DIVERSITY AND SEASONAL CHANGES OF SCALE INSECTS AND ASSOCIATED BIOTA ON CITRUS TREES IN COASTAL AND LOWER EASTERN COUNTIES, KENYA

BY

MICHAEL MATHENGE GITHAE

I56/12552/2018

(BSc. Biology-University of Nairobi (Kenya)

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL ENTOMOLOGY

UNIVERSITY OF NAIROBI

2020

Declaration and Recommendation

Declaration

This thesis is my original work and has not been presented to this or any other university for the award of a degree.

Mr. Michael Mathenge Githae

I56/12552/2018

Signature: Date: 12/11/2021

Recommendation

This thesis has been submitted to Graduate School of University of Nairobi with our approval as

University and National Museums of Kenya supervisors.

Dr. George O. Ong'amo

School of Biological Sciences, University of Nairobi

Signature: ………………… Date: 12/11/2021

Prof. John H. Nderitu

Department of Plant Science, University of Nairobi

Signature: Date: 13/11/2021

Dr. Wanja Kinuthia

National Museums of Kenya

Signature: Date: 13/11/2021

Dedication

This thesis is dedicated to my father, Peter Githae, and my mother, Lydia Githae, whose inspiration, encouragement, and support ensured I get the desired education. I also dedicate this thesis to my brothers, friends, and relatives, whose social, financial, and moral support and their continued prayers helped me complete my studies. You are a great blessing in my life.

Acknowledgement

I would like to pass my sincere gratitude to Dr. George O. Ong'amo and Prof. John Nderitu (my university supervisors) of the University of Nairobi and Dr. Wanja Kinuthia of National Museums of Kenya. Their counsel, advice, constructive criticism, guidance, and constant supervision made the completion of my Msc study and research project possible. Their invaluable support helped me in my research work and the thesis writing. My special and profound gratitude goes to the United Kingdom's Darwin Initiative scheme through The Natural History Museum, London, UK, (NHM), project 25–032, "Agriculture and biodiversity: Addressing scale insect threats in Kenya," for the financial support. Without this support, I would not have been able to conduct this research. In addition to my supervisors, I thank Dr. Gillian W. Watson (NHM) for capacity building and in the scale insect identification and Josiah Achieng of National Museums of Kenya for the assistance in insect identification. I also appreciate and thank the County governments of Kilifi, Kwale, Machakos and Makueni and the farmers for allowing me access to the study sites. Special thanks are due to the National Museums of Kenya and the University of Nairobi for providing research facilities and equipment for completion of the study. I wish to thank my fellow graduate students and laboratory colleagues for their support and encouragement during the difficult moments in my research period. Special gratitude goes to my family members for their earnest prayers, support, care, and love that helped me overcome situations when I felt like giving up. Above all this, I thank God for the fortitude and grace that He provided me with during my coursework and research; it was His provision that saw me through.

May God bless you!

Abstract

Citrus farming is a major source of revenue for large and small-scale farmers in Kenya. Despite its importance, citrus production is confronted with threats associated with pests and diseases. Together, pest infestations and disease infections cause a reduction in the quality of marketable produce, resulting to a high produce losses. Management of diseases and pests is thus vital in increasing citrus yield. In the recent past, the management of pests and diseases has solely depended on synthetic pesticides application. This does not only increase the cost of production but also associated with high health and environmental risks. The use of integrated pest management (IPM) has thus been recommended as a more sustainable alternative in the control of diseases and pests. However, knowledge of the pests and associated biota biodiversity is important in the development of any sustainable pest management strategy. A study to determine the diversity of scale insects pests and their associated biota was conducted in four counties: Kilifi and Kwale counties in the Coastal region and in Machakos and Makueni counties in the Lower Eastern counties in July/August (dry season) and in October/November (wet season), 2019. These are main citrus producing ares in the country. The study was aimed at filling the invertebrate diversity knowledge gap in the sample sites. The convenience sampling method was used to select 328 fruit orchards in the four counties. A total of 82 fruit orchards per county that were not more than 5 km on both sides of county main roads were sampled. The farms' selection was based on the availability of 10 citrus plants per farm, the height of the tree (2-3 m), and each farm's distance from the main road. A random sampling method was used to select three citrus plants per orchard, from which samples of scale insects, natural enemies, and ants were collected. The specimens were collected, properly stored, and later transported to the laboratory at the National Museums of Kenya for the identification process. 22 scale insect species were recorded belonging to four families; Diaspididae (hard scales), Coccidae (soft scales), Pseudococcidae (true mealybugs), and Monophlebidae (giant mealybugs). The Diaspididae and Coccidae were the most diverse scale insect families in both Coastal and Lower Eastern regions. In the study, four species of scale insects were recorded in Kenya for the first time; the armored scales; *Parlatoria ziziphi* (Lucas), *Parlatoria pergandii* (Comstock), *Aonidiella comperei* (McKenzie), and a soft scale; *Pulvinaria polygonata* (Cockerell). The scale insects were closely associated with the predators (coccinellids and lacewings) and attendant ants. Fourteen ladybird beetles and one lacewing species were associated with the scale insects from the sampled sites. Nine ant species in 3 subfamilies were found associating with the scale insects, facilitating pest resurgence. Seasons and regions were found to affect the abundance of scale insect pests and their associated biota in both regions. Some scale insects, attendant ants and predators species showed some varying trends between seasons and regions due to high temperatures and humidity which affected pest development. The information obtained in the study will be useful in the development of efficient control strategies against the scale insect pests improving citrus production in Kenya. The diversity of scale insect pests identified in this study will be useful in plant quarantine facilities to monitor and prevent accidental introduction of exotic-scale insect species.

Table of Contents

List of Figures

List of Tables

CHAPTER ONE

1.0 INTRODUCTION

1.1 Citrus production in the world

Citrus (Sapindales: Rutaceae) is among the major fruit crops grown globally as a food source. In addition to its importance as a food source, it also offers employment opportunities to many stakeholders in the industry (Taibi *et al.*, 2016; Aidoo, 2019). Citrus plays a crucial aspect in human diet as it is an important source of vitamin C and other essential micronutrients such as folate and potassium and in raw form, as an efficient source of diet fiber (Liu *et al*., 2012; Lv *et al.*, 2015; Tekkara *et al*., 2018). Citrus production is a revenue source in terms of international trade as it has two major markets; as fresh fruits and processed fruits (Liu *et al*., 2012; Tekkara *et al*., 2018). Citrus is ranked second after apple in the world trade (Pittaway, 2002; Kilalo, 2004).

Citrus has been cultivated over 4000 years in nearly all countries ranging from latitudes 40º N and 40º S (Pittaway, 2002; Kilalo, 2004). China, USA and Brazil are the 3 main citrus-producing countries globally, taking about 85% of the global market (Lv *et al*., 2015; Tekkara *et al*., 2018; Aidoo, 2019).

1.1.1 Origin and distribution

The origin of citrus fruits has a history full of controversy, complications, and exciting stories. The origin of citrus is believed by researchers to be sub-tropical and tropical regions of Asia: India, China, and the Malay Archipelago (Gmitter and Hu, 1990; Pittaway, 2002; Liu *et al*., 2012; Xu *et al*., 2018; Aidoo, 2019). Subsequent introduction of citrus cultivation is said to be slow in other parts of the world, such as South Europe and North Africa. Citrus was introduced to America between 1655 and 1769 by Spanish and Portuguese explorers (Liu *et al*., 2012; Aidoo, 2019). Currently, the main commercial production zones are northern and southern Mediterranean, north and south America, and their associated islands, China, Japan, Australia, and South Africa. Citrus was discovered in Africa on St Helena Island by Juan de Nova Castella (a Portuguese explorer) in 1502 from India heading home. Citrus was introduced by sailors in St Helena and was used for prevention and curing scurvy (Aidoo, 2019). In tropical and sub-tropical countries, citrus fruit production is practiced in the small-scale farming system for local sale (Kilalo, 2004).

1.1.2 Taxonomy and morphology

Citrus species are members of the Order Sapindales, family Rutaceae, genus *Citrus*. Within the family Rutaceae, genus *Citrus* belongs to subfamily Aurantioideae, tribe Citreae, subtribe Citrinae, (Davies and Albrigo, 1994; Kilalo, 2004; Lv *et al*., 2015). The tribe Citreae contains the true citrus group of six genera: *Citrus*, *Poncitrus*, *Eremocitrus*, *Microcitrus*, *Fortunella* and *Clymenia* (Davies and Albrigo, 1994; Kilalo, 2004). There is taxonomic controversy between the views of Swingle (1946) and Tanaka (1977), but it is generally agreed that there are eight cultivated citrus cultivars (Gmitter and Hu, 1990; Kilalo, 2004). They include sweet orange (*Citrus sinensis* (L) Osbeck), sour orange (*C. aurantium* Osbeck), tangerines (*C. reticulata* Blanco), grape fruit (*C. paradisi* Macf.), lemon (*C. limon* (L) Osbeck), lime (*C. aurantifolia* Swingle), shaddock (*C. grandis* Osbeck) and citron (*C. medica* Swingle) (Davies and Albrigo, 1994; Smith *et al*., 1997; Kilalo, 2004; Sun *et al*., 2015).

Citrus is an evergreen plant that grows to 4-8m tall (Kilalo, 2004). Citrus plant size control is achieved through two main types of pruning systems; heading back and thinning. The shapes of the trees vary from upright to a spreading canopy form. Citrus leaves are unifoliate. The leaf lamina ranges from very small to large; similarly, different citrus species have different petiole sizes. Flowers are either perfect or staminate and are developed either singly or in groups within leaf axils. Each flower has 4-5 sepals, 4-8 petals, 20-40 fused stamens, and 8-15 carpels, with 4-8 ovules in seeded cultivars. The fruit is a hesperidia berry, consisting of a single ovary of fused carpels surrounded by a leathery peel. The shape of the fruit is either prolate, spheroid, or oblate (Kilalo, 2004). Numerous oil glands are found in the peels. The fruit color varies from green-yellow to red-orange and deep orange. Seeds are ovoid to round and contain one to many embryos. The cotyledons' colors range from white to green (Davies and Albrigo, 1994; Kilalo, 2004).

1.2 Citrus production in Kenya

The horticultural industry (fruits, flowers and vegetables) is one of fastest growing sub-sectors in the Kenyan economy. The average annual growth rate of 20% in the sub-sector underscores the demand for Kenya's high quality produce in the world markets. It employs about 2 million people and 4.5 million directly or indirectly depend on horticulture with 95% of horticultural produce being traded domestically, and accounts for up to 21% of all agricultural exports (MoALD, 2012; Wangithi, 2019). Citrus fruits are important source of income to farmers with scarce resources, provides employment in rural areas, and for human nourishment. The production of citrus fruits occupies 13% of the total fruit production area due to low yields (Ouma, 2008). Citrus production in Kenya is ranked third after banana and mango, despite most farmers being on small-scale production (Olubayo *et al.*, 2011; Wangithi, 2019).

In the Coastal and Lower Eastern Kenya regions, citrus trees are among the most important fruit crops grown (Wangithi, 2019). Citrus species mostly grown are sweet oranges, *Citrus sinensis*; lemons, *C. limon*; limes, *C. aurantifolia*; tangerines, *C. reticulata* and grapes, *C. aurantium* (Wangithi, 2019). Citrus farming in Kenya produces 87,000 metric tonnes of fruit annually, valued at 1.7 billion shillings per annum (Mounde *et al*., 2009). However, this production does not meet the local demand, where 5-21% is supplemented by importation of the fruits (FAO, 2016). Over the last two decades, Kenya's citrus production has been declining, with no efforts to reverse the situation (FAO, 2016). This reduction has been attributed to pests and diseases, especially the Citrus greening disease. The main pests affecting citrus farming in Kenya are scale insects, whiteflies; aphids; psyllids, and the Citrus Greening disease transmitted by citrus psyllids (Kilalo *et al*., 2009; Wangithi, 2019). Among the many fruit trees infested by scale insects, the study focuses on citrus production. These trees, grown in different geographical areas, are the most preferred tropical fruits that are attacked by various scale pests.

The scale insects causing the most significant damage to citrus fruits in the country and globally are true mealybugs (Pseudococcidae), soft black scales (Coccidae), and armored scales (Diaspididae). Scale insects attack on citrus does not cause severe damage when their predators and parasitoids are present. However, non-selective pesticides have eliminated these beneficial insects, or if the attack is by an invasive species devoid of its natural enemies, damage can be catastrophic. Since the country's annual citrus production does not meet the demand (Kilalo *et al.*, 2009; Wangithi, 2019), huge amounts of citrus fruits are imported from other countries, which risks the introduction of exotic pests to the state (Wangithi, 2019). Globally, alien invasive organisms mostly contribute to agricultural, economic environmental problems. However some alien scale species are controlled efficiently through abiotic and biotic forces, whereas some lack effective natural control, and their population exponentially increases, resulting in geographic spread. Such alien species impacts negatively on the native ecosystems, threatening biotic integrity and contributing to loss of local endangered species. There is limited information on the diversity of scale insects infesting citrus and their associated biota, their pest status, or economic impact on Kenya's industry. Therefore, this study assessed the diversity and seasonal changes of scale insects on citrus trees and the associated biota, mainly natural enemies and attendant ants in Kilifi, Kwale, Machakos, and Makueni Counties in Kenya.

1.3 Statement of the problem and justification for the study

The cryptic nature of scale insects enables them to avoid detection during quarantine inspection, allowing them to thrive in non-native habitats. They can become severe pests of agriculture or local flora when accidentally introduced outside their native range, which commonly occurs without their natural enemies. According to García Morales *et al.*, 2016, about 29% of scale insects found in Kenya were introduced from other parts of the world, i.e., 66 out of 227 documented species. Low levels of taxonomic expertise and poor documentation of the local scale species faunas in sub-Saharan Africa makes identification of exotic pests found on crop and fruit during inspections at ports of entry difficult. Lack of in-country scale species expertise and relevant literature has led to the development of a project to study scale pests diversity in Kenya, of which this work is a component. Lack of identification aids and biodiversity information reduces the entomologists,' extension officers' and farmers' ability to identify citrus scale insect pests, and related biota. The broad-spectrum pesticides used are ineffective in eliminating scale insect pests. This is mainly because scale insects have a protective cover layer and natural enemies are the first casualty of chemicals applied to any plant. Pesticide use increases production costs for farmers and negatively impacts environmental, human, and animal health. Subsequently, the reduction of the natural enemies' population has led to more pest incidences, resulting in a never-ending cyclic problem. This has led to low citrus production in the country.

To reduce crop loss and improve household income, a biological control management strategy for scale insects need to be developed. This will provide a long-term reduction in pesticide use and thus improve the wide range of natural control on farms (Kondo *et al*., 2008; Mansour *et al*,. 2017). In a stable ecosystem, many scale insects attacking citrus trees and other plants have host-specific predators and parasitoids suitable for biocontrol agents. The development of sustainable integrated scale insects management requires accurate knowledge and identification of both the pests and the related biota. The present study conducted a survey to document the diversity of scale insects and their associated biota and the seasonal changes on citrus trees in the Coastal and Lower Eastern regions of Kenya. The knowledge gained will be used to develop appropriate control measures against scale insects attacking citrus trees in these regions resulting to improved income to the farmers and the country in general.

1.4 Broad objective

This study aimed at assessing the diversity and seasonal changes of scale insects and associated biota on citrus trees in Kilifi, Kwale, Machakos, and Makueni Counties of Kenya with hopes of using generated results in the development of appropriate management strategies.

1.4.1 Specific objectives

- To assess the diversity and abundance of scale insects on citrus trees in Kilifi, Kwale, Machakos, and Makueni Counties of Kenya.
- To assess the diversity and abundance of the natural enemies and attendant ants associated with scale insects attacking citrus trees in Kilifi, Kwale, Machakos, and Makueni Counties of Kenya
- To determine the seasonal changes of scale insects and associated biota in Kilifi, Kwale, Machakos, and Makueni Counties in Kenya.

1.5 Research hypothesis

Citrus trees in the Coastal and Lower Eastern counties of Kenya are attacked by diverse of scale insect species that are associated with different natural enemies and attendant ants.

1.6 Scope and limitation

The study mainly targeted small-scale citrus farmers. The factors that were used for the analysis were limited to some of the socio-economic factors and the availability of scale insects and associated biota. The counties were selected deliberately for the citrus producing-farmers only. The study was limited as to the information given since it also depended on the farmers' loyalty.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Scale insects

Scale insects are small, soft-bodied, phytophagous insects. Scale insects belongs to the Order Hemiptera, Suborder Stenorrhyncha, and Infraorder Coccomorpha; Superfamily Coccoidea, with about 8,000 described species (Gullan & Cook, 2007; Mansour *et al*., 2017). Currently, 50 scale insect families are known; 34 are extant and 16 are extinct (Kondo *et al.*, 2008; Garcia Morales *et al.,* 2016). Scale insects are grouped into different families on the basis of morphological features on the adult female's cuticle and sometimes anatomy of adult male. The families include: soft scales (Coccidae), hard scales (Diaspididae), true mealybugs (Pseudococcidae), giant mealybugs (Monophlebidae), putoids (Putoidae), felt scales (Ericococcidae), ground pearls (Margarodidae), cochineal insects (Dactylopidae), and lac insects (Keriidae) (Kondo *et al*., 2008). The largest and most dominant families according to diversity are the Diaspididae, Pseudococcidae, and Coccidae.

2.1.1 Biology of scale insects

The biology of scale insects is tremendously diverse. The body size ranges from 0.1mm to 25 mm long (Gullan & Cook, 2007; Gullan & Martin, 2009; Miller *et al*., 2014) and have different development patterns depending on species, environment, and sex. Scale insects attacking citrus trees have different reproduction modes. Most scale insects reproduce sexually where the winged adult male is attracted to the adult female by following a gradient of sex pheromones detected by his antennae for mating (Pellizzari & Germain, 2010). Some adult females reproduce parthenogenetically (without mating), for example, *Coccus viridis* (Green), *Coccus hesperidum* (Linnaeus), (García Morales *et al*., 2016) while other species reproduce through facultative parthenogenesis (if unmated) or sexually if males are present, e.g., *Planococcus citri* Risso, (CABI, 2020). This helps the species perpetuation in the absence of the males. A few scale insect species are hermaphrodite, with both male and sexual organs present in the same individual, e.g., cottony cushion scale *Icerya purchasi* Maskell (Gullan & Martins, 2009; Malumphy, 2015).

