ALTITUDINAL DISTRIBUTION AND DAMAGE OF CYPRESS APHID (*CINARA CUPRESSIVORA*; HOMOPTERA: APHIDAE) ON *CUPRESSUS LUSITANICA* (PINALES: CUPRESSACEAE) IN SUA TRAINING FOREST, OLMOTONYI, ARUSHA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN FORESTRY OF SOKOINE UNIVERSITY OF AGRICULTURE, MOROGORO, TANZANIA.

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ABSTRACT

Altitudinal distributionand damage intensity of Cypress aphidon *Cupressuslusitanica*of different age classes was investigated at SUA Training Forest. Abundance of natural enemies of Cypress aphidat different age classes (young 1-10years, middle 11-25 and old >25years) and altitudinal ranges (lower 1700-1930 m.a.s.l, middle 1931-2125 m.a.s.l and upper 2126-2300 m.a.s.l) was also determined. Systematic sampling was used, whereby every 5th tree along the row of the study plot/block was considered as a candidate. Five shoots in lower, middle and upper crown part of selected tree were randomly cut and put in labeled zipped plastic bags for laboratory assessment of the aphids and natural enemies. Results from this study indicated that Cypress aphid was un-equally distributed throughout the altitudinal ranges and age classes. The abundance of Cypress aphid per twig was 19.6, 24.9 and 33.7 individuals for lower, middle and higher altitude respectively and was significantlydifferent ($p<0.05$ and $f=6.57$). Also the abundance of Cypress aphid was 33.7, 16.6 and 18.8 per twig for young, middle and old age classes, respectively although the abundance was not significantlydifferent ($p<0.05$ and $f=10.82$). Mean damage intensity was 37.62%, 22.02% and 27.03% for young, middle and old trees respectively and the differences was significant ($p<0.05$ and $f=7.04$). Younger treesat higher altitude were more attacked by Cypress aphid. Three natural enemies namely *Pauesiajuniperunum*, Hoverfly larvae and Spider miteswere detected on the affected twigs but they were verylow in numbers. Therefore, in order to reduce the damage and spread of Cypress aphid in Olmotonyi, it is recommended that mature trees must be harvested and release *Pauesiajuniperunum* bio-control agent which has given positive results in Kenya and Malawi.

Key words: *Cinaracupressivora, Cupressuslusitanica,*altitude, age classes and damage intensity.

DECLARATION

I, SALUMYAKUTI do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and it has neither been, nor concurrently being submitted for higher degree awards in any other institution.

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I dedicate this work to my mother Swaumu S. Mayola, my father Said M. Yakuti,family members, friends and relatives for their love and support during my study.

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LIST OF ABBREVIATIONS AND SYMBOLS

ANAPA	Arusha National Park
ANOVA	Analysis of Variance
GPS	Geographical Positioning System
IPM	Integrated Pest Management
KEFRI	Kenya Forestry Research Institute
m.a.s.l	Meters above the sea level
R.H.A	Royal Horticulture Association
SUA	Sokoine University of Agriculture
SUATF	Sokoine University of Agriculture Training Forest
TZS	Tanzanian Shillings
UK	United Kingdom
USD	United State Dollars

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Insects are a natural and necessary part of a healthy forest ecosystem andmost insect species are actually beneficial and only a few are real problem to forests and forest products. This is because most of them do not become abundant enough to cause serious economic damage (Andrew *et al*., 2013).The establishments of exotic plantations in most countries of the tropics and subtropics have resulted into invasion of these plantations by a number of diseases and insect pests (Nair, 2001; Chamshama and Nwonw, 2004). The introduction, distribution, abundance and outbreak of insect pestsare influenced to a greater extent by biotic and abiotic factors such as food quality and quantity, natural enemies mostly predators and parasitoids, temperature, humidity and precipitation (Flinte*et al*., 2011). Climate change also influencesinsect pest establishment in new locations, as well as increasing the severity of impacts for both indigenous and non-indigenous pests (FAO, 2010).

