ECOLOGICAL CONDITIONS INFLUENCING THE DISTRIBUTION OF BLACK ANTS (*Carebara vidua* Smith) AND ITS CONTRIBUTION TO FOOD SECURITY

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DECLARATION

This thesis is my original work and has not been submitted for the award of any degree or diploma in any other University or institution.

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DEDICATION

This dissertation is dedicated to Jaramogi Oginga Odinga University of Science and Technology the school of Agricultural and Food Sciences, communities, my family and friends.

I dedicate this Thesis to my family; my father, Mr. Aluoch Lucas, my mother Syprose Awuor, all my siblings and to almighty God for grace and favor, thank you for your continuous support.

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ABSTRACT

Black ants, *Carebara vidua* (Smith) is of critical value both in nutrition and medicine in Kenya. The insect is relatively widespread in the country, however, knowledge regarding its geographical distribution range and factors that influence its distribution pattern is scanty. Lack of a clear understanding of the requisite ecological conditions for *C. vidua* is a hindrance to instituting conservation measures. This study objective is to determine the spatio-temporal distribution pattern of *C. vidua*, eco-climatic conditions influencing the distribution and the prevailing environmental management practices enhancing chances of survival and its contribution to food security. The study was carried out in different agro ecological zones of Siaya, Kisumu and Homabay Counties of Western Kenya. The study adopted cross sectional approach of community representation. Purposive sampling method was used in the selection of suitable participants of the study. Key informant interviews (KIIs) and focus group discussion (FGDs) were qualitative data collection methods used to assess and explore the community's knowledge of the insect in relation to its distribution and influence of eco-climatic factors in order to establish the spatio-temporal distribution pattern. The audio recorded data were transcribed verbatim and translated into English, coded and analysis were thematically done using ATLAS ti version 7.5 software. Our results showed a significant change in the distribution of *C. vidua* between the year 2000 and 2020 across the lower midland zones (LMs) in Siaya, Kisumu and Homabay. The population of insect emerging have declined and its emergence has become unpredictable; they are no longer emerging yearly as they used to in late 1990's. In LM 5; Siaya and Homabay the insect emergence has not been experienced for the last 30 years. However, in LM 1 to LM 4, the insect population is dwindling due to anthropogenic activities disturbing the habitat. Data was presented using individual quotes and tables. In conclusion, the population of *Carebara vidua* has fluctuated over the years across the LM zones and the insect has become an endangered species, its habitat has been encroached by anthropogenic activities and the population has been influenced by climate change therefore, environmental management practices have been presented to enhance its survival and availability.

Keywords: Spatio-temporal, distribution, agro ecological zones, *Carebara vidua*

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ABBREVIATIONS

AVE.	Average
CO2	Carbon (iv) oxide
CP	Crop protection
DRC	Democratic Republic of Congo
FGD	Focused Group Discussion
ICM	Integrated Crop Management
INSEFOODS	Insects as Food and Feed
IPM	Integrated Pest Management
KI	Key Informant
KII	Key Informant Interviews
LM	Lower Midland zone
MASL	Meters Above Sea Level
SCAO	Sub County Agricultural Officer
WAO	Ward Agricultural Officer

CHAPTER ONE
INTRODUCTION

1.1 Background information

Edible insects have been widely consumed throughout the world as a regular part of the diet for many years as they provide significant food sources not only in the world but also in Africa (Feng *et at.,* 2018). They are used as an alternative source of proteins, contain fats, calcium, minerals, iron and zinc hence used as traditional part of regional and national diets for food security purposes (Matandirotya *et al.,*2022). The insects are distributed and found in over 113 countries which includes countries in Asia, South America and Africa (Tao and Li 2018). There are various groups of insects that most commonly consumed such as caterpillars, grasshoppers, locusts, beetles, ants, crickets, termites and flies (Srivastava *et al.,* 2009)

Black ant (*Carebara vidua* (Smith), also called the thief ant (Van Huis, 2021) is a nutritious edible food for millions of people around the globe and ranked second as one of the most important edible insect for food security after falciger (Okia *et al* 2017). The insect is widely distributed in oriental such as Pakistan, India, Thailand, and Southern China; and Afro-tropical regions including Zambia, Sudan, Malawi, Botswana, South Sudan, Eritrea, and Kenya Globally, ants are the third most commonly eaten insects, especially in Latin America, and are mostly eaten in their larval or pupal stage (Raheem *et al*., 2019). *Carebara vidua* is found within Western region where it is consumed as a traditional snack due to its nutritional quality (Ayieko *et al*., 2012). *Carebara vidua*, like most other edible insects, is rich in protein, fat, vitamins, iron and zinc (Rumpold and Schlüter, 2013) and it is valued as food by humans and also preserved in capsules for industrial purposes(Tang and Dai, 2018). In communities around Lake Victoria, it is eaten raw or fried (Christensen *et al*., 2006).

According to Adeyeye *et al*., (2017), food insecurity is a major threat worldwide with increased malnutrition and undernourishment especially in Sub-Saharan Africa. As a result, most African countries are food insecure and do not have access to daily nutritious and well balanced diet. Despite the role of *C. vidua* and potential to upgrade the nutritional status on Kenyan population, their distribution, abundance and frequent occurrence remains a challenge as a result of natural calamities, biotic and abiotic factors. Biotic factors such as agricultural intensification,

urbanization, industrialization and fragmentation have resulted on loss of biodiversity, change in species composition and alteration in ant-derived ecosystem services (Ondede *et al*., 2022). In addition, they jeopardize the safety of ants as sources of food and their future availability (Payne and Itterbeeck, 2017). On the other hand, biotic stresses which are climatic variables may prolong metamorphism, survival, occurrence, distribution and their abundance (Khaliq *et al.*, 2014).

Edible insects have been recommended as a source of nutrient which help to curb food insecurities (Zielinska *et al.,* 2015. Several strategies, such as food fortification with micro-nutrients, amino acids, vitamins and diversification have been suggested (Goyal *et al.,* 2017). However, these strategies have achieved little success since they are expensive and unsustainable (Ritchie and Higgins, 2018). Furthermore, scientific research studies on nutritional value, sensitization by resource managers to recapture the natural ecosystem, interdependency of these insect species and other natural forests ecosystem have been negatively impacted by uncertainties. Therefore, understanding the ecology and factors influencing the distribution and abundance of *C. vidua* remains a challenge as the insect is an endangered species in many parts of Kenya. The increasing concerns are mass destruction of the habitat as ants are more susceptible to environmental disturbance (Underwood and Fisher, 2006). They are also dependent on moisture and temperature, thus, found in wetlands. The knowledge of ant species present or absent cannot be enough to predict their influence on ecosystems because they are unevenly distributed and interact differently under various disturbance regimes (Jason *et al*., 2008).

Learning more about *C. vidua's* ecology not only provides a better understanding of the overall ant fauna but also guides their current management, future conservation and restoration (Hill *et al*., 2008). This study of *C. vidua's* ecology, which entails its interactions with the abiotic and biotic environment, its spatial and temporal pattern of distribution and abundance (Van Huis,*et al*., 2013) will create knowledge for the future conservation of *C. vidua* as an alternative food source to enhance food security. Furthermore, understanding the spatial distribution of the insect over a while is of great importance for effective conservation since the insect is currently endangered. Therefore, the study will improve our understanding of the effects of anthropogenic threats on its population distribution patterns as well as create awareness of its current status

hence improving the environmental management practices that enhance its survival. The study adopted qualitative research where phenomenological approach was used to gain valuable research insight from a sample population.

1.2: Statement of the problem

Carebara vidua is an edible insect of importance because of its nutritional value and its conspicuously oily abdomen which gives it a unique rich flavor. Its abdomen contains 44.64% protein content, it has high level of fat content of 50% and the insect is specifically rich in iron and zinc, minerals that are often deficient in many vulnerable groups such as children, elderly and nursing women (Ayieko *et al*.,s 2012).

A lack of clear understanding of the requisite ecological conditions for *C. vidua's* survival and natural multiplication creates a greater challenge for instituting its restoration. Current and future climate is determined by natural factors and anthropogenic activities which have been of great concern in *C. vidua's* ecology. However, the gap between achievable and actual ecosystem management of *C. vidua* is large because of various constraints. *Carebara vidua* is an endangered species and its population declining because of environmental degradation (Ayieko *et al*., 2012). The distribution and abundance are threatened by disturbance regimes and ecological gradients hence reducing the consumption rate. These threats are more profound in their habitats, which have drastically affected their metamorphic stage, survival, and natural multiplication (Khaliq *et al*., 2014). Therefore, little data is available on spatio distribution over a period of time, knowledge on the factors that cause decline in population and the actions to be taken to ensure survival and abundance of *C. vidua* in western Kenya.

This study therefore aims to bridge the gap in understanding ecological distribution of *C. vidua* and successful and continuous ecosystem management which is a key to global food security as this ensure abundance and high consumption of *C. vidua*, especially in tropical and afro-tropical regions where *C. vidua* is in existence and is a food supplement.

1.3 Significance of the study

1. The findings from this study will provide evidence-based information to the policymakers to guide the formulation of environmental policies for the preservation and management of *C. vidua*.
2. Despite the nutritional and medicinal values of *C. vidua*, it is facing threats to extinction due to ecological disturbances resulting from natural and anthropological phenomena (Ayieko *et al*., 2012). This study will provide in-depth knowledge and understanding of the possible environmental management practices for the management of *C. vidua* and enhance its restoration.

1.4: Objective of the study

1.4.1: Overall objective

The objective of the study was to contribute to the determination of the ecological conditions influencing the distribution pattern of *C. vidua*

1.4.2: Specific objectives

1. To determine the Spatio-temporal distribution patterns of *C. vidua* in Siaya, Kisumu, and Homabay Counties.
2. To identify the eco-climatic conditions influencing the distribution pattern.
3. To identify environmental management practices enhancing the survival of *C. vidua* and its contribution to food security.

1.5: Research questions

1. Where and when was C. *vidua* are distributed Siaya, Kisumu and Homabay counties?
2. What are the eco- climatic factors influencing the change in distribution of *C. vidua?*
3. What are the environmental management practices that can enhance the survival of C. vidua?

1.6 Limitation of the study

The study had the following limitations:

i. Some participants did not want to give sufficient and necessary information concerning the actual state of affairs on subject under study for fear of revealed identity or fear of lack of protected confidentiality since with respondents was being audio taped. However, to curb this limitation, the researcher assured the participants of treatment of their responses with total confidentiality.

ii. Covid 19 pandemic delayed the research as there was government restrictions of movement and lockdown, data was collected after later after the movements were allowed

iii. Some participants arrived late at the data collection site for focused group discussion, this delayed the process. This was solved by rescheduling the meeting time

iv. Poor weather and infrastructure could interfere with the flexibility of the research.

1.7 Definition of terms

Agro- ecological zones: This is a geographic areas exhibiting similar climatic conditions

Spatio-temporal :	This refers to both space and time (where and when)
Distribution:	This is referred to a geographic area or regions where *Carebara vidua* occurred.
Eco-climatic:	This is defined local climate as an influenced on ecological issues
Lower midland zone:	Is a geographic and cultural region with altitude range of 800 - 1500 meters, warm temperature with mean annual range of 21°C - 24°C, mean minimum temperature of about 14°C and suitable for growth of cotton, maize and rice.
Coding:	Is a qualitative data analysis strategy in which some aspect of the data is an assigned a descriptive label that allow the researcher to identify related content across the data.
Ecological gradients	Measures of the physical environment that explain the distribution of insect species and ecosystems in terms of environmental tolerances through space and time.

CONCEPTUAL FRAMEWORK

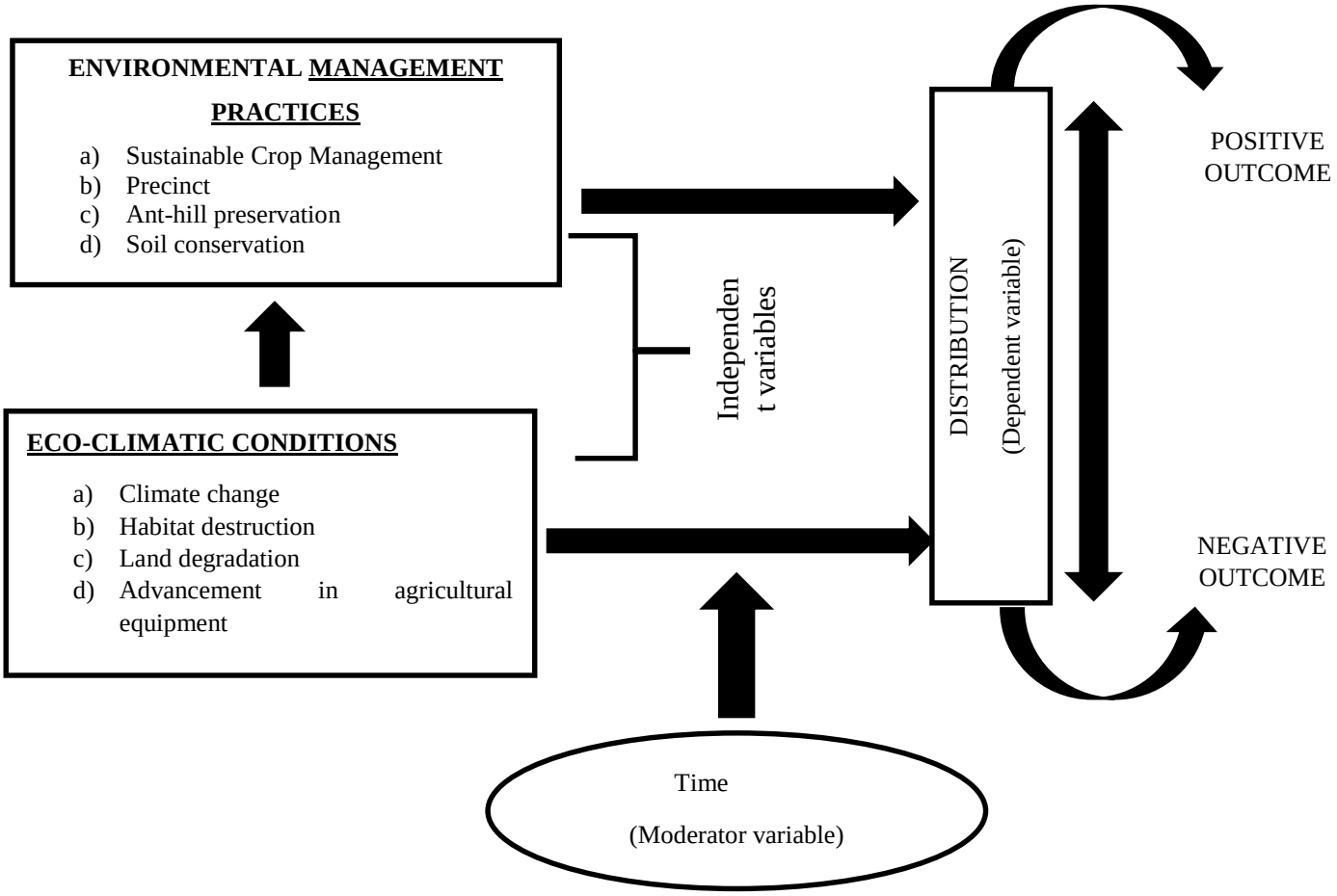

Figure 1. Shows the visualized concept of the study

The attribution of eco-climatic conditions has an undesirable outcome on the distribution of *C. vidua*. Time factor, explains the period of transition of causal-effect realization on the distribution outcome as impacted by the eco-climatic conditions.

Effective environmental management practices may directly have a positive impact on the outcome of the distribution of *C. vidua*. However, incorporating eco-climatic conditions into environmental management practices for management might prove to be an essential aspect in the enhancement of *C. vidua* distribution.

CHAPTER TWO
LITERATURE REVIEW

2.1 Black ant (*Carebara vidua* Smith)

Carebara vidua (Smith), is known as "Onyoso" by the Luo living around the Kenyan Lake Victoria region, "Thigiri" by the Kikuyu, and "Kamachichi" by the Abaluhya communities, respectively. The insect is an edible species among the Luo and the Abaluhya communities of western Kenya (Ayieko *et al*., 2012). *C. vidua* was being collected and consumed by the Luo communities to manage many body ailments including sexuality and this being the reason why the communities could not sell the small portion of the catch, ants' role in medicinal properties leads to their conservation (Kumara *et al*., 2012). *Carebara vidua* emerges secretly and this makes it difficult for communities to detect when and where it will emerge, during their emergence the tiny little workers and soldiers precede and are not easily noticeable on the ground. They build mounds underground, near buildings, and under rocks, and emerge from the holes on the ground then quickly fly away (Ayieko *et al*., 2012).