Sexual dimorphism is exhibited by scale insects; the adult female is relatively large and larviform, neotenic, sessile, and is usually able to feed. In contrast, the small adult male is winged and mobile but lacks mouthparts and cannot feed, which shortens his lifespan to a few hours or days (Kondo *et al.*, 2008; Gullan & Martins, 2009; Mansour *et al*., 2017). The adult male resembles a fly, with one pair of forewings while the hindwings are reduced to a pair of hamulohalteres used for balancing during flight. The scale insect adult male flies to a female for mating, after which most female scale insects lay eggs, usually into a waxy ovisac or a marsupium under the abdomen. The females of some scale species can lay up to 8,000 eggs per individual, e.g., the cottony maple scale, *Neopulvinaria immunerabilis* (Coccidae) (Pellizzari & Germain, 2010). Other scale insects can give birth to first-instar nymphs known as crawlers, which move to new feeding sites on the plant and are responsible for dispersal. In the female, the eggs hatch into crawlers with three larval instars before the larviform adult stage. The male undergoes two feeding nymphal instars before molting to a non-feeding pre-pupa, then a non-feeding pupa, and finally to the winged adult male (Kondo *et al.*, 2008).

2.1.2 Effects of scale insects on citrus

Scale pests inflict direct damage to citrus trees by extracting plant sap containing water and nutrients, thus reducing the host plant vigor and causing wilting. During the feeding process, toxic saliva is injected into the plant (Bhagat & Qureshi, 2016), which causes direct damage or death of the plant tissues. Massive attack results in the development of yellow chlorotic spots, leaf necrosis and premature defoliation, branch dieback, leaf and stem distortion and reduced new shoot formation, and can result in the death of the affected plant, e.g., damage by the spherical mealybug (*Nipaecoccus viridis* Newstead), (Franco *et al.*, 2004; Kondo *et al.*, 2008; Hassan *et al*., 2012; Martins *et al*., 2015; Buss & Dale, 2016). Some scale insects are also vectors of viral and bacterial diseases transmitted from one plant to another while feeding, mainly by the first-instar crawlers. Fungal infections can gain access to the plant tissues through the feeding punctures left by the first-instar nymphs. *Planococcus citri* (Risso) and *P. ficus* (Signoret) are major citrus pests; being polyphagous, they can be vectors of grapevine closterovirus type III in grapes (Ioannou *et al*., 1999; Pellizzari & Germain, 2010).

After feeding, scale insects (mealybugs and soft scales) eliminate surplus sugary fluid as honeydew, which indirectly impacts the citrus plants. Honeydew fouling of nearby surfaces acts as a substrate for the fungus growth, which later manifests into sooty moulds. The sooty moulds block light and carbon dioxide from reaching the leaves, impeding photosynthesis, causing plant productivity to decrease. The presence of sticky honeydew and black sooty moulds lowers plant products' market value and ornamental plants (Muniappan *et al.*, 2009; Martins *et al.*, 2015).

2.1.3 Dispersal of scale insects

The main dispersal stage in scale insects affecting citrus is the first nymphal instar (crawlers), which actively looks for a suitable feeding site. Crawlers can walk less than a meter but can be dispersed passively over longer distances by wind, water, and passing animals such as insects, birds, and men (Muniappan *et al.*, 2008). Due to the small size and cryptic habits of scale insects, the movement of infested plant material by humans in trade has led to their spread worldwide. After finding a suitable host, the crawler starts feeding using sharp stylets to pierce plant tissues. As a result, a higher reproduction rate starts (Pellizari & Germain, 2010).

2.2 Pests and diseases of citrus

Citrus plants are greatly affected by pests and diseases (Kilalo *et al*,. 2009), resulting in a drop in citrus production in Kenya. Citrus production experienced a significant decline from 129,532 tonnes/ha in 2003 to 1154 tonnes/ha in 2013 in Kenya (Gitahi, 2018; Wangithi, 2019), resulting to low farm income, food insecurity, and unemployment. This was due to the effects of diseases and pest attacks that are difficult to control. Food security in Kenya is greatly affected by pests, diseases, and weeds, where 50% of the yield is lost before harvest (Kilalo *et al*,. 2009). Infestations by newly introduced scale insects have led up to 91% of crop loss, particularly papaya, on some Kenyan farms in recent years (Macharia *et al*., 2017).

Most scale insects are not good vectors of diseases as they are sedentary except for most mealybugs as they are able to move from one plant to another and are good vectors of viruses to various plant varieties (Mani & Shivaraju *et al*,. 2016). Nineteen species of mealybugs belonging to 13 genera are known to occur on Musaceae. The Banana streak virus (BSVs) is transmitted by citrus mealybugs (*Planococcus citri* (Risso)) and sugarcane mealybug (*Saccharicoccus sacchari* (Cockerell)), both of which colonize bananas. Citrus mealybug also transmits Grapevine leafroll disease in grapes and Piper Yellow Mottle Virus in pepper (Mani & Shivaraju *et al*,. 2016).

2.2.1 Scale insects on citrus

Scale insects are amongst important pests of citrus in Kenya (Kilalo, 2004; Olubayo *et al.*, 2011). The main scale insect families known to cause damage to citrus worldwide are true mealybugs (Pseudococcidae), soft scales (Coccidae), and hard scales (Diaspididae) (Kondo *et al.*, 2008; Mansour *et al.*, 2017). Most are phloem sap-sucking pests, except for the armored scales that feed on parenchyma tissues (Buss & Dale, 2016). Most of the scale insects affecting citrus worldwide are either polyphagous or oligophagous (Kilalo, 2004; Franco *et al.*, 2004; Hassan *et al*., 2012). Many scale insects become major pests after they are introduced into a new area out of the range of their natural enemies' control (Franco *et al.*, 2004). This is due to commerce and international trade.

The armored scales (Diaspididae) comprise of the most biodiverse and abundant scale insect family, with 2,648 described species worldwide (Gullan & Cook, 2007; García Morales *et al*., 2016). They are found in countries throughout the globe except in the Arctic and Antarctica's extreme cold areas (Tawfeek, 2012). Armored scale insects are most commonly transported insect group in plant trade and, thus, the most successful invasive groups of insects (Pellizari & Germain, 2010; Rachida & Mohamed, 2015). Armored scales are small in size compared to many individuals in other scale insect families, and hence, their cryptic habits facilitate their concealment in nature. They have become widespread across the world due to difficulty in detecting them on plant materials in trade (Pellizzari & Germain, 2010). The armored scales' shape varies from circular, sub-circular, oyster-form, elongate to threadlike (Hassan *et al*., 2012). They don't produce honeydew and sooty moulds; however, they secrete wax-like any other scale insects. In armored scale insects, the wax is attached to the exuviae to form a roof-like scale cover for protection (Hassan *et al*., 2012). Many notorious pests of citrus fruits in the world belong to this family introduced as alien species during trade (Pellizari & Germain, 2010; Dao *et al.*, 2018). Armored scale insects usually attack plants with a lifespan of more than one year, such as citrus, palms, and forest trees (Çalişkan & Ulusoy, 2017). The diaspidids reported to damage citrus trees in Kenya are California red scale (*Aonidiella aurantii* (Maskell)), Florida red scale (*Chrysomphalus aonidum* (Linnaeus)), and citrus mussel scale (*Lepidosaphes beckii* (Newman)) (Kilalo, 2004). Armored scales that are of great economic importance worldwide on citrus include; *Aonidiella aurantii*, *Chrysomphalus aonidum*, dictyospermum red scale (*Chrysomphalus dictyosperm*i (Morgan)), *Lepidosaphes beckii*, glover scale (Lepidosaphes gloverii (Packard)), chaff scale (*Parlatoria pergandii* Comstock) and black parlatoria scale (*Parlatoria ziziphi* (Lucas)), (Pellizzari & Germain, 2010; Smith *et al*, 2012; Tawfeek, 2012; Jendoubi, 2018; Haddad & Ali-Ahmed, 2018; Aroua *et al.*, 2020).

The true mealybugs (Pseudococcidae) are the second diverse family, with more than 2,020 described species worldwide (Wakgari & Giliomee, 2005; Gullan & Cook, 2007; García Morales *et al*., 2016). Most true mealybugs are polyphagous, while a few are host species-specific. Worldwide, more than sixty species of mealybugs are reported to attack citrus.

However, only a few are of economic importance as they affect fruit yield and quality (Franco *et al.*, 2004). Mealybug species that cause most economic damage on citrus trees are commonly found in tropical, subtropical, and Mediterranean regions (Franco *et al.*, 2004). These pests commonly affect the fast-growing tissues, ingesting the copious amount of plant fluids from the phloem and parenchyma tissues using sharp stylets, leading to the elimination of large quantities of honeydew. The honeydew attracts ants that use it as a source of carbohydrates. It also facilitates sooty molds development that affects the plant photosynthesis and gaseous exchange and can thus grow. The economic importance of mealybugs reflects the occurrences of recurring outbreaks and vulnerability of some citrus species. Mostly, mealybugs are occasional or minor pests of citrus, but they can become significant pests under certain conditions. The main mealybugs causing economic damage to the citrus trade in the world include citrus mealybugs (*Planococcus citri*), citriculus mealybugs (*Pseudococcus cryptus* Hempel), long-tailed mealybugs (*Pseudococcus longispinus* (Targioni Tozzetti)), obscure mealybug (*Pseudococcus viburni* Signoret), spherical mealybugs (*Nipaecoccus viridis*) and *Delottococcus aberiae* (De Lotto), (Franco *et al.*, 2004; Walton *et al.*, 2009; Martínez-Blay *et al.*, 2018).

The soft scales (Coccidae) is the third diverse scale insect family having more than 1,220 species described worldwide (Gullan & Cook, 2007; García Morales *et al*., 2016). Soft scales are small, sedentary insects attached to the citrus trees using sharp stylets for sucking plant-sap. Adult females may form crusty or waxy bumps on the plant surface (Kamel, 2010). They cause direct damage by sucking copious quantities of phloem sap from citrus twigs, leaves, stems, and fruits of the citrus trees. They eliminate copious amounts of honeydew that form a medium for sooty mold growth (Rosen, 1967). Sooty moulds give plants a sickly appearance and interfere with physiological activities such as photosynthesis and gaseous exchange (Kamel, 2010). Soft scales have been previously reported as pests of citrus trees in Kenya (Kilalo, 2004; Olubayo *et al.*, 2011). Soft scales species that have been reported attacking citrus in Kenya include; green scale, *Coccus viridis* (Green), brown scale, *Co hesperidum* (Linnaeus), soft wax scale, *Ceroplastes destructor* (Newstead) and black scale, *Saissetia oleae* (Olivier) (Kilalo, 2004; Olubayo *et al.*, 2011). Worldwide, the soft scales known to cause great economic damage to citrus include; brown scale, *Coccus hesperidum*, Florida wax scale, *Ceroplastes floridensis* (Comstock), fig wax scale, *Ceroplastes rusci* (Linnaeus), and *Saissetia oleae* (Olivier) (Rosen, 1967; Kapranas *et al.*, 2007; Gebreslasie & Meresa, 2018).

Members of the aforementioned families are serious pests of citrus trees (García Morales *et al.*, 2016). Due to their sessile habit, small size, and cryptic lifestyle, they often go undetected until significant damage has been caused to the host-plants (Baghat & Qureshi, 2016).

2.3 Beneficial insects associated with citrus pests

2.3.1 Predators

Several types of predators may be expected to be found in crops that have not been sprayed with pesticides (Kilalo, 2004). The predatory members include; ladybird beetles (Coleoptera: Coccinellidae), ground beetles (Coleoptera: Carabidae), staphylinid beetles (Coleoptera: Staphylanidae), lacewings (Neuroptera: Chrysopidae), mites (Acarina: Phytoseiidae), spiders (Araneida), hoverfly larvae (Diptera: Syrphidae) and some bugs from (Hemiptera: Heteroptera) in the families Nabidae, Anthocoridae, Reduviidae, and Pentatomidae. However, the only important families that have been used in biological pests control are Coleoptera, Diptera, Hemiptera: Heteroptera, Hymenoptera, Neuroptera, and Odonata (Koul & Dhaliwal; 2003; Kilalo, 2004). Predators have got a variety of feeding methods. Some feed by biting while others use piercing and sucking, involving the injection of powerful toxins, which quickly paralyzes the prey. Most predators are quick, fierce hunters actively searching for their food (Ferran & Dixon, 1993). Some of the predatory insects have specially adapted organs for seizing prey, such as the barbed legs of praying mantis; and the extensible labial masks of aquatic dragonfly nymphs (Debach & Rosen, 1991; Koul & Dhaliwal, 2003).

Most predatory insects are predacious in both the larval and adult stages. They feed on all stages of the prey; eggs, larval, pupal, and adult (Debach & Rosen, 1991; Kilalo, 2004). Ladybird beetles (Coleoptera: Coccinellidae) are predators, both during the larval and adult stages, and are usually brightly colored (Debach & Rosen, 1991; Kilalo, 2004; Roy *et al.*, 2011). They have been used to control many citrus pests such as scale insects, mealybugs, aphids, whiteflies, blackflies, and mites (Lo, 2000; Kilalo, 2004; Smaili *et al.*, 2009). In 1889, cottony cushion scales (*Icerya purchasi*) in California citrus groves were biologically controlled using a ladybird beetle (*Rodolia cardinalis* (Mulsant)) introduced from Australia. The predator was also used to achieve control of this pest in 25 other countries effectively. Mealybug destroyer (*Cryptolaemus montriezueri* (Mulsant)) provided effective control against *Planococcus citri* in California back in 1891. In ancient times, Chinese fruit growers used the predatory ant *Oecophylla smaragdina* (Fabricius) to control citrus pests on citrus trees (Debach & Rosen, 1991; Caltagirone & Doutt, 1989; Kairo *et al.*, 2013). In New Zealand, *Ceroplastes destructor*, a serious citrus pest there was effectively controlled using *Cryptolaemus montriezueri* and *Rhyzobius forestieri* (Mulsant) (Lo, 2000). Ladybird beetles and parasitic hymenopterans have proven invaluable in managing scale insects and mealybugs (Kilalo, 2004). Coccinellids beetles that have been reported earlier in Kenya in previous studies include *Cryptolaemus montriezueri* and *Rordonalia cardinalis* (Kilalo, 2004; Kairo *et al*., 2013). Coccinellids beetles that have been recorded as predators of these pests worldwide are*; Chilocorus bipustulatus* (Mulsant), *Ch nigrita* Mulsant, *Ch septempuctata* (Mulsant), *Ch sulphurea* (Olivier), *Cryptolaemus montriezueri*, *Exochomus spp, Harmonia axyridis* (Pallas), *Nephus reunioni* (Fursch), *Platynaspis vittigera* (Mulsant), *Rodolia cardinalis* and *Scymnus morelleti* (Thurnberg) (Franco *et al.,* 2004; Kilalo, 2004; Kern *et al*., 2006; Smaili *et al*., 2009; Niu *et al.*, 2014; Bouvet *et al*., 2019). Biological control is the best method to control scale insect pests as it is cheaper and safer than pesticides, self-regulating, and self-propagating.

2.3.2 Parasitic insects (parasitoids)

Most parasitoids are wasps (Hymenoptera: Parasitica) or flies (Diptera: Cryptochaetidae) (Gullan & Martins, 2009). Parasitoids feed on host body tissues from outside or develop inside feeding on the host's internal tissues (Mayhew & Blackburn, 1999). Most parasitic insects are protelean insects being parasitic during their larval stages only and live free lives in the adult stage (Koul & Dhaliwal, 2003). The most important parasitoids in Order Hymenoptera are the Superfamily Ichneunomoidea (Ichneumonidae and Braconidae), comprising more than 100,000 species worldwide that attack arthropods. The other key parasitic group is the Superfamily Chalcidoidea, a very diverse group with a number of species almost equal to that of Ichneunomoidea, (Koul & Dhaliwal, 2003; Kilalo, 2004, Ghahari *et al*., 2010). Most of the parasitoids found in citrus orchards are endemic in nature. This facilitates effective control of the citrus pests at any developmental stage (Kilalo, 2004). The most important parasitoids of citrus pests are ichneumoids, chalcidoids and proctotrupoids, (Rosen, 1993). The Chalcidoidae group is made up by families Encrytidae, Aphelenidae, Trichogrammatidae and Eulophidae among others; they are important parasitoids of scale insects, aphids, whiteflies, blackflies and psyllids, (Kilalo, 2004, Ghahari *et al*., 2010). The most easily detectable sign of the impact of parasitoids is the presence of emergence holes in the scale insects (Muegge & Merchant, 2014).

Parasitoids reported to eliminate citrus scale insects across the globe include *Anagyrus pseudococci* (Girault) and *Leptomastix dactylopii* (Howard), used against citrus mealybugs in Israel and *Coccidoxenoides peregrinus* (Timberlake) and *Anagyrus pseudococci* (Girault), used against citrus mealybugs in South Africa. *Aphytis lingnanensis* (Comperei) is an important parasitoid of *Aonidiella aurantii* (California red scale) (Koul & Dhaliwal, 2003; Wakgari & Giliomee, 2003; Mendel *et al*., 2016). Another biological control successfully used to control mealybugs was the use of hymenopteran parasitoids, *Anagyrus sawadai* (Ishii) (Hymenoptera: Encrytidae) used against *Pseudococcus cryptus* in the Mediterranean region (Franco *et al.*, 2004). Classical biological control was used in Japan in 1900 to control several citrus pests: *Ceroplastes rubens* Maskell was successfully controlled using an introduced encrytid, *Anicetus beneficus* (Hymenoptera: Encrytidae) (Ishii & Yasumatsu). Similarly, the arrowhead scale, *Unaspis yanonensis* (Kuwana), was successfully controlled by aphelinid wasps, *Aphytis yanonensis* (Debach & Rosen), and

Coccobius fulvus (Comperei and Annecke), 80 years after the citrus scale pests were introduced in Japan (Takagi, 2003). However, the success of a biological control strategy is dependent on many factors, particularly the accurate of the pest identification and host and the originality of the pest (as a source of potential control agents) and the quality of the crop management practices. (Kilalo, 2004).

In Kenya, biological control has not been widely used to control scale insect pests of citrus; however, it should be encouraged to reduce excessive use of pesticides, as it is safer and cheaper (Koul & Dhaliwal, 2003; Kilalo, 2004).

