiversity (Anand, 2006). Monitoring of biodiversity loss, however, should be a means to an end rather, than an end in itself. Therefore, identifying the species involved in specific ecological processes and the effects of modifications on their abundance, diversity and richness is essential for understanding the ecosystem.

2.3 Forest vegetation

The term forest, as defined by the Food and Agriculture Organization (FAO), is an area greater than 0.5 hectares with trees taller than five meters and a canopy level of more than 10% or trees able to reach this threshold on the site. Land under agricultural cultivation or urban land use is not included. There are two main types of tropical forest, tropical rain forest and monsoon forest (Sutton & Collins, 1991). Rainforests are found in humid climates where rain falls throughout the year, although it may not be evenly distributed. Rainfall in these areas can average 100mm or more per month, although there may be drier periods in certain months (Whitmore, 1984). Tropical monsoon forests occur where there are long dry seasons, typically with more than three months and less than 60 mm of rainfall (Sutton & Collins, 1991). Tropical rainforests are found in three major regions; South American rainforest covers the largest area, followed by Southeast Asian rainforests and African rainforests with average temperatures usually between 25 °C and 28 °C. The tropical rainforest is a complex community and probably the most diverse terrestrial ecosystem on earth, with the highest number of plants - and animal species that coexist (Whitmore, 1984). Tropical rainforests are known as centers of biological diversity and much attention has been paid to the ecological processes responsible for the generation and maintenance of their diversity. Although it covers 6% of the Earth's total land area, it contains approximately half of all animal and plant species in the world, including 70-75% of all known arthropods (Huang *et al*.,

2003). Although tropical rainforests are rich in biodiversity, they are among the most threatened of all habitats due to exploitation of the forests for timber and economic development, as well as anthropogenic disturbance (Bowman & Wilson, 1988). Biodiversity in Ghana's forests is increasingly threatened by socio-economic activities such as urban expansion, pollution, quarrying, industrial and tourism developments (Allotey, 2007). There are many factors affecting biodiversity in Ghana, the most notable being land use change, overexploitation, pollution, invasive species, habitat loss and fragmentation. Habitat fragmentation has an important impact on flora and fauna (Goheen *et al*., 2003). The management of natural forests is considered to be an appropriate measure for the long-term conservation of forest habitats and the biological diversity living in the forest ecosystem (Parren & de Graaf, 1995).

Another great biodiversity threat is logging. Excessive logging affects the structure of the forest and the diversity of species living in the forest (Osei, 2016). Invasive species can exert strong competitive effects on the growth, reproduction, and resource allocation of native species and eventually take their place, thus reducing diversity (Winterbottom & Eilu, 2006). Forest degradation is the change within the forest that affects the structures and functions of the forest, thereby reducing its capacity to provide products and services (Keenan *et al*., 2015). Sustainable forest management is the practice of managing permanent forest lands to achieve a defined goal in terms of producing desired forest products and services without undermining their intrinsic values and the environment. Sustainable forest management indicates multiple human interventions ranging from actions aimed at protecting and conserving forest ecosystems and their functions for enhanced production of goods and services (Chapman *et al*., 2003). Sustainable forest management ensures that the benefits derived from the forest meet the needs of present and future generations (Tomppo *et al*., 2014). A sustainable forest has great potential to serve as a tool to combat climate

change and pollution, protect people and livelihoods, and provide a basis for sustainable economic and social development. The conversion of natural habitats into land use areas can completely destroy the living conditions of a given species, alter species composition and initiate species extinction. Selective logging can affect forest structure and the amount of light reaching the forest floor as a result of changes in canopy cover (Hamer *et al*., 2003). Forest ecosystems provide habitats for a disproportionate amount of the world's biodiversity. The ethical and ecological importance of this biodiversity has motivated professional forest management to work towards conserving this intrinsic diversity while meeting the needs of timber and other forest products (Nagaike, 2002). Several studies have shown that logging and related activities have the potential to affect the richness, diversity, and composition of fruit-eating butterflies (Koh, 2007).

2.4 Effect of rainfall on insect diversity

Altered precipitation patterns have been shown to affect the functioning of ecosystems and processes such as primary production and nutrient cycling (Fay *et al*., 2003), particularly in semiarid and arid regions where water is the main limiting factor on primary production. Since future precipitation patterns are expected to be highly variable (Zhu *et al*., 2014), this creates much uncertainty about possible ecosystem responses to climate change (Fay *et al*., 2003). A better understanding of the impact of changing precipitation patterns therefore, has significant implications for conservation planning and ecosystem management. Previous studies on the effects of precipitation variability on the plant and the community suggest that modified precipitation can affect species richness, shape community composition, and alter primary productivity. Furthermore, it has also been suggested that organisms at higher trophic levels are vulnerable to changes in precipitation because water availability exerts strong control over their community structure and dynamics through direct and indirect effects.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The research was conducted in Mowire near Kodie in the Ashanti Region of Ghana. The area lies between Latitude 6° 48' 21.38" (6.8347°) North, and Longitude: 1° 38' 25.43" (1.7172°) West, with an elevation of 280 m meters (918.64 feet), in the Afigya Kwabre District (Fig 1). The Afigya-Kwabre District is one of the five Districts created in 2008 in the Ashanti Region. The District is bounded by Kumasi Metropolitan Assembly to the South, Offinso Municipal to the West, Atwima to the South-West and Kwabre- East District to the East. The average temperature here is 25.0 °C between July and, August and 28.0 °C between March and April. The average annual rainfall is 1400 mm (Bannerman *et al*., 2013). The total area of the district covers 342.3 km^2 , constituting 1.4% of the Ashanti Region (Bannerman *et al*., 2013). The district experiences relatively high humidity, ranging from 90% to 98% in the rainy season. Night and early morning humidity drop to below 75% in the dry season (Bannerman *et al*., 2013). The district has a population density of 397.3 persons per square kilometer with increasing demand for land for residential purposes, while available land for agriculture and natural vegetation has been depleted. The forest vegetation has been degraded by lumbering, settlement development, and agriculture. Part of the forest has been disturbed by various human activities such as farming, logging, and quarry mining. The economy of the district is mainly agrarian, employing about 61 % of the total workforce.

K.K Quarry and Brosa Mineral Resource Limited are located in the township of Mowire approximately 6 km from Kodie off the Offinso Highway. These two companies mine in the quarry enclave on the outskirts of the town. The massive presence of granite rock in the district supports

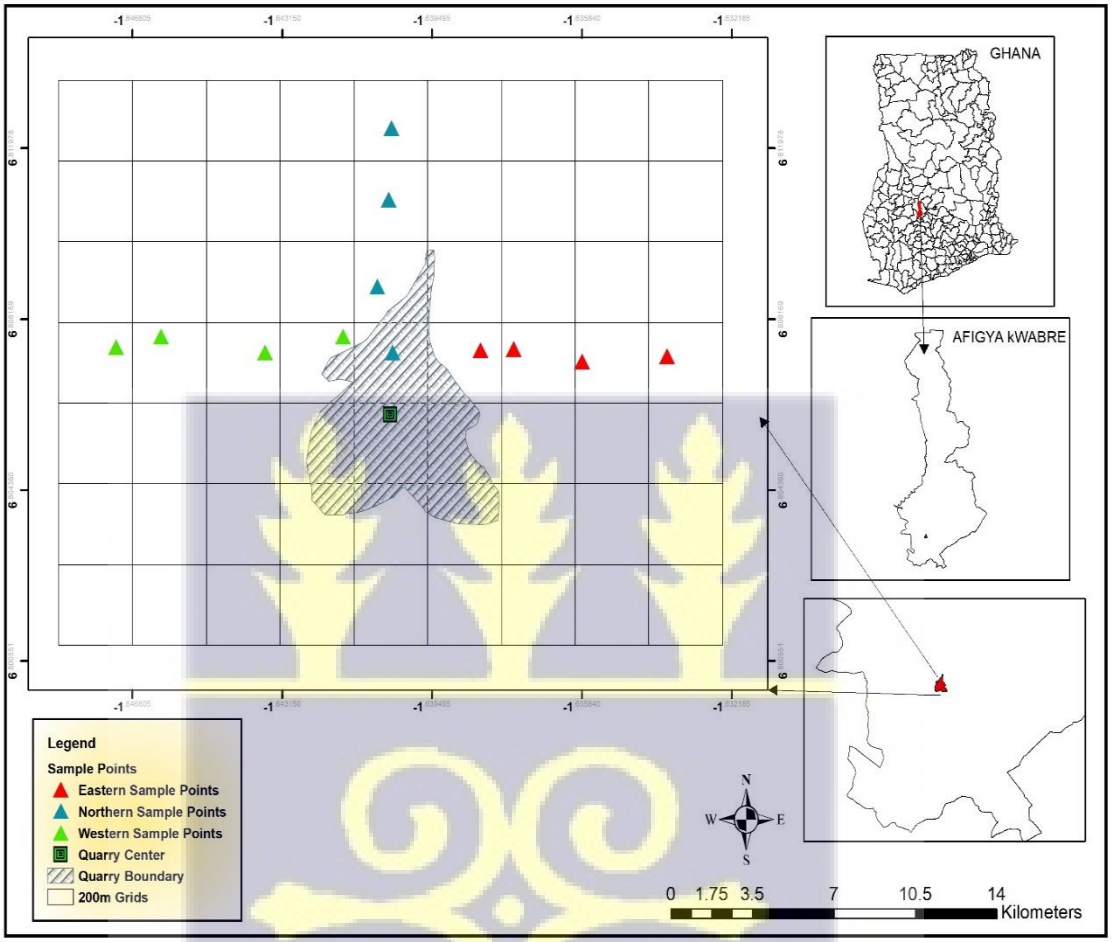
quarrying. The quarry has existed and been active for fourteen years. Quarrying is the main activity of the two quarrying companies. The stones are crushed into relatively small, gravel-sized pieces, which are transported daily by heavy-duty vehicles. Rock blasting is performed on Tuesdays and Fridays. The KK Quarry Company blasts on Tuesdays while the Brosa Mineral Resource blasts on Fridays. It is estimated that approximately 51% of the workers on the quarry concession are women with the remainder being men. With an average age of 27 years, young people are the dominant group in the quarry. The study was conducted between August 2018 and February 2019, which spanned the dry and rainy seasons.

Figure 1. A map of the quarry site in Afigya- Kwabre District.

3.1.1 Study Site

The study area was positioned in the form of a radial map with three cardinal points (Northern, Eastern and Western). Line transects of 200 m, 400 m, 600 m and 800 m in all three directions

were defined for the data collection. Insect traps (pitfall, Charaxes, yellow and blue sticky traps, flight interception traps) were placed along each transect line of the three cardinal points for insect collections.



Source: Addae, 2020

Figure 2: Map showing transect points along the three cardinal directions.

3.1.2 Zonation of the Quarry Site

Eastern Zone

This zone extended eastward from the center of the quarry. The location is preferred by the residents of the area for agriculture. Oil palm (*Elaeis guineensis*) is the main crop grown in the zone. Significant quarrying activities are carried out on this side of the quarry using the rock cracker (Plate 1), a compact, cost-effective and transportable piece of machinery used to split and break stones and rock blocks, to reduce rocks and split reinforced concrete. Here rocks are crushed into small chunks of rocks. The crushing plant consists of a vibratory feeder, jaw crusher, impact crusher (or cone crusher), vibrating screen, belt conveyor and a central electrical control system. When the stones are broken down into smaller sizes, screens are used to separate them into equally sized heaps. The Rock cracker works 24 hours almost every day and generates a lot of noise and dust in the surrounding area. The zone has been divided into four transect points east from the center of the quarry. Lined transect points from by the center of the quarry were established at 200 m intervals to select four sampling points

200 m – (92°E 6° 48' 32"N 1° 38' 27"W) 270 m.

400 m – (103°E 6° 48' 31"N 1° 38' 30"W) 270 m.

600 m – (96°E 6° 48' 30"N 1° 38' 30"W) 280 m.

800 m – (87°E 6° 48' 28"N 1° 38' 30"W) 280 m.

A secondary forest was located between the 400 m and 600 m transect points with the zone stretching along to the Northern part of the quarry.

Plate 1: Rock Cracker located at the Eastern part of the quarry

Western Zone

This zone stretches west from the center of the quarry and has two secondary forest patches and a sacred grove. The zone has a vast land that has been degraded by many flying stones from the quarry. This is the direction in which the dust moves after each blasting of the quarry on Tuesdays and Fridays. The zone was divided into four transect points from the center of the quarry to the west. Lined transect points from the center of the quarry was established at intervals of 200 m to pick samples from four sampling points.

200 m – (271°W 6° 48' 30"N 1° 38' 18"W) 280 m.

400 m – (268°W 6° 48' 27"N 1° 38' 15"W) 280 m.

600 m – (270°W 6° 48' 26"N 1° 38' 12"W) 290 m.

800 m – (264°W 6° 48' 26"N 1° 38' 9"W) 290 m.

The first secondary forest was at the 600 m transect point and the second was at 800 m transect point. The Sacred Grove shares a boundary with the 200m transect point demarcation. The point receives strong vibration when the rock is blasted. A small stream flows around the 400 m demarcation point.