The reproductive males and females begin nuptial flights once a year during the long rains when temperature and humidity are acceptable for them which usually correlate with the season's first rain. They often emerge from the holes from 11: 00 a.m to 3: 00 p.m (Christensen *et al*., 2006). During swarming the male and female pair up then the male dies while the female seeks out a suitable nesting site in the ground where it lays the first brood of eggs. Because the chambers are shallow the eggs receive enough warmth and hatch after five to seven days. The colony of this species can survive for many years depending on the level of habitat disturbance. Swarming frequency is once a year but the quality that emerges from the colony reduces and each reproductive adult is picked as it emerges from the holes (Ayieko *et al*., 2012),

2.1.1 Taxonomy and classification of *Carebara vidua*

Scientific classification

Kingdom	Animalia
Phylum	Arthropoda
Class	Insecta

Order	Hymenoptera
Family:	Formicidae
Subfamily	Myrmicinae
Tribe	Crematogastrini
Genus	Carebara
Species	*C. vidua*

Binomial name: *Carebara vidua*, Smith, 1858

Carebara vidua is an insect that belongs to the Order Hymenoptera which includes ants, bees, and wasp, and Family Formicidae in the Subfamily Formicinae, Smith (1858) described the insect and placed it in the subfamily Formicidae, which is known to have stinging characteristics. Formicidae subfamily has 75 species consisting of 12 genera that have already been identified (Ayieko *et al*., 2012)

2.1.2 Characteristics of the black ant

Carebara vidua female is a large, black, and winged insect and has a large round abdomen and narrow gaster with one nodule, it is about 20 to 25mm long and 6 to 6.2 mm diameter of the abdomen which consists of eggs and fatty substances. The fat body nourishes the developing eggs and for substances during the nuptial flight, oviposition, and starting of a new colony. The males are half the size of the females and winged with a 10 mm white abdomen, its mouth is facing downwards, has three simple eyes, and one pair of compound eyes. They have an antenna and multi-segmented flagellum compared with species of other subfamilies in the same order and the mouthparts are a chewing type of mandibulate. This ant has a worker caste which is 3 to 5 mm long with a string which is a morphological characteristic for predatory species (Ayieko *et al*., 2012).

Figure 2. *Carebara vidua*

According to Ayieko *et al*., (2012) the insect has a short thorax and the segments are closely attached where the first segment is relatively not attractive and the middle segment forms the large part of the thorax and has major flight muscle. Dorsally the middle segment is covered by a mesonotum which is separated into a speculum and a scutellum and the first abdominal segment strongly connects with the middle segment to form a stalk and bears no dorsal projections. The stalk has a transverse flexible suture across the middle segment Scutum and this region forms a deep constriction between the first and second abdominal segments both dorsally and ventrally. The adult insect has two pairs well developed, transparent wings that are the same in texture and without scales. There is a small oval sclerite at the base of the wings and in both males and females the fore wings are larger than the hind wings.

2.2 Geographical distribution

The insect is mostly found and consumed in Oriental regions such as Asia and Pakistan and Afro-tropical regions which include Zambia by the Tonga, Nyanja, Zimbabwe by the Shona, Kenya by the Luo, Sudan, Malawi, Botswana, South Sudan Eritrea, Mozambique, South Africa, Namibia (Ebenebe, 2020) and Uganda where they are consumed by the Ganda and Nyoro (Van Huis, 2017). It is also found in DRC (Raheem *et al.*, 2019). In Zimbabwe they are found in Matebeleland, Maswingo, Midlands, Mashonaland, and Manicaland provinces; plenty of them are harvested in Mashonaland *(Dube et al.*, 2013). In Zambia, they are consumed by Tonga in Southern and Western provinces and Nyanja communities in Eastern and Central provinces. In Uganda, they are consumed by the Ganda and Nyoro communities (Van Huis, 2021) In tropical regions, edible insects such as *C. vidua* are mostly consumed and consumption patterns have

been influenced by ecological factors that are related to the abundance of insect species because of the high level of biodiversity in the regions. Most edible insects exist in the lower latitude of tropical regions and various climates such as humid rainforests, dry, and monsoon zone create the marginal areas for the abundance of edible insects. An increase in latitudes decreases the use of edible insects.

2.3 The ecology of the black ant

According to reviews done by Ayieko *et al*., (2012), *C. vidua* still lives and is commonly found in a subterranean colony that is constructed and mixed with many different and connected structures of galleries and chambers in which the members of the colony store their food at their larval stage.

In the colonies, there is a queen, king, soldiers, and non-reproductive wingless workers which are small in size compared to the reproductive males and females. At the start of the rain, the kings, and queens depart from the colony, mate, and then shade their wings so that they can start a new colony. The duties of the workers are to construct the nest by excavating the subterranean chambers and galleries and foraging for food for consumption by the members of the colony (Van Huis, 2017). C*arebara vidua* are omnivores, they feed on living and dead animals that include insects, vegetable matter, nectar, and glandular products from plants, flowers, and, honeydew from aphids and scales. They feed on smaller insects such as the small lepidopteran larvae worms and termites (Lepage and Darlington, 1984). Ants played an ecological role in the structuring of the insect communities in the canopy of *Senegalia drepanolobium* around Laikipia in Kenya and ants species such as *Crematogaster sjostedti* associated closely with Hemipteran species where they had a symbiotic relationship (Kuria, 2006). The nests are built close to the nest termites for them to prey on termites (Van Huis, 2017).

2.4 Climatic conditions and distribution of insects.

2.4.1 Climate change and climatic conditions

Climate is an important factor that determines the insects' abundance and distribution. Climate change is not a new fact that is observed to happen, the temperature and climate have changed to a large extent over the past many years ago and the current and future changes are predicted by

human activities and natural factors which cause the concentration of atmospheric carbon dioxide to continue increasing thus causes a great extent changes in climate (Wilkie *et al*., 2010). The climate of the earth has changed at exceptional rates, temperatures are predicted to increase in the future in the range of 2.5 -5.4^0 C by 2100 which is higher than the temperature that was observed in the 20th century (Gadsden *et al*., 2017). Climate change threatens the insect and subterranean ecosystems, it leads to global temperature increases, shifts in species distribution range, and extinctions (Cardoso *et al.*, 2020). Species move to areas that are climatically suitable and move from areas that become too warm as climate change causes range shifts to higher latitudes and elevations, it also reduces habitat availability (Morris, 2010). Climate variables include elevated temperature, carbon (iv) oxide (CO_2), precipitation, and extreme weather events on the insect, which have been shown to alter to alter the distribution, reproductive potential, and abundance of insects (Katsaruware-chapoto *et al*., 2017).

2.4.2 Effects of climatic conditions on the distribution of insects

Climate is a principal factor that defines the potential range of insects and climate change directly affects the distribution of many insect species. The average global temperatures will increase by 2–4˚C between the present and 2100 under several different greenhouse gas emission scenarios. Global warming will likely affect almost all aspects of insect life history and population dynamics such as development rate, and distribution range (Ning *et al.*, 2017).
Worldwide, change in climate has not only altered the distribution of insect species in a form of range shift and extinction but also has impacted the ecosystem (Walther *et al*., 2002).

When the average temperature of the Earth's atmosphere and oceans rises, it causes global warming due to the impact of the increasing concentration of greenhouse gases such as carbon dioxide, methane, and chlorofluorocarbons produced by human activities such as deforestation and burning fossil fuels (Wilkie *et al*., 2010). Climate is changing at a greater rate and may change physiological performance and lead to reduced survival of ant species, this may result in extinction when the ant species cannot be able to respond to global warming (Thomas *et al.*, 2004). Changes in the environment result in a species becoming extinct and can also migrate from their current distribution range. Species can shift their distribution in response to changes in climate. Temperature is a factor that influences the physiology and ecology of ant species with

latitudinal and altitudinal effects on the distribution of species. Temperature establishes the survival of insects and their distribution thus they respond to climate change (Wilkie *et al*., 2010). Rising temperatures can significantly influence the key physiological characteristics that affect the distribution (Ning *et al.*, 2017). Changes in precipitation patterns may also have effects on the distribution of insect species by altering distribution and abundance (Vanhanen *et al*., 2007).

Despite the effort of reducing the amount of greenhouse gas emissions, the atmospheric temperature is predicted to increase continuously beyond the 21st century (Negara, 2015). Elevated temperature, extreme weather events like floods, carbon dioxide, and shifts in rainfall patterns and relative humidity impact on survival, distribution, and fecundity of insects in a changing climate. When the temperatures increase, it leads to changes such as a shift in geographical distribution (Katsaruware-chapoto *et al*., 2017).

2.5 Land use

Land-use change is one of the drivers that leads to the decline of biodiversity and anthropogenic activities cause the extinction of insect species. Habitat loss and fragmentation are a result of a habitat that is disturbed by trampling that is associated with either grazing or sporting activities such as horse riding and hiking.(Kulma *et al*., 2015). Past and current land-use changes have altered the terrestrial ecosystem and the land has been converted for agricultural activities and other uses (Kanianska, 2018).

An increase in the human population has resulted in a transformation of habitat in which natural habitat is being interfered with by human activities (Morris, 2010). This transformation interferes with resources that could enable the organisms to survive in a particular region. It also degrades the natural habitat of species, thus leading to a decline in biodiversity and enhancing species extinction (Rubiana *et al*., 2015).

2.5.1 Effects of land use on the distribution of insects

2.5.1.1: Urbanization

The leading drivers of biodiversity loss are human land use, an example being urbanization**.** One of the forms of land use that tends to cause disruption is urbanization, this happens when the human population continues to move from rural to urban living thus causing impacts on insect ecological communities. The urbanization gradients cause changes to the structure of habitat that includes loss of habitat and fragmentation, habitat modification, and increased human disturbances (Holly, 2013).

During the construction or building of towns, the materials used such as concrete disturbs the community of fauna that lives in the soil and also the soil's natural activities and makes the soil impermeable thus affecting the distribution pattern of ant communities living in the soil. An increase in urbanization leads to fragmentation and loss of natural habitat for fauna Urbanization also results in urban heat effects which are the increase of high temperature in towns than it is in non-urban areas because the solar radiation of concrete is highly absorbed thus high temperature causes impacts in any communities in the soil Urbanization results to chemical pollution in which the concentration of many chemicals, metals and heavy metals such as mercury interferes with the soil composition due to urban landscapes as a form of human activities (Deroisy and Aucourd, 2016).

Biodiversity is majorly threatened by urbanization which causes the extinction of species and biotic homogenization, urbanization creates a disturbance that damages the habitat of most species and often creates attractive habitats for few species which can adapt to the conditions. Urbanization affects species richness in various ways such that those ants that nest on the below-ground and above-ground materials are physically removed due to the removal of tree cover and topsoil (Buczkowski & Richmond, 2012). A Shift of population to urban areas has led to a dietary shift to a westernized diet in many Countries thus a decline in the consumption of edible insects in the regions which used to consume insects (Payne and Itterbeeck, 2017).

2.5.1.2 Agricultural expansion

The agricultural policy has focused on land use intensification, and modern agro-technical methods are being applied for maximization of economic benefits, yet these agro technical have negative impacts on insects' communities such as the use of excessive insecticides in farmlands, use of pesticides, and chemical fertilizers during the production that causes the decline of insects (Kulma *et al*., 2015). Intensive use of pesticides and inappropriate risk assessment regulation leads to the decline and extinction of insects. The pesticides are toxic, have sub-lethal effects, and alter the habitat of the insects, these impact the insect population. Excessive use organic and mineral fertilizers in agricultural production widely impact on insect population as they cause soil acidification due to too much nitrogen contained in the fertilizers (Cardoso *et al*., 2020). Farmers tend to clear the wild lands and adopt the use of agrochemicals which threaten the habitat of many edible insects, this jeopardizes the safety of edible insects as sources of food and the insects' future availability (Payne and Itterbeeck, 2017).

2.6 Contribution of Insect to food security

Edible insects are mostly valuable as a supplement of food for undernourished children as most of the insects are rich in nutrients such as proteins, vitamins, fats, fatty acids and minerals.
More than 470 species of insects are eaten in Africa as reported by Kelemu *et al*.,2015. In most African and Asian countries, entomophagy is prevalent due to more cases of undernourishment which are rampant (Kelemu *et al.*,2015; Van Huis *et al*., 2013).

Globally, ants are the third most commonly eaten insects, especially in Latin America, and are mostly eaten in their larval or pupal stage (Raheem *et al*., 2019). *Carebara vidua* are collected during the nuptial flight, the abdomen is eaten raw or roasted (Van Huis, 2017). The decline in population of edible insects converge to instant threats to food security. Black ants being among the edible insects have the highest fibre of 9.2%, protein content and fats. The fibre content in it adds bulkiness to the food and also recommended for proper digestion of food. The processed food consumed in urban areas contain few or very little fibre which can be supplemented by consumption of *C. vidua*.

The insect is of importance because of its nutritional value and medicinal potential and has a conspicuously oily abdomen that gives it a unique rich flavor. All the body parts of the insect are equally nutritious and is eaten. Both males and females are collected for human consumption and are rich in nutrients and thus fit for human consumption. The abdomen of the insect has 44.64% protein content hence making the insect rich in proteins (Ayieko *et al*., 2012). It has a high level of fat content and this is one of the reasons why the insect is a favorite of many people in the Luo community. Its abdomen is approximately 50% fat content and 44.64% protein content. The larvae and pupae of the queen are the most common food in Asia (Raheem *et al*., 2019). The black ant contains iron and zinc which are lacking in many vulnerable people in the community such as children, and breastfeeding women. Since the insect is well endowed with essential zinc, it has several health benefits to the human body (Ayieko *et al*., 2012), Zinc is important in treating and managing prostate cancer. It also supplies some amount of vitamin B which is not normally available in animal proteins. Males and females have similar fatty acid composition and the insect is endowed with fatty acids as the content of palmitic and oleic acids are also significant in males (Ayieko *et al*., 2012). In many parts of the world, ants are highly searched for delicacies. They have important ecological services in which they recycle nutrients and also predators of many pests in the orchard (Del Toro *et al*., 2015).

2.7 Management strategies for survival of endangered insect species

Management actions to protect endangered species and conserve ecosystem function may not always be in precise alignment.

Due to the increase in global fragmentation of natural environments, insects need quality habitat so that they can be preserved and restored. This is because most insects need little space to survive, even partial conversion of lawns to minimally disturbed natural vegetation.

Agrochemicals including pesticides and herbicides have had harmful effects to the population and abundance of edible insects because they often harm non targeted species. To curb the effects of pesticides and ensure abundance of insects, Integrated pest management approach which is ecologically friendly has aided in enhancing the insect diversity and reduction of pesticide use in farms has helped to mitigate climate change.

Management of food insect resource can not only lead to a better human nutrition but also helps in maintaining diversity of habitats. Generally, to maintain the diversity of edible insect species, different approaches are used including; reduction of pesticide use, enhancement of forest management and conservation, reduction of wildlife preserves and parks, example are caterpillars in Malawi which are allowed to be used sustainably by the local people, reduction of organic pollution by recycling agricultural and forestry waste into high quality food or animal feedstuffs such as palm weevils and increasing environmental and economic efficiency through development of dual product systems.

Planting of native or indigenous plants are beneficial to insect species because of close ecological relationship. Insect species rely on native plants for food and some of decomposed leaves are used as food by some insect species. These trees are more important than nonnative species of trees in the ecology of insects. The native ones are easier to maintain as they can easily adapt to local climate and rainfall regimes.

2.8 Research gap being addressed

As the world is striving to achieve Sustainable Development Goal 2 of Zero Hunger, achieve nutrition and improve food security by the year 2030, the human population continues to grow at a rate of 1.05% per year with an average annual increase of people estimated at eighty-one (81) million (*World Population Clock, 2021*). The high and increasing population has piled pressure on the output from the available agro-ecosystem which is unable to sustain the current human population. The unmet need for agriculture to sustain the current human population has resulted in an estimation of 841 million hungry and food insecure people around the world (*UN report, 2021*). Edible insects however, as the prospect of an alternative food and hunger crisis, is under threat because *Carebara vidua,* which is among other edible insects that provide proteins, mineral ions, and vitamins is currently facing extinction (Ayieko *et al*., 2012). Despite continued conservation effort, the status of many endangered insect species remain unchanged. The population of insect has decline and little information is known about its spatial distribution and the causes for its change in distribution pattern

CHAPTER THREE
MATERIAL AND METHODS

3.1 Study site and characteristics

The study was conducted in the Lower Midland Zones of Siaya, Kisumu, and Homabay. The three counties have been reported to be associated with *C. vidua* around the Lake Victoria region of western Kenya. They have varied agro ecological zones. Few communities still witness the emergence of *C. vidua*, therefore strategic communities were identified for the study. In each county, the study was carried out in LM 1, LM 2, LM 3, LM 4 and LM 5. Except in Kisumu county which does not have the LM 5.

Siaya County receives an average annual rainfall of 1572 mm, an average temperature of 27^0 C-30^0 C, and is characterized mainly by ferrosols. The County lies between latitude 0.06120S, longitude 34.28820E, and an altitude of 1140m a.s.l (Abura *et al*., 2017). Kisumu County receives an average annual rainfall of 1200-1300 mm, an average temperature of 27^0 C and lies between latitude 0.09170S, longitude 34.76800E, and an altitude of 1131m a.s.l. Homabay County receives an average annual rainfall of 1226 mm, an average temperature of 22.5^0 C, and is characterized by sandy and clay soils through the red loamy soils. The County lies between latitude -0.52730S, longitude 34.45710E, and an altitude of 1330m a.s.l.