2.4 Ants

Many honeydew-producing sternorrhynchans like aphids, whiteflies, psyllids, and scale insects (Hemiptera: Sternorrhyncha), are major pests of citrus and produce sugary honeydew. They are visited by hymenopterans such as ants, wasps, and bees, which feed on this source of carbohydrates (Ülgentürk, 2001). Ant attendance provides mutual benefits to both the scale insects and the ants. The ants benefit as they obtain carbohydrates from the honeydew, a sugary liquid waste eliminated by the scale insects (Ülgentürk, 2001; Kenne *et al*., 2008; Mansour *et al.*, 2011). The soft scales and mealybugs benefit from the removal of honeydew from their bodies, saving them and their young ones from drowning in it or being suffocated by the sooty moulds that develop on it. The pests are also protected from predators and parasites by the attendant ants, as the ant looking for honeydew disrupts the parasitoids and predators' activities. Ants may transport scale insects to more favorable feeding sites, as the scales are mostly sedentary except for the first-instar crawler stage (Ülgentürk, 2001).

There is no substantial evidence that ants can protect coccids from predation and parasitism (Ülgentürk, 2001), but in the presence of ants, the scale insect mortality rate decreases. This, in turn, facilitates scale insect multiplication, resulting in increased plant damage (Mansour *et al.*, 2011). However, there is some evidence that the presence of ant does not affect predation and parasitism levels of scale insects; the amount of protection provided by different ant species to scale insects depends on the aggression level of the ant species (Peeters *et al*., 2017; Fanani *et al*., 2020).

Some ants construct tents (called carton shelters) over colonies of scale insects. (Peeters *et al.*, 2017). The covers provide protection from predation, parasitism, intense sunlight, and harsh weather. Close proximity with the ants in the shelters may also reduce coccid disease due to antibiotic secretions produced by the ants. This kind of protection is most beneficial to scales found in tropical climates (Ülgenturk, 2001; Shiran *et al*., 2013). Some predatory ants that are dependent on sugary honeydew, like species of *Anoplolepis*, *Oecophylla*, *Dolichoderus*, *Solenospis*, and *Azteca*, may be used for biological control of a wide range of other pests. The association of such ants with some plants like citrus has been proven to reduce pest population levels, increasing the fruit yield (Ülgenturk, 2001).

Ants associated with scale insects recorded worldwide are species of *Anonychorma*, *Anoplolepis*, *Azteca*, *Cardiocondyla*, *Cladomyrma*, *Iridomyrmex*, *Linepithema*, *Nylanderia*, *Papyrius*, *Myrmex*, *Podomyrma*, *Pseudomyrmex*, *Solenopsis*, *Tetraponera*, and *Zacryptocerus* (Bodenheimer, 1951; Way, 1963; Rosen, 1967; Buckley & Gullan, 1991; Way & Khoo, 1992; Ülgentürk, 2001; Mansour *et al*., 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study sites

The study was undertaken in Kilifi, Kwale, Machakos, and Makueni counties of Kenya, which are the main citrus production areas (Fig. 1).

Kilifi County is situated between 2º 20ˈ S and 4º S and between 39º 05ˈ E and 40º 14ˈ E and covers a total area of 12,610 km². It borders the Tana River County to the North, Taita Taveta County to the West, Mombasa County to the South, and the Indian Ocean to the East. Kilifi county lies at an altitude range of 30 m and 310 m above sea level. It receives an average rainfall of 300 mm to 1,300 mm with an average temperature of 21ºC to 34ºC. In Kilifi County, citrus is mainly produced in Kilifi North, Kilifi South and Malindi sub-counties. The main crops grown are mango, cashew nut, citrus fruit, cassava, coconut, maize, papaya, and vegetables.

Kwale County lies between 4º10ˈS and 39º 27ˈE with an area of 8,270 km². The county borders Kilifi County to the North, Tanzania to the South West, Taita Taveta County to the West and North West, and North East, Mombasa County to the East, and the Indian Ocean to the East and South East. The county lies at an altitude of between 100 m and 462 m above sea level. It has a tropical climate and receives mean yearly rainfall of 400 mm to 1,200 mm, with an average temperature of 24.2ºC to 34ºC. In Kwale county, citrus is mainly produced in Kubo South, Matuga and Lunga Lunga sub-counties. The main crops grown are mango, citrus fruit, coconut, cashew nut, cassava, papaya, maize, and sugarcane.

Machakos County lies between 01º14ˈS and 37º23ˈE, covering a total area of 5,952.9 km². It borders Nairobi and Kiambu counties to the West, Embu to the North, Kitui County to the East, Makueni County to the South, Kajiado County to the South West, and Murang'a and Kirinyaga counties to the North West. The local climate is semi-arid with hilly terrain and an altitude of 1000 m to 2100 m above sea level. The county receives a mean annual rainfall of 800 mm and mean temperature of 24º C. In the county, citrus is mainly produced in Yatta, Mwala and Kathiani sub-counties. The main crops grown are drought-resistant maize, cassava, sorghum, millet, cowpea, beans, and citrus fruit.

Makueni County covers an area of 8,034.7 km². The county borders Kajiado County to the South, Taita Taveta County to the East, Kitui County to the North, and Machakos County to the West. It occurs between 1º 35΄ S and 30º 00΄S and 37º 10΄ E and 38º 30΄E. The county is situated in the lower eastern Kenya with an arid and semi arid environment. It receives an average bi-modal rainfall of 400-1200 mm and an average temperature of 35.8ºC. The county main producing areas are Kaiti and Wote sub-counties.The main crops grown are drought-resistant maize, cassava, sorghum, millet, beans, cowpea, and citrus fruit.

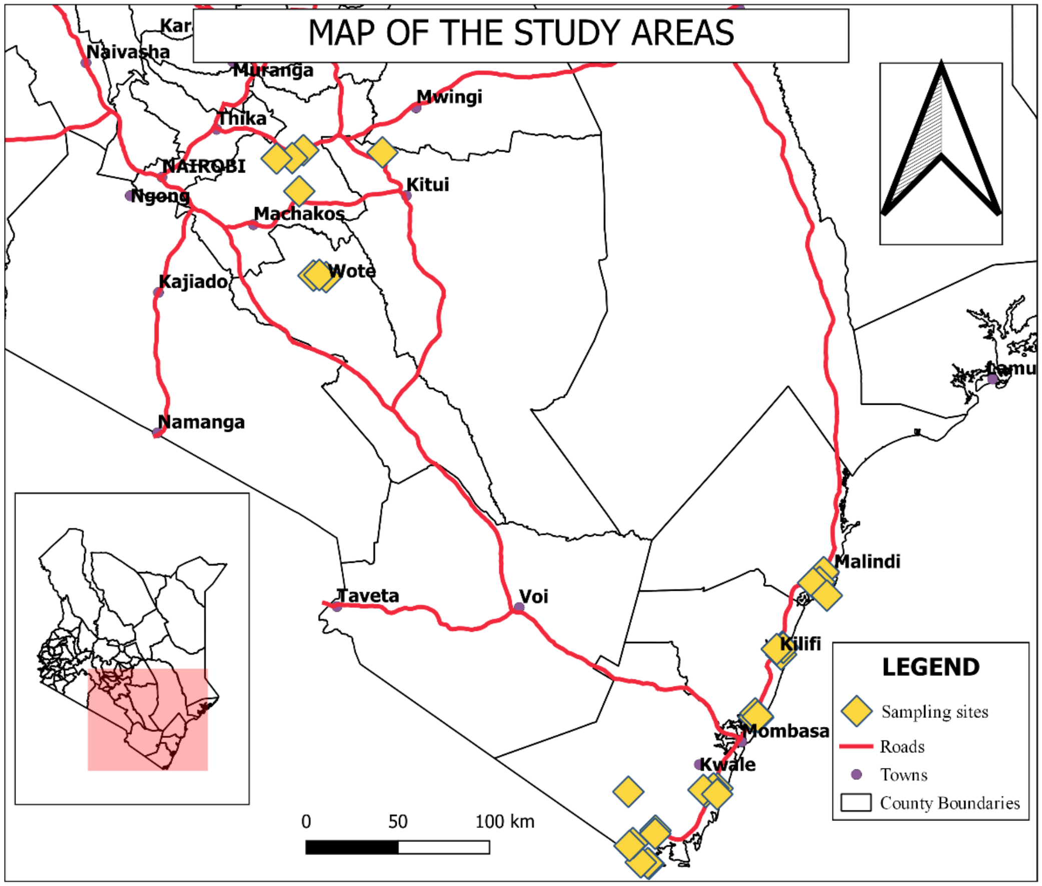

Figure 1: Map of study areas

3.2 Study design

The field surveys were conducted in July/August (dry season) and October/November (wet season), 2019 in two Coastal and two Lower Eastern counties of Kenya. A convenience sampling system was used to select 328 fruit orchards in the four counties. A total of 82 fruit orchards that were 1km to 5km on both sides of the main roads were sampled in each county for both seasons. The sample size was determined using Cochran formula (1963) as shown below:

$$n = \frac{Z^2 pq}{e^2}$$

Where

n = sample size; Z^2 = Z statistics indicating alpha level at 95% confidence level = 1.96; p = proportion of an attribute in population = 0.5; q = variance (1-p) = 0.5; e^2 = desired level of precision = 0.054

The sampling checkpoints were 10-15 km apart along the main roads that pass through the four counties, with occasional traversing through feeder roads during the survey. The farms' selection was based on the availability of 10 citrus plants per farm, the height of the tree (2-3 m), and each farm's distance from the main road. A random sampling method was used to select three plants per farm where sampling for scale insect and related biota was done. Each selected plant was inspected for scale insects, natural enemies, and ant presence on the leaves, branches, stems, and fruits. The data collected was on scale insects and associated biota species and their numbers for biodiversity analysis. Information on citrus variety, age, number of trees present on each sample site and farm management practices utilized by farmers was recorded using semi-structured questionnaires.

3.3 Collection and identification of scale insects

Identification of scale insects was based on the morphological features on the cuticle of adult females. Samples for identification were collected by cutting infested host-plant parts together with the insects to avoid damaging the cuticle and placing them in brown Khaki paper bags. The top of the paper bag containing each sample was folded, stapled and then sealed using a masking tape to prevent sample loss.

Each bag was labeled with county name, locality, GPS coordinates, collector's name, host-plant sampled, and collection date. The samples were placed in a cool box to prevent heat damage and, thereafter, transported to the laboratory at the National Museums of Kenya for sorting and identification. In the lab, the specimens were processed and mounted on slides using the methodology described in Sirisena *et al*., (2013). The scale specimen slide mounts were examined using a Zeiss compound microscope with phase contrast illumination at magnifications of ×25 to ×800. Scale insect specimens were identified to species level using unpublished keys (Watson and Ouvrard, (Submitted.); Watson, (In prep.)).

3.4 Collection and identification of parasitoids

During the sampling process, plant parts infested with scale insects were cut off. Before each sample was placed in a paper bag to be taken to the laboratory for further examination. The scale insects were examined under a hand lens for any signs of parasitoid activity (altered appearance or presence of emergence holes); any parasitized specimens were placed individually in emergence vials to capture any parasitoids that could emerge later.

3.5 Collection and identification of predators and ants

During the field sampling process, a thorough inspection of each plant's parts was conducted for any arthropod predators or any ants associated with scale insects found on the plant regardless of the developmental stage. Any available predator or ant was collected (using either an aspirator, handpicking technique, or a fine camel-hair brush, dipped in ethanol) and placed in a killing jar to immobilize it. They were transferred to a vial containing 70% ethyl alcohol with a few drops of glycerin to keep the tissues soft for easier handling during the identification process. Specimens were transported to the Invertebrates Zoology Laboratory at the National Museums of Kenya for identification. Ants and coccinellids were identified using the keys of Bolton (1994) and Hodek (2013), respectively, and by comparison with reference specimens in the national repository at the National Museums of Kenya.

3.6 Statistical analysis

The data collected was cleaned before being analyzed for internal validity. It was then coded, categorized, and tabulated. Analyses were computed using R software version 4.0.2 (R Core Team, 2019). Scale insects, predators and ant fauna abundance data was modelled using generalized linear mixed models (GLMM) as a function of region and season as the data was not normal and variances were different. The analysis was conducted using the replicates as a random factor using R package lme4 (Bates *et al*., 2015). Several models were built based on the formula (Variable ~ Region + Season + Region: Season + (1|Replicate: Region), such that terms could be added or removed from the model. The term 'Region' referred to places where sampling was done, whereas 'Season' was when the sampling was conducted. Negative binomial regression analysis was chosen as an extension of the Poisson distribution to allow for the count data with a significant proportion of zero values. When analysis of variance (ANOVA) showed significant main or interactive effects, Tukey's post-hoc comparisons were performed at $\alpha= 0.05$. Shannon diversity index (H') was computed for scale insects and related biota in each region and season. Shannon diversity *t*-test was used to compare statistical differences between regions and seasons.

CHAPTER FOUR

4.0 RESULTS

4.1 Diversity of scale insects, their associated predators and ants affecting citrus in Coastal and Lower Eastern Counties, Kenya.

Seven families of scale insects, associated predators and ants were reported in both regions and seasons Table 4.1. Taxonomically, these insect species recorded belonged to four orders: Coleoptera, Hemiptera, Hymenoptera and Neuroptera. Among the individuals collected, Coccidae and Diaspididae families showed the highest species diversity in both seasons and regions. The number of scale insect species in the family Diaspididae (33.3%) was equal in both regions and seasons. The family Monophlebidae of scale insects were the least diverse (11.1%) group on citrus in both seasons and regions.

The predatory species belonging to the order Coleoptera, family Coccinellidae and subfamily Chilocorinae were the most diverse predators (>50%) associated with scale insect pests of citrus. The diversity of Chilocorinae was higher in both the regions during the wet season (66.7%) compared to the dry season (36.4%). The diversity of species in two other coccinellid families, Ortallinae and Scymninae, was relatively low (9.1%) during the dry season, Table 4.1, with none reported during the wet season, in both regions. The green lacewing belonging to the order Neuroptera, family Chrysopidae, had low diversity (9.1%) during the dry season compared to wet season (11.1%) in the both regions during this study.

The attendant ant species sampled in the order Hymenoptera, family Formicidae and subfamily Myrmicinae, had higher diversity compared to Dolichoderinae and Formicinae in both seasons and regions. The ants in the subfamily Myrmicinae were more diverse (62.5%) during the wet season in both regions, whereas species in subfamily Dolichoderinae had the least diversity (12.5%) in both regions during the wet season, Table 4.1.

Table 4.1: Insect species diversity on citrus by taxonomic orders in Coastal and Lower Eastern counties during the dry season and wet season in 2019 (% of the total number of species)

	Order	Families	Subfamilies	Dry season	Wet season
Pests	**Hemiptera**	Coccidae		38.9	33.3
		Diaspididae		33.3	33.3
		Monophlebidae		11.1	11.1
		Pseudococcidae		16.6	22.2
Beneficial insects	**Coleoptera**	Coccinellidae	Chilocorinae	36.4	66.7
			Coccinellinae	36.4	22.2
			Ortallinae	9.1	0
			Scymninae	9.1	0
	Neuroptera	Chrysopidae	Chrysopinae	9.1	11.1
Ants	**Hymenoptera**	Formicidae	Dolichoderinae	16.6	12.5
			Formicinae	33.3	25
			Myrmicinae	50	62.5

No. of pest species in both seasons = 18; No. of beneficial insects species, wet season = 9, dry season = 11; No. of ant species, wet season = 8, dry season = 6

4.2 Scale insects pests and their distribution

Twenty two scale insect species were found infesting citrus trees and were distributed in the two regions surveyed Table 4.2. and Fig 2-5. The scale insect pests belonged to four families: Coccidae (soft scales), Diaspididae (hard scales), Monophlebidae (giant mealybugs), and Pseudococcidae (true mealybugs). Eight species of Coccidae were found attacking the citrus trees, followed by seven Diaspididae then five Pseudococcidae respectively, distributed in both regions and seasons (Table 4.2). The Diaspididae species affecting citrus trees were found distributed in all four counties where the survey was conducted in both seasons. The Monophlebidae were represented by only two species on citrus trees distributed in all the four counties in both seasons, Table 4.2. In Coastal counties (Kilifi and Kwale), all scale insects species attacking citrus trees were reported except for two, papaya mealybug (*Paracoccus marginatus* Williams and Granara de Willink) and Florida wax scale (*Ceroplastes floridensis* Comstock), which were only found distributed in Lower Eastern counties (Machakos and Makueni) on lemon (*Citrus limon*) and orange (*Citrus sinensis*) respectively Table 4.2.

Table 4.2: Scale insects species attacking citrus trees and their distribution in Coastal and Lower Eastern counties, Kenya in dry season and wet season, 2019

Families	Species name	Common names	Host-plants	Klf	Kle	Mcks	Mni
Coccidae	*Ceroplastes floridensis*	Florida wax scale	*Citrus limon*	×	×	×	✓
	Ceroplastes stellifer	Stellate scale	*Citrus sinensis*	×	✓	×	×
	Coccus viridis	Coffee green scale	*Citrus sinensis*	✓	✓	×	✓
	Coccus hesperidum	Brown soft scale	*Citrus sinensis*	✓	✓	✓	×
	Eucalymnatus tesselatus	Tessellated scale	*Citrus reticulata*	✓	×	×	×
	Eucalymnatus tesselatus	Tessellated scale	*Citrus sinensis*	✓	×	×	×
	Pulvinaria polygonata	Cottony citrus scale	*Citrus sinensis*	✓	✓	×	×
	Saissetia zanzibarensis	**	*Citrus sinensis*	✓	✓	×	×
	Udinia farquharsoni	**	*Citrus sinensis*	×	✓	×	×
Diaspididae	*Aonidiella aurantii*	California red scale	*Citrus sinensis*	✓	✓	×	✓
	Aonidiella aurantii	California red scale	*Citrus reticulata*	✓	✓	✓	✓
	Aonidiella aurantii	California red scale	*Citrus limon*	✓	✓	✓	×
	Aonidiella comperei	False yellow scale	*Citrus sinensis*	✓	✓	✓	✓
	Chrysomphalus aonidum	Circular purple scale	*Citrus sinensis*	✓	✓	✓	×
	Fiorinia proboscidaria	**	*Citrus sinensis*	✓	✓	×	×
	Lepidosaphes beckii	Citrus mussel scale	*Citrus sinensis*	×	✓	✓	✓
	Parlatoria pergandii	Chaff scale	*Citrus limon*	×	✓	×	×
	Parlatoria ziziphi	Black parlatoria scale	*Citrus sinensis*	✓	✓	✓	×
Monophlebidae	*Icerya purchasi*	Cottony cushion scale	*Citrus sinensis*	✓	✓	✓	✓
	Icerya seychellarum	Seychelles scale	*Citrus sinensis*	×	✓	✓	✓
Pseudococcidae	*Crisicoccus longipilosus*	Long-tailed mealybug	*Citrus sinensis*	✓	✓	×	×
	Crisicoccus longipilosus	Long-tailed mealybug	*Citrus limon*	✓	✓	×	×
	Nipaecoccus viridis	Spherical mealybug	*Citrus sinensis*	×	✓	×	×
	Paracoccus marginatus	Papaya mealybug	*Citrus sinensis*	×	×	✓	×
	Planococcus kenyae	Coffee mealybug	*Citrus sinensis*	✓	✓	×	×
	Pseudococcus cryptus	Citriculus mealybug	*Citrus sinensis*	✓	✓	×	✓
	Pseudococcus cryptus	Citriculus mealybug	*Citrus reticulata*	✓	✓	×	✓
	Pseudococcus cryptus	Citriculus mealybug	*Citrus limon*	✓	✓	×	✓

** = Scale insect species with no common name; ✓= Present, × = Absent
Key to counties: Mcks = Machakos, Mni = Makueni, Klf = Kilifi, Kle = Kwale

Fig 2: Circular purple scale (*Chrysomphalus aonidum*) on an orange at Yatta, Machakos county
© MM 2019

Fig 3: Mussel scale (*Lepidosaphes beckii*) at Matuga, Kwale county
© MM 2019

Fig 4: Citriculus mealybugs (*Pseudococcus cryptus*) at Ukunda, Kwale county
© MM 2019

Fig 5: Giant mealybugs (*Icerya sp*.) producing honeydew at Kaiti, Makueni county
© MM 2019

4.3 Predators associated with scale insects and their distribution

Fifteen species of predators were reported to be associated with scale insects attacking citrus trees and were distributed in both regions surveyed (Table 4.3a and 4.3b; Fig 6-9). They belonged to two families Coleoptera: Coccinellidae and Neuroptera: Chrysopidae. Seven species of ladybird and one species of lacewing were found predating scale insects during the wet season, and nine species of ladybirds were found during the dry season. Only five ladybird species and one lacewing species were distributed in Coastal counties, compared to only two species in Lower Eastern counties during the wet season, whereas eight ladybird species were distributed in Coastal counties compared to only two species in Lower Eastern counties during the dry season. In both regions, the number of scale insects species preyed on by ladybirds and lacewings were relatively higher during the dry season (14 species) than during the wet season (13 species) Table 4.3a and Table 4.3b. Lacewings were only reported during the wet season in Coastal region only.