Northern Zone

This zone stretches from the center of the quarry to the northern part and it includes a settlement forming a large community. Sampling points were located within the community. Key among them in the community was a hospital located at the transect point 400 m in the zone. This zone experiences a lot of vibrations as a result of heavy vehicles that transport rock particles from the quarry site daily. A lined transect from the center of the quarry was established at intervals of 200 m to pick samples at four sampling points.

200 m – (200°S 6° 48' 28"N 1° 38' 46"W) 270 m.

400 m – (177°S 6° 48' 39"N 1° 38' 26"W) 260 m.

600 m – (178°W 6° 48' 40"N 1° 38' 28"W) 250 m.

800 m – (179°S 6° 48' 41"N 1° 38' 29"W) 240 m.

There was a secondary forest which linked the eastern zone to this zone, and a reservoir bush at the 600 m demarcation point.

3.1.2 Field Sampling Method

Insect collection was done using the habitat-specific approach. This strategy was chosen because it enables big amounts of data to be collected, and provides the use of standardized techniques that are cost efficient. Traps were set at each of the transect points for insect sampling. A 50 m × 50 m demarcated plot at each of the transect points across all the zones was used for sampling. The traps set included Pitfall trap for ground dwelling insects, Flight interception trap, Yellow and Blue Sticky traps, Pan Trap, Turning of stones and tree logs, and Charaxes trap. A sweep net was used to sweep the vegetation for insects that rest on the leaf canopy and vegetation cover during each visit. Lastly flying insects and fruit feeding butterflies were captured by Ariel/butterfly net. The Charaxes traps were baited with mashed, fermented or rotting banana mixed with beer. Baits were replaced with fresh ones after weekly collection. In addition, butterfly net was employed within a one kilometer line in each transect point to capture butterflies that were not easily attracted by the baited traps. At each transect point, each Pitfall, Flight interception trap, Yellow and Blue sticky trap, Pan/Bowl trap and Charaxes trap were placed randomly and at a distance of 5m apart for insect collection. In all, a total of twelve Pitfall traps, Flight interception traps, Yellow and Blue sticky traps, Pan/Bowl traps and Charaxes traps were set for insect collection in all the twelve transect points in the quarry area. These traps were retrieved every six days between 7:00 am and 12:00 noon for catches and reset throughout the sampling period. Direct counts of individuals were recorded along transects and random walk sampling involved two individuals in the study area.

3.1.3 Collection Methodology

Flight Interception Trap (F.I.T) Ground

This trap is mainly used to collect flying insects which are not likely to be attracted to baits or light by disrupting the path of their flight. Part of the trap is suspended at 90^0 to the ground using supporting poles and ropes (Plate 2). This is done in a way that the net never touches the ground, ensuring that space is left beneath it for trays that contain a killing agent made of water and detergent to reduce surface tension. The principle or technique of this trap is that flying insects will be intercepted by the black mesh and fall into the water containing a detergent at the bottom of the trap. The black colour of the mesh material makes it difficult for flying insects, and the height of the trap is about chest level. Trapped insects were collected after 5-6 days and emptied into a container containing 70% alcohol for subsequent identification.

Plate 2: Flight interception trap

Charaxes Trap

The Charaxes trap is made up of a net with four cross-sections and a string at the edges (Plate 3). The strings at the bottom edge are attached to a square wooden plate. The strings at the top edges are tied to tree branches to hold the trap in a horizontal position. Bait made up of mashed rotten

banana mixed with palm wine was placed on the board. Alcohol-loving insects are mostly trapped by this method. Standard field handling of specimens captured from Charaxes traps consisted of firmly squeezing the thorax to disable the specimen and put it in an envelope (Oduro & Aduse-Poku, 2005).

Plate 3: Charaxes trap

Pitfall Traps

This trap consists of a plastic container sunk into a hole (Plate 4). This is set up by digging a hole in the ground. The size of the hole should be approximately equal to the size of the container with

an open diameter of 7.5 cm and a depth of 15 cm. The containers were buried with the opened end at the same level as the ground and half filled with a detergent solution for drowning collected specimens. The container could be baited or without bait. It is a passive form of sampling which relies on insects that crawl on the ground to accidentally fall into the container pit rather than the observer initiating the action that leads to capture (Wilson & Thomas, 2002).

Plate 4: Pitfall trap

Yellow Pan/Bowl Trap

(Kevan & Baker, 1983) Yellow pan traps collect insects that are attracted to the yellow color. Yellow and white colors represent widely visited colors with high reflectance and are often used as a standard for pan trapping (Vrdoljak & Samways, 2012). It is made up of a yellow colored tray filled with detergent water (Plate 5). The tray is particularly attractive to these insects and the detergent is mainly to break the surface tension thus preventing the insects from crawling. The bowls usually have steep edges to prevent the insects from escaping. Trapped insects were collected after 5-6 days and emptied into plastic containers with 70% alcohol for subsequent identification. These yellow pans are placed on the ground in the locations. Flying insects are attracted to the trap and fall into the mixture accidentally.

Plate 5: Yellow pan/bowl trap

Sweep Net

The sweep net was used to collect insects around vegetation. It consists of a metallic rim with a cloth attached to form a sac (Plate 6). It was swung through the vegetation with alternating forehand and backhand strokes about 20 times at each collection point and the content wae carefully emptied into a killing jar. The catches were later poured into a container with 70% alcohol for subsequent preservation and identification.

Plate 6: Sweep net

Aerial Net/Butterfly Net

The aerial net consisted of a metallic rim with a metallic handle and a fine mesh net forming a sack (Plate 7). Butterflies, dragonflies and moths were spotted and collected by sweeping. The butterflies caught were killed by squeezing their thorax, and placing them in envelopes with wings folded together at the back. This technique prevented the insects from losing their scales, a feature

very vital for identification. The other insects were transferred into killing jars containing ethyl acetate and kept for later identification.

Plate 7: Aerial nets in use

3.1.4 Species Handling and Identification

Insect species collected were killed with ethyl acetate in a killing jar while butterflies were killed by gently pressing the thorax and put in an envelope for identification. These together with insects collected from the traps were preserved in 70% ethanol for later examination and identification. Butterflies collected were identified to species level whiles other insects were properly identified to the family level with the assistance of a taxonomist (Roger Sigsmund Anderson at the African Regional Postgraduate Program in Insect Science, University of Ghana) using a dichotomous key to reference specimens at the Entomology Museum of the Department of Animal Biology and Conservation Science, University of Ghana, Legon.

Additionally, the vegetation was classified as either excellent, very good, good, average, degraded and most degraded using FAO National Forest Monitoring and Assessment (Saket *et al.*, 2010). All the zones assessed at the study site were mostly degraded. Floral density and diversity in each transect point were visually identified and counted with the assistance of a technician Mr Sampson Obuobi from the Department of Biological Science at the Kwame Nkrumah University of Science and Technology.

3.2 Data Analysis

Analysis of species richness, species abundance, evenness, species diversity and habitat similarities or differences in all the zones were examined and computed. Data from all zones were pooled to obtain the total diversity of insects per study site and sampling period. Three diversity indices were computed using PRIMER 6 & PERMANOVA+ to compare data from all three zones. This was preferred because qualitative assessment of sites was done by comparing their diversity indices (Chao *et al.*, 2005) which were treated as bio-indicators for biodiversity assessment

(Marshall, 2006). Diversity indices (Margalef index, Shannon-Wiener index, Simpson index and Evenness) were calculated and compared between habitats. Bray-Curtis similarity index was used to cluster species and families based on their species numbers and abundance, respectively.

1. Species richness (Margalef): $d = (S-1)/Log\,(N)$ - This is a measure of the number of species present, making some allowance for the number of individuals.

S = Total number of species

N = Total number of individuals in the sample

2. Pielou's evenness: $J = {H'}/{In(S)}$ - this is a measure of equitability, a measure of how evenly the individuals are distributed within the habitat.

3. Shannon-Wiener index: $H = -\Sigma\, pi\, ln(pi)$ – incorporates both species richness and equitability components.

H'= Shannon-Wiener index

S = Total number of species sample

In = Natural logarithm

4. Simpson index (D): It is influenced by dominant species (Measures dominance and evenness).

ni = the number of individuals of species in the sample,

$\Sigma\, ni = N.pi$ = the proportion of individuals of species i in the sample,

$pi = ni/N$. S = the number of species in the sample,

N= the total number of individuals in the sample.

Cluster analysis: Bray Curtis index is used to establish the similarities between the zones and the demarcated transect points. Values above 50 % mean the demarcated points are similar and below 50 % mean the demarcated points are dissimilar.

CHAPTER FOUR

4.0 RESULTS

4.1 Butterfly Abundance in the zones

A total of 417 individuals belonging to 68 species from 5 families from all zones were collected during the entire sampling period. These species belonged to the families Nymphalidae (45 species, 106 individuals), Papilionidae (2 species, 21 individuals), Pieridae (14 species, 123 individuals), Hesperiidae (4 species, 17 individuals) and Lycaenidae (3 species, 150 individuals). At the family level, Papilionidae and Hesperiidae recorded the lowest number of individuals, while Lycaenidae had the highest number of individuals (Fig 3).

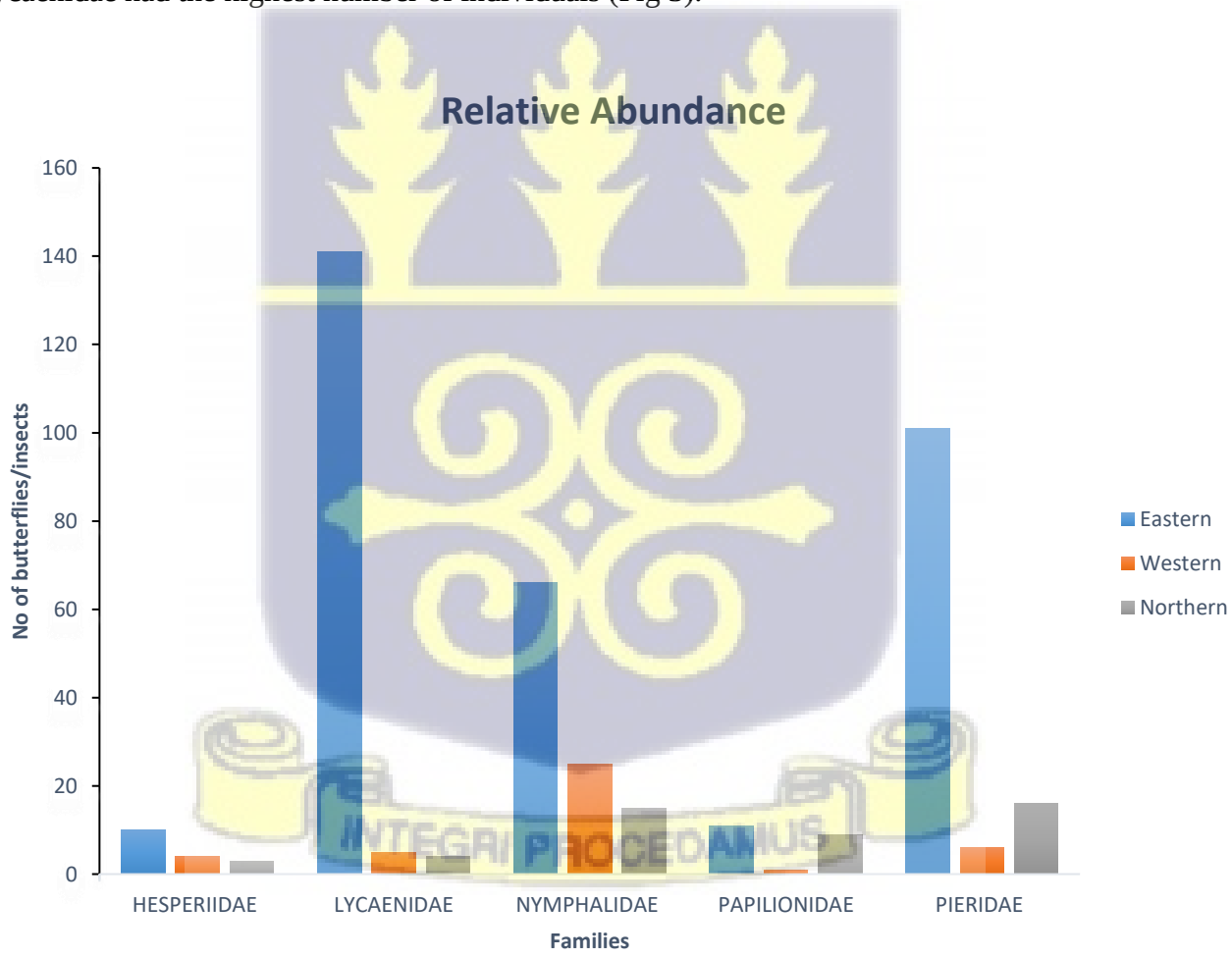


Figure 3: Relative abundance of butterfly families from the three zones

Butterfly abundance, diversity and richness

The Eastern zone (EZ) was the most diverse site for butterflies, with the highest abundance (N = 329) and the highest species diversity (S = 55), which was corroborated by the highest Margalef index (d) of 9.317 with a Shannon Weiner index (H') of 2.616 (Table 1). Two families, Lycaenidae and Pieridae, had the highest abundance (42.9 % and 30.7 %) (Appendix 9).