The study was conducted in the LM zones of Siaya, Kisumu, and Homabay counties. Each county has 5 LM zones except Kisumu County which has LM 1 to LM 4. Each LM has different climatic characteristics as shown in table 1 and described below:

1. **LM 1**; this zone lies between an altitude of 1300 to 1350 meters above sea level (m.a.s.l). It experiences average annual rainfall between 1500mm to 1900mm. Its annual mean temperature ranges from 20.9 to 21.8^0 C (Jaetzold *et al*.,2009).
2. **LM 2**; this zone lies between an altitude of 1200 to 1350 meters above sea level (m.a.s.l). It experiences average annual rainfall between 1450mm to1600mm. Its annual mean temperature ranges from 21.5 to 22.3^0C (Jaetzold *et al*.,2009).
3. **LM 3;** this zone lies between an altitude of 1140 to 1250 meters above sea level (m.a.s.l). It experiences average annual rainfall between 1220mm to1390mm. Its annual mean temperature is between 22.0 to 22.7^0 C (Jaetzold *et al*.,2009).

LM zone 4 and 5 are known to be arid and semi-arid areas

4. **LM 4**; this zone lies between an altitude of 1135 to 1200 meters above sea level (m.a.s.l). It experiences average annual rainfall between 890mm to 1020mm. Its annual mean temperature is between 22.3^0 C to 22.7^0 C (Jaetzold *et al*.,2009).
5. **LM 5;** this zone lies between an altitude of 1135 to 1180 meters above sea level (m.a.s.l). It experiences average annual rainfall between 700mm to 800mm. Its annual mean temperature is between 22.4^0 C to 22.7^0 C (Jaetzold *et al*.,2009).

Since each LM has different climatic variables, *C. vidua* being a seasonal insect which only emerges during the heavy rainfall season, conducting research in these LM zones helped to determine where and when the insect was and is emerging. The distribution in each county could be affected under the influence of LM zones as the occurrence is dependent on rainfall and temperature. After determining the spatial temporal distribution and eco climatic factors influencing the distribution of *C. vidua*, in objective 3 to determine the environmental management practices enhancing the survival of C. vidua was dependent on the results got from Lm zones in objective two. This assisted in knowing which LM zones these management practices could be implanted first due to availability or unavailability of the insect.

Table 1: Representation of climatic parameters of the Agro ecological zones (AEZs)

AEZ	Altitude (m)	Mean annual temp ^{0}C	Ave. annual rainfall(mm)
LM1	1300 – 1350	20.9 – 21.8	1500 – 1900
LM2	1200 – 1350	21.5 – 22.3	1450 – 1600
LM3	1140 – 1250	22.0 – 22.7	1220 – 1390
LM4	1135 – 1200	22.3 – 22.7	890 – 1020
LM5	1135 – 1180	22.4 – 22.7	700 – 800

Source: (Jaetzold *et al*.,2009)

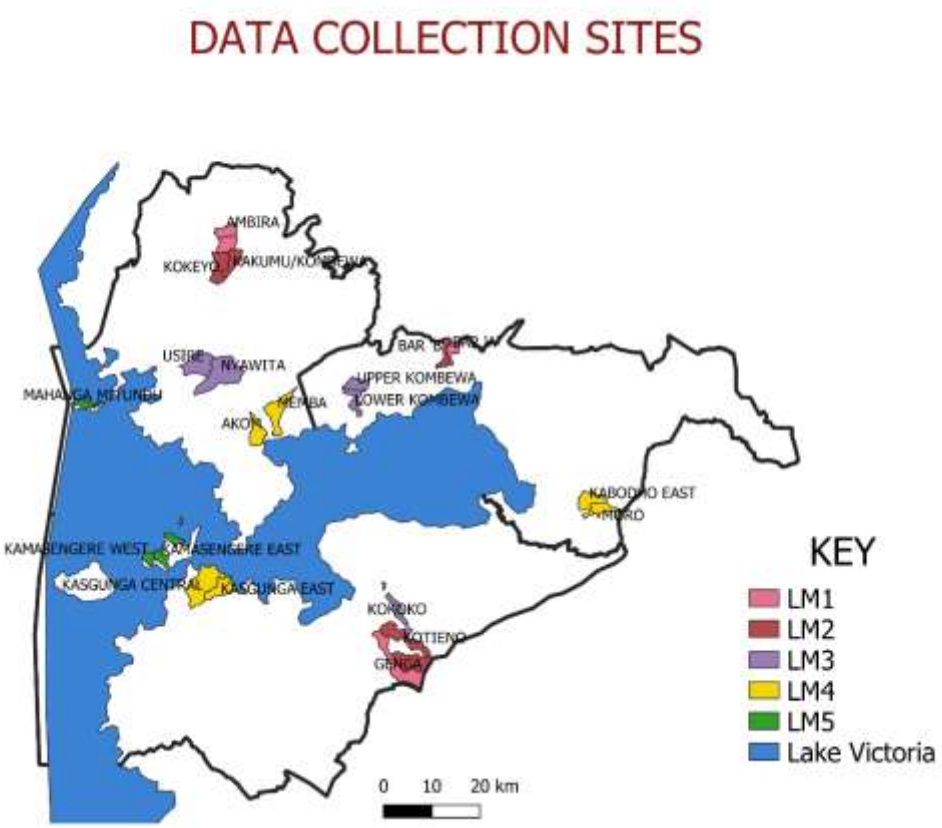

Figure 3. Areas of data collection in various agro ecological zones in Siaya, Kisumu and Homabay counties

Figure 3 shows the map of Siaya, Kisumu and Homabay counties with different AEZs including; LM 1, LM 2, LM 3, LM 4 and LM 5.

3.2 Research design

This study adopted a qualitative research approach for all the objectives of the study; objective 1, 2 and 3 which provide the researcher with a means of understanding a phenomenon through interacting with the participants of the study and by observation. The research design used for this study was phenomenological approach which applied to all the objectives.

3.2.1 Phenomenological approach

Phenomenological approach was used in establishing the distribution of *C. vidua*, understand the phenomena influencing C. vidua distribution as per the participants' conceptualization as well as

discovering the possible environmental management practices enhancing the survival of *C. vidua*. Phenomenological studies were used to examine human experiences through descriptions provided by the participants. In this study, respondents were asked to describe their experiences as they perceive them.

3.3 Sampling method

3.3.1 Purposive sampling

This method was used in the selection of suitable participants from the sampling frame. Participants were selected based on their knowledge and information contained on the subject of the study. Focus Group Discussants were selected on their aspect of living in the area for over ten years. Study population were identified and selected to provide the best information to achieve the study objectives. It was useful to find the in-depth information.

The study adopted a cross-sectional approach to community representation; males and females of above forty (40) years of old to get a range of views on each topic from those that have experience in the topic and general knowledge of *C. vidua*. Key Informants were identified, interested, knowledgeable, and experienced people on the study subject who knows more information than the general population of the community. Key informants were older people of age fifty (50) and above who were identified with the help of pre-identified village informants. Most of the adults above 40 and 50 years of age have seen the changes that have taken place in the ecosystem. Sub-County Agricultural officers (SCAO) and Ward Agricultural Officers (WAO) assisted in community mobilization

3.3.2 Sample size

Siaya, Homabay and Kisumu had 5 LM zones, 5 LM zones and 4 LM zones respectively as study sites. In each LM, 2 FGDs and 1 KII were conducted on the selected participants. There were 8 participants per FGD conducted. The total number of FGDs conducted were 28 in all the 3 counties which is equivalent to 124 participants and 14 KIIs as well.

In qualitative research an FGD is comprised of 6 to 12 participants according to the previous study done by Eeuwijk and Angehrn, (2017).

The sample of 124 participants and 14 KIIs remained adequate to reach the saturation levels. According to Alevesson and Scoldberg (2010), saturation interviews are defined as the point when there is no new datad being given after all the questions asked have been exhausted initially. The sample size was complete when the data reached saturation.

3.3.2 Summary of demographics of the Participants

The table below show the representation of the participants in terms of age, number of individuals participated in the study. In Kisumu county the mean age for participants were 61 years that was between the range of 41 to 83 years old. Siaya had a mean age of 63 years with the range of 40 to 89 years old while Homabay had a mean of 60 years and the range was between 42 to 93 years old.

Table 2**:** Demographic characteristics of the study population in FGDs in Kisumu, Siaya, Homabay and Kisumu Counties.

Variable/County	**Number of participants**	**Age in years, *mean* (range)**
Kisumu	64 (26 Females, 38 Males)	61 (41-83)
Siaya	80 (41 Females, 39 Males	63 (40-89)
Homabay	80 (41Females, 39 Males	60 (42-93)

Table 3: Demographic characteristics of key informants in, Siaya, Kisumu and Homabay Counties.

Table 3 showed that the mean age of KIs of Kisumu County was 70 years old for the four (4) KIs with the range of 55 to 78 years old, Siaya and Homabay had 5 KIs each with a mean age of 67 and 60 and the range was 50 to 83 and 56 to 81 respectively.

Variable/ County	Number of KII	Age in years, *mean* (range)
Kisumu	4	70 (55-78)
Siaya	5	67 (50-83)
Homabay	5	60 (56-81)

3.4 Data Collection Process

The qualitative techniques for data collection used in this study were Focus Group Discussion, Key Informant Interviews. The data collection tool used for these methods were unstructured questionnaires or interviews. A sample of a well unstructured questionnaire as provided in appendix 1 was administered to the FGs and KIs which contained data to be collected for the objectives. A pretest was done on the data collection tool before the actual day of data collection. This was done in LM 2, LM 3 and LM 4 in Kisumu county since these the common LMs in all the study counties. Pretest helped in identifying some of the challenges during the interviews and discussions such as observation of time, duration taken during the interview which was adjusted and how the questionnaire was being addressed. It also helped to check how long could audio recorder took to get off before the next interview. This assured certainty that the tool collected data that was intended

3.4.1 Focus Group Discussions

This method was used to collect primary data from a purposively selected group of individuals to gain in-depth information on the Spatio-temporal distribution of *C. vidua*, factors influencing its distribution, and possible environmental management practices for *C. vidua*.

The focus group of this study engaged a total of eight (8) participants (Gundumogula, 2020) per group. The initial process involved explaining to the participants what is expected of them including their right to opt-out during the discussion process. Participants were informed about the protection of confidentiality of their details and information.

With the consent of participants, an audio recording device was used during the discussion process. The discussion process was guided by the use of unstructured questionnaire into

sections as per the flow of objectives. The discussions were facilitated using the local language of the discussants. The facilitator, with the help of a research assistant, moderated the discussion while taking notes on key concepts raised during the discussion, a process that lasted for approximately an hour.

3.4.2 Key Informant Interviews

Face-to-face in-depth interview with the key informants was used to collect in-depth information on the subject of this study. This method was important as it helped to understand individual perspectives on the topic of the matter. The key informants were explained what is expected from them including their right to withdraw from the interview at their free will.

Informed consent was administered to the key informants and their consent to use an audio recording device aided the data collection process.

An unstructured questionnaire was used in the exploration of data. A probing technique was used where relevant to enquire more information from the key informants. The concept of asking interviewees “why” allowed them to explain further their experiences and thoughts, and also allowed more thinking time. The interview lasted for approximately fifty (50) minutes.

3.5 Field note taking

Field notes were taken during FGDs and KIIs. The notes taken were detailed and included a description of the physical setting of the study, the behavior of the participants, and the unspoken attitude. The notes helped as an immediate resource for reflection; during the interview and at the end of the interview. During the interview, it helped to consider the discussants' comments and clarify the views of the discussants and when the interview was completed, the notes were quietly reviewed and information annotation was added to help in the analysis.

3.6 Data analysis process

The data analysis process for objective I, II and III was conducted in two distinctive phases. The initial phase encompasses transcription verbatim of the audio recording into Microsoft office

word with the help of audio codec software. The purpose of the audio assistant software was to help in tuning to the desired playback speed and also enhance the clarity of the recorded voice.

The second phase involved the translation of transcribed data into the English language for analysis. Translated scripts were reviewed repeatedly for familiarity and to check for recurrent flaws or omitted information.

Thematic analysis was conducted by use of ATLAS. ti version 7.5, where the translated data scripts were imported into the software. Codes were critically generated that were further classified into similar families and subsequently themes.

3.6.1 Steps of Thematic analysis

I. **Familiarization with the data**

This was the first step in qualitative analysis where the transcripts were read and re-read. All the FGDs and KIIs entire body of data were familiarized with at this early stage.

II. **Generation of initial codes**

This was the phase where data was organized into meaningful and systematic way. This phase reduced a lot of data into small pieces of meaningful themes.

III. **Searching for themes/ Generating**

Codes were examined and some fitted well into theme then they were arranged into themes.

IV. **Reviewing themes**

This was a stage where the preliminary themes that were identified when searching for themes were reviewed, modified and developed. Themes were checked if they were sense and all data that were related to each theme were gathered.

V. **Defining and naming themes**

The goal of defining themes was to identify the essence of what each theme is about. This helped to conclude how each subtheme relate and interact to themes and how the themes were relating to each other.

VI. **Presenting and Discussing results (write-up)**

This was the end point where report was generated for thesis writing.

3.6.1.1 Steps of coding in qualitative data analysis

There were 3 steps and types of coding that was used for analysis of all objective; one, two and three. These include open coding, axial coding and selective coding.

3.6.1.1 Open Coding

This encompassed recursive reading of the data set to comprehend the flow of pattern. It entailed critical examination of data with constant contrast and comparison for similarities (Kolb, 2012). During this process, related utterances were identified and assigned names. This was essentials in developing comparable excerpts (De Vos, 2005). While coding using the software, the excerpts were highlighted using colors codes based on similarity.

3.6.1.2 Axial coding

This process entailed grouping and linking related codes into similar subcategories and families. The identified and highlighted similar excerpts were grouped from the open coding and grouped them according to their logical comparisons into subcategories (Kolb, 2012).

3.6.1.3 Selective coding

This was the final process of coding in the analysis based on the grounded theory by De Vos (2005). At this stage, the subcategories were combined and broader concept that accounted for reporting were generated (Kolb, 2012).

3.7 Ethical consideration

Ethical approval was obtained from Jaramogi Oginga Odinga University of Science and Technology Ethics Review Committee with approval number ERC/18/11/20-1. Permission and support were also sought from the Local Administration authorities of the relevant locations.

CHAPTER FOUR
RESULTS

4.1 Introduction

This chapter displays the results of the data collected from the study sub-set. Primary sources of data were obtained through Focus Group Discussion (FGD) and Key Informant Interview (KII) methods. The data analysis process is already discussed in the previous chapter of material and methods. The results presentation was in logical relation to the study objectives.

4.1 Spatio-temporal distribution of *C. vidua*

The results from the analysis were displayed as per the LM (Lower Midland zones) 1 to 5 of the AEZ. Table 1 in the previous chapter shows the description of LM zones where the study was conducted. The themes that were generated in objective one include; Place of occurrence, seasonality, the insect population and extinction threat.

4.1.1 Lower Midland zone 1

Place of occurrence: *C. vidua* were seen emerging in large quantity in the past years of 1960s to 1990s as shown in the table 4 below. Participant 1 in Siaya County noted that they used to occur at Ambira and Ngunya sub-locations (Sirunga and Ngagara villages) whereas in Kisumu County, the locals reported to have seen the insect occurring at Kapuonja and Bar 'B' sub-locations. Schools fields and farms provided good sites for *C. vidua* habitation.

Respondents stated that *C. vidua* used to emerge in undisturbed land and silent places. Due to that aspect, some participants called it the "*silent insect*." Participants predominantly associated *C. vidua* with termites as they could frequently see them occurring at places near the termite hills, however, they also occurred at different places away from the mounds (Lepage and Darlington, 1984).

Seasonality: Respondents stated that *C. vidua* was emerging during certain intervals within the calendar month, especially during the rainy seasons. Some participants reported having harvested them in chilly morning hours when the land was fairly moist.

Participants noted that *C. vidua* being seasonal insects, could emerge once, twice, or thrice in a calendar year. There is no predefined timeline for their emergence but the participants were

using weather patterns to predict their error of emergence. Another participant added that in certain cases, they could emerge more than thrice a year. They were mostly associated with April, May, and August and other months that were known for intermittent rainfall.

The insect population: *Carebara vidua* emerged in plenty during certain periods. Key informants and the discussants noted that they would harvest approximately a kilogram, whereas, other participants could fill to brim their cans to about 1.5 kilograms. Another participant stated that such a harvest would serve a household of five people with a one-day meal. In the year 2000s the population of *C. vidua* that was emerging started reducing.

Extinction threats: The participants reported that the frequency of their emergence and volume, however, started to gradually decline over the years. In some areas, they started to disappear much earlier than other localities. Some participants also reported that with time, they were unable to see any emergence.