Table 4.3a: Predators associated with coccids (scale insects) and their distribution in Coastal and Lower Eastern counties, Kenya during wet season, 2019

Predator	Coccid	Host-plant of coccid	Klf	Kle	Mcks	Mni
Chilocorus sp.	*Coccus viridis*	*Citrus limon*	✓	×	×	×
Chilocorus sp.	*Lepidosaphes beckii*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Coccus hesperidum*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Coccus viridis*	*Citrus sinensis*	×	✓	×	×
Chilocorus nigrita	*Crisicoccus longipilosus*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Fiorinia proboscidaria*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Icerya seychellarum*	*Citrus sinensis*	×	✓	×	×
Chilocorus nigrita	*Lepidosaphes beckii*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Pseudococcus cryptus*	*Citrus sinensis*	×	✓	×	×
Chilocorus nigrita	*Pulvinaria polygonata*	*Citrus sinensis*	✓	×	×	×
Chilocorus bipustulatus	*Aonidiella aurantii*	*Citrus sinensis*	×	×	✓	×
Chilocorus bipustulatus	*Coccus hesperidum*	*Citrus reticulata*	×	×	✓	×
Chilocorus bipustulatus	*Coccus viridis*	*Citrus reticulata*	×	×	✓	×
Harmonia axyridis	*Icerya purchasi*	*Citrus limon*	×	✓	×	×
Harmonia axyridis	*Lepidosaphes beckii*	*Citrus sinensis*	×	✓	×	×
Exochomus flavipes	*Coccus viridis*	*Citrus sinensis*	×	×	✓	×
Exochomus flavipes	*Lepidosaphes beckii*	*Citrus sinensis*	×	×	✓	×
Exochomus ventralis	*Aonidiella comperei*	*Citrus sinensis*	✓	×	×	×
Exochomus ventralis	*Chrysomphalus aonidum*	*Citrus sinensis*	✓	×	×	×
Exochomus ventralis	*Icerya seychellarum*	*Citrus sinensis*	✓	×	×	×
Exochomus ventralis	*Parlatoria ziziphi*	*Citrus reticulata*	✓	×	×	×
Exochomus ventralis	*Pseudococcus cryptus*	*Citrus sinensis*	✓	×	×	×
Micraspis amoenola	*Coccus viridis*	*Citrus sinensis*	×	✓	×	×
Micraspis amoenola	*Parlatoria ziziphi*	*Citrus sinensis*	×	✓	×	×
Chrysopa chloris	*Aonidiella aurantii*	*Citrus sinensis*	✓	×	×	×

✓= Present; × = Absent

Key to counties: Mcks = Machakos, Mni = Makueni, Klf = Kilifi, Kle = Kwale

Table 4.3b: Predators associated with scale insects and their distribution in Coastal and Lower Eastern counties, Kenya during the dry season, 2019

Predator	Coccid	Host plant of coccid	Klf	Kle	Mcks	Mni
Chilocorus nigrita	*Aonidiella aurantii*	*Citrus sinensis*	×	×	✓	×
Chilocorus nigrita	*Ceroplastes floridensis*	*Citrus reticulata*	×	×	×	✓
Chilocorus nigrita	*Chrysomphalus aonidum*	*Citrus limon*	✓	×	×	×
Chilocorus nigrita	*Coccus viridis*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Icerya seychellarum*	*Citrus sinensis*	×	×	×	✓
Chilocorus nigrita	*Parlatoria ziziphi*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Planococcus kenyae*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Pseudococcus cryptus*	*Citrus sinensis*	✓	×	×	×
Chilocorus nigrita	*Pulvinaria polygonata*	*Citrus sinensis*	✓	×	×	×
Chilocorus bipustulatus	*Aonidiella aurantii*	*Citrus sinensis*	×	✓	×	×
Chilocorus sulphurea	*Icerya purchasi*	*Citrus sinensis*	×	×	✓	×
Chilocorus sulphurea	*Lepidosaphes beckii*	*Citrus sinensis*	×	×	✓	×
Cryptolaemus montrouzieri	*Coccus hesperidum*	*Citrus sinensis*	✓	×	×	×
Cryptolaemus montrouzieri	*Coccus viridis*	*Citrus sinensis*	✓	×	×	×
Cryptolaemus montrouzieri	*Pseudococcus cryptus*	*Citrus sinensis*	✓	×	×	×
Exochomus nigrimaculatus	*Lepidosaphes beckii*	*Citrus limon*	✓	×	×	×
Exochomus nigrimaculatus	*Lepidosaphes beckii*	*Citrus sinensis*	✓	×	×	×
Exochomus nigrimaculatus	*Chrysomphalus aonidum*	*Citrus sinensis*	✓	×	×	×
Micraspis amoenola	*Coccus viridis*	*Citrus sinensis*	×	✓	×	×
Micraspis amoenola	*Parlatoria ziziphi*	*Citrus sinensis*	×	✓	×	×
Micraspis discolor	*Aonidiella comperei*	*Citrus limon*	×	✓	×	×
Micraspis discolor	*Coccus hesperidum*	*Citrus sinensis*	×	✓	×	×
Micraspis discolor	*Coccus viridis*	*Citrus sinensis*	×	✓	×	×
Micraspis discolor	*Fiorinia proboscidaria*	*Citrus sinensis*	×	✓	×	×
Micraspis sp.	*Chrysomphalus aonidum*	*Citrus limon*	×	✓	×	×
Micraspis sp.	*Lepidosaphes beckii*	*Citrus reticulata*	×	✓	×	×
Micraspis sp.	*Parlatoria ziziphi*	*Citrus sinensis*	✓	×	×	×
Ortallia pallens	*Coccus viridis*	*Citrus sinensis*	×	✓	×	×
Ortallia pallens	*Lepidosaphes beckii*	*Citrus limon*	×	✓	×	×

✓= Present; ×= Absent

Key to counties: Mcks = Machakos, Mni = Makueni, Klf = Kilifi, Kle = Kwale

Fig 6: Black armoured lady beetle (*Exochomus nigrimaculatus*) feeding on armoured scales at Malindi, Kilifi county

Fig 7: Lady beetle (*Chilocorus sp.)* feeding in armoured scales at Mtwapa, Kilifi county

Fig 8: Lady beetle feeding (*Chilocorus sp.*) on an armored scales (*Lepidosaphes beckii)* at Kwale County

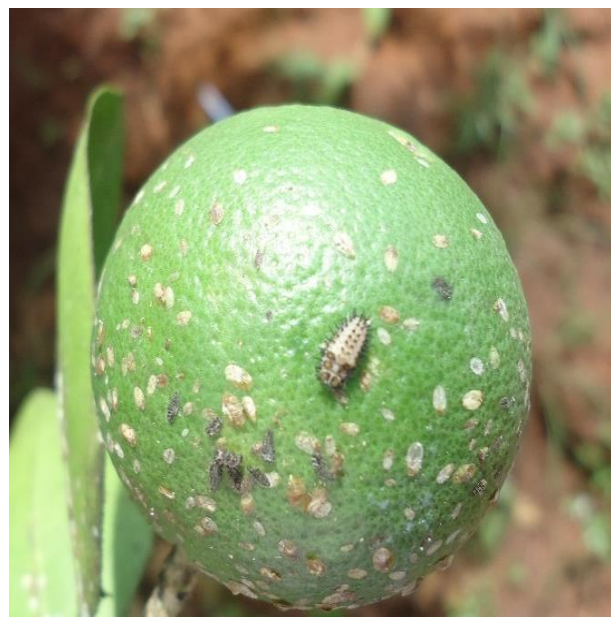

Fig 9: Ladybird beetle larvae feeding on green scales (*Coccus viridis*) at Yatta, Machakos county

4.4 Ants associated with scale insects and their distribution

Nine ant species in three subfamilies Dolichoderinae, Formicinae and Myrmicinae were reported to be attending the scale insects and were distributed in both regions Table 4.4a and Table 4.4b; Fig 10-13. During the dry season, only six scale insect species were found to be attended by ants whereas nine scale insect species were found to be attended by ants during wet season in both regions Table 4.4a and 4.4b. During the dry season, two ant species, *Oecophylla longinoda* and *Myrmicaria opaciventris* were found attending three soft scale species namely *Coccus hesperidum*, *Coccus viridis* and *Pulvinaria polygonata* at different localities. *Oecophylla longinoda* and *Pheidole sp.* were observed attending the two soft species, *Coccus viridis* and *Icerya seychellarum* during the different seasons in different localities on the same host-plant (*Citrus sinensis*). *Monomorium afrum* Andre and *Pheidole sp*. were the only attendant ant species that were not reported in the Coastal region during the both seasons whereas *Camponotus rufoglaucus*, *Cataulacus brevisetosous* and *Crematogaster sjostedti* were not reported during the dry season in both regions. The ant diversity was relatively higher in Coastal counties (7 species) compared to only one species in Lower Eastern counties during the wet season. However, during the dry season, the ant diversity was equal (3 species from each region).

Table 4.4a: Ant species attending scale insects on citrus trees and their distribution in Coastal and Lower Eastern counties, Kenya during the wet season, 2019

Subfamily	Ants	Coccid	Host-plant of the coccid	Klf	Kle	Mcks	Mni
Dolichoderinae	*Technomyrmex albipes*	*Icerya seychellarum*	*Citrus sinensis*	✓	×	×	×
	Technomyrmex albipes	*Pseudococcus cryptus*	*Citrus sinensis*	✓	×	×	×
Formicinae	*Camponotus rufoglaucus*	*Coccus hesperidum*	*Citrus limon*	✓	×	×	×
	Camponotus rufoglaucus	*Coccus viridis*	*Citrus sinensis*	✓	×	×	×
	Camponotus rufoglaucus	*Pulvinaria polygonata*	*Citrus sinensis*	✓	×	×	×
	Oecophylla longinoda	*Coccus hesperidum*	*Citrus sinensis*	×	✓	×	×
	Oecophylla longinoda	*Coccus viridis*	*Citrus sinensis*	×	✓	×	×
	Oecophylla longinoda	*Icerya seychellarum*	*Citrus sinensis*	×	✓	×	×
	Oecophylla longinoda	*Pseudococcus cryptus*	*Citrus reticulata*	✓	×	×	×
	Oecophylla longinoda	*Pulvinaria polygonata*	*Citrus sinensis*	×	✓	×	×
	Oecophylla longinoda	*Saissetia zanzibarensis*	*Citrus sinensis*	×	✓	×	×
	Oecophylla longinoda	*Undinia farquharsoni*	*Citrus sinensis*	×	✓	×	×
Myrmicinae	*Cataulacus brevisetosous*	*Coccus hesperidum*	*Citrus sinensis*	×	✓	×	×
	Cataulacus brevisetosous	*Icerya seychellarum*	*Citrus sinensis*	×	✓	×	×
	Crematogaster castanea	*Icerya seychellarum*	*Citrus sinensis*	×	✓	×	×
	Crematogaster castanea	*Coccus hesperidum*	*Citrus sinensis*	×	✓	×	×
	Crematogaster castanea	*Crisicoccus longipilosus*	*Citrus sinensis*	×	✓	×	×
	Crematogaster sjostedti	*Icerya seychellarum*	*Citrus sinensis*	×	✓	×	×
	Crematogaster sjostedti	*Icerya purchasi*	*Citrus sinensis*	×	✓	×	×
	Crematogaster sjostedti	*Pseudococcus cryptus*	*Citrus sinensis*	×	✓	×	×
	Myrmicaria opaciventris	*Coccus hesperidum*	*Citrus sinensis*	✓	×	×	×
	Myrmicaria opaciventris	*Pseudococcus cryptus*	*Citrus sinensis*	✓	×	×	×
	Myrmicaria opaciventris	*Pulvinaria polygonata*	*Citrus sinensis*	✓	×	×	×
	Pheidole sp.	*Coccus viridis*	*Citrus sinensis*	×	×	×	✓

✓= Present; × = Absent

Key to counties: Mcks = Machakos, Mni = Makueni, Klf = Kilifi, Kle = Kwale

Table 4.4b: Ant species attending scale insects on citrus trees and their distribution in Coastal and Lower Eastern counties in Kenya during the dry season, 2019

Subfamilies	Ants	Coccids	Host-plant of the coccid	Klf	Kle	Mcks	Mni
Dolichoderinae	*Technomyrmex albipes*	*Pseudococcus cryptus*	*Citrus sinensis*	✓	×	×	×
	Technomyrmex albipes	*Saissetia zanzibarensis*	*Citrus sinensis*	✓	×	×	×
Formicinae	*Oecophylla longinoda*	*Icerya seychellarum*	*Citrus sinensis*	×	✓	×	×
	Oecophylla longinoda	*Saissetia zanzibarensis*	*Citrus sinensis*	×	✓	×	×
Myrmicinae	*Crematogaster castanea*	*Coccus hesperidum*	*Citrus sinensis*	×	×	✓	✓
	Crematogaster castanea	*Icerya purchasi*	*Citrus sinensis*	×	×	✓	✓
	Myrmicaria opaciventris	*Coccus viridis*	*Citrus limon*	✓	×	×	×
	Monomorium afrum	*Coccus viridis*	*Citrus sinensis*	×	×	✓	✓
	Pheidole sp	*Coccus viridis*	*Citrus sinensis*	×	×	×	✓
	Pheidole sp	*Icerya seychellarum*	*Citrus sinensis*	×	×	×	✓

✓= Present; × = Absent

Key to counties: Mcks = Machakos, Mni = Makueni, Klf = Kilifi, Kle = Kwale

Fig 10: Ant (*Pheidole sp.*) attending soft scales at Kaiti, Makueni county
© MM 2019

Fig 11: Ant (Myrmicaria opaciventris) attending scale insects at Malindi, Kilifi county
© MM 2019

Fig 12: Ant (*Oecophylla longinoda*) attending green scales (*Coccus viridis*) at Vanga, Kwale County
© MM 2019

Fig 13: Ant (*Oecophylla longinoda*) attending mealybugs at Matuga, Kwale County
© MM 2019

4.5 Effect of region on scale insects, predators and ant species abundance

4.5.1 Scale insects

The different regions affected the abundance of scale insect fauna, Table 4.5. For instance, the average number of the scale *Aonidiella comperei* was five times more in the Coastal region (2.5 individuals per plant) compared to the Lower Eastern region (0.5 individuals per plant). The trend was also similar in *Aonidiella aurantii*, *Parlatoria ziziphi* and *Pseudococcus cryptus* with, 35.3, 13.6 and 4.4 individuals per plant in the Coastal region and 34.2, 1.6, and 0.8 individuals per plant in the Lower Eastern region respectively, Table 4.5. In the Lower Eastern region, *Coccus viridis* had a species abundance of (76.2 individuals per plant), 15 times higher than its average in the Coastal region (5.1 individuals per plant). Similarly, *Icerya seychellarum* (Westwood) abundance was four times higher in the Lower Eastern region (2.5 individuals per plant) compared to the Coast region (0.5 individuals per plant). In the Coastal region, *Icerya seychellarum* abundance showed significant differences between seasons; 1.1 individuals per plant in the wet season but only 0.1 individuals per plant in the dry season. In contrast, *Parlatoria ziziphi* in the Lower Eastern region had 3.8 individuals per plant during the dry season compared to 0.0 individuals per plant in the wet season. The abundance of this species showed significant differences in the Coastal region, where it was five times higher in the wet season (0.5 individuals per plant) compared to the dry season (0.1 individuals per plant) (Table 4.5). Shannon diversity t-test revealed a statistical difference in diversity during the dry season (Shannon t-test=10.3; d.f=4455; $p<0.001$) whereas there was no statistical difference during the wet season (Shannon t-test=66.6; d.f=7347; p=0).

The species richness was higher in Coastal region during the wet season (18 species) compared to dry season (15 species). In Lower Eastern region, the species richness was higher during the dry season (9 species) compared to 7 species during the wet season.