The Western zone (WZ) had low species diversity (S = 22) and the lowest abundance (N= 41), with the highest Shannon Weiner index (H') of 2.807 corroborated by the highest Pielou evenness (J') of 0.908 (Table 1). Family Nymphalidae accounted for 61% of all the butterflies recorded in this zone (Appendix 9).

The Northern zone (NZ) had the lowest species diversity (S = 21) and a low abundance of individuals (N= 47) corroborated by the lowest Margalef index (d) of 5.195 and a Shanon Weiner index (H') of 2.696 (Table 1). Family Pieridae and Nymphalidae had the highest abundance (34.0 %) and (32.0 %) respectively for all the butterflies recorded in this zone (Appendix 9).

Table 1: Diversity indices for butterflies from the three zones.

Diversity index	Eastern	Western	Northern
H'	2.616	2.807	2.696
D	0.822	0.921	0.907
J'	0.653	0.908	0.886
d	9.317	5.655	5.195
N	329	41	47
S	55	22	21

Simpson's index (D), Shannon-Weiner diversity index (H'), Pielou evenness (J'), Margalef (d), Number of individuals (N) and Number of species / species richness (S).

Butterfly similarity index

This shows the similarity between the Eastern and Northern zones at 39.81 % and the similarity between Eastern, Western and Northern Zone at 27.74 % (Figure 4). From the dendrogram, all the Zones are dissimilar since their percentages fall below 50 %, with Western and Northern Zones being more dissimilar.

Butterfly similarity index

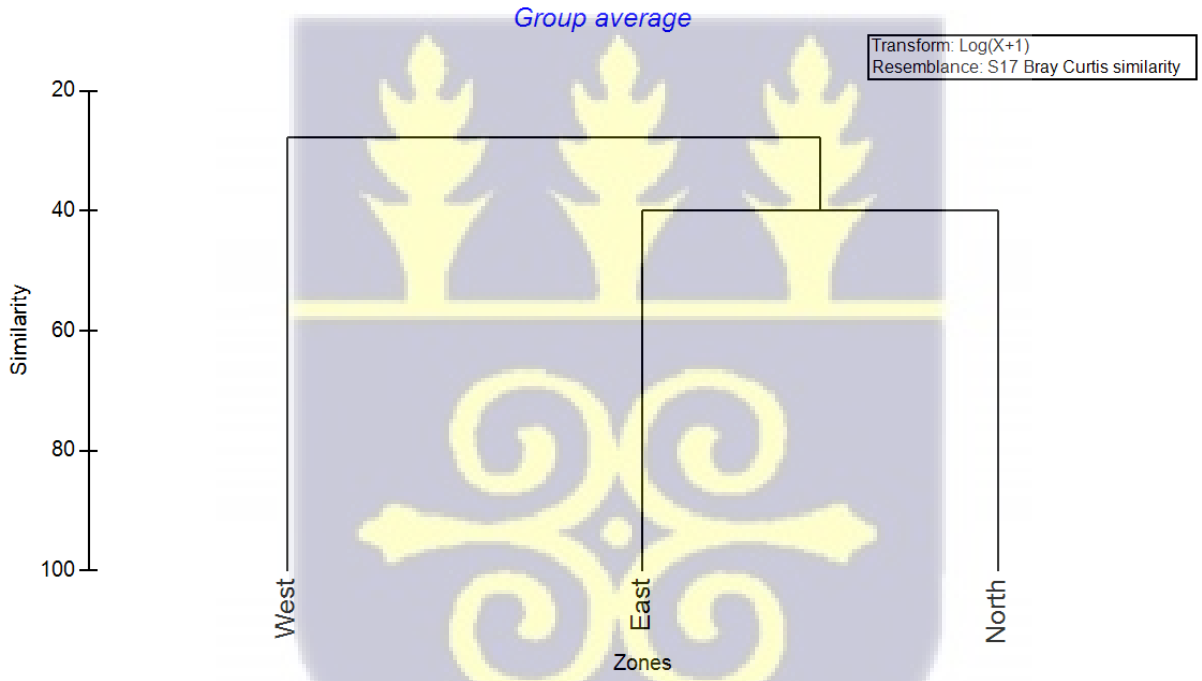


Figure 4: Dendrogram showing similarity indices of butterflies in the three zones

4.2 Relative abundance of insects in the zones for both seasons

A total of 2,485 individual insects were recorded from 56 families and ten orders across all three zones. These species belonged to Coleoptera (12 families and 659 individuals), Diptera (16

families and 385 individuals), Orthoptera (5 families and 892 individuals), Hymenoptera (5 families and 361 individuals), Hemiptera (5 families and 122 individuals), Dictyoptera (45 individuals), Homoptera (4 individuals), Phasmida (3 individuals), Dermaptera (6 individuals) and Odonata (8 individuals) (Table 3).

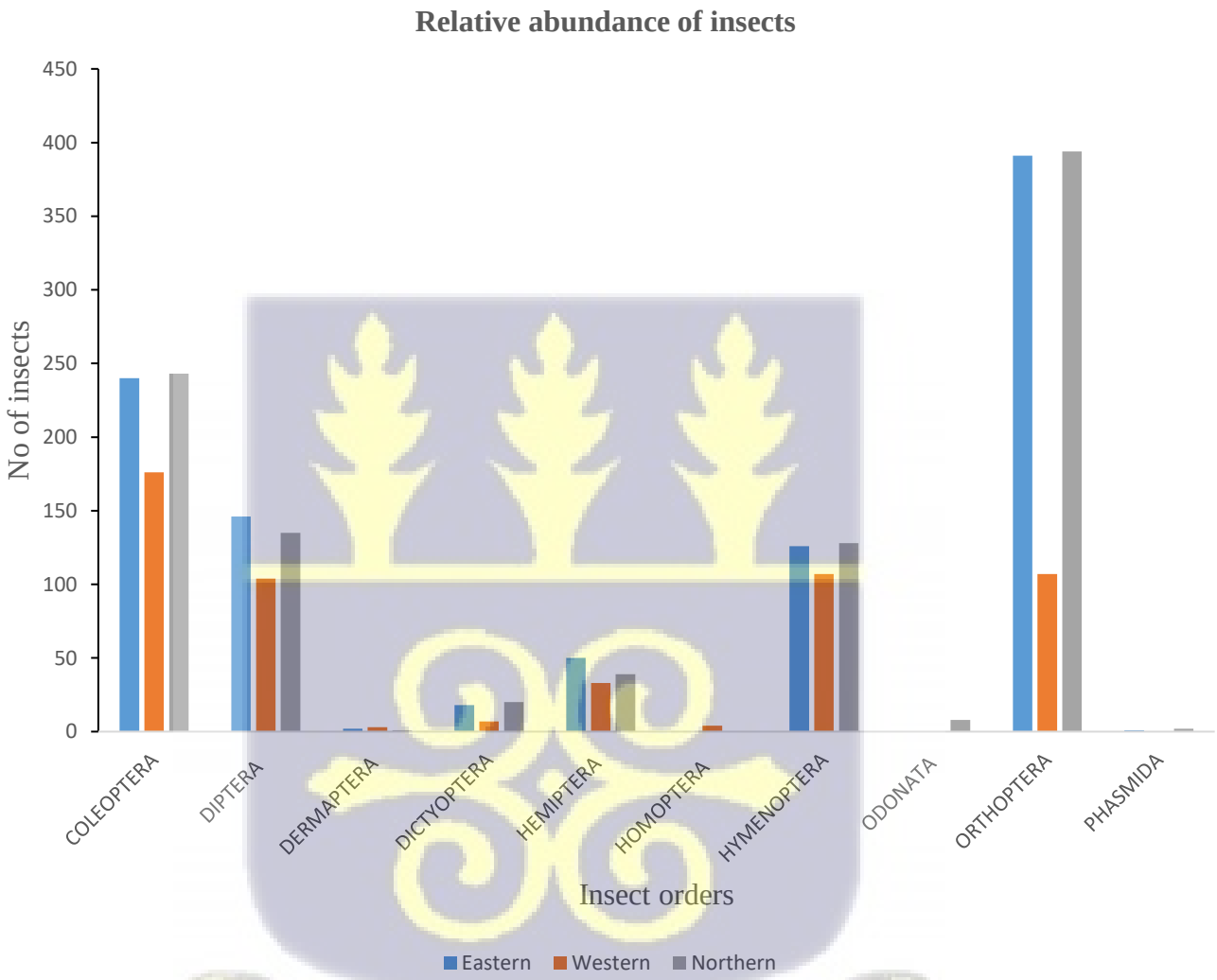


Figure 5: Relative abundance of insect orders in the three zones.

Diversity indices of insect orders across the three zones

The Eastern zone had the highest abundance of individuals (N = 974), species richness (S = 49) and highest Shannon Weiner index (H'= 2.620) which was corroborated by the highest Margalef

index (d = 6.975) (Table 2). Coleoptera and Orthoptera together had the highest abundance of individuals (40.1% and 24.6 %, respectively) (Appendix 10). Conversely, the Western zone had the lowest species richness (S = 37), and abundance of individuals (N = 541), and was corroborated by a high Pielou evenness (J' = 0.682) (Table 2).

The Northern zone (NZ) had high species richness (S = 47), a high abundance of individuals (N= 970), a high Margalef index (d = 6.696) and the lowest diversity (H'= 1.523) (Table 2). Again, Coleoptera and Orthoptera were the most common orders recorded in this zone (40.6% and 25.0%, respectively).

Table 2. Pooled diversity indices of insect orders for all three zones for two seasons.

Diversity index	Eastern	Western	Northern
H'	2.620	2.461	1.523
D	0.869	0.855	0.865
J'	0.673	0.682	0.666
d	6.975	5.720	6.696
N	974	541	970
S	49	37	47

Simpson's index (D), Shannon-Weiner diversity index (H'), Pielou evenness (J'), Margalef (d), Number of individuals (N) and Number of species / species richness (S).

4.3 Relative abundance of insects at the transect points across the three zones for two seasons

In the Eastern zone, a total of 974 insect specimens belonging to 35 families from 8 orders were collected from all four transect points (Appendix 8). These species belonged to the Orders Coleoptera (7 families, 240 individuals), Diptera (10 families, 146 individuals), Orthoptera (5 families, 391 individuals), Hymenoptera (4 families, 126 individuals), Hemiptera (6 families, 50 individuals), Dictyoptera (18 individuals), Phasmida (1 individual), and Dermaptera (2 individuals)

A total of 540 insects belonging to 47 families from 8 orders were captured from all four transect points in the Western zone during the sampling period (Appendix 8). These species in order of abundance belonged to the Orders Coleoptera (12 families, 176 individuals), Diptera (15 families, 104 individuals), Orthoptera (5 families, 107 individuals), Hymenoptera (5 families, 107 individuals), Hemiptera (7 families, 33 individuals), Dictyoptera (7 individuals), Homoptera (3 individuals) and Dermaptera (3 individuals).

A total of 970 insects belonging to 47 families from 8 orders were captured from all four transect points in the Northern zone (Appendix 8). These species belonged to the Orders Coleoptera (10 families, 243 individuals), Diptera (16 families, 135 individuals), Orthoptera (5 families, 394 individuals), Hymenoptera (5 families, 128 individuals), Hemiptera (7 families, 39 individuals), Dictyoptera (20 individuals), Phasmida (2 individuals), Dermaptera (1 individual) and Odonata (8 individuals).