Table 4: Excerpts from respondents on places of occurrence, season, and insect population and extinction threats

No.	Reference	Quotation
1.	PART1/LM1/KSM/ATLAS.TI	*Carebara vidua were so many in 1960's in Ngunya, and started declining in 1970s.*
2.	PART4/LM1/SIAYA/ATLAS.TI	*They were emerging during the rainy season. We used to harvest them near Ngunya primary school.*
3.	PART3/LM1/KSM/ATLAS.TI	*"It used to emerge in lawalawa (dry places). I used to see it when I was grazing. It was emerging after the rains."*
4.	PART7/LM1/HBAY/ATLAS.TI	*They used to be many after the rains, between the month of April and May then again in August at the same time with the termites. They emerged twice in a year.*
5.	PART6/LM1/SIAYA/ATLAS.TI	*In 1990s the insects were so many then they started reducing in the year 2000."*

4.1.2 Lower Midland 2

Places of occurrence: *Carebara vidua* used to emerge at various places within this Agro-Ecological Zone. Participants reported having seen them in their villages, on farms, along the pathways, and around the school premises where they could go and harvest them. Participants mentioned that *C. vidua* could emerge in Bar A and Nyahera sub-locations (Kandalo, Sidika, and Usembe villages) in the North Kisumu location. Their occurrence was similarly experienced in Ojwando 'A' and Kakum Kombewa, Central Alego Sub-Location in Siaya County (Ulongi, Lwala, Kaya, Liganwa, Dodi, Pap Boro, Segere, Ndere, Uhanya, and Gombe villages).
Participants in Homabay County responded to have been harvesting the insect in Kajulu, Gem Central, and Kotieno sub-locations (Nyaundho, Orobi, Wi Koteng, Kotieno, and Nyakwadha Wakeru villages) in the Rangwe sub-county.

Majority of participants associated *C. vidua* with ant hills as they could see the insect occurring near the ant hills. According to respondents' ant-hills environments were undisturbed and as such, some participants believed it to be a co-factor in the occurrence of *C. vidua* around the ant-hills. Another participant reiterated that undisturbed lands were also known to be silent areas which could most likely favor the occurrence of *C. vidua*.

Seasonality: The locals reported that *C. vidua* emerged in the morning hours when the land was still moist at around 10:00 Am and that they only emerged once a day on the specific days of their emergence. Another respondent explained that before *C. vidua* emerged on the surface, soldier ants could emerge first, then the elate ants would follow.
Participant 4 gabbed C. *vidua* mostly emerged once in a calendar year, though at certain localities they could emerge more than once a year. The respondents observed that the ants emerged in March when there was enough rainfall and sometimes in May, and August, but predominantly in April in most areas, this was between 2013 and 2015 when their emergence was experienced in this LM zone. It is during these months that most agricultural activities take place in this agricultural zone.

The insect population: The participants noted that *C. vidua* emerged in fairly large amounts that children harvested adequate for their lunch meal. Another participant added that along *C. vidua*,

there also emerged elate termites in large numbers. Participants observed that the population of termites was normally higher than that of *C. vidua.* Participants stated that they could harvest about one *gorogoro* (three-quarters of a two-kilogram can). However, at some other emergence sites, collectors could barely fill a kilogram can.

Extinction threats: Over the years, participants noted that *C. vidua* is currently reducing in numbers and slowly disappearing. They can no longer harvest in plenty as before. Participants stated that the long absence of insect emergence in the area has caused a lack of interest in the collection by the locals.

Table 5: Excerpts from respondents' observations on places of occurrence, season, and insect population and extinction threats

No.	Reference	Quotation
1.	PART5/LM2/HBAY/ATLAS.TI	*"These things were so many in Nyahera and Bar A but we do not see C. vidua emerging nowadays."*
2.	PART3/LM2/SIAYA/ATLAS.TI	"*In 2013, C. vidua were emerging in undisturbed fields around the ant hills.*"
3.	PART2/LM2/HBAY/ATLAS.TI	*"They were emerging at 10:00am in the morning. You could see its ants emerging first and surrounding the hole then they would follow later."*
4.	PART6/LM2/KSM/ATLAS.TI	*"After planting during weeding between the month of March and April. They were emerging once in a season in the morning hours."-*
5.	PART4/LM2/SIAYA/ATLAS.TI	*"They started reducing in 2015 and currently people cannot harvest more C. vidua. We lost interest in them since they started.*

4.1.3 Lower Mid land 3

Place of occurrence: In Siaya County, participants reported to have experienced the occurrence of *C. vidua* around Bondo Township and Usire sub-location, and West Sakwa location (Nyawita,

Nyakasumbi, Oseno, and Ramula villages). Whereas, in Kisumu County respondents reported to have seen *C. vidua* occurring in Upper and Lower Kombewa sub-locations, (Kanyawanda, Koketch, Malela, Kamonye, Korwenje, and Kasayi villages) Seme Central ward. Homabay County, the participants cited to have experienced *C. vidua* in Kamwa, Kanjira, and Kakoko sub-locations, and Kokoth kateng location (Atop, Imbo, Agumba, Katieno, and Kowiti villages).

Seasonality: Participants stated that *C. vidua* emerged in the morning before or around 10:00 am. However, depending on the weather, participants could see the insect emerging in the afternoon at around 2:00 pm. This was normal after the rains when it was calm and chilly. They were emerging during the rainy seasons. Across all the respondents, *C. vidua* were emerging once in a calendar year but in different months per region. For instance, they were seen emerging and harvested in December after a spell of drought and on the onset of a rain spell. Customarily, they used to emerge between April and May. Carebara vidua was emerging in plenty during 1960s to 1990s.

The insect population: Participants responded that *C. vidua* used to emerge in mass over the past years. They harvested *C. vidua* using a traditionally woven carrier called baskets *'adita.' Adita* (a 2 kg basket) were in small sizes and the harvest could fill the *'adita.'* The harvest was enough for a meal for a sizable household of five people. '*Adita'* can be equated with a 2-kilogram container.

Extinction threat: Respondents stated that *Carebara vidua* has been disappearing over recent years. Some respondents saw *C. vidua* last in the year 2020 whereas, other participants reported to have last seen them in the year 2001. They, however, are currently not being seen emerging in some of the areas they used to emerge. Participants reported that in the current places the insects are emerging, in small numbers. There is evidence that a substantial amount of the insects can be seen emerging during the rainy season as they used to. However, the yield is intermittent as reiterated by another respondent.

Table 6: Excerpts from respondents on places of occurrence, season, insect population and extinction threats

No.	Reference	Quotation
1.	PART2/LM3/KSM/ATLAS.TI	"*They used to be found in many places such as Maranda, Bar kowino, Nyawita and Nyakasumbi villages, these are the places I know very well."*
2.	PART5/LM3/HBAY/ATLAS.TI	*"They can even emerge near the verandas in the morning around 9'00am to 10'00am."*
3.	PART1/LM3/KSM/ATLAS.TI	*"There were months when C. vidua used to emerge, we called them "Due Onyoso – (the month of C. vidua)" around April during weeding. They were emerging at the same time with the termites ."*
4.	PART4/LM3/HBAY/ATLAS.TI	*"there was something called (Adita) which I used to put in my harms and fully filled it with the harvested C. Vidua."*
5.	PART6/LM3/KSM/ATLAS.TI	"*In Opoda we could find them every season of the year but currently in the year 2020, 2021 we cannot see them emerging every season- their emergence have become unpredictable."*

4.1.4 Lower Midland 4

Places of occurrence: C. vidua occurred in different parts of this Agro-Ecological Zone. Respondents cited occurrences in Akom, south Asembo, and Member sub-location in Siaya County. Some locals reported having seen them emerging on school premises, on their farms, and along the pathways. Another participant added that in Kisumu County, they were seen emerging in Olembo, Moro, and Kabodho East, Wasare, Pap- Onditi, and Rang'ul sub-locations in the lower Nyakach ward. Participants also responded that they saw them emerging at Kasgunga central, Kasgunga East sub-location, Gembe west location, (Kirindo, Kisiu, Lwanda, Kaksingre, lower kochola and Got bura villages) Mbita, Homabay county.

Seasonality: Participants noted that *C. vidua* used to emerge mostly in the morning hours at around 9:00 am and 10:00 am when the soil was still moist. Locals reported that they were emerging once a day on the actual day of their emergence which could last for relatively an hour as noted by another participant. Participants also stressed that during harvesting, the silence was maintained to avoid scaring *C. vidua* away.

Just like Lower Midland Zone 1, 2, and 3, the locals reported that *Carebara vidua* used to emerge in April and May when there was enough rainfall, whereas sometimes they were seen emerging in March. When asked about the frequency of emergence, participants responded that *C. vidua* could emerge twice in a calendar year. Mostly, *C. vidua* were emerging at the time when intense agricultural activities were taking place, their emergence was vital in predicting the season of planting and weeding.

The insect population: *Carebara vidua* used to emerge in mass in this. Most participants could harvest them using '*adita.*' Respondents explained that the quantity of harvest could be enough for a one-time meal for the four household members.

Extinction threat: Respondents cited that *the C. vidua* population started to gradually decrease over time as the years advanced. Another participant explained that they stopped experiencing the emergence of *C. vidua* in some areas they used to see them and in case they emerge, their numbers were quite low. In some areas, they started to disappear long before other places. For instance, some participants saw them last in the year 1990s while others reported having seen them last in 2015.

Table 7: Excerpts from respondents on places of occurrence, season, insect population and extinction threats

No.	Reference	Quotation
1.	PART8/LM4/KSM/ATLAS.TI	"We *used to harvest them in Radieda, nyore village in Akom sub location."*
2.	PART2/LM4/HBAY/ATLAS.TI	*They were emerging at 9:00am, they were to be harvested silently without making noise to avoid them turning back. They were taking an hour to emerge. This was during the rains in April. This was happening in Kaksingre."*
3.	PART7/LM4/SIAYA/ATLAS.TI	"Carebara viduaw*ere so many and people could harvest them with (Adita)*
4.	PART1/LM4/HBAY/ATLAS.TI	"*I saw them in the year 2020 here in Kirindo but they were few. Though Agoro (a type of termites) and cricket are still existing."*

4.1.5 Lower Midland 5

Place of occurrence: Participants re-counted to have seen *C. vidua* occur in the Mageta sub-location (Osieko, Manyala, Mitundu, and Mahanga villages), Siaya County. They also occurred on Rusinga Island at Sienga village in Homabay County.

Most respondents accounted that *C. vidua* used to occur in places where there are termite ant hills. They reiterated that soil near the termite ant hills is moist which could favor the occurrence of *C. vidua.* Another participant noted that *C. vidua* occurred in flat and soft areas within this Agro-Ecological Zone.

Seasonality: Participant 5 accounted that they emerged in the morning hours at around 10:00 am. During that time, the soil is quite moist and the surrounding is quite silent. Respondents re-counted that *C. vidua* is an insect that likes a silent environment.

Carebara vidua emerged in April during the rainy season while sometimes they could emerge in August. Some respondents noted that *C. vidua* could sometimes emerge twice a year in April and

August. Predominantly, they emerge once in a calendar year. During their time of emergence, agricultural activities were also carried out in this area.

Respondent 8 accounted that as much as *C. vidua* used to emerge in this LM, their numbers were fairly low. They emerged in the areas, then started to gradually decline with time for a couple of years

Table 8: Excerpts from respondents on places of occurrence, season, and extinction threats

No.	Reference	Quotation
1.	PART3/LM5/SIAYA/ATLAS.TI	*"I used to see onyoso in Osieko, Manyala, although they are not there as well."*
2.	PART5/LM5/KSM/ATLAS.TI	"*They were emerging twice a year; April and August. It was in 1993 when I saw termites and C. vidua.*
3.	PART8/LM51/KSM/ATLAS.TI	*"They started disappearing in 1980s, then I saw few of them again in 1996 till now have never seen them."*

Table 9: ATLAS.ti Word count Results

The table displays frequency list of corpora and main texts used during the analysis to formulate key' concepts. In this contents analysis, the compiled list of most used words shown in the table aided in coming up with key lines and ideas during data analysis.

WORDS	Length	P 6	%	Total Count	%
Abdomen	7	19	3.17%	19	3.17%
About	5	57	9.50%	57	9.50%
'Adita'	5	1	0.17%	1	0.17%
Adults	6	2	0.33%	2	0.33%
Afternoon	9	4	0.67%	4	0.67%
Age	3	3	0.50%	3	0.50%
Ago	3	22	3.67%	22	3.67%
Alternative	11	2	0.33%	2	0.33%
Alternatives	12	2	0.33%	2	0.33%

Ant	3	144	24.00%	144	24.00%
Anthill	7	1	0.17%	1	0.17%
Ants	4	80	13.33%	80	13.33%
Carebara vidua	6	1	0.17%	1	0.17%
Ate	3	4	0.67%	4	0.67%
Childhood	9	1	0.17%	1	0.17%
Children	8	37	6.17%	37	6.17%
Delicacy	8	2	0.33%	2	0.33%
Delicious	9	8	1.33%	8	1.33%
Eat	3	73	12.17%	73	12.17%
Eaten	5	18	3.00%	18	3.00%
Eating	6	61	10.17%	61	10.17%
Edible	6	16	2.67%	16	2.67%
Sunlight	8	2	0.33%	2	0.33%
Tunnel	6	1	0.17%	1	0.17%
Twice	5	11	1.83%	11	1.83%
Two	3	26	4.33%	26	4.33%
Warmth	6	2	0.33%	2	0.33%
Total:		600	100.00%	600	100.00%

4.2 Eco-climatic factors affecting the distribution of *C. vidua*

In objective 2, the themes that were generated when Atlas ti software version 7.5 was used for analysis include; Climate change, advancement in agricultural equipment, habitat destruction, increased settlement, industrialization, land degradation, and predation were some of the themes generated. These themes have been presented as per the LM zones and supported by participants' quotations in the excerpts.

4.2.1 Lower-midland 1

Climate Change: Climate change was generated as a theme that exhibited the significant change in weather patterns or changes in the atmospheric condition over the years as experienced by the participants in the study areas.

Participants noted much concern about the gradual change in the weather pattern over the years. However, they distinguished that in the 1990s there was high rainfall amount compared to the year 2000's especially during the planting seasons. Participants said that they mostly experienced *C. vidua* emergence during the rainy seasons when intense agricultural activities were being carried out.

In Kisumu County, when talking about the climate parameters, participants compared the temperatures in the 1990s and 2000s echoing the significant differences. Another respondent explained that the temperature change contributed to soil moisture loss which interfered with the condition of *C. vidua* habitat triggering their disappearance.

Table 10: Excerpts from respondents on climate change

No.	Reference	Quotation
1.	PART7/LM1/SIAYA/ATLAS.TI	*"There was a lot of rainfall in the past during the planting season compared to nowadays which we experience little rainfall therefore C. vidua cannot get a chance to emerge."*
2.	PART3/LM1/KSM/ATLAS.TI	*"Nowadays there is a lot of sun, it is so dry. I saw them emerging in the month of August last year 2020. In 1990s the insects were so many then they started reducing in the year 2000."*

Advancement in agricultural equipment: This is a collective theme that encompasses the innovation and use of sophisticated agricultural farm machinery such as tractors. The theme was theoretically linked to farm tools as a code. The code accounts for the gradual changes in the upgrade and application of farm tools over the years.

Most participants in Kisumu, however, have adopted the whirling change in modern agricultural technology. When asked about the reasons for the disappearance of *C. vidua*, some participants stated that due to shifting in the use of farm tools from hoes to tractors in land preparation for cultivation could have destroyed the habitat for *C. vidua*.

Participants in Siaya County also shared their opinion on the disappearance of *C. vidua* reiterating the shift from hand digging to the use of tractors which were not widely used in the previous years.

Table 11: Excerpts from respondents on advancement of agricultural equipment

No.	Reference	Quotation
1.	PART1/LM1/KSM/ATLAS.TI	*"Nowadays people use tractors when farming which was not there in the past. This can contribute to their disappearance since their habitat are being dug deep."*
2.	PART6/LM1/HBAY/ATLAS.TI	*"People were hand digging; they were not using tractors."*

Land degradation: This theme encompasses the results of various anthropological processes acting upon the land that lowers the value of the biophysical environment. The theme, however, was theoretically linked to codes of soil use, deforestation, charcoal burning, and chemical use.

Participants cited that *C. vidua* were adversely affected by the way residents are putting soil into use. Most participants in Kisumu County talked of the soil used to make charcoal stove liners for economic purposes and as a means of earning a livelihood. Two participants from Kisumu however emphasized that soil harvesting was practiced more due to a lack of alternative jobs in the area. They however noted on the impact of their soil use to have destroyed the habitats of *C. vidua* in the area.

In Siaya County, participants recounted charcoal burning as one of the primary activities in recent days. They noted that in the year 1970, charcoal burning was not a priority though they emphasized the use of firewood as their initial source of energy. Participants observed that

charcoal burning was key in the destruction of the habitats of *C. vidua* as they explained that heat generated from charcoal burning activities was harmful to soil bio-components. Charcoal burning was mostly done in the forests where trees were readily available, an activity that also adversely impacted the available forest cover.

Participants believed that the population of *C. vidua* was stressed by the frequent use of toxic chemicals applied during agricultural activities. Another respondent explained further that the chemical pesticides and fertilizers were deemed to cause soil pollution and eventually habitat loss. Chemicals particularly aerosols were frequently applied to ant hills in amid of destroying the ants. According to participants, the ant hill structure has channels that most probably connect to the habitat of *C. vidua*. This aspect plays a role in the eradication of *C. vidua* and its habitat

Table 12: Excerpts from respondents on land degradation

No.	Reference	Quotation
1.	PART5 & 2/LM1/KSM/ATLAS.TI	*"We are only using the soil to make charcoal stove liners."*
2.	PART4/LM1/SIAYA/ATLAS.TI	*"There are no industries, we only practice sand harvesting and making of charcoal stove liners using the soil."*
3.	PART8/LM1/HBAY/ATLAS.TI	*"People are currently burning charcoal and it never used to be there."*
4.	PART5/LM1/KSM/ATLAS.TI	*There is a chemical that people are spraying to kill grasses and shrubs for them to cultivate (Roundup) or used to control weeds.*

Habitat Destruction: As a theme, it incorporates the anthropological measures that were undertaken instead of destroying the ant hills. It was linked to a code of ant hill destruction.
Most participants reported that *C. vidua* was mostly found in places where there were ant hills. However, participants also reported that people are destroying and removing ant hills from their environments.