Table 4.5: Influence of the region on scale insects abundance (mean ± SE)

Scale insect description		Region						*p*-values		
		Coast			Lower eastern					
		Seasons								
Family	**Genera/Species**	**Dry**	**Wet**	**Mean**	**Dry**	**Wet**	**Mean**	**Region**	**Season**	**R*S**
	Aonidiella comperei	1.4±1.4^{a}	3.6±1.6^{a}	**2.5±1.5^{A}**	1.1±1.1^{a}	0.0^{a}	**0.4±0.3^{B}**	<0.001	0.628	1.000
	Aonidiella aurantii	0.0^{a}	0.4±0.4^{a}	**35.3±0.6^{A}**	30.8±9.5^{a}	38.4±18.8^{a}	**34.2±15.5^{B}**	<0.001	0.027	1.000
	Chrysomphalus aonidum	9.1±5.0^{a}	5.1±2.4^{a}	7.1± 3.9^{A}	5.2±4.9^{a}	3.0±2.7^{a}	3.9±3.8^{A}	<0.001	<0.001	1.000
Diaspididae	*Fiorinia proboscidaria*	2.3±2.3^{a}	0.7±0.7^{a}	1.4±1.2^{A}	0.0^{a}	0.0^{a}	0.0^{A}	<0.001	<0.001	1.000
	Lepidosaphes beckii	5.4±3.8^{a}	9.8±3.8^{a}	13.2±3.8^{A}	8.8±3.5^{a}	16.3±12.5^{a}	7.7±6.9^{A}	1.000	1.000	<0.001
	Parlatoria ziziphi	17.0±10.8^{a}	10.3±3.1^{a}	**13.6±7.9^{A}**	3.8±2.6^{a}	0.0^{b}	**1.6^{B}(1.7)**	<0.001	0.307	1.000
	Parlatoria pergandii	0.6^{a}0.6^{a}	0.0^{a}	0.3±0.3^{A}	0.0^{a}	0.0^{a}	0.0^{A}	<0.001	1.000	1.000
	Ceroplastes floridensis	0.0^{a}	0.0^{a}	0.0^{A}	0.6±0.6^{a}	0.0^{a}	0.2±0.2^{A}	<0.001	1.000	1.000
	Ceroplastes stellifer	0.4±0.4^{a}	0.1±0.1^{a}	0.2±0.2^{A}	0.0^{a}	0.0^{a}	0.0^{A}	<0.001	0.006	1.000
	Coccus viridis	2.6±2.2^{a}	7.6±3.6^{a}	**5.1± 3.0^{A}**	10.1±5.8^{b}	122.3±26.6^{a}	**76.2±24.6^{A}**	<0.001	0.013	0.227
Coccidae	Coccus hesperidum	6.9±3.5^{a}	4.4±2.7^{a}	5.7±3.1^{A}	0.0^{a}	7.4±11.6^{a}	4.4±3.9^{A}	1.000	<0.001	1.000
	Eucalymnatus tesselatus	0.0^{a}	0.9±1.4^{a}	0.5±0.5^{A}	0.0^{a}	0.0^{a}	0.0^{A}	1.000	<0.001	1.000
	Saissetia zanzibarensis	1.3±1.6^{a}	1.0±0.3^{a}	1.1±1.4^{A}	0.0^{a}	0.0^{a}	0.0^{A}	<0.001	0.188	1.000
	Udinia farquharsoni	0.0^{a}	0.6±0.3^{a}	0.3±0.1^{A}	0.0^{a}	0.0^{a}	0.0^{A}	<0.001	0.167	1.000
Pseudococcidae	*Nipaecoccus viridis*	0.7±0.7^{a}	0.3±0.3^{a}	0.5±0.5^{A}	0.0^{a}	0.0^{a}	0.0^{A}	<0.001	0.002	1.000
	Paracoccus marginatus	0.0^{a}	0.0^{a}	0.0^{A}	0.7±0.7^{a}	0.0^{a}	0.3±0.3^{A}	1.000	0.002	1.000
	Planococcus kenyae	0.5±0.5^{a}	0.9±0.9^{a}	0.7±0.7^{A}	0.0^{a}	0.0^{a}	0.0^{A}	<0.001	0.742	1.000
	Pseudococcus cryptus	3.4±2.4^{a}	5.4±2.3^{a}	**4.4±2.3^{A}**	0.0^{a}	1.3±1.3^{a}	**0.8±0.6^{B}**	<0.001	0.230	1.000
	Crisicoccus longipilosus	0.0^{a}	1.4±1.4^{a}	0.7±1.1^{A}	0.0^{a}	0.0	0.0^{A}	<0.001	0.001	1.000
Monophlebidae	*Icerya purchasi*	0.1±0.1^{a}	0.7±0.7^{a}	0.4±0.4^{A}	0.9±0.9^{a}	0.0^{b}	0.4±0.4^{A}	1.000	0.464	<0.001
	Icerya seychellarum	0.1±0.1^{b}	1.1±0.7^{a}	**0.6±0.5^{A}**	3.3±2.2^{a}	2.0±2.0^{a}	**2.5±2.2^{A}**	<0.001	0.307	0.139
S		15	18		9	7				
H'		1.9	2.4		1.6	1.1				

The mean shows an aggregate effect of the region on individual species. Within the rows, mean in bold and followed by a different letter in superscript are significantly different at $p < 0.05$ (n=3). The uppercase letter shows the differences based on regions while lowercase indicates differences within seasons. Means were separated based on Tukey's honest significant differences (HSD) test. S=Species richness, H'=Shannon diversity index, R*S= Interaction between regions and seasons.

4.5.2 Predators

The different regions affected the abundance of some predators (Table 4.6). For instance, the average number of *Chilocorus bipustulatus* was ten times higher in Lower Eastern region (10.7 individuals per plant) compared to the Coastal region (0.0 individuals per plant). The trend was also similar with *Ch. sulphurea* with 1.0 individuals per plant in the Lower Eastern region whereas in the Coastal region the abundance was low (0.0 individuals per plant). *Exochomus flevipes* abundance was four times higher in Lower Eastern region (4.2 individuals per plant) compared to Coast region (0.0 individuals per plant). Notably, the abundance of all three species that were significantly different was very low at the Coast region (0.0 individuals per plant). In the Lower Eastern region, species *Ch. bipustulatus* showed significant differences between the seasons; in the wet season, the average number of individuals was 13 times higher (22.3 individuals per plant) than in the dry season (1.7 individuals per plant) (Table 4.6).

Shannon diversity t-test revealed a statistical difference in diversity (Shannon t-test=8.9; d.f=130; $p<0.001$) during the dry season whereas there was no statistical difference during the wet season **(**Shannon t-test=0.9; d.f=579; p=0.394**)** between the regions. The species richness of the predators was higher in Coastal region (7 species) during the dry season compared to wet season (4 species). In Lower Eastern region, species richness was similar where four species were reported in each season.

Table 4.6: Predators abundance (mean ± SE) influenced by the region (n=3)

Ladybird description		Region						*p*-values		
		Coast			Lower eastern					
		Seasons								
Family	**Genera/Species**	**Dry**	**Wet**	**Mean**	**Dry**	**Wet**	**Mean**	**Region**	**Season**	**R*S**
Chilocorinae	*Chilocorus sp.*	0.2±0.1[a]	0.0[a]	0.1±0.1[A]	0.0[a]	0.0[a]	0.0[A]	0.235	1.000	1.000
	Chilocorus nigrita	4.2±1.9[a]	9.5±4.6[a]	6.3±3.2[A]	4.7±1.9[a]	1.5±1.1[a]	3.3±1.6[A]	1.000	<0.001	0.281
	Chilocorus bipustulatus	0.0[a]	0.0[a]	**0.0[B]**	1.7±0.6[b]	22.3±8.3[a]	**10.7±5.8[A]**	<0.001	<0.001	0.998
	Chilocorus sulphurea	0.0[a]	0.0[a]	**0.0[B]**	1.7±0.9[a]	0.0[a]	**1.0±0.7[A]**	<0.001	<0.001	1.000
	Exochomus multinota	0.0[a]	1.0±0.7[a]	0.4±0.4[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
	Exochomus nigrimaculatus	0.4±0.4[a]	0.0[a]	0.3±0.3[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
	Exochomus ventralis	0.0[a]	2.3±0.8[a]	0.9[A](0.5)	0.0[a]	0.8±0.6[a]	0.3±0.2[A]	0.013	<0.001	0.999
	Exochomus flavipes	0.0[a]	0.0[a]	**0.0[B]**	0.0[a]	9.7±4.3[a]	**4.2±3.0[A]**	<0.001	<0.001	1.000
Coccinellinae	*Harmonia axyridis*	0.0[a]	1.0±0.8[a]	0.4±0.5[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
	Micraspis spp	6.3±6.3[a]	0.0[a]	3.8±3.0[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
	Micraspis amoenola	3.9±3.9[a]	0.1± 0.1[a]	3.2±3.2[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
	Micraspis discolor	3.9±2.3[a]	0.0[a]	2.3±1.9[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
Ortallinae	*Ortallia pallens*	1.0±0.7[a]	0.0a	0.6±0.6[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
Scymninae	*Cryptolaemus montrouzieri*	2.6±0.9[a]	0.0[a]	1.6±1.3[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	0.909
S		7	4		4	4				
H'		1.7	0.8		1.1	0.9				

The mean gives an aggregate effect of the region. Within the rows, mean in bold and followed by different letter in superscript are significantly different at $p < 0.05$ (n=3). Uppercase letter indicate the differences based on regions while lowercase indicate differences within seasons. Means were separated based on Tukey's honest significant differences (HSD) test. S= Species richness, H'= Shannon diversity index, R*S= Interaction between regions and seasons.

4.5.3 Ants

The different regions affected the abundance of some ant species (Table 4.7). For instance, *Oecophylla longinoda* abundance was higher in the Coastal region (64.2 individuals per plant) than in the Lower Eastern region (0.0 individuals per plant). In contrast, *Pheidole sp*. ant had a higher abundance in the Lower Eastern region (43.5 individuals per plant) compared to the Coastal region, where the abundance was 0.0 individuals per plant, (Table 4.7).

Shannon diversity t-test revealed a statistical difference in diversity (Shannon t-test=5.9; d.f=105; $p<0.001$) during the dry season as well as during the wet season (Shannon t-test=11.4; d.f=1719; $p<0.001$). The species richness of the ants was higher during the wet season in Coastal region (7 species) compared to 4 species during the dry season. In Lower Eastern region the species richness was similar in both seasons (3 species per season).

Table 4.7: Ant abundance (mean ± SE) influenced by region (n=3)

Ant description		**Region**						**p-values**		
		Coast			**Lower eastern**					
		Seasons								
Family	**Genera/Species**	**Dry**	**Wet**	**Mean**	**Dry**	**Wet**	**Mean**	**Region**	**Season**	**R*S**
Dolichoderinae	*Technomyrmex albipes*	9.7±6.1[a]	1.4±1.4[a]	2.8±2.8[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
Formicinae	*Camponotus rufoglaucus*	0.0[a]	4.3±3.2[a]	3.6±2.9[A]	0.0[a]	0.0[a]	0.0[A]	<0.001	<0.001	1.000
	Oecophylla longinoda	24.4±7.6[a]	72.8±26.4[a]	**64.2±24.7[A]**	0.0[a]	0.0[a]	**0.0±0.0[B]**	<0.001	<0.001	1.000
Myrmicinae	*Crematogaster castaneas*	37.0±22.5[a]	5.9±3.5[a]	11.3±9.8[A]	5.0±2.4[a]	15.9±8.3[a]	12.8±10.4[A]	0.679	<0.001	<0.001
	Crematogaster sjostedti	0.0[a]	3.8±3.7[a]	3.2±3.1[A]	0.0[a]	5.6±4.2[a]	4.0±3.5[A]	1.000	<0.001	1.000
	Monomorium afrum	0.0[a]	0.0[a]	0.0[A]	3.3±1.5[a]	0.0[a]	0.9±0.8[A]	1.000	<0.001	1.000
	Myrmicaria opaciventris	42.4±19.2[a]	14.6±11.3[a]	19.5±13.0[A]	0.0[a]	0.0[a]	0.0[a]	<0.001	<0.001	1.000
	Pheidole sp.	0.0[a]	0.0[a]	**0.0[B]**	15.8±4.4[a]	54.6±18.4[a]	**43.5[A](16.0)**	<0.001	<0.001	1.000
	Cataulacus brevisetosus	0.0[a]	3.6±2.7[a]	3.0±2.8[A]	0.0[a]	0.0[a]	0.0[a]	1.000	<0.001	1.000
S		4.0	7.0		3.0	3.0				
H'		1.3	1.1		0.9	0.8				

The mean gives an aggregate effect of the region. Within the rows, mean in bold and followed by different letter in superscript are significantly different at $p < 0.05$ (n=3). Uppercase letter indicate the differences based on regions while lowercase indicate differences within seasons. Means were separated based on Tukey's honest significant differences (HSD) test. S= Species richness, H'= Shannon diversity index, R*S= Interaction between region and season

4.6 Effect of seasons on scale insects, predators and ant species abundance

4.6.1 Scale insects

Based on seasons, the abundance of some scale insects showed varying trends, Table 4.8. For instance, *Aonidiella comperei* abundance was generally higher during the wet season in the Coastal region (4.5 insects per plant in Kwale County and 2.5 insects per plant in Kilifi County), whereas in the Lower Eastern region, this species showed higher abundance during the dry season (2.9 insects per plant in Makueni County). Similarly, *Aonidiella aurantii* had higher abundance during the wet season in the Coastal region (0.8 individuals per plant in Kwale County) whereas there was no varying difference between Lower Eastern counties. *Chrysomphalus aonidum* had higher abundance during the dry season at the Coastal region (18.0 insects per plant in Kilifi County and 1.3 insects per plant in Kwale County), whereas in the Lower Eastern region abundance was higher during the wet season (7.9 insects per plant in Kwale county and 2.1 insects per plant in Kilifi County).

Fiorinia proboscidaria Green, *Coccus hesperidum* and *Nipaecoccus viridis* abundance were higher during the dry season in the Coastal region in Kwale County only, (4.2, 11.8 and 1.2 individuals per plant) than in wet season (1.7, 1.2 and 0.0 individuals per plant) respectively, (Table 4.8). *Lepidosaphes beckii*, *Parlatoria ziziphi*, *Saissetia zanzibarensis* and *Udinia farquharsoni* Newstead abundance were higher in the Coastal region, in Kwale County only during the wet season, (11.3, 10.1, 1.9 and 1.2 individuals per plant) as compared to 5.0, 7.2, 0.3 and 0.0 individuals per plant during the dry season respectively (Table 4.8). *Coccus viridis* had higher abundance in the Lower Eastern counties during the wet season (127.6 and 118.1 individuals per plant in Machakos and Makueni County respectively) whereas in the Coastal region the species abundance was two times higher in Kwale County compared to Kilifi County during the same season (10.4 and 4.5 individuals per plant respectively). During the dry season, *C. viridis* had lower abundance in the Coastal region (3.1 individuals per plant in Kilifi County and 2.2 individuals per plant in Kwale County) than in the Lower Eastern region (16.0 individuals per plant in Machakos County). *Icerya purchasi* had a higher abundance in the Lower Eastern region during the dry season (1.1 insects per plant in Makueni County and 0.9 insects per plant in Machakos County) whereas in the Coastal region the abundance was higher during the wet season (1.4 insects per plant in Kwale County). *Icerya seychellarum* abundance in the Lower Eastern region was higher during the wet season in Makueni County (8.0 insects per plant) compared to the dry season in Machakos County (4.4 insects per plant).

Based on seasons, the diversity and species richness showed varying trends in some counties. Kilifi and Kwale had higher species richness during the wet season (13 and 16 species) compared to dry season (10 and 13 species). The species richness in Lower Eastern counties was equal (5 species) in both seasons except in Machakos during the dry season that had eight species. Similarly, Kilifi and Kwale had a higher diversity index during the wet season (2.2 and 2.3) compared to 1.6 and 1.9 during the dry season. Machakos and Makueni had higher diversity index during the dry season (1.5 and 1.2) compared to the wet season (1.2 and 0.7) during wet season. (Table 4.8).

Table 4.8: Scale insects abundance (mean± SE), taxonomic richness and diversity in Coastal and Lower Eastern Counties in the dry and wet season

Scale insect description		Region								*p*-values		
		Coast				Lower eastern						
		Counties										
		Kilifi		Kwale		Machakos		Makueni				
		Seasons										
Family	**Genera/Species**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Region**	**Season**	**R*S**
Diaspididae	*Aonidiella comperei*	**0.0^{b}**	**2.5±1.1^{a}**	**2.6±2.0^{b}**	**4.5±1.8^{a}**	0.0^{a}	0.0^{a}	2.9±3.1^{a}	0.0^{a}	<0.001	0.630	1.000
	Aonidiella aurantii	0.0^{a}	0.0^{a}	**0.0^{b}**	**0.8±0.8^{a}**	36.8±11.3^{a}	47.1±22.1^{a}	20.5±6.4^{a}	31.6±14.1^{a}	<0.001	0.030	1.000
	Chrysomphalus aonidum	**18.0±7.0^{a}**	**2.1±1.1^{b}**	**1.3±1.1^{b}**	**7.9±3..0^{a}**	8.2±6.1^{a}	0.0^{a}	0.0^{a}	5.5±3.2^{a}	<0.001	<0.001	0.980
	Fiorinia proboscidaria	0.0^{a}	0.4±0.4^{a}	**4.2±3.7^{a}**	**1.0±1.0^{b}**	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	<0.001	1.000
	Lepidosaphes beckii	5.9±5.0^{a}	8.6±4.4^{a}	**5.0±2.6^{b}**	**11.0±3.1^{a}**	10.6±3.5^{a}	33.4±18.0^{a}	5.6±4.8^{a}	2.8±2.4^{a}	1.000	1.000	<0.001
	Parlatoria ziziphi	28.3±15.7^{a}	10.6±3.5^{a}	**7.2±4.2^{b}**	**10.1±2.9^{a}**	0.0^{a}	6.0±3.2^{a}	0.0^{a}	0.0^{a}	<0.001	0.030	1.000
	Parlatoria pergandii	1.2±1.2^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	1.000	1.000
Coccidae	*Ceroplastes floridensis*	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	1.5±1.5^{a}	0.0^{a}	<0.001	1.000	1.000
	Ceroplastes stellifer	0.0^{a}	0.0^{a}	0.7±0.7^{a}	0.2±0.2^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	0.010	1.000
	Coccus viridis	3.1±2.7^{a}	4.5±3.4^{a}	**2.2±1.7^{b}**	**10.4±3.8^{a}**	**16.0±7.0^{b}**	**127.6±25.0^{a}**	**0.0^{b}**	**118.1±25.1^{a}**	<0.001	<0.001	0.230
	Coccus hesperidum	1.4±1.0^{a}	8.0±3.7^{a}	**11.8±4.7^{a}**	**1.2±0.8^{b}**	0.0^{a}	17.1±17.5^{a}	0.0^{a}	0.0^{a}	1.000	<0.001	1.000
	Eucalymnatus tesselatus	0.0^{a}	2.0±2.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0$^{a.}$	0.0^{a}	0.0^{a}	1.000	<0.001	1.000
	Saissetia zanzibarensis	2.3±2.3^{a}	0.0^{a}	**0.3±0.3^{b}**	**1.9±1.9^{a}**	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	0.190	1.000
	Udinia farquharsoni	0.0^{a}	0.0^{a}	**0.0±0.0^{b}**	**1.2±1.2^{a}**	0.0^{a}	0.0a	0.0^{a}	0.0^{a}	1.000	<0.001	1.000
Pseudococcidae	*Nipaecoccus viridis*	0.0^{a}	0.5±0.5^{a}	**1.2±1.0^{a}**	**0.0^{b}**	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	<0.001	1.000
	Paracoccus marginatus	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	1.1±1.1^{a}	0.0^{a}	0.0^{a}	0.0^{a}	1.000	<0.001	1.000
	Planococcus kenyae	1.2±0.8^{a}	1.8±1.8^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	0.740	1.000
	Pseudococcus cryptus	4.9±3.1^{a}	4.6±2.1^{a}	2.0±1.7^{a}	6.2±2.4^{a}	0.0^{a}	0.0^{a}	2.4±2.3^{a}	0.0^{a}	<0.001	0.230	1.000
	Crisicoccus longipilosus	0.0^{a}	0.4±0.3^{a}	0.0^{a}	2.3±2.1^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	<0.001	1.000
Monophlebidae	*Icerya purchasi*	0.0^{a}	0.0^{a}	**0.3±0.1^{b}**	**1.4±1.1^{a}**	0.9±0.6^{a}	0.0^{a}	**1.1±0.8^{a}**	**0.0^{b}**	1.000	0.460	<0.001
	Icerya seychellarum	0.2±0.2^{a}	0.9±0.8^{a}	**0.0^{b}**	**1.2±0.6^{a}**	0.5±0.4^{a}	4.4±3.4^{a}	**8.1±4.5^{a}**	**0.0^{b}**	<0.001	0.310	0.140
S		10	13	13	16	8	5	5	5			
H'		1.6	2.2	1.9	2.3	1.5	1.2	1.2	0.7			

Mean separation was based on individual species. Within a row, values in bold followed by different superscript letters are significantly different at $p < 0.05$. S = Species richness, H′ = Shannon Wiener diversity index.