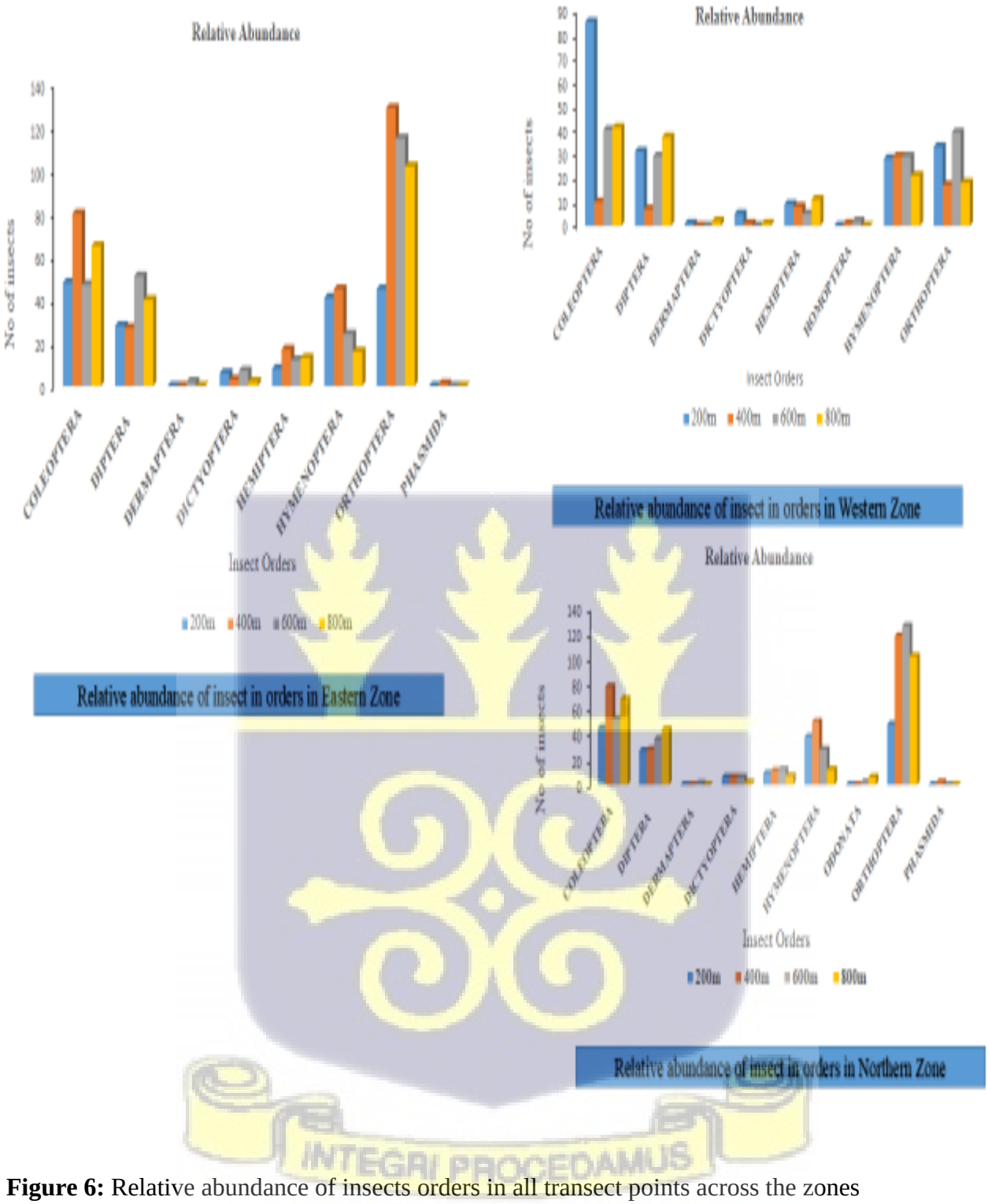


Figure 6: Relative abundance of insects orders in all transect points across the zones

4.4 Abundance and species richness at all transect points across the three zones for both seasons

Transect point 400 m in the Eastern zone had the highest abundance of individuals (N = 302) and low species diversity (S = 28) in the zone. Transect point 200 m had the highest diversity (H = 2.645) which was corroborated by the highest Simpson index (D = 0.892) at this zone.

Transect point 600 m in the Eastern zone had the highest species richness (S = 33), high abundance (N = 258) and highest Margalef index (d = 5.759) (Table 3). Insect orders Orthoptera and Diptera had the highest abundance of individuals in this zone (44.6 % and 19.7 %, respectively).

Transect point 800 m had the lowest species diversity (S = 24), lowest diversity (H' = 2.193) and the lowest Margalef index (d = 4.206) in the EZ (Table 3). Two orders Orthoptera and Coleoptera had the highest abundance of individuals (42.9% and 27.3%), respectively in this zone.

In the Western zone, transect point 200 m had the highest abundance of individuals (N = 192), highest species richness (S = 27) and the highest Margalef index (d = 4.945) (Table 3). Transect point 600m had the highest diversity (H' = 2.371) supported with the highest Simpson index (D = 0.868) for this zone.

Transect point 400 m had the lowest abundance of individuals (N = 73) and lowest species diversity (S = 16) as well as the lowest diversity (H' = 2.157) in the WZ (Table 3).

Transect point 400 m in the Northern zone had the highest abundance (N = 293) and highest species richness (S = 33). Transect point 200m had the highest diversity (H' = 2.537) corroborated by the highest Simpson index (D = 0.871) in this zone.

Transect point 800 m had the lowest species diversity (S = 24) as well as the lowest diversity (H' = 2.188) which was corroborated by the lowest Margalef index (d = 4.193) for this zone (Table 3).

Table 3. Diversity indices at transect points in all three zones

Diversity index	Eastern Zone				Western Zone			
	200m	400m	600m	800m	200m	400m	600m	800m
H'	2.645	2.342	2.616	2.193	2.164	2.157	2.371	2.255
D	0.8919	0.8401	0.8832	0.8066	0.7833	0.8155	0.8677	0.8527
J'	0.7855	0.703	0.7482	0.6900	0.6566	0.7779	0.7669	0.7803
d	5.415	4.728	5.759	4.206	4.945	3.496	4.22	3.487
N	176	302	258	238	192	74	144	131
S	29	28	33	24	27	16	22	18

	Northern Zone			
	200m	400m	600m	800m
H	2.537	2.475	2.427	2.188
D	0.8711	0.8556	0.8624	0.8111
J'	0.7533	0.7078	0.7208	0.6885
d	5.477	5.634	5.025	4.193
N	173	293	263	241

S	29	33	29	24

Simpson's index (D), Shannon-Weiner diversity index (H'), Pielou evenness (J'), Margalef (d),

Number of individuals (N) and Number of species / species richness (S).

4.5 Relative abundance of insect orders in both Wet and Dry seasons

A total of 1,765 insects belonging to 50 families from 9 orders were captured from all three zones in the wet season (Appendix 11). These species belonged to the Orders Coleoptera (12 families, 556 individuals), Diptera (16 families, 218 individuals), Orthoptera (5 families, 702 individuals), Hymenoptera (5 families, 215 individuals), Hemiptera (7 families, 46 individuals), Dictyoptera (20 individuals), Homoptera (2 individuals), Phasmida (2 individuals), Odonata (2 individuals), and Dermaptera (2 individuals).

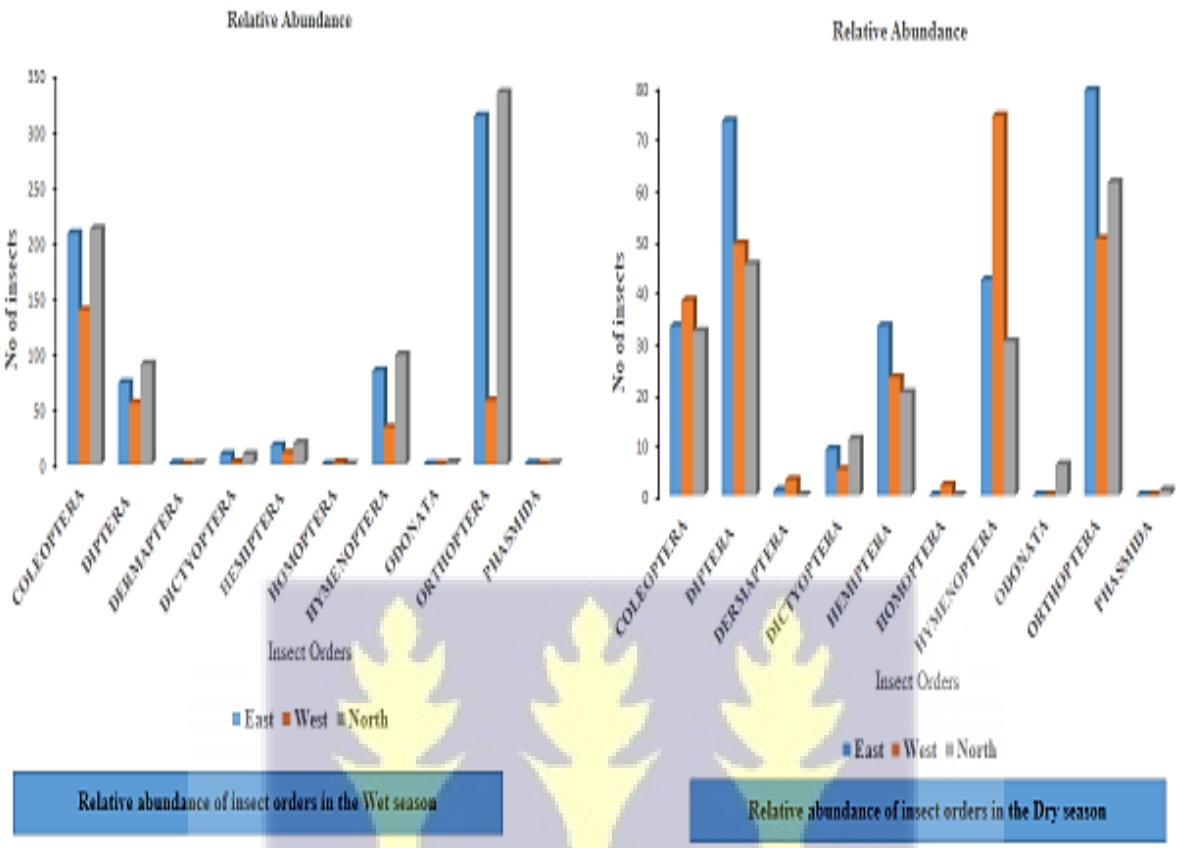


Figure 7: Relative abundance of insects orders across the zones for Wet and Dry season

In the dry season, a total of 720 insects belonging to 47 families from 9 orders were captured from all three zones (Appendix 11). These species belonged to the Orders Coleoptera (11 families, 103 individuals), Diptera (16 families, 167 individuals), Orthoptera (5 families, 190 individuals), Hymenoptera (7 families, 146 individuals), Hemiptera (6 families, 76 individuals), Dictyoptera (25 individuals), Homoptera (2 individuals), Phasmida (1 individual), Odonata (6 individuals), and Dermaptera (4 individuals).

4.6 Diversity indices of insect orders for all three zones for the Wet and Dry season

The Northern zone had the highest abundance of individuals (N = 764), highest species richness (S = 46), highest Margalef index (d = 6.779) and was corroborated with the highest diversity (H' = 2.336) in the Wet season (Table 4). On the contrary, the Western zone had the lowest species richness (S = 29), the lowest abundance of individuals (N = 297) and the lowest Margalef index (d = 4.918) in the same season (Table 4).

The Eastern zone had the highest abundance of individuals (N = 270), highest species richness (S = 43), highest Margalef index (d = 7.502) and was corroborated with the highest diversity (H' = 3.090) in the Dry season (Table 4). However, the Western zone had the lowest species richness (S = 29), the lowest abundance of individuals (N= 244) and the lowest Margalef index (d = 5.094).

Table 4: Diversity indices of insect orders for all three zones for both Wet and Dry season.

Diversity index	Wet season			Dry season		
	East	West	North	East	West	North
H'	2.274	2.099	2.336	3.090	2.618	3.080
D	0.8272	0.7794	0.8342	0.929	0.884	0.937
J'	0.6123	0.6233	0.6102	0.822	0.778	0.881
d	6.101	4.918	6.779	7.502	5.094	6.045
N	704	297	764	270	244	206
S	41	29	46	43	29	33

Simpson's index (D), Shannon-Weiner diversity index (H'), Pielou evenness (J'), Margalef (d), Number of individuals (N) and Number of species / species richness (S).

4.7 Number of plant species in all the three zones

A total of 386 individuals belonging to 21 genera were identified across all four transect points (200m, 400m, 600m and 800m) in all three zones for both seasons. The Eastern zone had the highest abundance (N = 175) followed by the Western zone (N = 111) and the least from the Northern zone (N = 100) (Table 5).

Table 5. Number of plant species recorded in all three zones for both seasons

Species	Local Names	East	West	North	Total
Antiaris toxicaria	Kyenkyen	4(2.3%)	0	4(2.3%)	8(2.1%)
Albizia adianthifolia	Pampena	1(0.6%)	0	9(5.1%)	10(2.6%)
Albizia zygia	Okoro	6(3.4%)	0	2(1.1%)	8(2.1%)
Amphimas pterocarpoides	Yaya	2(1.1%)	0	0	2(0.5%)
Baphia nitida	Odwen	30(17.1%)	10(9.0%)	0	40(10.4%)
Baphia pubescens	Odwenkobiri	10(5.7%)	3(2.7%)	8(4.6%)	21(5.4%)
Blighia sapida	Akye	1(0.6%)	0	0	1(0.3%)
Ficus sur	Nwadua	7(4.0%)	0	0	7(1.8%)
Ficus exasperate	Nyankyerene	11(6.3%)	11(10.0%)	21(12.0%)	43(11.1%)
Margaritaria discoidea	Pepea	1(0.6%)	22(19.8%)	0	23(6.0%)
Millettia zechiana	Fafraha	9(5.1%)	0	0	9(2.3%)
Morinda lucida	Konkroma	5(2.8%)	17(15.3%)	3(1.7%)	25(6.5%)
Newbouldia laevis	Sesemasa	0	0	6(3.4%)	6(1.6%)
Broussonetia papyrifera	York	6(3.4%)	18(16.2%)	11(6.3%)	35(9.1%)
Chromolaena odorata	Acheampong	25(14.3%)	0	0	25(6.5%)
Elaeis guineensis	Abe	55(31.4%)	7(6.3%)	16(9.1%)	78(20.2%)

Pseudospondias microcarpa	Akatawani	2(1.1%)	2(1.8%)	0	4(1.0%)
Leucaena leucocephala	Lucaena	0	4(3.6%)	0	4(1.0%)
Spondias mombin	Atoa	0	2(1.8%)	0	2(0.5%)
Cocos nucifera	Kobe	0	0	10(5.7%)	10(2.6%)
Caragana arborescens	Pea	0	0	4(2.3%)	4(1.0%)
Citrus medica	Akutoo	0	12(10.8%)	0	12(3.1%)
Mangifera indica	Mango	0	2(1.8%)	4(2.3%)	6(1.6%)
Tectona grandis	Tek	0	0	2(1.1%)	2(0.5%)
Alstonia boonei	Sinuro	0	1(1.0%)	0	1(0.3%)
Total		**175**	**111**	**100**	**386**

Table 6: Diversity indices of plant species for all the three zones.