Natural enemies play an important role in reducing population density and spreading of insect pest outbreak, they keep pest outbreaks in check. The natural enemy hypothesis predicts that exotic plant species might receive less pressure from natural enemies than do related coexisting native plants (Carrillo-Gavila´n, 2012). In such situations, introduced pests may have specific natural enemies e.g. *Pauesiajuniperunum*, *Pauesiaantennata,* Spider mites and Ladybird beetles for Cypress aphids(Cross and Poswal, 2013)that normally keep populations in balance**.** Plantations are characterisedby trees of similar age, size and structure, hence ecologically they influence homogeneity environmental conditions, few habitats and micro environmentswhich encourage occurrence of insect pests and few numbers of natural enemies.Nair (2007) found that single-species plantations suffer greater pest damage than mixed-species and that, natural forests and most tree species raised in plantations are attacked by one or more serious pests. Forest plantations of several species have also suffered varying degrees of attack by disease causing agents (Bekele, 2011).

It has been argued that multiple factors, operating across a hierarchy of spatial and temporal scales, shape insect species distributions (Flinte*et al*., 2011). Hodkinson (2005) reported that trends in species richness and abundance of individual terrestrial insects along elevational gradients are variable, decreasing with increasing altitude (Flinte*et al*., 2011), increasing with increasing altitude (Romero and Avila, 2000), peaking at middle elevation (Flinte*et al*., 2011), or showing no altitudinal trend (Casson and Hodkinson, 1991). Many processes explain these trends, including variation in abiotic (climatic) factors such as rainfall, humidity and temperature and variation of biotic factors such as host plants and natural enemies (Flinte*et al*., (2011). In tropical and subtropical mountains, abiotic factors have even greater effects on community structure and population density of the forest insect than in temperate regions (Hodkinson, 2005).

Moreover, the intensity and altitudinal distribution of the insect outbreaks were affected by age classes of the trees, where young trees are the most vulnerable to the disease, and are rapidly killed than mature trees (Kamunya*et al*., 1999). Madoffe(1989) reported that young *Pinuspatula* were vulnerable to pine woolly aphid infestation than old trees. This is in contrary with Ruohomak*et al*. (2000) who found that *Epirritaautumnata* outbreaks took place mostly in mature birch trees because of low parasitism or high foliage quality and availability of more suitable oviposition sites in mature trees. Tree age, however, may affect aphids adversely by influencing their growth rates, survival and fecundity. As a result of aphid attack, trees react by producing allelochemicals which have negative effects on the aphids. The quantities of these chemicals vary with age classes (Kamunya*et al*., 1999). It is however not well established on how the aphids are distributed attitudinally and between age classes in Cypress growing areas in Tanzania and in particular SUATF.Acquiring of such knowledge was important for management decisions.

SUA Training Forest (SUATF) is a mixed species plantation and the main species grown are *Pinuspatula, Eucalyptusmaidenii, Grevillearobusta and Cupressuslusitanica*. These species have been free from insect attack until in the last two decades when *C. lusitanica*was attacked by the Cypress aphid (*Cinaracuppressivora*) (Homoptera: Aphididae), which caused widespread deaths and economic losses not only to the SUATF but tothe entire country (SUATF, 2011).

The Cypress aphid is considered as one of the most important invasive pests in the world attacking Cupressaceae family such as *Cupressus, Juniperus, Thuja, Callitris, Widdringtonia, Chamaecyparis, Austrocedrus*, and the hybrid

Cupressocyparis(Alleck*et al*., 2005; Baldini and Aguayo, 2005). *Cinaracupressivora*is widely distributed in Southern Europe, Southwest Asia, India, North America, Africa and South America (Watson *et al.,* 1999). In Africa Cypress aphid was first recorded in Malawi in 1986 and the following year it was reported in Tanzania and by the end of 1988 it was observed in almost all Cypress growing areas across the country (Ciesla, 1991; Chilima, 1991). Sao Hill, Meru and SUATF plantations were the most affected areas. Cypress aphid feeding causes desiccation of the stems and progressive dieback of heavily infested trees of *C. lusitanica* (Madoffe and Day, 1996). The same authors reported that *C. lusitanica*is highly susceptible to the Cypress aphid eventually causing death of trees especially in young trees, because this causes physiological changes, such as increased respiration and decreased photosynthesis. In 1990 it was estimated that population of the Cypress aphid in Tanzania was up to 80 aphids/10cm branch and damage appears to be more severe during the dry season (June to September) (Kessy, 1990).