4.6.2 Predators

Based on seasons, the abundance of some predators showed varying trends (Table 4.9). For instance, *Chilocorus nigrita* showed significant differences in all the counties. Its abundance was higher during the dry season in three counties; Kilifi, Machakos and Makueni, (14.2, 1.7 and 1.7 individuals per plant respectively). During the wet season, its abundance was also higher in Kilifi, Kwale, Machakos and Makueni counties (9.9, 8.5, 1.5 and 1.5 individuals per plant respectively). *Exochomus ventralis* was three times more abundant in Kilifi County during the wet season (3.2 individuals per plant) than in the dry season (0.0 individuals per plant). Species *Harmonia axyridis* showed significant seasonal differences in Kwale County only, where the abundance was 3.7 individuals per plant during wet season compared to 0.0 individuals per plant in the dry season.

Based on seasons, diversity index and the species richness of the predators were different among counties. Kilifi and Kwale counties had a higher species richness during the dry season (5 and 4 species) compared to the wet season (3 species in both counties). Species richness in Machakos and Makueni was higher during the dry season (4 and 2 species) compared to the wet season (4 and 1 species). In Kilifi and Kwale counties, the diversity index was higher during the dry season (1.1 and 1.3) compared to the wet season (0.7 and 0.6). In Machakos and Makueni, the diversity index was higher during the wet season (1.3 and 0.5) compared to the wet season (0.9 and 0.0)

4.6.3Ants

Based on seasons, the abundance of some ants showed a varying trend (Table 4.10). The abundance of *Oecophylla longinoda* in Kwale County during the wet season was 115.7 individuals per plant compared to 0.0 individuals per plant in the dry season, whereas in

Kilifi County the abundance was higher during the dry season (28.5 individuals per plant) compared to 1.4 individuals per plant during the wet season. The abundance of *Crematogaster castanea* in Kwale County was higher in the dry season 259.0 individuals per plant compared to 9.5 individuals per plant in the wet season. The ant *Pheidole sp.* abundance was two times higher in Makueni County during the wet season (74.1 individuals per plant) compared to 31.5 individuals per plant during the dry season.

Based on seasons, diversity index and the species richness of the ants were different among the four counties. In Kilifi and Kwale counties, the species richness was higher during the wet season (5 and 4 species) compared to the dry season (3 and 2 species). In Machakos and Makueni, species richness was similar (2 species in the wet season) while Makueni county had only one species during the dry season. The diversity index in Kilifi and Kwale was higher during the wet season (1.2 and 0.4) compared to the dry season (0.5 and 0.7). In Machakos county, the diversity index was 0.7 compared to 0.0 in Makueni during the dry season. However, the diversity index was similar in both counties (0.4), during the wet season.

Table 4.9: Ladybird beetle abundance (mean ± SE), taxonomic richness and diversity in Coastal and Lower Eastern Counties during dry and wet seasons, 2019

Ladybird beetles description		**Region**								***p*- value**		
		Coast				**Lower eastern**						
		Counties										
		Kilifi		**Kwale**		**Machakos**		**Makueni**				
		Seasons										
Subfamilies	**Genera/Species**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Regions**	**Seasons**	**R*S**
	Chilocorus spp	0.3±0.1^{a}	0.0^{a}	0.0	0.0	0.0	0.0	0.0	0.0	0.24	1.00	1.00
	Chilocorus nigrita	**14.2±2.7^{a}**	**9.9±5.0^{b}**	**0.0^{b}**	**8.5±3.6^{a}**	**1.7±0.8^{a}**	**1.5±1.1^{b}**	**1.7^{a}(1.4)**	**1.5^{b}(0.6)**	1.00	<0.001	0.28
	Chilocorus bipustulatus	0.0	0.0	0.0	0.0	0.2±0.2^{a}	22.3±8.2^{a}	0.0	0.0	<0.001	<0.001	1.00
	Chilocorus sulphurea	0.0	0.0	0.0	0.0	1.1±0.5^{a}	0.0^{a}	0.8±0.8^{a}	0.0^{a}	<0.001	<0.001	1.00
Chilocorinae	*Exochomus multinota*	0.0	0.0	0.0	0.0	0.6±0.4^{a}	0.0^{a}	0.0	0.0	<0.001	1.00	1.00
	Harmonia axyridis	0.0	1.4±1.4^{a}	**0.0^{b}**	**3.7±0.8^{a}**	0.0	0.0	0.0	0.0	<0.001	<0.001	1.00
	Exochomus nigrimaculatus	1.5±0.6^{a}	0.0^{a}	0.0	0.0	0.0	0.0	0.0	0.0	0.00	<0.001	1.00
	Exochomus ventralis	**0.0^{b}**	**3.2±0.9^{a}**	0.0	0.0	0.0^{a}	0.8±0.6^{a}	0.0	0.0	0.01	<0.001	1.00
	Exochomus flevipes	0.0	0.0	0.0	0.0	0.0^{a}	9.7±4.3^{a}	0.0	0.0	<0.001	<0.001	1.00
	Micraspis spp	15.5±11.5^{a}	0.0^{a}	2.4±1.6^{a}	0.0^{a}	0.0	0.0	0.0	0.0	<0.001	<0.001	1.00
Coccinellinae	*Micraspis amoenola*	0.0	0.0	4.7±4.7^{a}	0.2±0.1^{a}	0.0	0.0	0.0	0.0	<0.001	<0.001	<0.001
	Micraspis discolor	0.0	0.0	5.5±2.8^{a}	0.0^{a}	0.0	0.0	0.0	0.0	<0.001	<0.001	1.00
Ortallinae	*Ortallia pallens*	0.0	0.0	1.4±0.8^{a}	0.0^{a}	0.0	0.0	0.0	0.0	<0.001	<0.001	1.00
Scymninae	*Cryptolaemus montriezueri*	9.0±5.4^{a}	0.0^{a}	0.0	0.0	0.0	0.0	0.0	0.0	<0.001	1.00	1.00
S		5	3	4	3	4	4	2	1			
H′		1.1	0.7	1.3	0.6	1.3	0.9	0.5	0.0			

Mean separation was based on individual species. Within a row, values in bold followed by different superscript letters are significantly different at $p < 0.05$. S = Species richness, H′ = Shannon Wiener diversity index, R*S=interaction between regions and seasons.

Table 4.10: Ant abundance (mean ± SE), taxonomic richness and diversity in Coastal and Lower Eastern Counties during dry and wet seasons, 2019

Ant description		Region								*p*-values		
		Coast				Lower eastern						
		Counties										
		Kilifi		Kwale		Machakos		Makueni				
		Seasons										
Subfamilies	**Genera/Species**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Region**	**Season**	**R*S**
Dolichoderinae	*Technomyrmex albipes*	11.3±6.5^{a}	3.5±2.3^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0a	<0.001	<0.001	1.000
Formicinae	*Camponotus rufoglaucus*	0.0^{a}	10.9±4.7^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	<0.001	1.000
	Oecophylla longinoda	**28.5±7.9^{a}**	**1.4±1.3^{b}**	**0.0^{b}**	**115.7±28.9^{a}**	0.0^{a}	0.0^{a}	0.0^{a}	0.0a	<0.001	<0.001	1.000
Myrmicinae	*Crematogaster castanea*	0.0^{a}	0.0^{a}	**259.0^{a}**	**9.5±4.6^{b}**	10.0±3.3^{a}	53.0±12.2^{a}	0.0^{a}	0.0^{a}	0.680	<0.001	<0.001
	Crematogaster sjostedti	0.0^{a}	0.0^{a}	0.0^{a}	6.4±4.5^{a}	0.0^{a}	0.0^{a}	0.0^{a}	8.0±4.9^{a}	1.000	<0.001	1.000
	Monomorium afrum	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	6.5±2.2^{a}	0.0^{a}	0.0^{a}	0.0^{a}	1.000	<0.001	1.000
	Myrmicaria opaciventris	49.5±20.5^{a}	39.5±17.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	<0.001	1.000
	Pheidole sp	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.1^{a}	**31.5±1.8^{b}**	**74.1±20.0^{a}**	<0.001	<0.001	1.000
	Cataulacus brevisetosous	0.0^{a}	0.0^{a}	0.0^{a}	6.0±5.9^{a}	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	<0.001	<0.001	1.000
S		3	5	2	4	2	2	1	2			
H'		0.5	1.2	0.7	0.4	0.7	0.4	0.0	0.4			

Mean separation was based on individual species. Within a row, values in bold followed by different superscript letters are significantly different at $p < 0.05$. S = Species richness, H′ = Shannon Wiener diversity index, R*S=interaction between regions and seasons.

4.6.4 Parasitoids

No parasitoids associated with scale insects were reported. Some of the scale insects collected had some emergence holes on them. This is a clear indication that they were parasitized. However, when they were collected and kept in emergence vials, none of the parasitoids emerged.

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Scale insects

From the findings, citrus trees in the Coastal (Kilifi and Kwale) and Lower Eastern counties, (Machakos and Makueni) were affected by scale insects. These pests were also reported to be serious citrus pests in other studies conducted in Kenya (Kilalo, 2004, Olubayo *et al*, 2011; Gitahi, 2018). There were twenty two scale insects species found to infest citrus trees in the two regions. Armoured scales (Diaspididae) were the second most speciose family, with a total of seven species attacking various citrus varieties. Soft scales (Coccidae) had a total of eight species, mealybugs (Pseudococcidae) had five species while giant mealybugs (Monophlebidae) had two species attacking the different citrus varieties. This differs from the statements of Gullan and Cook (2007), Kondo *et al*., (2008), Gullan and Martins (2009), Seljak (2010) and García Morales *et al*., (2016) stating that armoured scales are the most biodiverse species followed by mealybugs and then soft scales. *Aonidiella aurantii*, *Chrysomphalus aonidum* and *Lepidosaphes beckii* were the main diaspidids attacking citrus trees in the two regions studied. Similarly, the same pests have been recorded as main citrus pests elsewhere (Seljak, 2010; Tawfeek, 2012; Ouvrard *et al*., 2013; Dagnew *et al.*, 2014; Uygun & Satar, 2018). Most of the armored scale species recorded attacking citrus were found in the Coastal region. This could be due to the high humidity and temperatures that helps the pests to thrive (Camacho & Chong, 2015). In the findings, three diaspidid species were found to be introduced species in Kenya; *Parlatoria ziziphi*, *Parlatoria pergandii*, *Aonidiella comperei*. This corroborates with the other findings that most armoured scale insects are invasive, introduced species due to their sessile, small size and cryptic nature, (Pellizzari & Germain, 2010). These pest species are important citrus pests in other countries too, (Tawfeek, 2012; Taibi *et al.*, 2016)

Soft scales (Coccidae) were the most speciose family found during the study in the sample sites. This contrasts with findings in other countries where the armoured scales are most speciose species on trees (Gullan & Cook, 2007; Kondo *et al*., 2008; Ouvrard *et al*., 2013; García Morales *et al*., 2016). This may be the case due to that fact that scale insect sampling was on citrus plants only in 4 counties only of Kenya. With the exception of *Ceroplastes floridensis*, all the other soft scales recorded in this study were found mostly in the Coastal region. This could be attributed to high temperatures and humidity in the region which favors them to thrive well (Camacho & Chong, 2015) and also numerous ports of entry found in the region aiding in dispersal. One species of Coccidae was found to be new to Kenya; *Pulvinaria polygonata* Cockerell. It is a serious agricultural pest throughout the tropics (Mani & Krishnamoorthy, 1998). There is need to monitor this species to avoid catastrophic devastation of citrus industry in the region. *Coccus viridis* and *Co. hesperidum* have previously been recorded as serious citrus pests in Kenya, (Kilalo, 2004, Olubayo *et al*., 2011, Gitahi, 2018). Soft scales, being polyphagous, have been reported to be serious pests of other crops worldwide such as grape, mango and papaya (Kapranas *et al.*, 2007; Walton *et al.*, 2009; Martins *et al.*, 2015).

All the five mealybugs recorded in this study have been recorded in Kenya attacking the citrus before (García Morales *et al*., 2016, Macharia *et al*., 2017) and have been recorded elsewhere attacking citrus trees (Franco *et al.*, 2004). Most of the mealybugs were found in the Coastal region counties, attacking various citrus varieties. The finding is similar to Heya (2020) that indicated coastal region being a hotspot for mealybugs invasion followed by lower eastern counties and the central region. Their occurrence in the Coastal region could be attributed to high humidity and temperatures which suits the pests (Camacho & Chong, 2015; Heya, 2020). Being polyphagous, these pests are known to attack a wide host range. Papaya mealybug *Paracoccus marginatus* is an introduced, invasive species and polyphagous; it was first reported in Kenya in 2017 in the Coastal region attacking papaya (*Carica papaya*) (Macharia *et al*., 2017) and has been reported to attack citrus (Mastoi *et al*., 2011; Heya, 2020). Similarly, it was also found to attack citrus in this study. Two monophlebids were also recorded attacking citrus trees in the both regions. Although it occurs at a low frequency, *Icerya purchasi* can be a serious citrus pest. It was recorded in the Coastal region as well as in the Lower Eastern region in all four counties studied attacking only sweet orange, (*Citrus sinensis*). The species is also of great economic importance elsewhere (Walton *et al.*, 2009; Seljak, 2010; Jendoubi, 2018; Gebreslasie & Meresa, 2018).

Noteworthy, the Coastal and Lower Eastern regions affected the abundance of some scale insects that showed a varying trend. This could be due to the favourable climatic conditions in the Coastal region that suits the development and multiplication of some scale insects (Camacho & Chong, 2015; Heya, 2020). The abundance of *Aonidiella comperei, A. aurantii* and *Pseudococcus cryptus* was high in the Coastal region ($p < 0.001$) while that of *Coccus viridis* and *Icerya seychellarum* was higher in the Lower Eastern region ($p <$

0.001). The excessive use of pesticides in the two regions to control citrus pests could have affected the abundance of scale insects in the two regions.

Similarly, the scale insect diversity and richness showed a varying trend in the four counties between the two seasons. Being a lowland, the high temperatures and humidity in the Coastal region could be the main factor causing variation in scale insects abundance between seasons in the region. Additionally, with the Coast region having important international entry point, more pests may be present in the area due to international trade and inadequate quarantine services at the ports of entry. Flush growth of citrus trees probably accounts for scale insect increment during the wet season in these regions.

5.1.2 Beneficia l insects

Beneficial insects comprises of predators and parasitoids. The predators consisted of beetles and chrysopids. The coccinellids were the most abundant in the two regions, during both seasons. This is an indication that they form a crucial part of the natural enemy complex in citrus orchards. Ladybird beetles, particularly genus *Chilocorus* and *Exochomus* were the most abundant scale predators during the wet season in both regions while genus *Chilocorus* and *Micraspis* were most abundant scale predators during the dry season in both regions. The results concurs with the findings of Kilalo (2004), during a survey to determine the arthropod complex associated with citrus trees; ladybirds are important predators of scale insects, aphids, whiteflies and the blackflies (Kilalo, 2004). Coccinellids are believed to play a role in suppressing the scale insect populations in both regions. However, ladybird frequencies of occurrence were low in compared to those of scale insects and mealybugs, suggesting that there were certain scale insects and mealybugs that are not under control by the predators. This implies that probably predators play a secondary role in suppressing the scale insects and mealybugs (Koul & Dhaliwal, 2003; Kilalo, 2004).

A few predators showed a variation in abundance as an effect of the regions and seasons. This could be attributed to their low frequency in the two regions. Only three predators showed a significant change in their abundance; *Chilocorus schiedtus*, *Chilocorus sulphurea* and *Exochomus flevipes,* (p < 0.001). They were found in the Lower Eastern region, mostly during the wet season. This could be due to high scale insect abundance during the wet season in the region. Frequent use of non-selective pesticides by farmers to control the citrus pests negatively affects the natural enemies which leads to pest outbreaks due to the elimination of their natural control.

The abundance of some ladybird species also showed a varying trends as an effect of seasons. Only two predators had a varying trend in abundance namely *Chilocorus nigrita* and *Harmonia axyridis* (p < 0.001). *Chilocorus nigrita* was the only species whose abundance changed across regions and seasons. This implies that the predator is available throughout the year and can be a good pest regulator. The species has proven to be an efficient predator for Diaspididae and some Coccidae due to its short life cycle compared to these pests (Booth, 1998). The ladybird is of Indian origin but due to its effectiveness has spread across the world through introductions or invasions. The predatory beetle has complex prey relations making it able to survive in absence of its favorite prey (Schoeman, 1994; Omkar & Pervez, 2003; Ponsonby *et al*., 2009). *Harmonia axyridis* abundance was also higher during the wet season in the Coastal region. This is probably due to high scale insect abundance in the county during the wet season.