Diversity index	Zones		
	Eastern	Western	Northern
H'	2.173	2.241	1.992
N	175	111	100
S	16	13	13

* Shannon-Weiner diversity index (H'), Number of individuals (N) and Number of species / species richness (S).

Table 7: Diversity indices of plant species for all transect points in all the three zones.

Diversity index	Eastern				Western				Northern			
	200m	400m	600m	8000m	200m	400m	600m	8000m	200m	400m	600m	8000m
H'	1.898	1.618	1.874	1.653	1.143	1.691	1.249	1.276	1.871	1.208	1.526	1.748
N	87	49	55	42	29	25	37	27	36	20	20	35
S	10	7	9	7	5	6	6	4	8	4	5	7

* Shannon-Weiner diversity index (H'), Number of individuals (N) and Number of species /species richness (S).

4.8 Community structure of the three zones

The community structure of the Eastern and Northern zones was very similar at 87.02 % (Figure 7). The Western zone is also very similar to the Eastern and Northern Zone at 68.79 % (Figure 7). From the dendrogram, all the Zones are similar since their percentages are above 50%, with Eastern and Northern Zones being more similar.

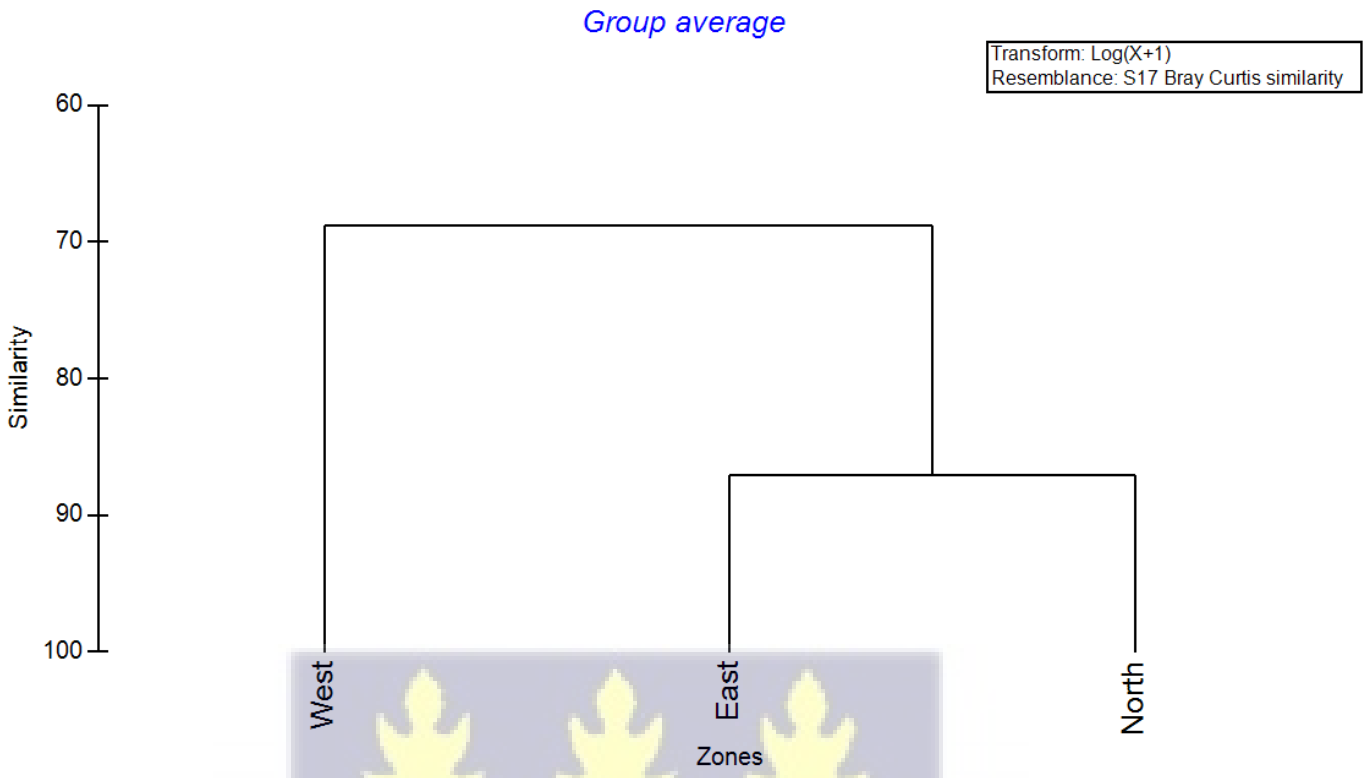


Figure 7: Dendrogram showing similarity of insect orders in the different zones

4.9 Transect point similarity indices

From the analysis using Bray-Curtis similarity, the Eastern 600 m and Northern 600 m were very similar at 85.13 % (Figure 8). Eastern 400m and Northern 400 m were also similar at 83.35%. Eastern 600 m, Northern 600 m, eastern 400 m and Northern 400 m were similar at 71.05 % (Figure 8).

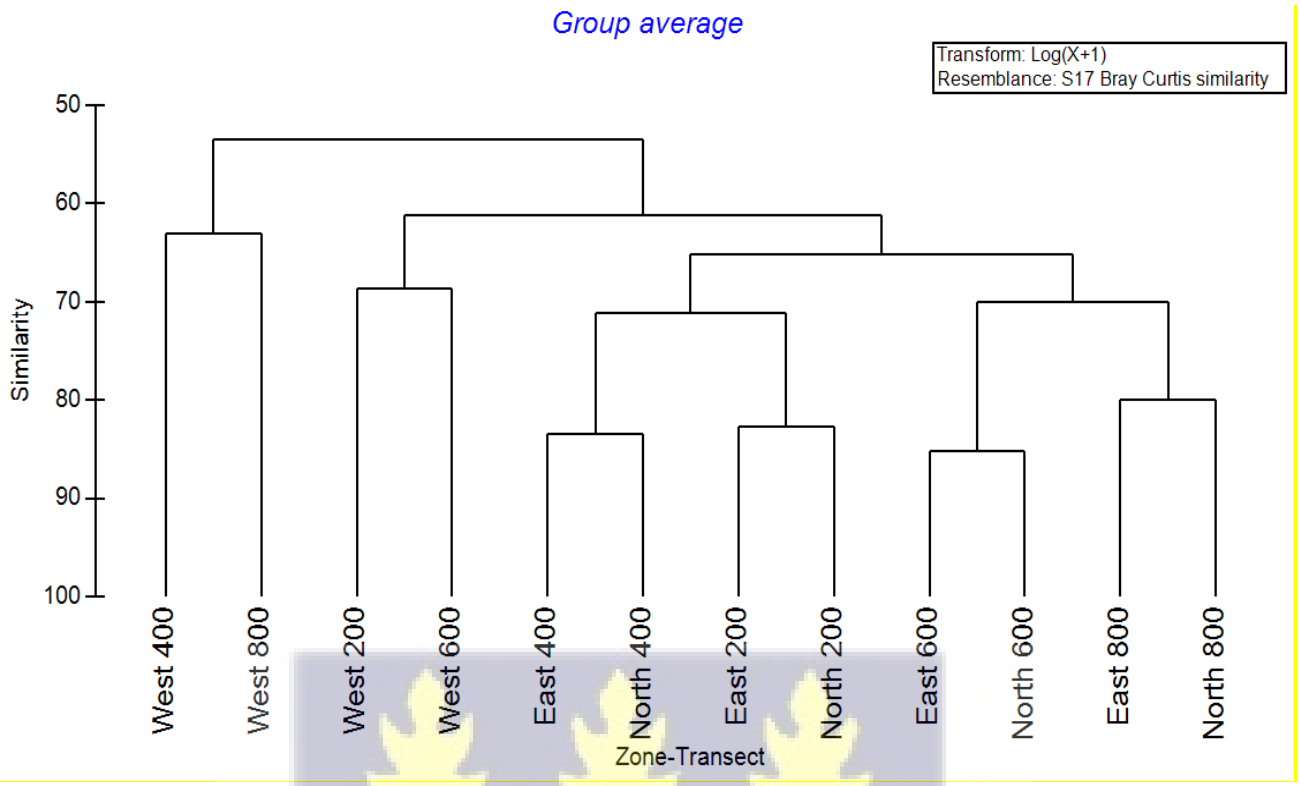


Figure 8: Dendrogram showing similarities of insect orders in different Transect points across the zone

CHAPTER FIVE

5.0 DISCUSSION

5.1 Comprehensive inventory of insect diversity and abundance in all three zones.

The study found that the Monwire Quarry site supported a good assemblage of flora and fauna. This was to be expected because although the area consists predominantly of three secondary forests, a mosaic of microhabitats is found in the area that includes riverine vegetation, grasses, sacred grooves and oil palm plantations, which in turn provide niches for a wide variety of invertebrates. In this study, there was a high correlation between plant diversity and insect diversity in the Eastern Zone (EZ) compared to the other zones. The distribution of any species is restricted by the suitability of its habitat in relation to the availability of food and other resources (Marciniak *et al*., 2007). Plant diversity is often positively correlated with insect diversity and affects insect community composition (Joern & Laws, 2013). This confirms the findings of (Husseini *et al*., 2019) who reported higher insect species diversity in an unlogged forest compared to a disturbed forest in Nigeria. Some studies report a correlation between species richness of different groups, e.g. beetles and dipterans (Pearson and Cassola 1992), butterflies and flowering plants (Kremen 1992), and several groups of insects and general biodiversity (Duelli and Obrist 1998). This confirms the findings of the study, which indicate high abundances of Orthoptera, Coleoptera and Lepidoptera correlate with high abundances of tree species in the Eastern zone of the quarry.

The western zone (WZ) habitat conditions were not conducive for insect assemblage and had the lowest abundance of individuals and species richness. Dust from quarry sites is a major source of air pollution, although the severity depends on factors such as local microclimate conditions, the concentration of dust particles in the ambient air, the size of the dust particles and their chemistry,

for example, limestone quarries produce highly alkaline (and reactive) dust, while coal mines produce acidic dust. The prevailing wind direction in a given area determines how dust from the quarry area travels to the surrounding area. It was observed that large amounts of dust move in the direction of the Western Zone after each blasting of the quarry. This could have accounted for the low diversity and richness of insect species and negatively impact the ecosystem health in the zone. (Stankovic & Stankovic, 2013) reported that dust can have physical effects on the surrounding plants, such as reduction of photosynthesis by blocking and damaging the internal structures of plants and abrasion of leaves and cuticles, and can also affect the abundance of insects and other invertebrate groups. Dust negatively affects insect larvae by prolonging insect development time and increasing mortality by 32%, and the weight of mature larvae is halved, and insect larvae feed on dust-covered leaves (Khan *et al*., 2013). The beetle population decreases with increasing levels of particulate matter pollution on the leaves of their host plants (ukowski *et al*., 2018). When disturbance frequency is very high, diversity decreases as only good colonizers or highly tolerant species can survive (Msalilwa *et al*., 2019). This confirms the work of (Kyerematen *et al*., 2014) who reported that insect biodiversity tends to provide clearer results on the ecological consequences of human-induced activities.

The findings of the study showed that insect abundance in the Northern Zone (NZ) was not significantly different from that in the Eastern Zone, but showed the lowest diversity among the three zones. This was to be expected due to the numerous anthropogenic activities such as the destruction of vegetation cover, habitat fragmentation, and destruction of farmland for buildings, road construction and human settlements. Over the years, more and more natural and semi-natural habitats have been cleared at an accelerating rate to make way for agriculture, roads, housing

developments, factories, truck parks, out-of-town shopping malls, and a multitude of other human endeavors. Insect populations existing in small, highly fragmented and isolated habitats may become extinct over time. The local population is increasingly inbred or poorly composed due to vagaries of fragmentation. One way or another, populations fizzle out, and if the sites where they are located are isolated from each other, there is a small chance that they will be recolonized (Goulson *et al*.. 2015). Roads can fragment habitats, degrade the environment, increase edge effects, isolate breeding populations, reduce population sizes and cause genetic bottlenecks (Muoz *et al*., 2015). Habitat fragmentation also affects the natural movement of insect species, ultimately affecting their foraging ability to locate their prey or hosts (Stireman, 2016). Therefore, higher trophic levels such as predators and parasitoids are expected to be most affected due to the habitat changes (Burkman & Gardiner, 2014).