Participants in Siaya cited the use of toxic chemicals Chlorpyrifos 20 % E on the ant hills. The primary application of chemicals was aimed at *destroying termites*. One Participant categorically explained that upon application of chemicals to the termite hills, some of the chemicals find their way into the *C. vidua* habitat and destroy them as well.

Participants observed that upon the destruction and removal of ant hills, the population of *C. vidua* started to decline gradually.

Table 13: Excerpts from respondents on habitat destruction

No.	Reference	Quotation
1.	PART6/LM1/SIAYA/ATLAS.TI	"*Removal of ant hills and using chemicals to kill the ants has led to the decline of Onyoso*."
2.	PART1 4/LM1/KSM/ATLAS.TI	*"Activities were less and there were less ant hills. This insect emerges at the same time with termites so being that the ant hills have been removed; the insect started declining because their environment had damaged."*

4.2.2 Lower Midland 2

Climate Change: The aspect of climate change has been experienced in the area over the decades. Knowledge of the change in rainfall and temperature parameters was wide among the participants. Participants stated that change in *rainfall pattern, amount, and distribution* was a contributing factor to the current distribution and threat to the extinction of *C. vidua*.

Respondents thought that the temperature rise has resulted in an increase in soil temperature and consequently reduction of the soil moisture content, altering the conditions of *the C. vidua* habitat. Participants believe that a temperature rise explained the current change in the disappearance of *C. vidua*.

Table 14: Excerpts from respondents on climate change

No.	Reference	Quotation
1.	PART8/LM2/KSM/ATLAS.TI	*"There was more rain, more cattle, the sun was not too much."*
2.	PART5/LM2/SIAYA/ATLAS.TI	*"There was enough rainfall and rains had its time. It was not just raining any month like it currently does."*
3.	PART3/LM2/KSM/ATLAS.TI	*"Climate change has also led to the disappearance of the C. vidua; change in rainfall pattern."*
4.	PART1/LM2/HBAY/ATLAS.TI	*"Nowadays there less forests and there is a lot sun. termites has also disappeared and Agoro are few."*

Advancement in Agricultural equipment: Agriculture is widely practiced in this LM just like LM 1. Participants explained that over the decades they have witnessed several changes taking place in the field of agriculture that most probably influenced the current distribution and population of *C. vidua* in the regions. Participants reiterated that in the year 1970's, simple agricultural equipment such as hoe and ox-plow were being used in land preparation. Hoes could not dig to the depth of destroying the insect's habitats.

The gradual shift in agricultural equipment has led to the wide use of more advanced tools such as tractors in cultivation and land preparation. Participants believe the use of tractors has to a significant extent contributed to the extinction of *C. vidua*. As explained by the participants the tractor plow goes deep in the soil which destroyed the habitats of the existing *C. vidua*. Participants reported that initially *C. vidua* could be seen emerging from the farmlands as compared to the current times.

Another respondent explained that the smell of fossil fuel from farm machinery is not friendly to *C. vidua*, and contributed to the migration of *C. vidua* to a different setting.

Participants reported that the insect liked to emerge in undisturbed areas. The use of tractors in agriculture is a major land disturbing aspect as it causes a lot of vibration on the ground, and air and noise pollution.

Table 15: Excerpts from respondents on advancement in agricultural equipment

No.	Reference	Quotation
1.	PART2/LM2/KSM/ATLAS.TI	*"People used to cultivate with ox plough and hand digging, they could cultivate in unity."*
2.	PART3/LM2/HBAY/ATLAS.TI	*"Hand digging and ox plough were being used to cultivate but people have now shifted to the use of tractors which dig deep into the soil and may destroy the habitat of onyoso."*

Land degradation: Respondents stated that land degradation due to anthropogenic activities and natural phenomena has contributed to the already decline of *C. vidua* over time.

Participants specified that charcoal burning is one of the major activities carried out in this LM. There were no official designated areas for charcoal burning, therefore, forest locations provide a favorable environment for the activity because of readily available trees. According to another respondent, charcoal burning alters the soil conditions including the moisture content. Participants explained that the heat generated during charcoal burning might help to answer the current distribution of *C. vidua*. Respondents reported that charcoal burning emits fumes that are not friendly to insects. *C. vidua* is known by participants to be an insect that is most thriving in areas with clean air.

Participants believed that the effect brought about by the use of chemical fertilizers and pesticides could have contributed to the disappearance of *C. vidua* in this LM. In the years 1970's, organic compounds were frequently used in the agricultural sector. Participant 2 went ahead to explain that in the year 2000, most organizations influenced farmers to use their

chemical products in controlling weeds, pests, and fertilizers. Respondents reiterated that the use of these toxic chemicals is not only harmful to *C. vidua* but also the general soil bio components. Chemical use is in the extensive application by the wider population. For instance, aerosols are used in the destruction of ant hills, especially near homesteads and farmlands. Participants believe that the application of these chemicals has accounted for the disappearance of *C. vidua.*

Participants stated that crop residues from the farms are burned by the farmers in the farmland and the effect might be heating of the soil that may result in a conditional change of *C. vidua* habitats influencing their migration. One participant stressed that the smoking effect from the crop residue burning could also explain the disappearance of *C. vidua* in this region. Respondents believe that this might be attributed to the formation of *acidic rainfall* which is a potential threat to *C. vidua* and other soil life.

Soil treatment has advanced to become a major practice in the agricultural sector. Most people have reverted to the use of the chemical oxidation method in soil treatment. The locals asserted that the chemicals used to achieve the process are harmful and destructive to the insect and its habitat. Soil from the ant hills provides raw materials for modeling charcoal stove liners. Participants also mentioned this as a potential effect on the disappearance of *C. vidua*. Locals dig ant hills to obtain the soil which is a direct destructive aspect. *C. vidua* being associated with ant hills by the participants, will most probably disappear or relocate to another favorable environment.

Participants in Siaya County noted the occurrence of the earthquake as a natural phenomenon in the area. Respondents noted that this might have led to the destruction of the *C. vidua* habitats and a potential result in their deaths. However, it was not reported as a frequent event.

Table 16: Excerpts from respondents on land degradation

No.	Reference	Quotation
1.	PART1/LM2/KSM/ATLAS.TI	*"Human activities such as charcoal burning has led to the disappearance of the C. vidua due to the heat produced when burning."*
2.	PART3/LM2/HBAY/ATLAS.TI	*"Increase use of chemicals to kill the ants' family has led to the reduction of the black ant."*
3.	PART6/LM2/SIAYA/ATLAS.TI	*"The soil has become acidic and there is low organic matter, people tend burn crop residues at the farm which is a problem to the soil fertility."*
4.	PART4/LM2/KSM/ATLAS.TI	*"General treatment of the soil is affecting the living organism in the soil."*
5.	PART1/LM2/HBAY/ATLAS.TI	*The soil from the ant hills are being used for making charcoal stove liners*
6.	PART7/LM5/KSM/ATLAS.TI	*"There are earthquakes in the area that may be interfering with the habitat of the insect."*

Habitat destruction: The Locals reported that the habitat for *C. vidua* was being destroyed in the process of destroying the ant hills around the houses and on the farmlands. Ants were known for destroying houses and plants.

In Siaya County, some people were using kerosene and salts to destroy and kill the ants in their natural settings. Participants believe that this practice is also destroying the habitats for insects**.**

Table 17: Excerpts from respondents on habitat destruction

No.	Reference	Quotation
1.	PART2/LM2/HBAY/ATLAS.TI	*"Removal of ant hills is a factor contributing to the disappearance of C. vidua because they live next to the ant hills."*

2.	PART7/LM2/KSM/ATLAS.TI	*"Destroying ant hills affect the habitat of C. vidua because people use kerosene and salt, gladiator to destroy these ant hills and these chemicals spreads under the ground and may reach the habitat of C. vidua and kill them."*

4.2.3 Lower midland 3

Climate change: climate change as referred to, denotes the significant changes in the weather pattern as experienced in these regions. Various factors ranging from anthropological to natural phenomena have contributed to climate change. Climate, being significant as a determinant of the atmospheric condition including the soil moisture content, is a potential determinant of *C. vidua's* distribution.

Participants talked about the difference between the past and current atmospheric conditions with a unison experience of higher rainfall amounts compared to the current weather status. Participant 7 stated that in the year 1970 rainfall amount was high until 1983 when there was a partial drought.

The emergence of *Carebara vidua* were mostly experienced during the rainy season, in the morning hours at around 10:00 am when it was cool. The atmospheric condition becomes phenomenal to the distribution of *C. vidua* when participants report a change in the distribution as a result of climate change.

Respondents reported on the application of the *knowledge of weather patterns* to predict the emergence of *C. vidua* and events in the agricultural calendar. Participants have since acknowledged the changes in climatic trends and associated their impact on the current distribution of *C. vidua*. The participants noted that rainfall and temperature parameters determined the soil moisture condition. The current higher temperatures have significantly impacted the soil moisture content and soil temperature. Respondents believe that this factor has a potential effect on the conditions of *C. vidua* habitat which might explain the current distribution of *C. vidua*.

Table 18: Excerpts from respondents on climate change

No.	Reference	Quotation
1.	PART3/LM3/HBAY/ATLAS.TI	*"Currently there is a lot of sun which has brought a lot of heat, so I'm thinking this too much heat has made things like C. vidua to start disappearing."*
2.	PART1/LM3/SIAYA/ATLAS.TI	"*Weather patterns has changed; There was a lot of rain that was enough for the soil but when drought started, there was a drought in 1983."*
3.	PART7/LM3/KSM/ATLAS.TI	"*The place is not as cool and wet as it used to be, we have destroyed our environment by cutting the forests, trees, shrubs. We should maintain our environment to enhance a lot of rain."*

Advancement in agricultural equipment: Agriculture as one of the key activities in this region, has evolved over the past and recent decades. This has established changes in the application of technology in agriculture from the use of simple to complex machinery in agricultural practices. Participants reported on the use of ox-plow and hoes for farming in the years 1970's. Another respondent added that this agricultural equipment was less harmful to the habitats of *C. vidua* and the general soil biota. The locals stressed that this equipment could not dig deep beneath the ground to interfere with the C. *vidua* habitat which could explain the previous distribution of *C. vidua* in this LM.

Participants emphasized the current wide and consistent use of tractors to plow and in the general land preparation procedures. Participants believe that tractors are an associative factor in the destruction of *C. vidua* habitats as attributed to their aspect of digging deep into the ground and potentially destroying *C. vidua* habitats and disturbing the insects.
Participants believed that the decline of *Carebara vidua* in this region could be explained by the *evolutions* in the agriculture sector.

Table 19: Excerpts from respondents on advancement in agricultural equipment

No.	Reference	Quotation
1.	PART2/LM2/KSM/ATLAS.TI	*"We used to dig with hoes (hand digging), the hoes could not interfere with the underground living organisms. In the traditional world you could not find a monogamous man, there were polygamous men with 2 or 3 or 4 wives; who had many children who could help in the farm activities."*
2.	PART7/LM3/HBAY/ATLAS.TI	*"Traditional farming, we could use hoes to dig because tractors were not there."*
3.	PART1/LM3/KSM/ATLAS.TI	*"We were using jembes, nowadays we use tractors that are destroying the habitat of C. vidua"*

Land degradation: Anthropogenic activities and natural occurrences have contributed to land degradation, thus interfering with the land biotic components of this region. It's a threat to the habitat of *C. vidua* and subsequently influences their distribution.

Participants reported on the making of bricks as one of the major economic activities of the residents. They reiterated that brick making involves digging of land to obtain soil, a process that leads to the destruction of *C. vidua* habitats. Brick-making has been increasing over the decades as the demand has kept increasing with change in time. The locals noted that the possible increase in brick making and demand was a causal factor in the disappearance of *C. vidua*. Brick making process demands fire as an essential, and so is charcoal burning which is also widely practiced in this area. These activities are unintentionally practiced in potential places where *C. vidua* is likely to emerge. Participants explained that the heat produced in both cases has resulted in the eradication of *C. vidua* and subsequently their disappearance.

Participants noted that carbon (IV) oxide produced during the burning of bricks and charcoal has a potential effect on the current distribution of *C. vidua*. Another participant cited that *the biology* of *C. vidua* demands clean air, thus contaminated air influenced its disappearance.

Table 20: Excerpts from respondents on land degradation

No.	Reference	Quotation
1.	PART5/LM3/KSM/ATLAS.TI	*"And people are cutting down the trees and use them to build houses and burn charcoal and may be the someone had built a house in the habitat of C. vidua"*
2.	PART8/LM3/SIAYA/ATLAS.TI	*"Brick making, this affect its habitat because of the heat that may interfere with its habitat and even kills them or may make them to relocate."*

Habitat destruction: Humans have taken diverse measures in the effort to destroy ant hills which results in the potential eradication of *C. vidua* habitats.

Participants recounted the mass distribution of ant hills in the year 1960's and *C. vidua* were mostly known to them to be emerging around the ant hill environment. Ant hills destruction therefore influenced the distribution of *C. vidua.*

Various reasons triggered the destruction or removal of ant hills as reported by the participants However, most participants were in consensus that ants were destroying their structures and crops and as such, they had to be controlled. Locals reported destroying ant hills using toxic aerosols. Another participant added that channeling these aerosols in the ant hills was not only harmful to ants but also *C. vidua.*

Respondents reported that the soil from ant hills is useful in the sector of agriculture. The farmers mixed the soil from the ant hills with the soil from their farms to improve soil fertility. Some participants stressed that this aspect has contributed to the digging down of ant hills hence the destruction of their habitats. Participants believe that the change in the *C. vidua* could potentially be connected with the destruction of ant hills.

Table 21: Excerpts from respondents on habitat destruction

No.	Reference	Quotation
1.	PART1/LM3/KSM/ATLAS.TI	*"Initially the population was low. Ants have been destroying the houses, therefore people surrounding the ant hills destroys them and in the past years the hills were there. If an ant hill which is 50m away has been destroyed, then the C. vidua will not emerge around there because elate termites are related to C. vidua."*

4.2.4 Lower midland 4

Climate change: Participants noted the changes in the atmospheric conditions over the years and the weather aspect was important in forecasting agricultural activities.

The respondents emphasized the difference in rainfall parameters as the cause of insect disappearance. In 1980s, adequacy of rainfall amount was reported. This is a phenomenal aspect of the emergence of *C. vidua* because the locals associated the insect with the rainfall season. Locals reiterated further that rainfall impacts the soil moisture content and water table level which may influence the emergence of *C. vidua*.

Participants reported the increase in temperature which might have a causal effect on the disappearance of *C. vidua* as a result of a change in the soil moisture content.

Table 22: Excerpts from respondents on climate change

No.	Reference	Quotation
1.	PART4/LM4/SIAYA/ATLAS.TI	*"I think it is because there has been less rainfall in the area. Some insects depend on moisture of the soil; I think they can be found in some wet areas."*
2.	PART1/LM4/KSM/ATLAS.TI	*"temperature nowadays is very high."*

Advancement in agricultural equipment: Participants stated the wide use of hoes and hand digging tools in the year 1970's as opposed to the current use of tractors in the agricultural sector. They explained that the impact of tractors has contributed to the gradual disappearance of *C. vidua* as a result of habitat destruction.

The respondents cited that heavy machines in agriculture are associated with noise, land disturbance, and toxic emissions. *C. vidua* is known by participants to be 'silent' insects and as such, causing land disturbance triggered their disappearance. When elaborating on emissions, participants reiterated that smoke and oil spillage from the tractors are not eco-friendly to *C. vidua* and other soil biota components. The respondents implied that the frequent use of fossil fuel machinery in agriculture is a potential determining factor in the current distribution of *C. vidua* in this zone.

Table 23: Excerpts from respondents on advancement in agricultural equipment

No.	Reference	Quotation
1.	PART2/LM4/KSM/ATLAS.TI	*"Hand digging was practiced and it was not deep therefore not affecting the habitat or reproduction of C. vidua."*
2.	PART5/LM4/HBAY/ATLAS.TI	*"The kind of farming we are currently practicing is affecting C. vidua; tractors are digging so deep even past the depth where C. vidua is living. This has destroyed the habitat."*

Land degradation: Various measures contributed to land degradation in this LM as reported by the participants. The aspect of land degradation has gradually increased over the recent decades due to uncontrolled human activities.

Participants recounted the use of organic fertilizers in the year the 1980s to improve soil fertility in the agricultural sector. They expounded that the use of extract from *Tithonia diversifolia* plant as organic compounds in agriculture was less harmful to soil biota composition and added that this element has potential cause in the past distribution of *C. vidua*. As reiterated by the

participants, there were emerging changes in trends in the agricultural sector leading to the wide use of inorganic fertilizers to improve soil value. Participants stated that inorganic compounds are toxic and impacting on the soil biota components. Another participant added that soil precipitation as a factor is a peril to *C. vidua* and its habitat.