5.1.3 Parasitoids

No parasitoids of scale insects were recorded in this study. Since most parasitoids are endemic species, this could have probably led to their low frequency in occurrence on exotic species. The low diversity and frequency of sampling techniques and duration could also have contributed to the fact that no parasitoids were captured in this study (Koul & Dhaliwal, 2003). With appropriate sampling methods, frequency and time scale, parasitoids captured could be reared for sustainable biological control of scale insect pests management in Kenya.

5.1.4 Ants

There were nine ant species belonging to three subfamilies: Dolichoderinae, Formicinae and Myrmicinae were found to be associated with the soft scale insects and mealybugs. This concurs to statements by Schneider *et al*., (2013) and Lakshmishree *et al*., (2019), that ants have a good mutual relationship with the soft scales and mealybugs due to the reward of honey dew.

According to the literature, *Camponotus rufoglaucus* Jerdon, *Cataulacus brevisetosus* Forel, *Monomorium afrum* Andre and *Technomyrmex albipes* Smith have not been found attending scale insects before (Hita *et al*., 2013); here they are recorded attending soft scales and mealybugs for the first time. *Crematogaster sjostedti* Mayr has been reported previously attending wax scales, *Ceroplastes sp.* (Coccidae: Coccomorpha), on an acacia tree in Kenya (Young *et al.*, 1997; Palmer & Young, 2017). In the present study, sweet orange (*Citrus sinensis*) was a new plant host for *Crematogaster sjostedti* attending *Icerya seychellarum* in Kwale County. *Crematogaster castanea* Smith and *Camponotus rufoglaucus* Jerdon have been recorded to be in Kenya before but without any ant-coccid association, (Young *et al.*, 1997). In the present study, they were found attending soft scales; *Coccus viridis*, *Co. hesperidum*, *Pulvinaria polygonata*, monophlebids; *Icerya purchasi* and *Icerya seychellarum* and mealybug *Crisicoccus longipilosus* in the both regions.

Oecophylla longinoda (Latreille) was found attending seven scale insect species during the wet season but only two during the dry season. In this study, *O. longinoda* was recorded attending *Saissetia zanzibarensis* (Coccidae) which concurs with the findings by Way 1954; Hita *et al*., 2013. It has also been found in close association with other mealybugs and scale insects (Dwomoh *et al.*, 2008; Lim *et al.*, 2008). This ant species has also been used as a biological control agent against non-scale tropical insect pests' worldwide (Way, 1954; Tellingen *et al.*, 2007; Olotu *et al*., 2013; Hita *et al*., 2013). The present study found relatively big headed *Pheidole megacephala* species in close association with two scale species on *Citrus sinensis* and *C. reticulata* during the wet and dry season; it has been recorded attending *Coccus viridis* before (Bach, 1991) but in this study its association with *Icerya seychellarum* is recorded for the first time. *Pheidole megacephala* is also associated with honeydew-producing psyllids (Hemiptera: Psyllomorpha) (Aléné *et al*., 2011). *Myrmicaria opaciventris* was found attending four different coccids in the present study. The literature describes this ant as a good attendant to leafhoppers and psyllids and few scale insects (Kenne *et al.*, 2008; Aléné *et al*., 2011). The present study recorded *Myrmicaria opaciventris* attending *Coccus hesperidum, Coccus viridis, Pulvinaria polygonata* (Coccidae) and *Pseudococcus cryptus* (Pseudococcidae) as new mutualistic association records.

Only two ant species showed a variation in abundance due to the effect of regions; *Oecophylla longinoda* and *Pheidole sp*. *Oecophylla longinoda* is a conspicuous arboreal ant, known to survive under humid conditions (Wetterer, 2017). A preference for high humidity may be why this ant species is only found in the Coastal region. *Pheidole* species are introduced, invasive species in Kenya and in areas where they are numerous, only few native invertebrates survives. *Pheidole sp.* tends to thrive well at high altitudes areas in open, disturbed habitats with weedy vegetation that can support high densities of plant-feeding hemipterans, which the ants tend for honeydew. This may be the probable reason *Pheidole sp.* was only found in the Lower Eastern region in this study (Wetterer, 2007, Seguni *et al*., 2011).

Out of nine ant species recorded in this study, the abundance of only *Oecophylla longinoda*, *Crematogaster castanea* and *Pheidole sp.* were influenced by the seasons. *Oecophylla longinoda* and *Crematogaster castanea* showed some population changes between the wet and dry seasons in Kilifi and Kwale Counties whereas *Pheidole sp*. population changes was in Makueni county only between the seasons. This implied that the seasons affected the occurrence of species and their abundance. The change in the amount of rainfall, farming practices and flush growth of citrus trees in the counties could be the reasons behind the change in abundance.

5.2 Conclusion

Citrus fruits provide income to farmers who cultivate it and nutrients to million consumers in Kenya. The crop is associated with both destructive and beneficial insects. There are many constraints affecting citrus production in the country but the greatest are the pests, diseases and low precipitation. Scale insects and mealybugs were the main pests attacking the various varieties of citrus trees, leading to great losses of yields and farm income. Some scale insects transmit diseases to the plants or facilitate infection of trees by pathogens through the puncture wounds made during pest feeding e.g. *Planococcus citri* which transmits cacao swollen shoot virus (CSSV), (CABI, 2020). Twenty-two scale insect species belonging to four families were found to be attacking the citrus trees in the two regions studied. Armoured scales (Diaspididae, seven species), soft scales (Coccidae, eight species) and mealybugs (Pseudococcidae, five species) were the main scale insect families attacking citrus trees. Several introduced invasive scale insect species were reported to be affecting the crop. The pest scales were found to be associated with both beneficial insects and ants. A total of 15 predatory species of coccinellid beetles and one lacewing chrysopid species were recorded associated with scale insects.

However, farmers mainly used non-selective pesticides as a strategy to deal with citrus pests; but due to lack of adequate information and understanding of scale insects, this control strategy is inadequate. In addition, the citrus tree canopy contains a rich and diverse natural enemy complex that is conspicuously dominated by the coccinellid beetles, lacewings, parasitoid wasps, heteropteran bugs and spiders. The implication is that most citrus pests are currently under some form of natural control that prevents pest outbreaks from occurring. The main challenge is the conservation of the natural enemies to control scale insect populations on citrus while controlling other pest species such as citrus leaf miner *Phyllocnistis citrella* (Lepidoptera; Gracillariidae) on the trees. This calls for a sound pest management program that caters for the whole citrus agroecosystem.

The scale insects on citrus trees were also associated with nine ant species that belongs to three subfamilies. The ant provides some kind of protection to the scale insects and mealybugs from natural enemies which in return provide with food in form of honeydew. The ants also help to transport scale insects crawlers to new uninfested plants, aiding pest dispersal. The presence of ants on the host plant can increase severity of scale insect infestations. However, some of the ant species also serve as biological control agents against some species of serious insect pests of citrus trees e.g. *Anoplolepis*, *Oecophylla*, *Dolichoderus*, *Solenospis* and *Azteca* (Ülgentürk, 2001); pest control strategy, therefore, needs to take this into account. Appropriate control strategies should be adopted to reduce the scale insect attendant ant populations but avoid totally eliminating the ant species that regulate other important pests on the trees.

The information obtained in the study will be useful in the development of efficient control strategies against the scale insect pests improving citrus production in Kenya. The diversity of scale insect pests identified in this study will be useful in plant quarantine facilities to monitor and prevent accidental introduction of exotic-scale insect species.

5.3 Recommendations

The study recommends that extension officers and farmers should be made aware of the diversity of scale insects and their associated biota to help them minimize usage of broad spectrum pesticides which will boost scale insects natural enemies that reduces the pest population to low levels efficiently.

The study recommends that the information on diversity of scale insects should be made available to plant quarantine facilities to help prevent accidental dispersal of the pests into or outside the country.

This study did not extend to all areas of Kenya where citrus is produced. Studies to identify the scale insects species on citrus throughout the country would provide the information needed to develop a complete crop protection package to optimize commercial citrus production across the country. In view of the wide variety of altitudes and ecosystems in Kenya, the control strategy needs to be customized to suit local conditions.

This study did not address the biological control aspects in full; no parasitoids were recorded. Therefore, further studies are required to determine the effectiveness of the coccinellids species potential for sustainable pest management. Investigation of potential use of ants as predators of different insect orders. This information is needed to evaluate biological control as an aspect of a citrus integrated pest management package.

This study only addressed one pest of citrus that is scale insects. Further studies would determine the insect pest complex of the citrus crop throughout the country. This would provide the information needed in development of a proper crop protection package for profitable commercial production of citrus across the country.

REFERENCES

Aidoo, O.F., 2019. Bio-ecology of the African citrus triozid *Trioza erytreae* Del Guercio (Hemiptera: Triozidae) on citrus in Kenya (Doctoral dissertation, Universität Bonn).

Aléné, D.C., Djiéto-Lordon, C. and Burckhardt, D. 2011. Unusual behaviour—unusual morphology: mutualistic relationships between ants (Hymenoptera: Formicidae) and *Diaphorina enderleini* (Hemiptera: Psylloidea), associated with *Vernonia amygdalina* (Asteraceae). *African Invertebrates*, 52(2): 353-361.

Aroua, K., Kaydan, M. B., Achiri, T. D. and Biche, M. 2020. The influence of the region and the host-plant on population dynamics of *Parlatoria ziziphi* (Lucas) (Hemiptera : Diaspididae) in Mitidja (Algeria), *Ecology, Environment and Conservation*, 26(1): 356–363.

Bach, C.E., 1991. Direct and indirect interactions between ants (*Pheidole megacephala*), scales (*Coccus viridis)* and plants (*Pluchea indica*). *Oecologia*, 87 (2): 233-239.

Bates, D., Maechler, M. and Bolker, B., 2015. Walker. S. Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1): 1-48.

Bhagat, R. C. and Qureshi, A. A. 2016. Biodiversity and Annotated Checklist of Scale-Insects, and Mealybugs (Hemiptera: Coccoidea) of Jammu, Kashmir and Ladakh (North-west Himalaya). India. *International Journal of Current Research and Academic Review*, 4(3): 56–62. doi: http://dx.doi.org/10.20546/ijcrar.2016.403.007

Bodenheimer, F.S., 1951. Citrus entomology in the Middle East with special references to Egypt, Iran, Irak, Palestine, Syria, and Turkey (No. BOD 634.3 (BR 533)). W. Junk, Publishers, p.663.

Bolton, B., 1994 Identification guide to the ant genera of the world. Harvard University Press, Cambridge Massachusetts, USA

Booth, R.G., 1998. A review of the species resembling Chilocorus nigrita (Coleoptera: Coccinellidae): potential agents for biological control. *Bulletin of Entomological Research*, 88(4): 361-367.

Bouvet, J.P.R., Urbaneja, A., Pérez-Hedo, M. and Monzó, C., 2019. Contribution of predation to the biological control of a key herbivorous pest in citrus agroecosystems. *Journal of Animal Ecology*, *88*(6): 915-926.

Buckley, R. and Gullan, P., 1991. More aggressive ant species (Hymenoptera: Formicidae) provide better protection for soft scales and mealybugs (Homoptera: Coccidae, Pseudococcidae). *Biotropica*, 22(3): 282-286.

Buss, E. A. and Dale, A. 2016. Managing Scale Insects on Ornamental Plants University of Florida, IFAS Extension, ENY323,1: 1–6. https://edis.ifas.ufl.edu/pdffiles/MG/MG00500.pdf (accessed 7 December 2020).

CABI, 2020 *Planococcus citri*. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc.

Çalişkan Keçe, A. F. and Ulusoy, M.R. 2017. Armoured scale insects (Hemiptera: Sternorrhyncha: Diaspididae) on ornamental plants in Adana, Turkey. *Turkish Journal of Entomology*, 41(3): 333–346. doi:10.16970/entoted.298572.

Caltagirone, L.E. and Doutt, R.L., 1989. The history of the vedalia beetle importation to California and its impact on the development of biological control. *Annual Review of Entomology*, 34(1): 1-16.

Camacho, E. R. and Chong, J. H. 2015. General biology and current management approaches of soft scale pests (Hemiptera: Coccidae). *Journal of Integrated Pest Management*, 6(1): 1–22. doi: 10.1093/jipm/pmv016.

Cochran, W. G. 1963.Sampling Techniques, 2nd Ed., New York: John Wiley and Sons, Inc.

Dagnew, A., Belew, D., Admassu, B. and Yesuf, M., 2014. Citrus Production, Constraints and Management Practices in Ethiopia: The Case of Pseudocercospora Leaf and Fruit Spot Disease. *Science, Technology and Arts Research Journal*, *3*(2): 4-18.

Dao, H. T., Beattie, G. A. C., Watson, G. W., Pham, V. L., Nguyen, V. L., Le, D. K., Nguyen, T. H., Nguyen, D. V. and Holford, P. 2018. Citrus diaspidids in Viet Nam: new, and confirmation of previous, records based on morphological and molecular verification of taxa. *Journal of Asia-Pacific Entomology*, 21(1): 81–96. doi: 10.1016/j.aspen.2017.09.010.

Davies, F. and Albrigo, L. 1994. Citrus Cambridge University Press, London. pp.600.

Debach, P. and Rosen, D., 1991. Biological control by natural enemies. CUP Archive. Development Corporation, Brisbane, Australia. pp.272.

Fanani, M.Z., Rauf, A., Maryana, N., Nurmansyah, A. and Hindayana, D., 2020. Parasitism disruption by ants of *Anagyrus lopezi* (Hymenoptera: Encyrtidae), parasitoid of cassava mealybug. *Biodiversitas Journal of Biological Diversity*, *21*(6): 2337-2343.

Ferran, A. and Dixon, A.F., 1993. Foraging behaviour of ladybird larvae (Coleoptera: Coccinellidae). European Journal of Entomology, 90(4): 383-402.

Franco, J. C., Suma, P., Da Silva, E. B., Blumberg, D. and Mendel, Z. 2004 'Management strategies of mealybug pests of citrus in Mediterranean countries, *Phytoparasitica*, 32(5): 507-522. doi: 10.1007/BF02980445.

FAO. (2016). Citrus Fruit - Fresh and Processed. Rome: Food and Agriculture Organization of the United Nations.

FAOSTAT. (2015, October 26). FOOD and Agriculture Organization of the UNITED Nations. Retrieved from FAO Statistical Databases (United Nations): http://www.fao.org/faostat/en/#compare

Garcia, Francisco Hita; Wiesel, Eva; Fischer, Georg (2013). The Ants of Kenya (Hymenoptera: Formicidae)—Faunal Overview, First Species Checklist, Bibliography, Accounts for All Genera, and Discussion on Taxonomy and Zoogeography. *Journal of East African Natural History*, 101(2), 127–222. doi:10.2982/028.101.0201

García Morales M, Denno BD, Miller DR, Miller GL, Ben-Dov Y, Hardy NB. 2016. *ScaleNet:* A literature-based model of scale insect biology and systematics. Database. doi: 10.1093/database/bav118. http://scalenet.info.

Gebreslasie, A. and Meresa, H., 2018. Identification of insect and disease associated to citrus in Northern Ethiopia. *African Journal of Microbiology Research*, *12*(13): 312-320.

Ghahari, H., Cetin Erdogan, O., Šedivý, J. and Ostovan, H., 2010. Survey of the Ichneumonidea and Chalcidoidae (Hymenoptera) parasitoids of Saturniidae (Lepidoptera) in Iran. *Efflatounia*, 10: 1- 6

Gitahi, D.W., 2018. Evaluation of knowledge and practices of managing citrus pests and diseases and the willingness to pay for an integrated pest management strategy in selected Counties in Kenya (Doctoral dissertation, Egerton University).

Gmitter, F. G. and Hu, X. 1990. The Possible Role of Yunnan , China , in the Origin of Contemporary Citrus Species. *Economic Botanical*, 44(2): 267–277.

Greathead, D.J., 1972. The rediscovery in Kenya of two introduced coccinellids (*Cryptolaemus montrouzieri* Muls. and *Rodolia cardinalis* (Muls.)). *East African Agricultural and Forestry Journal*, 38(2): 214.

Gullan, P. J. and Cook, L. G. 2007. Phylogeny and higher classification of the scale insects (Hemiptera: Sternorrhyncha: Coccoidea). *Zootaxa*, 1668: 413–425.

Gullan, P. J., & Martin, J. H. 2009. *Sternorrhyncha. Encyclopedia of Insects*, pp.*965–967.*

Haddad, N. and Ali-Ahmed, S.D., 2018. Distribution behavior of *Parlatoria pergandii* Comstock, *Aonidiella aurantii* Maskell and *Chrysomphalus dictyospermi* Morgan (Hemiptera: Diaspididae) on the canopy of citrus trees. *Bioscience Research*, 15(3): 2452-2462.

Hassan, N.A., Radwan, S.G. and El-Sahn, O.M.N., 2012. Common scale insects (Hemiptera: Coccoidea) in Egypt. *Egyptian Academic Journal of Biological Science*, 5(3): 153-160.

Heya, H.M., Khamis, F.M., Onyambu, G.K., Akutse, K.S., Mohamed, S.A., Kimathi, E.K., Ombura, F.L.O., Ekesi, S., Dubois, T., Subramanian, S. and Tanga, C.M., 2020. Characterization and risk assessment of the invasive papaya mealybug, Paracoccus marginatus, in Kenya under changing climate. *Journal of Applied Entomology*, 144(6): 442-458

Hodek, I., 2013. Biology of Coccinellidae. Springer Science and Business Media, The Hague.

Hoy, M. A., Smith, D., Beattie, G. A. C., & Broadley, R. (1998). Citrus Pests and Their Natural Enemies. Integrated Pest Management in Australia. *The Florida Entomologist*, 81(1): 131-133 doi: 10.2307/3496008

Ioannou, N., Hadjinicolis, A. and Hadjinicoli, A., 1999. Mealybug transmission and natural spread of grapevine closterovirus in Cyprus. Options Mediterraneennes. Serie B: *Studies and Research*, (29): 47-64.

Jendoubi, H., 2018. The scale insect fauna of citrus in Tunisia: A critical overview. *International Journal of Fauna and Biological Studies*, 5(3): 169-178.