The occurrence of Orthoptera as the most dominant insect order in all three zones is consistent with previous authors (Manzoor *et al*., 2013) who showed that insects such as grasshoppers, locusts and crickets are well adapted to the grasslands of open savannas. Therefore, forest fragmentation and the creation of open habitats and a large diversity of microhabitats favor heliophilic arthropods such as grasshoppers and butterflies (Vele *et al* ., 2011). Grasshoppers are indeed recognized as abundant insects in open environments, which explains the low species richness observed in this study. This finding is in contrast to work by Soliman *et al*. (2017) who reported higher species richness, abundance, and diversity at the less disturbed sites in South Cairo, Egypt. We can therefore assume that the behavior of grasshoppers in response to environmental disturbances is influenced by the eco climatic zone and the structure of plant and even animal communities.

Disturbed and new habitats may be important for the spread of some grasshopper forms (Latchininsky *et al*.. 2011).

The trend of Coleoptera as the second dominant insect order confirms the work of (Kudavidanage *et al*., 2012) who indicated that Coleoptera is generally herbivores, scavengers and predators and are extensively involved in the breakdown of organic materials. Dung beetles (Scarabaeidae) are an excellent indicator taxon for landscape diversity studies because they are ecologically sensitive and rely on the right combination of dung-producing animals (Nichols *et al* ., 2008). Dung beetles show high rates of species turnover along habitat gradients (Filgueiras *et al*., 2011), making them sensitive to habitat changes and even minor land-use changes (Almeida *et al*., 2011). Fragmentation and isolation are also important determinants of the distribution of dung beetle species (Escobar *et al*., 2008), making them useful indicators in transformed landscapes.

The low abundance of Hemiptera and Odonata species in all three zones confirms the impact of quarrying operations on their assemblage. The order as a whole is highly diverse, covering a wide range of ecological forms and abundant in almost all habitat types. Although species are difficult to identify in many families, they are easily identified to morphospecies and can therefore be used in biodiversity studies. Relatively easy to identify families such as the Reduviidae could be used as indicators of predator diversity (Gerhardt *et al*., 2004). As ecological indicators, bugs have been used as indicators of pollution (Jana et al. 2006) and the impact of drainage on habitats (Skern *et al*., 2010). It has also been used to study the progress of post-mining habitat restoration (Orabi et al. 2010). The Odonata are a group of insects that are used extensively as environmental indicators of river and catchment health (Simaika and Samways 2012). They have been used successfully to monitor freshwater systems (Rosset *et al*., 2012).

5.2 Spatial variations in insect diversity and abundance in all transect points

The forest ecosystem of Monwire Quarry is being seriously disturbed by the continuous exploitation of rock and natural resources, which is negatively impacting flora and fauna. In the Eastern zone (EZ), high insect abundance at transect point 400 m (TP 400) and high species richness at transect point 600 m (TP 600 m) were recorded. There was a high correlation between host plant diversity (Table 7) and insect diversity (Table 3) at TP 600 m compared to the other points in the East Zone (EZ). A high diversity of plants should lead to a high diversity of insect herbivores in the community (Lewinsohn & Roslin, 2008). This observation confirms the findings of Vailshery et al. (2013) who reported positive correlations between tree species diversity and insect diversity in India. The high abundance of individuals at TP 400 m could be due to a single species dominating the point as preferred plant species provide resources for the individuals. This was confirmed by the low Margalef Index (Table 3) compared to TP 600 m, which showed the highest species richness in the zone.

The sacred groove at TP 200 m in the West Zone (WZ) recorded the highest insect abundance and species richness (Table 3) in the Zone. This was to be expected since the sacred groove was a haven for plant species and a rich assemblage of insect species in the zone. This supports a study by Husseini et al. (2019), which indicates that the availability of food resources is known to be a determinant of insect distribution and abundance. The spatial distribution of resources in a heterogeneous environment strongly influences how animals inhabit a landscape and ultimately their abundance (Wang et al., 2006). Animals are expected to select areas of a higher complement to reduce travel costs (Dunning et al., 1992). However, TP 400 m in the west zone had the lowest

abundance, the lowest species richness and the lowest diversity (Table 3). This could be due to the direct amounts of quarry dust and flying rocks moving and settling at the transect point after each rock blast. This supports the work by Nisic (2018) who pointed out that quarry operations negatively impact the environment in a variety of ways during exploration, blasting, transportation and disposal of waste rock. Also, quarrying operations are involved in large-scale clearance of habitats, which are harmful to biota, emission of dust, noise and vibrations that degrade the quality of neighboring areas by making them unsuitable for plants and animals (Allington and White 2007). Habitat destruction is recognized as one of the main threats to biodiversity worldwide (Smith et al., 2003). The destruction of forest ecology for quarrying activities can also threaten the ecological balance of flora and fauna communities in the long term. In the Northern Zone (NZ), TP 400 m provided suitable habitat for high insect abundance and species richness (Table 3). The secondary forest at the site provided shelter for the insect population and also supported plants. However, TP 800 m had the lowest diversity. This may be due to the numerous anthropogenic activities such as building construction, road construction, vibration, noise, dust and pollution from heavy vehicles transporting quarry materials. Driving at night would reveal a blizzard of moths in the headlights (Bar-On et al. 2018).

Environmental changes can have various impacts on insect species, including physiological changes or changes in species number or abundance (Rainio & Niemel, 2003). Signaling in noisy environments can reduce perception by intended recipients, causing animals to flexibly adapt to their signals in response to natural fluctuations in noise.

In addition to natural biotic and abiotic sounds, noise generated by human activities has been increasingly understood that anthropogenic noise exerts a strong selection on acoustic

communication signals from animals. For example, anthropogenic noise is often loudest at low frequencies, and individuals of some anuran, insect, and songbird species shift the signal band up to avoid masking (Brumm 2017). For example, arthropod species have been shown to drastically decrease in abundance in noisy environments compared to quiet areas (Bunkley et al. 2017). A very large number of organisms depend on sounds, ie acoustic vibrations perceptible or imperceptible to humans to perform a variety of behaviors. For example, such vibrations are known to be used in communication and mating in a wide variety of insects, fish, amphibians, birds, and mammals (Bradbury & Vehrencamp, 1998). As the baseline level of environmental vibrations is greatly increased in anthropogenically disturbed environments, there are growing concerns about the impact of these man-made vibrations/sounds on the physiology and ethology of animals (including insects) and plants (Buxton et al., 2017). Recently, Barton et al. (2018) work on the impact of noise pollution on a model ecosystem showed a negative effects of noise pollution on the ecosystem.

5.3 Butterfly diversity and abundance in all three Zones

The main drivers of ecological changes that are threatening species worldwide are anthropogenic activities. Butterflies play an important role as pollinators, a source of food for birds and indicators of ecosystem health. Therefore, high butterfly abundance typically implies a healthier ecosystem (Moranz *et al.*, 2012). It was observed that the greatest diversity of butterflies was recorded in the Western zone, while the lowest diversity was recorded in the Northern zone. It was evident that the sacred groove supported a rich assemblage of flowering plants which undoubtedly provided a feeding and resting site for butterfly species in the Western zone. Adult butterflies require suitable

host plants for oviposition and larval development (Santhosh & Basavarajappa, 2017). The diverse nature of plant species in the forest ecosystem attracted butterflies for foraging and reproduction, which resulted in higher species richness and diversity (Wala *et al*., 2012). Also, the Eastern zone showed a positive response to high butterfly abundance than the other zones. It was apparent that the secondary forest in the Eastern zone provided shrub and tree-feeding food plants for butterfly assemblage. These findings corroborate the work of Bullock and Samways (2006) who found that butterflies are capable of utilizing forest as long as their host plant subsists in the habitat.

A higher butterfly population may indicate higher plant diversity and other pollinator groups within the area. This finding correlated positively with the high abundance of tree species in the Eastern zone, resulting in a high abundance of butterfly populations. The secondary forest vegetation in the zone had a dense canopy that reduced radiation penetration and had undergrowth of sweet nectar plants. Butterflies are attracted to flower gardens and nectar produced from flowers, which contains nutritious vitamins, lipids, sugars and amino acids that are an important food source for pollinators (Sourakov *et al*., 2012).

The movement of dust particles towards the Western zone after each quarry blast may have contributed to the low abundance of individuals in the zone, while dust and vibration from heavy vehicles in the Northern zone may have caused the decline in butterfly abundance and species richness. According to Iqbal et al. (2001), the effects of dust particles on plants include the potential to block and damage stomata, affecting photosynthesis and respiration. Butterfly communities are strongly affected by vegetation changes as most butterfly larvae have a strong association with host plants and adults require a specific range of nectar plants for reproduction (Lee *et al*., 2015).

5.4 Seasonal variations in insect diversity and abundance

Seasonal cycles provide a good assessment for species with various generations per year to assess the ecological impact of a changing environment. DeVries et al. (1997) reported that the short generation time of insects makes it perfect to study seasonal effects on species abundance and diversity. In general, larval host plants respond to increased precipitation by producing fresh leaves and shoots (Aide, 1993), which are preferred oviposition sites for many insects (DeVries et al., 1997). Hector et al. (1999) affirmed that precipitation is likely to have a consequential impact on ecosystem functioning, particularly by affecting insect productivity (Morgan et al., 2016), altering plant diversity and community composition, and even affecting soil nutrient cycling (While & Charlton, 2006). Toxic air pollutants (toxic chemicals in the air) and carbon monoxide residues from the heavy trucks that transport aggregates from the quarry site every day can cause acid rain in the quarry operational area. Precipitation washout is one of the main mechanisms for removing particulate pollutants from the air. Soluble pollutants are washed out with precipitation and carried away by the runoff that forms with residual pollutants at the earth's surface.

Acid rain also blocks the tiny pores on the leaf surface through which carbon dioxide is absorbed. Through physiological effects on reproduction, growth, or activity, precipitation can directly affect arthropod abundance. For example, rain is essential for the breeding of Diptera such as sandflies (Chaniotis et al., 1971) and mosquitoes (Bates, 1945). Similarly, the emergence of the adult dung beetle Heliocoris dilloni from the soil in Kenya is triggered by rain (Kingston & Coe, 1977). In contrast, herbivorous insects such as Homoptera and Orthoptera can respond to changes in vegetation influenced by rainfall.

Increased rainfall disrupts insect biological and morphological activities as well as habitat flooding. According to Wohlfarth et al. (2008), increases in rainfall may adversely affect arthropods by disrupting flight, reducing growth effectiveness, and increasing migration times. The Northern and Eastern zones continue to alternate in species richness and abundance as they have similar vegetation structures and a secondary forest existing between them. Species richness was very low in the dry season because food played an important role. Larvae foraging and growth of host plants are mainly influenced by rainfall, which increases the abundance of insect species. The major problem insects face during the dry season is maintaining water balance (Bates, 1945). This is consistent with research conducted by Wolda (1978) who suggested that herbivorous insects may cease reproduction due to a lack of suitable food as there is insufficient rain for plants to initiate leaf growth in the dry season. The high diversity of insect species in the dry season compared to the diversity in the rainy season was fascinating (Table 4). This could be due to the availability of food for most insects immediately after the rains, and also the movement of most insect species was hindered by the rains in the wet season, as well as habitat destruction or flooding, which may have affected insect richness.

5.5 Abundance of plant species in the zones

Man's exploitation of the natural forest for its survival usually leaves tremendous degradation and devastation in its aftermath. However, habitat loss due to forest degradation and unsustainable forest use continues at an alarming rate (Sheil, 2001). Only about 10-15% of Ghana's original forest cover has not been damaged, with severe fragmentation and degradation of what remains.

Increasing population numbers combined with urbanization and industrialization have led to overexploitation of forest resources, leading to increased deforestation and the disappearance of certain plant and animal species (Addai & Baidoo, 2013). Vegetation cover has been identified as a determinant of insect species diversity in fragmented landscapes (Von Braun, 1997). The Eastern Zone of the study area had the highest abundance of plant species, followed by the Western Zone and the least abundant was the Northern Zone. Although the Eastern Zone had a high number of individuals, the Western Zone had high diversity, followed by the Eastern zone and the northern Zone with the lowest diversity (Table 7).