The changing trend in agriculture has also led to the shift from the initial use of organic pesticides to the wide use of inorganic pesticides in pest control. Participants were aware that the spillage of inorganic fertilizers was harmful to *C. vidua* and its habitat. The locals believe that these practices have potentially contributed to the decline in the population of *C. vidua*.

Participants noted the wide practice of charcoal burning in the region over the recent decades. They explained that charcoal burning generates heat to the ground and produces carbonated air which is not eco-friendly to *C. vidua* and its habitat. Compared to other lower midlands, charcoal burning is not much intensive in this region.

Table 24: Excerpts from respondents on land degradation

No.	Reference	Quotation
1.	PART1/LM4/SIAYA/ATLAS.TI	*"Charcoal burning can kill C. Vidua because the heat may kill it, though charcoal burning is not much in this areas but it never used to be there"*
2.	PART7/LM4/KSM/ATLAS.TI	*"We are now using tractors, chemical fertilizers which are affecting and destroying them."*
3.	PART5/LM4/HBAY/ATLAS.TI	*"we were never using chemical fertilizers to plant and now we are using so I think these chemical fertilizers are killing them."*

Habitat destruction: Participants stated that *C. vidua* is currently not being experienced as a result of their habitat destruction due to human activities. Respondents reported that *C. vidua* mostly emerges in areas near the ant hills. However, residents destroy ant hills around their vicinities for economic importance.

When asked about the reasons for ant hill removal, they talked about the use of anthill soil in the making of charcoal stoves due to its clean debris and uniform texture, whereas some believe it has medicinal value on wounds. The process of ant hill removal is key since they also use toxic aerosols to achieve their purpose. The locals recounted that ant hills have channels that potentially connect to *C. vidua* habitat and result, *C. vidua* are also terminated. Ant hills which respondents associate with the emergence of *C. vidua* may account for the current distribution of *C. vidua*.

Table 25: Excerpts from respondents on habitat destruction

No.	Reference	Quotation
1.	PART1/LM4/SIAYA/ATLAS.TI	*"Currently even the children born in 1990s do not know about C. vidua. People have dug ant hills so much especially when they want to use the soil from ant hill to smear houses."*
2.	PART8/LM4/HBAY/ATLAS.TI	*"People started digging out ant hills and there has been less rainfall; these has made the population of C. vidua to start reducing during emergence."*
3.	PART5/LM4/KSM/ATLAS.TI	*"People destroyed ant hills because the ants cause damages to people's houses."*

4.2.5 Lower midland 5

Climate change: LM 5 is not prone to rainfall like other lower midland zones, however, participants reported on the aspect of climate change over the decades.

This zone is known for little rainfall per annum ranging between 700mm -800 mm, despite that, participants have reported a decline in rainfall amount over the years with an increase in temperature which ranges between 22.4 – 22.7^0 C *(*Jaetzold *et al*.,2009). *C. vidua* is known to participants to emerge during the rainy season. The respondents noted that the decline in rain experienced with increased temperature has contributed to the disappearance of the insect.

Table 26: Excerpts from respondents on climate change

No.	Reference	Quotation
1.	PART5/LM5/KSM/ATLAS.TI	*"We had a lot of rainfall compared in the past years because there were many trees which have been cut; many trees and bushes attracted rainfall."*
2.	PART7/LM5/HBAY/ATLAS.TI	*"Currently this place has high temperature that could be leading to the disappearance of C. vidua. This is drought makes the ground dwelling insects to die".*

Advancement in agricultural equipment: Technology in agriculture has made it possible for the shift from hand digging to the use of machinery in farming.

Participants have reported on the current wide use of tractors in farming as a replacement for hand-digging tools. Respondents believe that tractors are digging deep beneath the ground, hence affecting the potential habitats of *C. vidua*. This machinery also spills oil on the farm while in use along with the smoke emissions. Locals believe that the spillage and emissions are not eco-friendly to *C. vidua* and as such, they trigger their disappearance.

Carebara vidua also known by the participants as "silent" due to their nature, do not like a disturbance in the environment. Another local explained that the use of tractors causes a lot of vibration and disturbance in the C vidua environment potentially resulting in their disappearance.

Table 27: Excerpts from respondents on advancement in agricultural equipment

No.	Reference	Quotation
1.	PART3/LM5/SIAYA/ATLAS.TI	*"We were hand digging, we never used tractors on our farms. Nowadays tractors are digging deep into the soil and destroying the habitat of onyoso."*
2.	PART1/LM5/SIAYA/ATLAS.TI	*"Our method of farming has also affected them; tractors have interfered with the habitat of onyoso;*

		the older people were not allowing anyone to use tractors because they believe tractors damages the soil."

Land degradation: Participants reported frequent charcoal burning as one of the economic activities in the region. The locals noted that charcoal burning produces heat that is harmful to *C. vidua* and other soil biota components. They further stated that the smoke produced during charcoal burning has an impact on the ecosystem. Participants also explained that their effect on the air contamination and subsequent formation of acidic rain is harmful to *C. vidua* and could warrant their disappearance.

Participants talked about the current use of inorganic fertilizers and pesticides. Another respondent explained that when inorganic compounds find their way to the soil, they become toxic to *C. vidua* and its habitat.

Table 28: Excerpts from respondents on land degradation

No.	Reference	Quotation
1.	PART2/LM5/SIAYA/ATLAS.TI	*"Charcoal was being burnet but not in the high rate as it is being done today."*
2.	PART8/LM5/KSM/ATLAS.TI	*"People were not farming the crops like tomatoes that need to be sprayed with chemicals. Pesticides that people nowadays has also killed them."*

Habitat destruction: Participants reported on the destruction and removal of ant hills in the area. Ant hills were removed due to various reasons such as the use of anthill soil in making charcoal stoves, and the effect of ants on crops and temporary houses.

Participants noted that *C. vidua* emerged some distance away from the ant hills. Respondents believed that the application of toxic aerosol on ant hills interferes with soil biota composition and the subsequent disappearance of *C. vidua.*

Table 29: Excerpts from respondents on habitat destruction

No.	Reference	Quotation
1.	PART7/LM5/HBAY/ATLAS.TI	*"There were so many ant hills which have been destroyed, and the rainfall have reduced."*
2.	PART3/LM5/SIAYA/ATLAS.TI	*"They used to emerge from ant hills. The ant hills were removed and this made onyoso to relocate."*

4.3 Environmental management practices to enhance the survival of *C. vidua*

In objective 3 results, the environmental management practices in this context involve the different purposeful measures undertaken by participants in environmental and crop management which aided the survival of *C. vidua* and its habitat and this showed how *C. vidua* contributed and could contributed to food security incase these strategies will be put in place in the surrounding. The following themes were generated in all the 5 LM zones; sustainable crop management, precinct, type of tree species, soil conservation and ant hill preservation.

Sustainable crop management: When finding out the possible management practices, participants compared and contrasted the categories of fertilizers and pesticides applied before the 1980s and 2000 onwards. The concept of *integrated pest control* (IPC) *and crop management* methods was mostly applied before the 1980s with the wide selection of organic compounds. Participants gabbed on the consistent use of *Tithonia diversifolia* extracts as a pesticide in pest control, and other organic fertilizers in improving soil value during the 1980s. Participants noted that the use of organic compounds positively correlated to the distribution of *C. vidua* during the years 1980's as contributed by their characteristic of being eco-friendly to the general soil biota components, because of the abundance of *C. vidua* during the period they were being eaten raw or fried as food.

Respondents explained that the shift from organic to inorganic compounds as applied in the agricultural field is attributed to the current distribution of *C. vidua*. This gives a drive to the potential management approaches to enhance the survival of *C. vidua*. Emerging trends in IPC

and CP (crop protection) principles should therefore outline more focus on bio-organic fertilizers and pesticides, to avoid declining population.

Table 30: Excepts of respondents on sustainable crop management

No.	Reference	Quotation
1.	PART4/LM4/KSM/ATLAS.TI	*"We can moderate the use inorganic fertilizers, mix organic and inorganic to avoid much use of excessive inorganic fertilizers."*
2.	PART1/LM3/KSM/ATLAS.TI	*"We were never using chemical fertilizers, pesticides. We were just planting without fertilizers because the soil was so fertile and there was no pest."*
3.	PART4/LM2/SIAYA/ATLAS.TI	*"Farm yard manure were used in farming but nowadays people have been using DAP and CAN. Although we are practicing some sustainable agriculture such as use of Tithonia diversifolia as manure for manure for farming and as organic pesticide for fall army worm"*

Precinct: This denotes the boundaries set aside for specific activities within the AEZ. Participants stated that specific areas were set aside for charcoal burning, especially around the forested environment.

The participants noted that charcoal burning activities interferes with soil health. Soil properties and processes incorporating soil aggregate formation, biodiversity interaction, and nutrient cycle are compromised reducing the soil's capacity to meet its full function as an essential living ecosystem for the insect and microbiota. Participants, however, believed that setting aside zones for charcoal burning and post-harvest farm residue management would establish one of the best approaches to enhancing the chances of survival for *C. vidua* around forested environments which would help the community secure their delicacy as participants used to feed on them.

Participants emphasized on the categorization of brick-making zones. This is attributed to the effect of the brick kiln on soil biological components and the impact on *C. vidua* habitats. The process of brick making involves deep digging which alters soil structure. This practice directly destroys the habitats of the insect.

Table 31: Excerpts of respondents on precinct

No.	Reference	Quotation
1.	PART1/LM1/HBAY/ATLAS.TI	*"Identify one place for charcoal burning to avoid destroying many place where C. vidua could be emerging from"*
2.	PART5/LM3/KSM/ATLAS.TI	*"Forest officers should be active enough to control the burning of charcoal. If someone has to burn charcoal, then identify one corner to use to avoid destroying many places that might be the habitat of insects."*

Types of tree species: Participants, explained that *C. vidua* used to occur in large numbers due to the type of tree species that existed in the years the 1970s. Participants believed that *C. vidua* feeds on humus, and other plant decays matter. The availability of indigenous trees such as *Albizia cori*, *Markhamia Lutea*, *Prunus africana*, Soap berry trees, enhanced the formation of humus available for *C. vidua*.

Participants reiterated that the depletion of indigenous trees or their replacement with exotic trees has contributed to the current distribution of *C. vidua*. One Participant in particular, while citing *E. globulus*, explained further that humus formed from exotic tree species decay matter, are bitter and *C. vidua* cannot feed on them. The participant reiterated that some exotic tree species produce toxic compounds or smells that is not eco-friendly to the insect and other soil-living organisms. This defines the difference in morpho-functional attribution portrayed by indigenous and exotics trees in the endowment of ecosystem services.

As a management factor, participants believed that rolling back indigenous tree species, can be essential in retaining *C. vidua* in their natural ecosystem and enhancing biodiversity and food security.

Table 32: Excepts of respondents on types of tree species

No.	Reference	Quotation
1.	PART1/LM4/KSM/ATLAS.TI	*"Right now we are planting exotic trees which are different from indigenous ones that used to grow. Indigenous trees have been cut. This has led to disappearance of C. vidua."*
2.	PART2/LM1/HBAY/ATLAS.TI	*"The indigenous trees such as Albizia cori, Markhamia Lutea, Prunus africana, which existed decomposed to act as food for C. vidua, this enhanced their survival.*
3.	PART7/LM4/HBAY/ATLAS.TI	*"We should be planting trees more indigenous trees.*

Soil Conservation: This regards multiple practices and measures put in place to preserve soil health. A participant commented on the frequent occurrence of soil erosion which results in the washing away of top fertile soil and nutrients supporting soil life. Respondents explained that these factors also compromise soil ecosystem services reducing the soil productivity and multi-functional characteristics to provide habitation to *C. vidua* and soil biological composition.
Participants emphasized that afforestation, re-afforestation, and proper land use practices should be adopted to enhance the survival of *C. vidua*. enhance this will enable the community to get back to the traditional dish as they used to.

Table 33: Excerpts of respondents on soil conservation

No.	Reference	Quotation
1.	PART2/LM4/KSM/ATLAS.TI	*"We can prevent soil erosion which has been caused by deforestation leading the land bare."*

Ant-hill conservation: Participants, throughout the study, associated ant hills with the habitats of *C. vidua*. Participants emphasized that *C. vidua* was mostly emerging a few meters away from the Macrotermes mounds. This aids in explaining the distribution of *C. vidua* in the years 1970's as Macrotermes mounds flooded the plain and inhabited fields free from human interactions causing the disturbance. Participants emphasized that the change in the distribution of *C. vidua* can potentially be explained by the current destruction of ant nests as a factor due to anthropological activities. As one of the management factors, participants suggested that conservation of ant nests might be essential.

Table 34: Excerpts of respondent on ant-hill conservation

No.	Reference	Quotation
1.	PART2/LM5/SIAYA/ATLAS.TI	*"Carebara vidua lives in ant hills and the hill is cool, in the hill there is a long channel that can even reach the lake where the workers bring water."*
2.	PART5/LM4/HBAY/ATLAS.TI	*"There used to be C. vidua and termite specie in 1960s to 1990s. Ant hills were so many. Due to high population there are no uncultivated lands where we can find these ant hills and if ant hills happen to be found they are being destroyed by pouring chemicals in the dug ant hills which will spread along the ground. In the channel there are C. vidua and termite species that is, in between the ant hills. These chemical would kill any species of ants"*

CHAPTER FIVE
DISCUSSIONS

5.1 Spatio-temporal distribution of *C. vidua*

The findings of this study showed that *Carebara vidua* were emerging in large numbers across all the LMs; LM 1, LM 2, LM 3, LM 4 and LM 5, in the past years of 1960s to 1990s. This insect served as a potential delicacy in all the LM zones in Siaya, Kisumu and Homabay. As mentioned in the literature *C. vidua* is distributed across various countries and widely consumed despite facing threats of extinction. This is consistent with what Ayieko *et al*., (2012) report that *C. vidua* is one of the nutritious edible insects which is distributed widely.

The findings, however, revealed that *C. vidua* emerged during the heavy rainy season. It was a seasonal insect which could not only emerge at any time of the year but at a specified predicted month and time of the day. Rainfall was predictable until the 2000s when communities in the study areas could not when and where it will rain. The causality was related to the prevailing weather conditions during the rainy periods, which favored their survival. Apparently, the aspect of rainfall was vital in the change of soil moisture content and temperature, enticing *C. vidua* to emerge from their subterranean habitats. There was a similarity between the study of Ayieko *et al*., (2012) and this study, which agrees that *C. vidua* emerges in the morning hours at around 10:00 AM. Nevertheless, both studies found little information to deduce convincing explanations for the results.

However, besides *C. vidua* being used as food by the communities, their emergence was used to predict the agricultural activities of the calendar year. During their emergence, most agricultural activities such as land preparation, planting, and weeding were taking place; especially during the planting of maize, this period was referred to us as the "month of *C. vidua*" as people associated their emergence with planting season. *Carebara vidua* used to emerge in undisturbed land which had not been disturbed by the distraction of the vegetation and extensive agricultural activities which altered the soil. They were also emerging in silent places free from noise disturbances and distractions. These further explained their places of occurrence.

This study revealed that over the years, especially since the year 2000 the population of *C. vidua* and their frequency of emergence started dwindling in the LM zones. In other zones, they started declining earlier but in low numbers. In LM 5 (Mageta and Rusinga island) the communities have not been experiencing their emergence from 1991 and 1997 respectively. Mageta island was infested by tsetse flies which caused death to both human beings and animals between the years 1965 to 1967. The tsetse flies were controlled by the use of effective insecticides that was sprayed on the island for a long time, which potentially contributed to the decline of *C. vidua* in LM 5 than other LM 1, LM 2, LM 3 and LM 4 (Garg, 2015). The LM 5 are arid and semi-arid areas with high temperature and low rainfall, they have been lacking rainfall for a long time, and rising temperature occurs with changes in precipitation that impacted the emergence rate of the *C. vidua* due to an increase in aridification in LM 5. *Carebara vidua* is an endangered insect species that are not occurring in large numbers and is threatened with extinction. These findings were in agreement with those of Ayieko *et al*., (2012) and Christensen *et al*., (2006).

Our study noted that temperature and rainfall patterns have become less predictable and more variable across all the lower midland zones in Siaya, Kisumu, and Homabay counties. Thus, *C. vidua's* population emerging and swarming seasonally are declining and the occurrence is unpredictable because they no longer emerge every year as they used to in the past. This attributed to harsh weather conditions and extended periods of high temperatures brought about by climate change and not favoring the survival of *C. vidua* in some LM zones.

Carebara vidua is associated with termite mounds as they emerged near the termite hills because they build their nests underground in close association with termites' nests. This research confirmed the findings of Van Huis, (2021) as discussed in the introduction part. The findings showed that in between the nests of termites and *C. vidua* there is a tunnel underground that connects their nests. The moist environment of termite hills favors the survival of *C. vidua*. When *C. vidua* was about to emerge, there were signs of emergence; the workers emerge first from the holes in a line then followed by the emergence of *C. vidua*. This helps prepare for the harvesting before the insects take their nuptial flight.