Kairo, M.T.K., Paraiso, O., Gautam, R.D. and Peterkin, D.D., 2013. *Cryptolaemus montrouzieri* (Mulsant) (Coccinellidae: Scymninae): a review of biology, ecology, and use in biological control with particular reference to potential impact on non-target organisms. *CAB Review*, 8(5): 1-20.

Kamel, A.S., 2010. Insects attack citrus trees in Al-Qalyubiyah Governorate, Egypt. *Egyptian Academic Journal of Biological Sciences*, 3(2): 107-117.

Kapranas, A., Morse, J.G., Pacheco, P., Forster, L.D. and Luck, R.F., 2007. Survey of brown soft scale *Coccus hesperidum* L. parasitoids in southern California citrus. *Biological Control*, 42(3): 288-299.

Kenne, M., Fotso Kuate, A., Hanna, R., Tindo, M. and Goergen, G., 2008. Foraging activity and diet of the ant, *Anoplolepis tenella* Santschi (Hymenoptera: Formicidae), in southern Cameroon. *African Entomology*, 16 (1): 107-114.

Kerns, D., Wright, G. and Loghry, J., 2004. Citrus mealybug (*Planococcus citri*). Citrus Arthropod Pest Management in Arizona. The University of Arizona Cooperative Extension, pp.1-4. https://www.ag.arizona.edu/crop/citrus/insects/citrusmealy.pdf

Kilalo, D., Olubayo, F., Obukosia, S. and Shibairo, S.I., 2009. Farmer management practices of citrus insect pests in Kenya. *African Journal of Horticultural Science*, 2. Available at: http://hakenya.net/ajhs/index.php/ajhs/article/view/41 (Accessed: 13September2020)

Kilalo, D.C., 2004. Survey of the arthropod complex and monitoring and management of homopteran pests of citrus (Citrus spp) and their natural enemies (Doctoral dissertation, University of Nairobi).

Kondo, T., Gullan, P.J., and Williams, D.J. 2008. Coccidology. The study of scale insects (Hemiptera: Sternorrhyncha: Coccoidea). *Revista Corpoica - Ciencia y Tecnología Agropecuaria*, 9(2): 55–61.

Koul, O. and Dhaliwal, G.S., 2003. Predators and parasitoids: an introduction. *Predators and Parasitoids. New York: Taylor, Francis*, pp.1-15.

Lakshmishree SU, Mahalakshmi E, Ramya KP, Varsha Vishwanatha Rajapuriand Kokilamani AL., 2019. A study on scale insects (Hemiptera: Coccoidea) found in Tumakuru, India, *International Journal of Life Science*, 7(3): 495-500.

Liu, Y., Heying, E. and Tanumihardjo, S.A., 2012. History, global distribution, and nutritional importance of citrus fruits. *Comprehensive Reviews in Food Science and Food Safety*, 11(6): 530-545.

Lo, P.L., 2000. Species and abundance of ladybirds (Coleoptera: Coccinellidae) on citrus orchards in Northland, New Zealand, and a comparison of visual and manual methods of assessment. *New Zealand Entomologist*, 23(1): 61-65.

Lv, X., Zhao, S., Ning, Z., Zeng, H., Shu, Y., Tao, O., Xiao, C., Lu, C. and Liu, Y., 2015. Citrus fruits as a treasure trove of active natural metabolites that potentially provide benefits for human health. *Chemistry Central Journal*, 9: 68.

Macharia, I., Kimani, E., Koome, F., Kosiom, T., Heya, H., Otipa, M. and Oronje, M., 2017. First Report and Distribution of the Papaya Mealybug, *Paracoccus marginatus*, in Kenya. *Journal of Agricultural and Urban Entomology*, 33(1): 142-151.

Malumphy, C. 2015. Detection and identification of scale insects families', The Food and Environment Agency (U.K.), Fera 2015-v1, pp.1–23.

Mani, M. and Krishnamoorthy, A., 1998. Biological control studies on the mango green shield scale *Chloropulvinaria polygonata* (Ckll.) (Homoptera, Coccidae) in India. *Entomology*, 23(2): 105-110.

Mani, M. and Shivaraju, C. eds., 2016. *Mealybugs and their management in agricultural and horticultural crops*, New Delhi, India: Springer India, 65:123-130.

Mansour, R., Grissa-Lebdi, K., Suma, P., Mazzeo, G. and Russo, A., 2017. Key scale insects (Hemiptera: Coccoidea) of high economic importance in a Mediterranean area: host-plants, bio-ecological characteristics, natural enemies and pest management strategies–a review. *Plant Protection Science*, 53(1): 1-14.

Mansour, R., Mazzeo, G., Pergola, A., Lebdi, K. and Russo, A., 2011. A survey of scale insects (Hemiptera: Coccoidea) and tending ants in Tunisian vineyards. *Journal of Plant Protection Research*, 51(3): 197-203

Martínez-blay, V., Pérez-Rodríguez, J., Tena, A. and Soto, A. 2018. Ecology and Behavior Seasonal Distribution and Movement of the Invasive Pest *Delottococcus aberiae* (Hemiptera : Pseudococcidae) Within Citrus Tree : Implications for Its Integrated Management, *Journal of Economic Entomology*, (X): 1–9. doi: 10.1093/jee/toy279.

Martins, D.S., Fornazier, M.J., Culik, M.P., Ventura, J.A., Ferreira, P.S.F. and Zanuncio, J.C., 2015. Scale insect (Hemiptera: Coccoidea) pests of papaya (*Carica papaya*) in Brazil. *Annals of the Entomological Society of America*, 108(1): 35-42.

Mastoi, M.I., Azura, A.N., Muhammad, R., Idris, A.B. and Ibrahim, Y., 2011. First report of papaya mealybug *Paracoccus marginatus* (Hemiptera: Pseudococcidae) from Malaysia. *Australian Journal of Basic and Applied Sciences*, 5(7): 1247-1250.

Mayhew, P.J. and Blackburn, T.M., 1999. Does development mode organize life-history traits in the parasitoid Hymenoptera? *Journal of Animal Ecology*, 68(5): 906-916.

Mendel, Z., Gross, S., Steinberg, S. and Blumberg, D., 2016. Trials for the control of the citrus mealybug in citrus orchards by augmentative release of two encrytid parasitoids. *Entomologica*, 33: 251-265.

Miller, D., Rung, A., Parikh, G., Venable, G., Redford, A.J., Evans, G.A. and Gill, R.J. 2014. Scale Insects, Edition 2. USDA APHIS Identification Technology Program (ITP), Fort Collins, Colorado, U.S.A. http://idtools.org/id/scales/index.php

MoALD. (2012). Annual report. Kenya: Ministry of Agriculture and livestock development.

Mounde, L.G., Ateka, E.M., Kihurani, A.W., Wasilwa, L. and Thuranira, E.G., 2009. Occurrence and distribution of citrus gummosis (*Phytophthora* spp.) in Kenya. *African Journal of Horticultural Science*, 2.

Muegge, M. A. and Merchant, M. 2014. Scale Insects on Ornamental Plants.' House and Landscape Pests. *Texas A and M system. AgriLIFE EXTENSION*, B-6097, 8: 1–7.

Muniappan, R., Shepard, B. M., Watson, G. W., Carner, G. R., Sartiami, D., Rauf, A. and M. D. Hammig 2008. First Report of the Papaya Mealybug, *Paracoccus marginatus* (Hemiptera : Pseudococcidae), in Indonesia and India. *Journal of Agricultural and Urban Entomology*, 25(1): 37–40.

Niu, J.Z., Hull-Sanders, H., Zhang, Y.X., Lin, J.Z., Dou, W. and Wang, J.J., 2014. Biological control of arthropod pests in citrus orchards in China. *Biological Control*, 68: 15-22.

Olubayo, F., Kilalo, D., Obukosia, S., Shibairo, S., Kasina, M, Kasina, A. M. and Kasina, Muo 2011. Homopteran Pests Complex Of Citrus (*Citrus sinensis*). *International Journal of Sustainable Crop Production*, 6(2): 23–28.

Omkar and Pervez, A., 2003. Ecology and biocontrol potential of a scale-predator, *Chilocorus nigritus*. *Biocontrol Science and Technology*, 13(4): 379-390.

Ouma, G., 2008. Challenges and approaches to sustainable citrus production in Kenya. *African Journal Plant Science Biotechnology*, 2: 49-51

Ouvrard, D., Kondo, T. and Gullan, P.J., 2013. Scale insects: major pests and management. *Encyclopedia of Pest Management*, pp.1-4.

Palmer, T.M. and Young, T.P., 2017. 10 Integrating Ecological Complexity into Our Understanding of. Ant-Plant Interactions: Impacts of Humans on Terrestrial Ecosystems, p.200.

Peeters, C., Foldi, I., Matile-Ferrero, D. and Fisher, B.L., 2017. A mutualism without honeydew: what benefits for *Melissotarsus emeryi* ants and armored scale insects (Diaspididae). *PeerJ*, 5: 3599.

Pellizzari, Giuseppina; Germain, Jean-François (2010). Scales (Hemiptera, Superfamily Coccoidea). Chapter 9.3. *BioRisk*, 4(1), 475–510. doi:10.3897/biorisk.4.45

Pittaway, T.M., 2002. An investigation of the effect of time of pruning on the growth and fruiting of lemons [*Citrus Limon* (l.) Burmann f.] cv. Eureka. Unpublished Masters Thesis, Port Elizabeth Tecknikon.

Ponsonby, D.J., 2009. Factors affecting utility of *Chilocorus nigritus* (F.)(Coleoptera: Coccinellidae) as a biocontrol agent. CAB Reviews: Perspectives in Agriculture, Veterinary Science, *Nutrition and Natural Resources*, 4(6): 1-20.

R Core Team & DC, R., 2019. A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2012. URL https://www. R-project. org (accessed 7 December 2020).

Rachida, B. and Mohamed, B. 2015. Biodiversity of diaspididae scale insects (Homoptera), their host-plants and natural enemies in Algeria. *Journal of Entomology and Zoology Studies*, 3(1): 302–309. doi: 10.13140/RG.2.1.2643.8888.

Rosen, D. (1993). Biological and Integrated control of citrus insects and mites. Int. Org.

Rosen, D., 1967. On the relationships between ants and parasites of coccids and aphids on citrus. *Beiträge zur Entomologie*, 1 7(1-2): 281-286.

Rosen, D., 1967. The hymenopterous parasites of soft scales on citrus in Israel. Contributions to Entomology, *Beiträge zur Entomologie* 17(1-2): 251-279.

Roy, H., Brown, P., Frost, R. and Poland, R., 2011. Ladybirds (Coccinellidae) of Britain and Ireland. Natural Environment Research Council (NERC), pp.198

Schneider, S.A., Giliomee, J.H., Dooley, J.W. and Normark, B.B., 2013. Mutualism between armoured scale insects and ants: new species and observations on a unique trophobiosis (Hemiptera: Diaspididae; Hymenoptera: Formicidae: Melissotarsus Emery). *Systematic Entomology*, 38(4): 805-817.

Schoeman, S., 1994. Mass rearing and releases of the effective scale predator *Chilocorus nigritus*. *Inligtingsbulletin-Instituut vir Tropiese en Subtropiese Gewasse*, 262(1): 15.

Seguni, Z.S.K., Way, M.J. and Van Mele, P., 2011. The effect of ground vegetation management on competition between the ants *Oecophylla longinoda* and *Pheidole megacephala* and implications for conservation biological control. *Crop Protection*, 30(6): 713-717.

Seljak, G., 2010. A checklist of scale insects of Slovenia. *Entomologia Hellenica*, 19(2): 99-113.

Shiran, E., Mossadegh, M.S. and Esfandiari, M., 2013. Mutualistic ants (Hymenoptera: Formicidae) associated with aphids in central and southwestern parts of Iran. *Journal of Crop Protection*, 2(1): 1-12.

Sirisena, U. G. A. I., Watson, G. W., Hemachandra, K. S. and Wijayagunasekara, H. N. P. 2013. A Modified Technique for the Preparation of Specimens of Sternorryncha for Taxonomic Studies. *Tropical Agricultural Research*, 24(2): 139–149.

Smaili, M.C., Blenzar, A. and Fursch, H., 2009. First record of new species and phenotypes of ladybird (Coleoptera: Coccinellidae) in citrus orchards in Morocco. *Entomologie Faunistique-Faunistic Entomology*, 62:103-107.

Smith-Pardo, A. H., Evans, G. A. and Dooley, J. W. 2012. A review of the genus Chrysomphalus Ashmead (Hemiptera: Coccoidea: Diaspididae) with descriptions of a new species and a new, related genus. *Zootaxa*, 3570(1): 1–24. doi: 10.11646/zootaxa.3570.1.1.

Sun, Y.L., Kang, H.M., Han, S.H., Park, Y.C. and Hong, S.K., 2015. Taxonomy and phylogeny of the genus citrus based on the nuclear ribosomal DNA its region sequence. *Pak. J. Bot*, 47(1): 95-101.

Swingle, W.T., 1946. The botany of Citrus and its wild relatives in the orange sub family. The *Citrus Industry*, 1: 128-474.

Taibi, A., Gacemi, A., Medjdoub, Y., Medjdoub, I. and Doumandji, S., 2016. Citrus infestation by the black scale, *Parlatoria ziziphi* Lucas (Homoptera: Diaspididae) in Tlemcen, Algeria. *Journal of Entomological Research*, 40(3): 217-221.

Takagi, M., 2003, June. Biological control of citrus scale pests in Japan. In 1st International Symposium on Biological Control of Arthropods. USDA-Forest Service FHTET-03-05 pp. 351-355.

Tanaka, T., 1977. Fundamental discussion of Citrus classification. *Studia Citrologica*, 14: 1-6.

Tawfeek, M.E., 2012. Distributions of armoured scale insects infesting citrus trees in different localities in Egypt. *Journal of Entomology*, 9(6): 429-434.

Tekkara, A.O., Acipa, A., Wamani, S., Obalim, G., Otim, G.A. and Kumakech, A., 2018. Distribution, abundance and severity of citrus pests in northern Uganda. *Journal of Entomology and Zoology Studies*, 6(3): 1394-1399.

Ülgentürk, S., 2001. Ants (Hymenoptera: Formicidae) associated with soft scale insects in Turkey: a preliminary list. *Acta Phytopathologica et Entomologica Hungarica*, 36(3-4): 405-409.

Uygun, N. and Satar, S., 2008. The current situation of citrus pests and their control methods in Turkey. *IOBC-WPRS Bulletin*, 38: 2-9.

Vanek, S.J. and Potter, D.A., 2010. Ant-exclusion to promote biological control of soft scales (Hemiptera: Coccidae) on woody landscape plants. *Environmental Entomology*, 39(6): 1829-1837.

Wangithi, C.M., 2019. Evaluation of The Magnitude of Citus Yield Losses Due to African Citrus Triozid, False Codling Moth, the Greening Disease and Other Pests of Economic Importance in Kenya. *Journal of Economics and Sustainable Development*, 10(20): 87-97.

Wakgari, W.M. and Giliomee, J.H., 2003. Natural enemies of three mealybug species (Hemiptera: Pseudococcidae) found on citrus and effects of some insecticides on the mealybug parasitoid Coccidoxenoides peregrinus (Hymenoptera: Encyrtidae) in South Africa. *Bulletin of Entomological Research*, 93(3): 243-254.

Wakgari, W.M. and Giliomee, J.H., 2005. Description of adult and immature females of six mealybug species (Hemiptera: Pseudococcidae) found on citrus in South Africa. *African Entomology*, 13(2): 281-332.

Walton, V.M., Krüger, K., Saccaggi, D.L., Millar, I.M. and Michaud, J.P., 2009. A survey of scale insects (Sternorrhyncha: Coccoidea) occurring on table grapes in South Africa. *Journal of Insect Science*, 9(47): 1-6.

Watson, G.W. (In prep.) Towards identification of the scale insects (Hemiptera: Coccomorpha) of continental Africa: 2-7. *Zootaxa* (unpublished).

Watson, G.W. and Ouvrard, D. (Submitted) Towards identification of the scale insects (Hemiptera: Coccomorpha) of continental Africa: 1. Identification of families currently. *Zootaxa* (unpublished)

Way, M. J. (1954). Studies of the life history and ecology of the ant *Oecophylla longinoda* Latreille. *Bulletin of Entomological Research*, *45*(1), 93-112.

Way, M.J. and Khoo, K.C., 1992. Role of ants in pest management. *Annual Review of Entomology*, 37(1): 479-503.

Way, M.J., 1963. Mutualism between ants and honeydew-producing Homoptera. *Annual Review of Entomology*, 8(1):307-344.

Wetterer, J.K., 2007. Biology and impacts of Pacific Island invasive species. 3. The African big-headed ant, *Pheidole megacephala* (Hymenoptera: Formicidae). *Pacific Science*, 61(4): 437-456.

Wetterer, J.K., 2017. Geographic distribution of the African weaver ant, *Oecophylla longinoda*. *Transactions of the American Entomological Society*, 143(2): 501-510.

Xu, J., Zhang, Y., Zhang, P., Trivedi, P., Riera, N., Wang, Y., Liu, X., Fan, G., Tang, J., Coletta-Filho, H.D. and Cubero, J., 2018. The structure and function of the global citrus rhizosphere microbiome. *Nature Communications*, 9(1): 1-10.

Young, T.P., Stubblefield, C.H. and Isbell, L.A., 1997 Ants on swollen-thorn acacias: species coexistence in a simple system. *Oecologia*, *109* (1): 98-107.

Appendices

1. Farm survey questionnaire

NB: The findings for this study will be used for research purposes only and will be treated with utmost confidence and not reported but averaged. Kindly give clear and honest responses as much as possible. Your cooperation will be highly appreciated.

a) Details of Respondent(Tick where Necessary)

1. Name of Respondent	
2. Gender	(1) Male (2) Female
3. Marital Status	(1) Single (2) Married (3) Single parent (4) Others…………
4.Age (yrs)	
5.Relationship with household	(1) Manager (2) Self (3) Employee (4) Others…………
6.Name of household head(if not respondent)	
7.Occupation of household head	
8. County	
9. Sub County	

b) On farm Production(Tick where Necessary)

1. What citrus plant variety do you grow?	(1)………. (2)………….. (3)……… (4)……….. (5)………….
2. Uses of citrus plants grown?	(1) Family income (2) Subsistence use
3. Age of citrus plants in the farm	
4. Number of citrus bushes in the farm?	

5.	Major challenges facing citrus fruit production	(1)…………. (4)………… (2)…………. (5)………… (3)………….
6.	Management strategies employed in the farm	(1)…………. (3)…………. (2)…………. (4)………….
7.	Name of Pesticides used if any	(1)…………. (4)…………. (2)………….. (5)…………. (3)………….. (6)…………..