5.6 The similarity of zones and transect points

Species composition in the Eastern and Northern zones was more similar (68 %) than the Western zone mainly because the Eastern and Northern zones were geographically closer to each other than the Western zone. The Eastern zone transect point (TP) 600 m and Northern zone transect (TP) 600 m were also very similar as well as Eastern zone (EZ) (TP) 400 m and Northern zone (NZ) (TP) 400 m. EZ (TP) 600 m, NZ (TP) 600 m, EZ (TP) 400 m and NZ (TP) 400 m were equally similar. The similarity of total insect species found in EZ and NZ areas was 87.02 %. But the similarity between EZ, NZ and WZ was 68.79 %. Less similarity of species between the three zones may be because of habitat preference. This is an indication of the negative effect of quarry operations on the diversity of insect species in the area.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This research explored the relationship between insect diversity and quarry operations in the Ashanti region of Ghana. The Mowire quarry site exhibited a clear case of how quarry operations affect biodiversity. The goal of this research was to assess the relationship between quarrying operations and the diversity of insects in an unprotected tropical forest site, with a focus on the diversity and abundance of insects as indicator species in quarry operational areas. The limitations of this research were lack of data on environmental parameters by the district assembly, time constraint and adequate resource to assess particulate matter of the quarry dust. A total of 2,902 individual insects were recorded from 61 families and eleven orders across all three zones. The Eastern zone of the quarry operational area supported a rich assemblage of insects with high diversity, abundance and species richness. However, the Western zone of the quarry operational area was not conducive to insect assemblage and this accounted for the low abundance, richness and diversity. It was observed that the zone received dust, flying rocks and other negative impacts of the quarry after each blast. Active quarry operations affected the abundance of phytophagous insects which represent a significant percentage of the invertebrate group. Destruction of vegetation cover, species habitat, farmlands and other anthropogenic activities accounted for the low diversity of species in the Northern zone. It is necessary to have a balance between population growth, agriculture, development and the preservation of insects and their natural ecosystem must be found in the Northern zone. The quarry operational area did not support a rich assemblage of insect species along the transect points in all the three zones.

The microhabitat in the quarry transect point 400 m in the Western Zone did not support endemic species and had the lowest abundance, diversity and richness. However, high abundance and diversity were observed in transect points 400 m and 600 m in the Eastern zone of the quarry operational area. The wet season showed an increase in insect numbers compared to the dry season because host plants responded to an increase in precipitation by producing new leaves and shoots which were preferred for oviposition and development by many insect species. Notwithstanding there was a high diversity of species in the dry season compared to the wet season. Rainfall disrupted foraging efficiency, arthropod flight, biological and morphological activities of insects and sometimes flooding of habitats. These findings illustrate a need to control quarry dust, where needed to protect insect abundance and diversity. The loss of insect biodiversity, which is mainly a consequence of anthropogenic pressure, will ultimately lead to a subsequent decline in ecosystem stability and functioning in the quarry operational area. In this respect, better knowledge of the genetic, morphological, and functional aspects characterizing the great level of insect biodiversity will be decisive for the safeguarding of ecosystems. This research provides further awareness of insect diversity, the importance of contemplative land use, and affirms the interconnectedness of humans, quarry operations, agriculture, and insect biodiversity. However, sophisticated manipulation of the environment in quarrying project either directly or indirectly (habitat modification) results in serious implication where by rare and endangered species will become non-adaptive, while more adaptive species that are fewer in number will persist due to pollution (Osha, 2006).

6.2 Recommendation

The following are some recommendations for quarrying companies needed for the protection and preservation of biodiversity in the operational site:

1. Further studies should be done using this research as a baseline to assess the impact of the quarry operations on the oviposition of insect species in the area.
2. Edge effect in the areas dominated by humans should be managed to prevent further decline of insect species and fragmentation.
3. There should be the urgent need and protection of Hesperiidae and Papilionidae species in all the three zones from going on extinction.
4. The drainage system in and around the quarry operational area must be improved to prevent runoff of heavy metals into water bodies and thereby conserve Odonata species.
5. Reclamation and restoration of quarry sites to prevent local extinction of certain insect species.
6. State institutions should ensure mandatory environmental impact assessment reports from the quarry companies.
7. The establishment of a dust control mechanism in the area to support flight and insect movement.

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APPENDICES

Appendix 1: Relative abundance of butterflies in all three zones for both seasons

Family	**Species**	**Zone**		
		East	West	North
NYMPHALIDAE	*Euphaedra harpalyce*	1	0	0
	Euphaedra themis	1	0	0

Euphaedra janetta	2	1	0
Euphaedra sarcoptera	1	0	1
Euphaedra medon	0	4	0
Euphaedra eleus	1	0	0
Euphaedra xypete	1	1	0
Eurytela dryope	0	1	0
Hamanumida daedalus	9	1	3
Euriphene simplex	0	0	1
Pseudacraea eurytus	1	0	0
Pseudacraea lucretia	2	0	0
Pseudacraea warburgi	0	0	1
Phalanta phalantha	1	0	0
Neptis melicerta	2	0	0
Neptis metella	1	0	0
Neptis morosa	0	1	0
Byblia anvatara	2	0	0
Cymothoe caenis	0	1	0
Cymothoe coccinata	1	0	0
Junonia terea	2	0	0
Junonia oenone	8	1	0
Junonia westermanni	1	0	0
Junonia octavia	1	0	0
Hypolimnas misippus	3	0	0
Hypolimnas dinarcha	1	0	0
Acraea consanguinea	1	0	0
Kallimoides rumia	1	0	0
Melanitis leda	0	1	0
Gnophodes chelys	3	7	0
Ypthimomorpha itonia	2	0	1
Acraea zetes	1	0	1
Acraea egina	1	0	0
Acraea pseudegina	2	1	0
Colotis euippe	1	0	0
Charaxes varanes	0	2	0
Charaxes cynthia	1	0	0
Bicyclus zinebi	0	0	1
Bicyclus safitza	1	0	1
Bicyclus dorothea	1	0	2
Bicyclus auricruda	0	1	1
Amauris niavus	2	1	0
Amauris hecate	1	0	0
Amauris democles	1	0	0
Danaus chrysippus	5	1	2

PAPILIONIDAE	*Papilio demodocus*	9	1	8
	Papilio menesthius	2	0	1
PIERIDAE	*Eurema brigitta*	1	0	0
	Eurema senegalensis	1	0	0
	Eurema hecabe	4	1	1
	Nepheronia argia	2	0	0
	Nepheronia pharis	1	0	0
	Belenois calypso	0	1	0
	Belenois aurota	1	0	0
	Belenois theora	0	0	1
	Mylothris chloris	22	0	0
	Mylothris poppea	1	0	0
	Mylothris rhodope	36	0	6
	Catopsilia florella	29	4	8
	Appias phaola	2	0	0
	Appias sylvia	1	0	0
HESPERIIDAE	*Coeliades forestan*	0	4	0
	Tagiades flesus	7	0	2
	Osmodes adosus	2	0	1
	Osmodes adon	1	0	0
LYCAENIDAE	*Euchrysops albistriata*	127	4	2
	Hypolycaena liara	11	0	2
	Hypolycaena hatita	3	1	0

Appendix 2: Relative abundance of insect orders in the eastern zone for both seasons

Order	Family	200m	400m	600m	800m
Coleoptera	Scarabaeidae	80	8	30	34
	Staphilinidae	1	0	2	0

	Carabidae	0	0	4	0
	Meloidae	4	0	3	0
	Cerambycidae	0	0	0	0
	Coccinellidae	0	0	0	1
	Curculionidae	0	0	0	0
	Bostrichidae	0	0	0	0
	Chrysomelidae	0	2	0	6
	Ptinidae	0	0	0	0
	Mordellidae	0	0	0	0
	Dytiscidae	1	0	2	7
Diptera	Sarcophagidae	19	3	12	2
	Calliphoridae	2	3	13	24
	Drosophilidae	2	1	1	2
	Muscidae	2	0	1	0
	Acroceridae	1	0	0	0
	Agromyzidae	1	0	1	0
	Tachnidae	0	0	0	0
	Syrphidae	0	0	0	0
	Diopsidae	0	0	0	0
	Tephritidae	0	0	0	0
	Anthomyiidae	0	0	0	0
	Mydidae	0	0	0	0
	Phoridae	1	0	0	0
	Sepsidae	1	0	0	0
	Tipulidae	1	0	0	1
	Otitidae	13	6	8	6
Orthoptera	Gryllidae	15	7	24	2
	Pyrgomorphidae	3	4	4	11
	Acrididae	1	0	1	0
	Tettigonidae	0	0	1	0
	Tetrigidae	11	23	15	12
Hymenoptera	Formicidae	10	6	12	8
	Vespidae	3	0	2	1
	Evaniidae	3	0	0	0
	Aphelinidae	0	0	0	0
	Ichneumonidae	1	0	0	0
Hemiptera	Naucoridae	1	0	0	1
	Reduvidae	2	2	0	2
	Pentatomidae	2	0	2	0
	Braconidae	1	2	1	0
	Coreidae	4	2	2	3
	Pyrrhocoreidae	0	0	0	0

	Lygaeidae	0	2	0	5
Homoptera	Cicadellidae	0	1	2	0
	Cercopidae	3	1	1	1
Dictyoptera	Blattidae	2	0	0	0
Phasmida	Phasmatidae	0	0	0	0
Dermaptera	Forfinculidae	1	0	0	2
Odonata	Libellulidae	0	0	0	0

Appendix 3: Relative abundance of insect orders in the western zone for both seasons

Order	Family	200m	400m	600m	800m
Coleoptera	Scarabaeidae	35	68	40	52
	Staphilinidae	0	2	0	0
	Carabidae	8	3	5	9
	Meloidae	1	1	0	0
	Cerambycidae	0	0	0	1
	Coccinellidae	2	4	0	0
	Curculionidae	0	0	1	2
	Bostrichidae	0	2	0	0
	Chrysomelidae	0	0	0	0
	Ptinidae	1	0	1	0
	Mordellidae	1	0	0	1
	Dytiscidae	1	7	8	12
Diptera	Sarcophagidae	1	4	14	10
	Calliphoridae	9	2	11	7
	Drosophilidae	1	0	3	1
	Muscidae	0	0	4	1
	Acroceridae	1	0	2	0
	Agromyzidae	3	2	2	2
	Tachnidae	2	2	2	2
	Syrphidae	1	1	1	1
	Diopsidae	0	2	1	0
	Tephritidae	1	2	0	1
	Anthomyiidae	0	0	0	2
	Mydidae	0	0	1	1
	Phoridae	0	1	2	0
	Sepsidae	0	0	0	0
	Tipulidae	2	1	0	0
	Otitidae	8	24	6	19

Orthoptera	Gryllidae	31	67	41	68
	Pyrgomorphidae	5	31	58	4
	Acrididae	5	6	4	4
	Tettigonidae	1	4	5	7
	Tetrigidae	3	6	3	11
Hymenoptera	Formicidae	30	34	16	4
	Vespidae	5	3	1	0
	Evaniidae	2	1	0	0
	Aphelinidae	0	0	0	1
	Ichneumonidae	1	1	3	0
Hemiptera	Naucoridae	0	0	2	0
	Reduvidae	1	6	2	7
	Pentatomidae	1	2	0	0
	Braconidae	3	0	2	2
	Coreidae	1	9	2	4
	Pyrrhocoreidae	1	0	2	0
	Lygaeidae	1	0	4	0
Homoptera	Cicadellidae	0	0	0	0
	Cercopidae	3	1	3	1
Dictyoptera	Blattidae	3	2	4	1
Phasmida	Phasmatidae	0	1	0	0
Dermaptera	Forfinculidae	0	0	2	0
Odonata	Libellulidae	0	0	0	0

Appendix 4: Relative abundance of insect orders in the Northern zone for both seasons

Order	Family	200m	400m	600m	800m
Coleoptera	Scarabaeidae	32	65	44	56
	Staphilinidae	1	2	0	0
	Carabidae	7	3	6	10

	Meloidae	0	0	0	0
	Cerambycidae	1	2	0	1
	Coccinellidae	1	3	1	0
	Curculionidae	1	1	1	1
	Bostrichidae	0	2	0	0
	Chrysomelidae	0	0	0	0
	Ptinidae	1	0	0	0
	Mordellidae	1	0	0	0
	Dytiscidae	0	0	1	2
Diptera	Sarcophagidae	3	4	11	12
	Calliphoridae	7	4	10	12
	Drosophilidae	1	3	3	6
	Muscidae	1	1	4	7
	Acroceridae	1	1	1	0
	Agromyzidae	1	1	2	1
	Tachnidae	3	3	1	1
	Syrphidae	1	1	0	1
	Diopsidae	1	2	0	0
	Tephritidae	1	2	0	0
	Anthomyiidae	0	0	0	1
	Mydidae	0	0	0	1
	Phoridae	0	0	1	0
	Sepsidae	0	1	0	0
	Tipulidae	2	1	1	0
	Otitidae	9	9	7	13
Orthoptera	Gryllidae	35	72	49	72
	Pyrgomorphidae	4	29	60	5
	Acrididae	4	7	5	6
	Tettigonidae	1	4	4	6
	Tetrigidae	4	5	7	3
Hymenoptera	Formicidae	25	35	18	9
	Vespidae	4	4	1	0
	Evaniidae	2	1	0	0
	Aphelinidae	1	0	0	0
	Ichneumonidae	1	2	2	0
Hemiptera	Naucoridae	1	3	1	1
	Reduvidae	0	3	2	1
	Pentatomidae	1	1	0	2
	Braconidae	0	0	2	2
	Coreidae	0	6	1	0
	Pyrrhocoreidae	0	0	0	1
	Lygaeidae	1	1	6	0