5.2 Eco-climatic factors influencing the distribution of *Carebara vidua*

The findings of the study showed that over the years across the LMs there have been changes in the distribution of *C. vidua* and the population of insect emerging has reduced due to climate changes; rainfall patterns and amount since the insect is a seasonal which is associated with heavy rainfall. This study was in agreement with the study of Kiritani, (2013) which reports that the population dynamics of insects have been influenced by climate change. The rainfall pattern has changed as there used to be heavy rainfall which was predictable during the emergence of *C. vidua*. The insects were many and emerged during the period of heavy rainfall when the soil was moist since *C. vidua* is a subterranean ant. This finding confirms the study of Lewis *et al*., (2014) which stated that termites and other subterranean ants live in a moist environment in the soil. The period of emergence was associated with the agricultural calendar as the weather pattern predicted when the farm activities were to take pace. The weather pattern has changed and the population of *C. vidua* has gradually declined; the month and year of emergence can no longer be predictable as the temperature has increased affecting soil moisture content and hence the distribution of the insect. There are no previous studies that support our findings. LM 5 has become too hot due to climate change hence the insect has not been experienced for many years ago.

The findings showed that the use of farm tools such as tractors have caused damage to the habit of *C. vidua* since tractors dig deeper into the soil where the underground insects live, this also exposes the eggs or the immature insects to the hot sun during cultivation in cases where cultivation is done during the reproduction stage unlike in the past when people only use hoes and ox plow for the cultivation of land in which most of the lands were undisturbed. Tractors have caused air and noise pollution as it produces CO_2 gas which led to formation of acidic rain that destroyed the habitat of the insect. This confirms the study of Arapatsakos and Gemtos, (2008) which states that the emission of gases such as CO_2 are affecting atmospheric air and they are also deposited to the ground through rainfall. Noise and vibration made by tractors during cultivation have made the insects relocate to some unknown places as land has been disturbed and gases emitted in the air.

The finding showed that the habitat of soil-dwelling insects has been lost due to anthropogenic activities, including deforestation which has reduced the forest cover hence changing the rainfall pattern and increasing the air temperature. These have caused changes in the distribution of the insect across the LMs as its population trend are declining over the years. Charcoal burning has negatively affected the life of the underground living organism as heat generated increases the temperature of the soil which tends to kill the *C. vidua* or alter their reproduction capabilities and cause migration of these insects to another unknown place, the carbon emitted from toxic smoke also suffocates the subterranean insects. This study concurred with the study of Engstrom, (2010) which stated that fire burning influences soil-dwelling organism through soil heating and produces noxious smoke which causes death to the subterranean living organisms.

Over the years, continuous and inefficient use of chemical fertilizers, and pesticides on the farm have destroyed the ecosystem of *C. vidua*, which in turn has polluted the soil where *C. vidua* lives. Pesticides, herbicides, and fungicides have contaminated the soil and killed the soil-dwelling invertebrates. The intensive use of agrochemicals has been influenced by most research organization which have encouraged farmers to be controlling weeds, pests, and diseases, this in turn has led to the reduction of the population of *C. vidua*. emerging from their habitat. The application of aerosol chemicals in ant hill to destroy the ants has caused havoc in the environment in which *C. vidua* lives as there is a connection channel between the nests of termites and *C. vidua* underground (Garg, 2014).

The use of soil in the making of charcoal stove liners, briquettes, and bricks for economic purposes has contributed to the loss of habitat as a large surface area of soil is dug and removed. During the brick making, the heat generated increases the soil temperature which kills and suffocates the insect, the CO_2 produced during brick making is harmful to the health of subterranean insects.

Habitats of ground-dwelling insects such as *C. vidua* have been lost and destroyed through the application of harmful chemicals such as gladiators to the ant hills to kill the ants. Since the nests of *C. vidua* are built near the nests of termites, these harmful chemical spreads along the *C. vidua* nests and in turn kills them. This has affected the population dynamics of *C. vidua* over the

years across the LMs since most of them are killed and the surviving ones tend to migrate hence influencing the distribution. The ant hills were being destroyed due to competing use of land for agricultural purposes as the population increased since the available land could not support the growing population. Kerosene and salts could sometimes be used to destroy the ants in the process of destroying the ant hills this suffocates black ants as kerosene blocks the air spaces in the soil. In the 1980s backward when people never used to destroy the ant hills, *C. vidua* was emerging in plenty around the areas associated with the hills. The environment around the ant hills supported the survival of *C. vidua* because the environment is moist. The hills were being destroyed due to various reasons; ant hill soil was fertile and was used for farming, making charcoal and the ants were destroying crops and mad houses as well.

5.3 Environmental management practices to enhance the survival of *C. vidua* and its contribution to food security

The findings of the study showed that sustainable crop management was being practiced in the year 1980s backward, periods in which *C. vidua* was reported to emerge in plenty and were used as food since it was a delicacy. Organic compounds such as farm yard manure was used during planting to release nutrients and improve soil health, and organic pesticides in which a mixture of *Tithonia diversiflia*, peppers, and ashes was also used to control pests. A study done by Chau and Heong, (2005) revealed that organic compounds have minimum fatal effects on soil insects, thus, the use of organic compounds establishes as a factor for the mass emergence of *C. vidua* in the 1980s. Contrasting the emergence between the years 1980's and 2000's forth, the current reporting on emergence of *C. vidua* is relatively lower. This emergence has been attributed to the transition and selection from organic to inorganic agrochemical fertilizers and pesticides. Environmental management for *C. vidua* should incorporate consistent use of pure organic compounds or controlled use of agrochemicals which also conserves the soil ecosystem. These will positively influence the declining population of the insect hence leading to availability of the insect in their zones of emergence. When *C. vidua* is eaten, nutrients found in it can command the diets of many people and the high increasing population, thus contributing to food security in the country.

Environmental management practices should encompass the use of narrow spectrum pesticides as the alternative component for agrochemicals in the Integrated Pesticide Management (IPM) package. The incorrect use of wide spectrum agrochemicals with the inconsiderate thresh-hold level of application in crop protection and pest management has endangered the insect species This was in agreement with the study of Bueno *et al*., (2017) which reported that many insects species are endangered with the incorrect use of wide spectrum agrochemicals.

Practices such as cover cropping help to improve organic matter levels prevent soil erosion, and moderates soil temperature hence protecting *C. vidua* in the soil. Another practice is shifting cultivation which was being practiced by the communities in the early years. Mulching, crop rotation, and shifting cultivation were also some of the farming practices that were done to improve general soil health, maintain the soil temperature, and also protected soil living organisms since the soil was fertile no agricultural fertilizers and pesticides were used and this enhanced the survival of *C. vidua* because the environment surrounding the insect were less disturbed with chemicals.

According to the findings of this study, indigenous trees which were naturally grown favored the existence of *C. vidua* as these trees provided a favorable ecological condition for the survival of the insect. The leaves from these trees decomposed in the soil to form humus which was part of the food to *C. vidua* and their roots extended below ground that was absorbing water and making the environment to be moist. Indigenous trees were not sprayed with pesticide chemicals which was harmful to the natural habitat in *which C. vidua* lived and this increased their chances of survival. To support the survival of *C. vidua* mostly in areas where they are still thriving in, many indigenous trees should be planted to regenerate the natural vegetation and forest cover, the seedling or seed can be raised with the help of the Kenya Forest Research Institute (KEFRI) to assist the communities since most of the indigenous trees have disappeared due to replacement with the exotic ones. Indigenous trees were big and attracted rainfall that was also supporting the emergence of *C. vidua* since it could only emerge during periods of heavy rainfall.

Research in forestry, regeneration of natural vegetation, forests and enforcement of regulation aids in improving the diversity of plants and reduction of pressure on forests through the planting

of trees to help in curbing climate change thus creating a conducive environment for *C. vidua* and other associated ground-dwelling organisms in their natural habitat.

The findings showed that conservation measures should be put in place to prevent soil erosion which destroyed the habitat of *C. vidua*. These measures include planting barriers, live fences, and wind breaks to prevent the runoff water as the runoff waters clog the soil pores. Planting of cover crops, contour farming, and building of terraces, banks, and Fanya juu structures also helps to prevent soil erosion hence helping in preserving the habitat of *C. vidua*. This measure used to be practiced and they were associated with the emergence of *C. vidua*.

In the findings, it is shown that; the identification of one particular place for charcoal burning every time charcoal is burnt should be put into practice instead of burning them all over places where trees are cut, these controlled the rate at which fire damages the habitat of ground-dwelling insects such as *C. vidua*. The practice helped to positively influence the distribution of *C. vidua as* most areas were not affected by the fire which could not destroy the soil since the heat produced during burning sped up the soil temperature and interfered with the general surrounding where *C. vidua* could be emerging. However, when charcoal is burnt, the ground dug could be the spot of the habitat of *C. vidua,* therefore when one place is identified it will prevent many places to be dug each time.

The findings showed that ant hills were known to be associated with the emergence places of *C. vidua.* in the areas where the hills were located, *C. vidua* were emerging around those areas if not then it could take some distance of around 50 Meters to find the habitat of *C. vidua*. The ant hills were well preserved because they had a meaningful purpose of influencing the distribution of *C. vidua* and other signs such as the use of the soil from the hill to smear mud houses. Preserving these hills in the areas where *C. vidua* are still existing would help to restore them from disappearance since the environment around the ant hills is moist enough to enhance their survival.

The findings of objective 3 has shown that when all these environmental management practices are put in place to conserve the ecosystem of *C. vidua* then Kenya will be a more food secure country in terms of availability, accessibility and affordability. This is due to ever increasing

food costs in the country, however, *C. vidua* can supplement meat as the main source of proteins which is one of the most critical food components in the diet of adults and children. The insect has also been reported to fight malnutrition. These contributes to food security since in the past years the community were feeding on the insect even though they did not know the nutritional part of it.

5.4 Emerging framework for environmental management of *C. vidua*

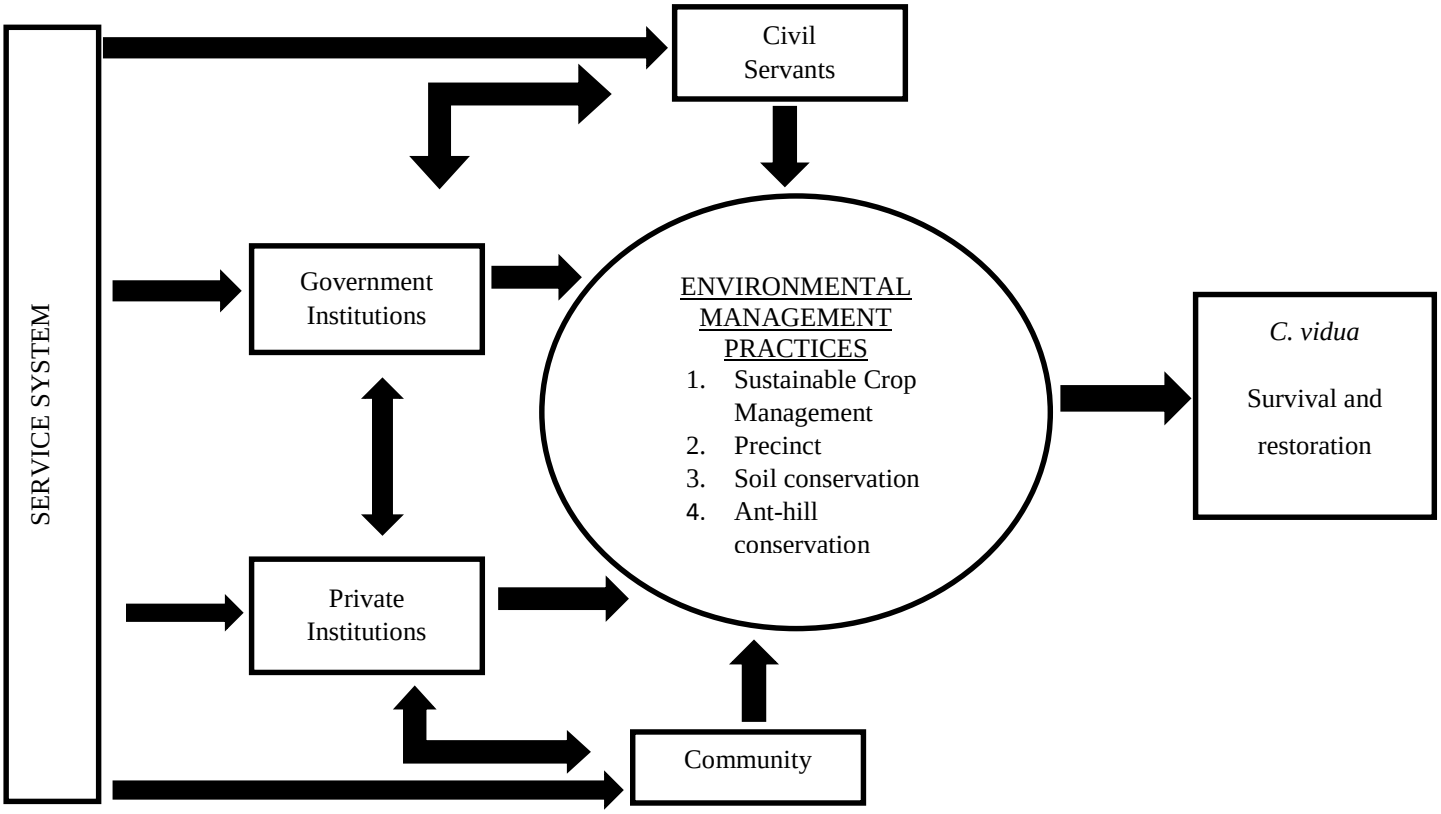

Figure 4: Emerging framework for environmental management of *C. vidua*

The service system comprises of all the key actors who have roles to play in the environmental management of *C. vidua*. Civil servants are the government employees such as SCAO, WAO, and Agricultural Extension Workers among others, who should promote the application of environmental management practices in the community. Government Institutions such as the Ministry of Agriculture, Ministry of Environment, and Parastatals should promote organic farming and proper environmental management practices. Private institutions such as Private

Agricultural and Environmental Colleges should spearhead the innovations for environmental management, whereas, the community should take charge of their environment and engage in organic farming. This model re-affirms the importance of partnership among the key actors for efficient service delivery and policy-making for environmental management practices directed towards enhancing the survival and restoration of *C. vidua.*

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 Conclusions

Carebara vidua were emerging in large numbers in all the LM zone in Siaya, Kisumu and Homabay counties. The population emerging was large between 1960s to 1990s, over the years since 2000s the population of *C. vidua* has fluctuated. There was a change in the distribution pattern and the population of insect is declining gradually even though they can still be found in some LMs such as LM 4 (Mbita and Pap Onditi), LM 2 (Rangwe and Central Alego) and LM 3 (Bondo).

Changes in the distribution of *C. vidua* were influenced by climate change and anthropogenic activities such as land degradation, and intensification of agriculture which led to the advancement of agricultural equipment, and habitat destruction. These has resulted to the decline of the population of insects hence endangered.

To overcome the gradual decline of black ants' emergence, various environmental management strategies such as sustainable crop management, precinct, planting of indigenous trees, soil conservation, ant hill preservation are presented to enhance the survival of the insect in different AEZs and enhance the contribution of *C. vidua* to food security.

6.2 Recommendations

Based on the findings of this study, the researcher recommends further studies to determine the potential for rearing of *C. vidua* to increase food security as they will be more and readily available when the insect is reared.

Awareness should also be created on the environment management, importance of biodiversity of the insect to inspire others to take action on protection of natural habitat of *C. vidua*. this can be done through airing programs on televisions, radio stations, physical meetings and establishing edible insect programs in schools.

More research studies to be done on *Carebara vidua* as there are no recent studies done about the insect and there are fewer previous studies done before. This will increase more knowledge and enable the scientists to compare and contrast the findings.

Government and other stakeholders should aid in the funding of the management of *C. vidua*, provide programs for the conservation of endangered species, and implementation of national regulations that govern the use of insects as food and feed to promote sustainable consumption.

Extension officers, SCAO, and WAO should work together with the communities to capacity build on the preparation of organic manures such as compost, farm yard, and green manures not only for crop production but also for insect habitat preservation for aid in the management of the environment.

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APPENDICES

APPENDIX 1: DATA COLLECTION TOOL FOR FGDS AND KIIS

ECOLOGICAL CONDITIONS INFLUENCING THE DISTRIBUTION OF BLACK ANTS (*Carebara vidua* Smith) AND ITS CONTRIBUTION TO FOOD SECURITY

1. **Interaction/ experience with the insect: How long have you interacted with *C. vidua?* Probe**

- Current distribution? Emergence of *C. vidua*
- The past distribution of *C. vidua?*
- The change in distribution pattern of *C. vidua?*
- When the insect was last seen.

2. **Eco climatic factors influencing distribution pattern of *C. vidua*.**

- Factors influencing change in distribution pattern
- Reason for observed change in distribution (What is responsible for change)
- What contributes to their disappearance? The reasons why the insect started disappearing? Probe
- The habitat of the insect? Where is it/was it likely to be found? within farmed land or undisturbed natural environment

3. **Land use change and how it has affected the survival of *C. vidua*.**

- Uses of the land for in the past 30 years.
    - Agricultural activities
        - Clearing of virgin land for production
        - Existence/non-existence of fallow land
        - Changes in crops grown over time
        - Others Practice agricultural production
- Were fertilizers and pesticides used in crop production
- Types of fertilizer used for crop production; Inorganic or organic fertilizers?
- Some changes in the use of land currently? Probe
- What is the topography of the land/ land forms?
- Are there some industries/ factories in this region?