Homoptera	Cicadellidae	0	0	0	0
	Cercopidae	3	4	3	1
Dictyoptera	Blattidae	3	2	3	1
Phasmida	Phasmatidae	0	1	0	0
Dermaptera	Forfinculidae	0	0	1	0
Odonata	Libellulidae	0	0	2	6

Appendix 5: Relative abundance of insects in the wet season for all three zone

Order	Family	Zone		
		East	West	North
Coleoptera	Scarabaeidae	123	179	183
	Staphilinidae	1	1	1
	Carabidae	3	17	17
	Meloidae	4	1	0

	Cerambycidae	0	1	2
	Coccinellidae	1	3	3
	Curculionidae	0	2	2
	Bostrichidae	0	1	1
	Chrysomelidae	5	0	0
	Ptinidae	0	1	1
	Mordellidae	0	1	1
	Dytiscidae	1	0	0
Diptera	Sarcophagidae	6	16	16
	Calliphoridae	42	26	33
	Drosophilidae	2	0	2
	Muscidae	3	4	10
	Acroceridae	1	2	2
	Agromyzidae	0	1	1
	Tachnidae	0	6	6
	Syrphidae	0	3	3
	Diopsidae	0	1	1
	Tephritidae	0	3	3
	Anthomyiidae	0	1	1
	Mydidae	0	1	1
	Phoridae	0	1	1
	Sepsidae	0	0	1
	Tipulidae	0	0	1
	Otitidae	1	8	8
Orthoptera	Gryllidae	37	198	214
	Pyrgomorphidae	16	84	89
	Acrididae	2	14	14
	Tettigonidae	0	15	15
	Tetrigidae	2	1	1
Hymenoptera	Formicidae	28	73	84
	Vespidae	2	5	5
	Evaniidae	2	3	3
	Aphelinidae	0	0	1
	Ichneumonidae	1	3	5
Hemiptera	Naucoridae	1	0	1
	Reduvidae	1	4	4
	Pentatomidae	2	2	2
	Braconidae	0	2	2
	Coreidae	2	4	4
	Pyrrhocoreidae	0	0	1
	Lygaeidae	4	5	5
Homoptera	Cicadellidae	1	0	0

	Cercopidae	1	0	0
Dictyoptera	Blattidae	2	9	9
Phasmida	Phasmatidae	0	1	1
Dermaptera	Forfinculidae	0	1	1
Odonata	Libellulidae	0	0	2

Appendix 6: Relative abundance of insects in the dry season for all three zone

Order	Family	**Zone**		
		East	West	North
Coleoptera	Scarabaeidae	29	16	14
	Staphilinidae	2	1	2
	Carabidae	1	8	9
	Meloidae	3	1	0

	Cerambycidae	0	0	2
	Coccinellidae	0	3	2
	Curculionidae	0	1	2
	Bostrichidae	0	1	1
	Chrysomelidae	3	0	0
	Ptinidae	0	1	0
	Mordellidae	0	1	0
	Dytiscidae	9	28	3
Diptera	Sarcophagidae	30	14	14
	Calliphoridae	0	3	0
	Drosophilidae	4	5	11
	Muscidae	0	1	3
	Acroceridae	0	1	1
	Agromyzidae	2	8	5
	Tachnidae	0	2	2
	Syrphidae	0	1	1
	Diopsidae	0	2	2
	Tephritidae	0	1	0
	Anthomyiidae	0	1	0
	Mydidae	0	1	0
	Phoridae	1	2	0
	Sepsidae	1	0	0
	Tipulidae	2	3	3
	Otitidae	32	49	30
Orthoptera	Gryllidae	11	9	14
	Pyrgomorphidae	6	14	9
	Acrididae	0	5	8
	Tettigonidae	1	2	0
	Tetrigidae	60	22	18
Hymenoptera	Formicidae	8	11	3
	Vespidae	4	4	4
	Evaniidae	1	0	0
	Aphelinidae	0	1	0
	Ichneumonidae	0	2	0
Hemiptera	Naucoridae	1	2	5
	Reduvidae	5	12	2
	Pentatomidae	2	1	3
	Braconidae	4	5	2
	Coreidae	9	12	3
	Pyrrhocoreidae	0	3	0
	Lygaeidae	3	0	3
Homoptera	Cicadellidae	2	0	0

	Cercopidae	5	8	11
Dictyoptera	Blattidae	0	1	0
Phasmida	Phasmatidae	0	0	1
Dermaptera	Forfinculidae	3	1	0
Odonata	Libellulidae	0	0	6

Appendix 7: Relative abundance of plant species for all three zone

Species	East	West	North
Antiaris toxicaria	4	0	4
Albizia adianthifolia	1	0	9
Albizia zygia	6	0	2
Amphima pterocarpoides	2	0	0
Baphia nitida	30	10	0
Baphia pubescens	10	3	8
Blighia sapida	1	0	0
Ficus sur	7	0	0
Ficus exasperata	11	11	21
Margaritaria discoidea	1	22	0
Millettia zechiana	9	0	0
Morinda lucida	5	17	3
Newbouldia laevis	0	0	6
Broussonetia papyrifera	6	18	11
Chromolaena odorata	25	0	0
Elaeis guineensis	55	7	16
Pseudospondias microcarpa	2	2	0
Leucaena leucocephala	0	4	0
Spondias mombin	0	2	0
Cocos nucifera	0	0	10
Caragana arborescens	0	0	4
Citrus medica	0	12	0
Mangifera indica	0	2	4
Tectona grandis	0	0	2
Alstonia boonei	0	1	0

Appendix 8: Relative abundance of insect orders captured in transect points in all zones.

Order	Eastern Zone 200m	400	600m	800m	Total
COLEOPTERA	48(27.3%)	80(26.5%)	47(18.2%)	65(27.3%)	240(24.6%)
DIPTERA	28(16.0%)	27(9.0%)	51(19.7%)	40(16.8%)	146(15.0%)
ORTHOPTERA	45(25.5%)	129(42.7%)	115(44.6%)	102(42.9%)	391(40.1%)
HYMENOPTERA	41(23.3%)	45(15.0%)	24(9.3%)	16(6.7%)	126(13.0%)
HEMIPTERA	8(4.5%)	17(5.6%)	12(4.7%)	13(5.5%)	50(5.0%)
HOMOPTERA	0 (0)	(0)	0(0)	0(0)	0(0)
DICTYOPTERA	6(3.4%)	3(0.9%)	7(2.7%)	2(0.8%)	18(2.0%)
PHASMIDA	0(0)	1(0.3%)	0(0)	(0)	1(0.1%)
DERMAPTERA	0(0)	0(0)	2(0.8%)	0(0)	2(0.2%)
Total	**176**	**302**	**258**	**238**	**974**

Order	Western Zone 200m	400m	600m	800m	**Total**
COLEOPTERA	85(44.3%)	10(13.6%)	40(27.8%)	41(31.3%)	176(32.6%)
DIPTERA	31(16.1%)	7(9.6%)	29(20.1%)	37(28.0%)	104(19.3%)
ORTHOPTERA	33(17.2%)	17(23.3%)	39(27.1%)	18(14.0%)	107(19.8%)
HYMENOPTERA	28(14.6%)	29(39.7%)	29(20.1%)	21(16.0%)	107(19.8%)
HEMIPTERA	9(4.7%)	8(11.0%)	5(3.5%)	11(8.4%)	33(6.1%)
HOMOPTERA	0 (0)	1(1.4%)	2(1.4%)	0(0)	3(0.5%)
DICTYOPTERA	5(2.6%)	1(1.4%)	0(0)	1(0.8%)	7(1.3%)
DERMAPTERA	1(0.5%)	0(0)	0(0)	2(1.5%)	3(0.5%)
Total	**192**	**73**	**144**	**131**	**540**

Order	Northern Zone 200m	400m	600m	800m	**Total**
COLEOPTERA	45(26.0%)	78(26.6%)	52(19.7%)	68(28.2%)	243(25.0%)
DIPTERA	27(15.6%)	28(9.5%)	36(13.6%)	44(18.2%)	135(14.0%)

ORTHOPTERA	48(27.7%)	118(40.3%)	126(48.0%)	102(42.3%)	394(40.6%)
HYMENOPTERA	38(22.0%)	50(17.1%)	28(10.6%)	12(5.0%)	128(13.2%)
HEMIPTERA	9(5.2%)	11(3.8%)	12(4.6%)	7(3.0%)	39(4.0%)
DICTYOPTERA	6(3.5%)	6(2.0%)	6(2.3%)	2(0.8%)	20(2.1%)
PHASMIDA	0(0)	2(0.7%)	0(0)	(0)	2(0.2%)
DERMAPTERA	0(0)	0(0)	1(0.4)	0(0)	1(0.1%)
ODONATA	0(0)	0(0)	2(0.8%)	6(2.5%)	8(0.8%)
Total	**173**	**293**	**263**	**241**	**970**

Appendix 9: Numbers of butterflies recorded in all three zones

Family	Eastern	Western	Northern	**Total**
HESPERIIDAE	10(3.0%)	4(9.8%)	3(6.4%)	17(4.1%)
LYCAENIDAE	141(42.9%)	5(12.2%)	4(8.5%)	150(36.0%)
NYMPHALIDAE	66(20.1%)	25(61.0%)	15(32.0%)	106(25.4%)
PAPILIONIDAE	11(3.3%)	1(2.4%)	9(19.1%)	21(5.0%)
PIERIDAE	101(30.7%)	6(14.6%)	16(34.0%)	123(29.5%)
Total	**329**	**41**	**47**	**417**

Appendix 10: Number of insect orders recorded in all three zones for both seasons.

Order	Eastern	Western	Northern	**Total**
COLEOPTERA	240(24.6%)	176(32.5%)	243(25.0%)	659(26.5%)
DIPTERA	146(15.0%)	104(19.2%)	135(14.0%)	385(15.5%)

DERMAPTERA	2(0.2%)	3(0.6%)	1(0.1%)	6(0.2%)
DICTYOPTERA	18(2.0%)	7(1.3%)	20(2.1%)	45(1.8%)
HEMIPTERA	50(5.0%)	33(6.1%)	39(4.0%)	122(5.0%)
HOMOPTERA	0 (0)	4(0.7%)	0(0)	4(0.1%)
HYMENOPTERA	126(13.0%)	107(19.8%)	128(13.2%)	361(14.5%)
ODONATA	0(0)	0(0)	8(0.8%)	8(0.3%)
ORTHOPTERA	391(40.1%)	107(19.8%)	394(40.6%)	892(36.0%)
PHASMIDA	1(0.1%)	0(0)	2(0.2%)	3(0.1%)
Total	**974**	**541**	**970**	**2,485**

Appendix 11: Relative abundance of insect orders in both Wet and Dry seasons

	Wet Season			
Order	East	West	North	**Total**
COLEOPTERA	207(29.4%)	138(46.5%)	211(27.6%)	556(31.5%)
DERMAPTERA	1(0.1%)	0(0)	1(0.1%)	2(0.1%)
DICTYOPTERA	9(1.3%)	2(0.7%)	9(1.2%)	20(1.1%
DIPTERA	73(10.4%)	55(18.5%)	90(11.8%)	218(12.4%)
HEMIPTERA	17(2.4%)	10(3.4%)	19(2.5%)	46(2.6%)
HOMOPTERA	0 (0)	2(0.7%)	0(0)	2(0.1%)
HYMENOPTERA	84(12.0%)	33(11.1%)	98(12.8%)	215(12.2%)
ODONATA	0(0)	0(0)	2(0.3%)	2(0.1%)
ORTHOPTERA	312(44.3%)	57(19.1%)	333(43.6%)	702(39.8%)
PHASMIDA	1(0.1%)	0(0)	1(0.1%)	2(0.1%)
Total	**704**	**297**	**764**	**1,765**

Dry Season				
Order	East	West	North	**Total**
COLEOPTERA	33(12.2%)	38(15.6%)	32(15.5%)	103(14.3%)
DERMAPTERA	1(0.4%)	3(1.2%)	0(0)	4(0.6%)
DICTYOPTERA	9(3.3%)	5(2.0%)	11(5.3%)	25(3.5%)
DIPTERA	73(27.0%)	49(20.0%)	45(21.8%)	167(23.1%
HEMIPTERA	33(12.2%)	23(9.4%)	20(9.7%)	76(10.6%)
HOMOPTERA	0 (0)	2(1.0%)	0(0)	2(0.3%)
HYMENOPTERA	42(15.6%)	74(30.3%)	30(14.6%)	146(20.3%)
ODONATA	0(0)	0(0)	6(3.0%)	6(0.8%)
ORTHOPTERA	79(29.3%)	50(20.5%)	61(29.6%)	190(26.4%)
PHASMIDA	0(0)	0(0)	1(0.5%)	1(0.1%)
Total	**270**	**244**	**206**	**720**

Appendix 12: Photos showing plant sample covered with dust pollution from the quarry activities.