- Construction activities
    - Buildings
    - Roads
- Mining
- Others (Specify)

4. Climatic conditions

- Climate at the time of disappearance (The time they started disappearing).
- Climate during emergence time (when they used to emerge).
- Adverse weather conditions in the region (such as rainfall pattern)

5. Biotic factors

- Are there predators which used to feed on *C. vidua.*
- Competition with other insects for food.

6. Management of environment that will enhance their survival and abundant (Management strategies).

- Environmental management practices in the land use to reduce threats of extinction
- Conditions that are ideal for survival of C. *vidua* (conditions under which the insect can survive).
- Changes in the management of environment that will reduce extinction threats.
- Chemical fertilizers used in the crop production
- Any sustainable management of the crops applied in the region?
- Any organization/ institution/ who has communicated/ engaged you on the vales of *C. vidua* for human well-being.
- Reduction of the carbon foot print (to combat climate change).
- Consumption of organic food (do not contain artificial fertilizers).
- Association of *C. vidua* with other plants.

APPENDIX 2: AGRO ECOLOGICAL ZONES IN WESTERN KENYA

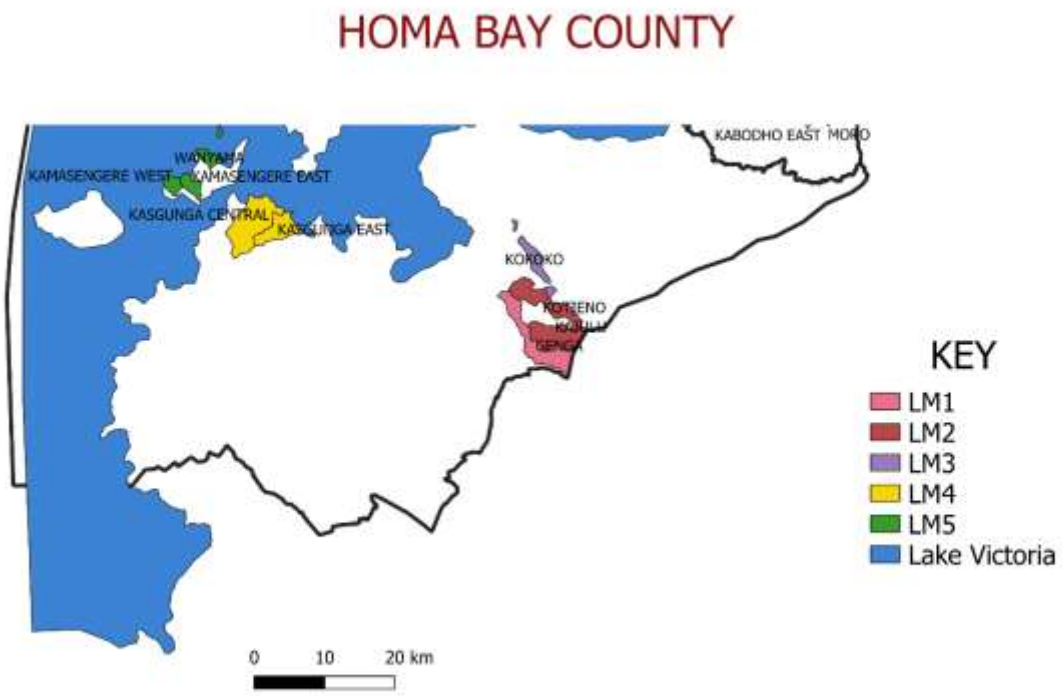

Figure 5: A map of Homabay county showing different AEZs; LM 1 to LM 5.

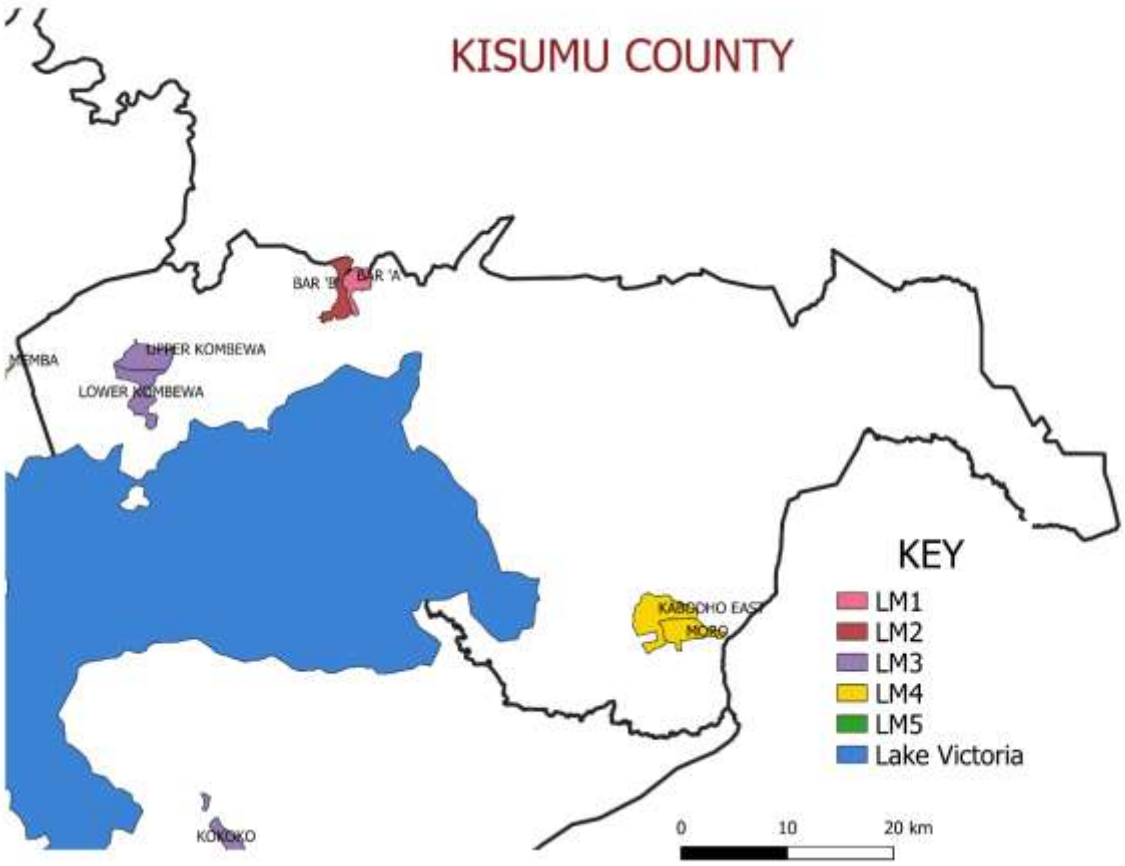

Figure 6: A map of Kisumu county showing different AEZ; LM 1 to LM 4

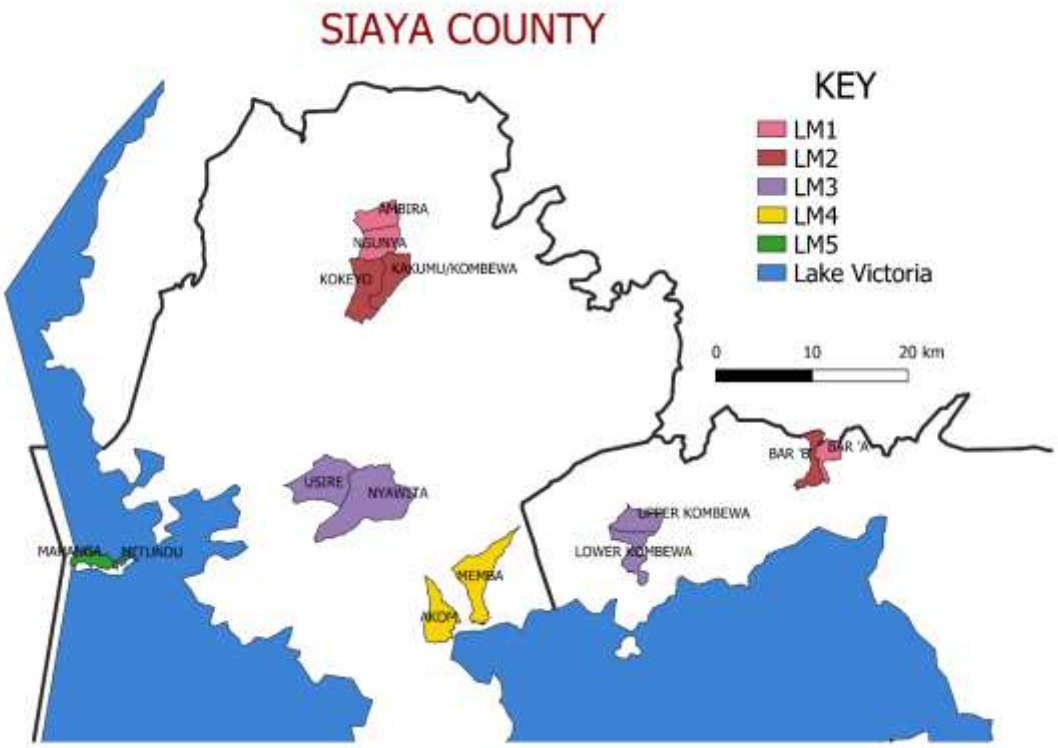

Figure 7: A map of Siaya county showing different AEZs; LM 1 to LM 5.

APPENDIX 3: PHOTOS DURING FOCUSSED GROUP DISCUSSION AND KEY INFORMANTS INTERVIEWS

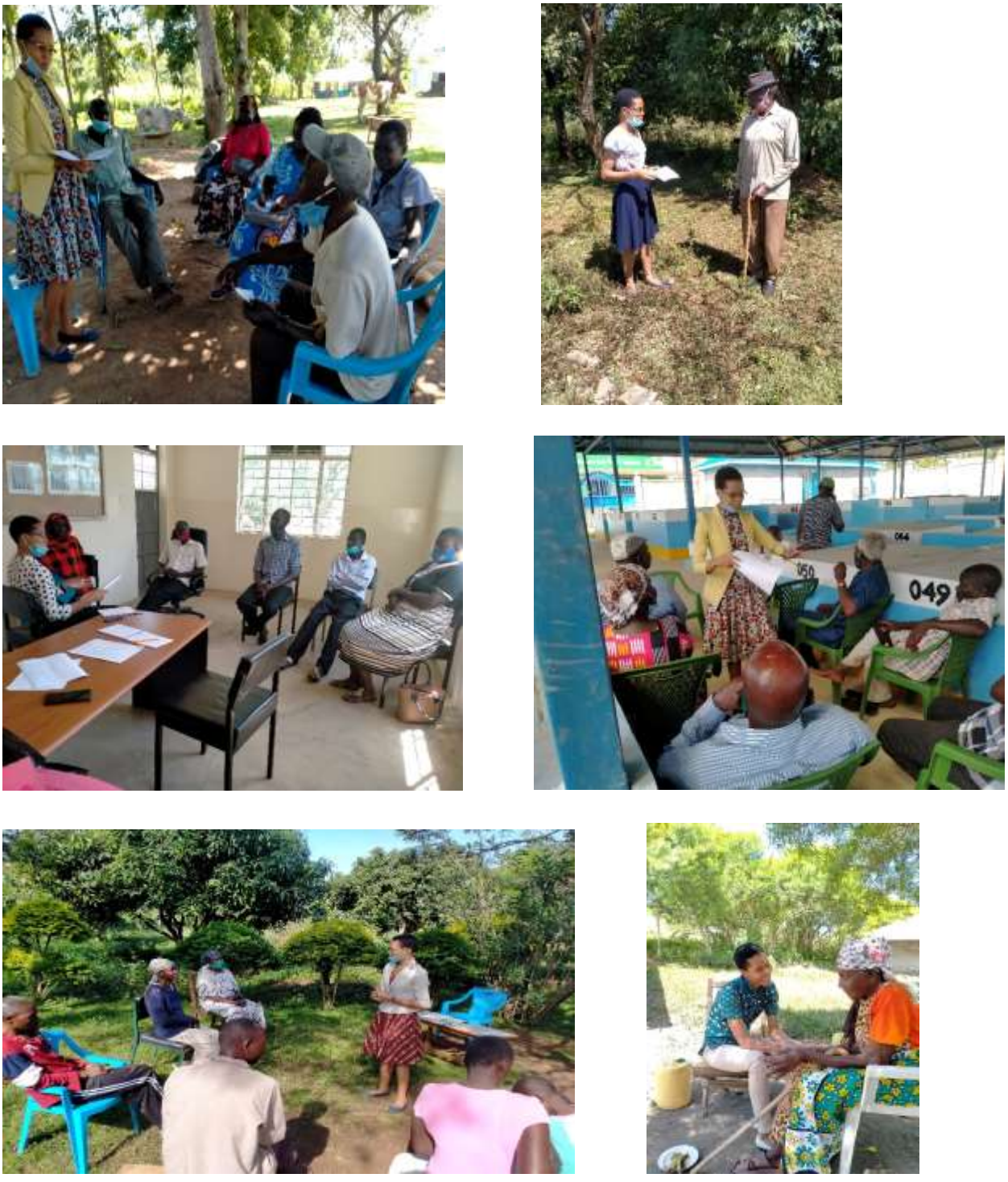

Figure 8: photos taken during FGDs and KIIs in the communities.

APPENDIX 4: RESEARCH PERMIT - NATIONAL COMMISIION FOR SCIENCE, TECHNOLOGY AND INNOVATION REDEARCH LICENCE

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **185072**

Date of Issue: **28/January/2022**

RESEARCH LICENSE

This is to Certify that Miss.. Davine Atieno Ondede of Jaramogi Oginga Odinga University of Science and Technology, has been licensed to conduct research in Homabay, Kisumu, Siaya on the topic: ECOLOGICAL CONDITIONS INFLUENCING THE DISTRIBUTION OF BLACK ANTS (Carebara vidua Smith) AND ITS CONTRIBUTION TO FOOD SECURITY for the period ending : 28/January/2023.

License No: **NACOSTI/P/22/15335**

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NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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APPENDIX 5: BOARD OF POST GRADUATE LETTER OF AUTHORIZATION

JARAMOGI OGINGA ODINGA
UNIVERSITY OF SCIENCE AND TECHNOLOGY

DIVISION OF RESEARCH, INNOVATION AND OUTREACH
JOOUST-ETHICS REVIEW OFFICE

Tel. 057-2501804
Email: erc@jooust.ac.ke
Website: www.jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

OUR REF: JOOUST/DVC-RIO/ERC/E2

18th November, 2020

DAVINE ATIENO ONDEDE
A451/4083/2019
JOOUST

Dear Miss Ondede,

RE: APPROVAL TO CONDUCT RESEARCH TITLED *"ECOLOGICAL CONDITIONS INFLUENCING THE DISTRIBUTION OF BLACK ANTS (CAREBARA VIDUA SMITH) AND ITS CONTRIBUTION TO FOOD SECURITY"*

This is to inform you that JOOUST ERC has reviewed and approved your above research proposal. Your application approval number is **ERC/18/11/20-1.** The approval period is from 18th November, 2020 – 27th November, 2021.

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations and violations) are submitted for review and approval by JOOUST IERC.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to NACOSTI IERC within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks of affected safety or welfare of study participants and others or affect the integrity of the research must be reported to NACOSTI IERC within 72 hours.
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to JOOUST IERC.

Prior to commencing your study, you will be expected to obtain a research permit from National Commission for Science, Technology and Innovation (NACOSTI) https:oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely,

Prof. Francis Anga'wa
Chairman, JOOUST ERC
Copy to: Deputy Vice-Chancellor, RIO Director, BPS Dean, SAFS

APPENDIX 6: JOOUST ETHICS REVIEW COMMITTEE CLEARANCE LETTER

JARAMOGI OGINGA ODINGA UNIVERSITY OF SCIENCE & TECHNOLOGY

BOARD OF POSTGRADUATE STUDIES

Office of the Director

Tel. 057-2501804
Email: bps@jooust.ac.ke

P.O. BOX 210 - 40601
BONDO

Our Ref: A451/4083/2019

Date: 6th October 2020

TO WHOM IT MAY CONCERN

RE: DIVINE ATIENO ONDEDE - A451/4083/2019

The above person is a bonafide postgraduate student of Jaramogi Oginga Odinga University of Science and Technology in the School of Agricultural and Food Sciences pursuing Master of Science in Food Security and Sustainable Agriculture. She has been authorized by the University to undertake research on the topic: **"Ecological Conditions Influencing the Distribution of Black Ants (*Carebara vidua Smith*) and its Contribution to Food Security".**

Any assistance accorded her shall be appreciated.

Thank you.

JARAMOGI OGINGA O... ...
DIRECTOR BOARD OF
POST GRADUATE STUDIES
DATE .....
P.O. BOX 210 - 40601, BONDO
UNIVERSITY OF SCIENCE & TECHNOLOGY

Prof. Dennis Ochuodho
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

APPENDIX 7: PUBLICATIONS

1. **Ondede, D. A**., Ochuodho, D. O., & Ayieko, M. A. (2022). Eco-Climatic Factors Influencing the Distribution of Black Ants (Carebara vidua) in Western Kenya. Advances in entomology