1.2 Problem statement and justification

It is generally believed that outstanding initial performance of exotic tree species in the areas of introduction is attributed to the absence of pests or diseases (Chamshama and Nwonwu, 2004). Flinte*et al*. (2011) found that insect species distributions are influenced by abiotic factors (e.g. rainfall, humidity and temperature), biotic (e.g. host plants, predators/parasitoids) and by their physiology. Recently, great focus is being given to the role of temperature due to the rising concern on how climatic change will affect insect species distribution (Battisti*et al*., 2006). In Tanzania forest insect particularly *Cinaracupressivora*which was first observed in 1987 is now reported in all Cypress growing areas and in some places like Sao Hill, Meru, West Kilimanjaro and SUA Training forest plantations it has caused massive death of *C. lusitanica*. *Cupressuslusitanica* has been the most preferred exotic timber tree in Arusha and Kilimanjaro so its attack by Cypress aphid and decision to stop planting the species in 1990s caused a great set-back to timber dealers, wood industries and some ecosystem services (OKting'ati and Nangawe, 1996).

In spite of shoot die-back and death of *C. lusitanica* being common in SUATF, planting of *C.lusitanica*was never stopped. Planting was however done at a very low pace and confined to lower altitudes since most attacks were recorded in higher altitudes particularly during dry season. This recorded localized attack is however, not well studied besides giving some hopes for subsequent planting of *C. lusitanica* in the entire plantation. The distribution, abundance and damage intensity variations within age and altitudes are also not well known. It's also alleged that generally the extent of damage has been reduced. Perhaps due to exotic and native natural enemies attacking*Cinara* or*C. lusitanica* being more adapted to the growing conditions. These speculations need to be confirmed through scientific research. Hence, the aim of this study was to determine the status of Cypress aphid in terms of its distribution and abundancealong the gradient and age classes, damage level and natural enemies in SUATF plantation. The informationgenerated from this study could be used by policy makers and forest manager for making proper management decision in dealing with Cypress aphid problems.

1.3 Objectives

1.3.1 Main Objectives

To determine altitudinal distribution and damage intensity of *Cinaracupressivora*on *Cupressuslusitanica*growing in SUA Training Forest, Arusha

1.3.2 Specific Objectives

i. To determine the altitudinal distribution and abundance of Cypress aphid in SUATF,

ii. To assess the altitudinal distribution and abundanceof natural enemies,

iii. To assess damage intensity of *Cupressuslusitanica* of different age classes as a result of Cypress aphid attack.

1.4 Hypotheses

H_{o1}: The distribution of Cypress aphid is not influenced by altitudinal range.

H_{O3}: The distribution of natural enemies is not influenced by altitudinal range and age classes.

H_{o2}: There is no difference in altitudinal abundance and damage level of Cypress aphid on *Cupressuslusitanica* of different age classes.

CHAPTER TWO

2.0 LITERATURE RIVIEW

2.1 General overview of forest insect pests

2.1.1 Global introduction and spread of forest insect pests

Most introductions of exotic forest pests to foreign countries have beenaccidental and the process has been going on for over a centuryin those countries **(**Campbell and Schlarbaum, 2014**)**. For example in Africa,*Cinaracupressivora* native to Southern Europe wasfirst recorded in Malawi in 1986 (Ciesla, 1991),*Heteropsyllacubana* originated from Central and South Americawas introducedin Burundi, Kenya and Tanzania in 1992 (FAO, 1998) and*Pineus?boenari*originated from Europe was first detected inKenya and Zimbabwe in 1962(Massawe, 1991).Most of the insect pests now recognized in different parts of the world originated from Europe.Accidentalintroduction of exotic forest pests can be either through, global trade of forest commodities (FAO, 2010) andimportation of wood packaging material and living plants (Campbell, and Schlarbaum, 2014).These unintended consequences provide numerous opportunities for occurrence and spread of non-native species globally (Campbell, and Schlarbaum, 2014). Nevertheless, insect pests can spread locally within a country from one location to another during the movement of site preparation equipment and routine silvicultural activities, such as pruning and thinning (FAO, 2010).

Anothercause of spreading andoutbreak of insect pests is dueto climate change which is dominantlydue to rising of global temperatures. Forestry Commission

(2011) reported thata trend towards warmer and wetter weather may cause a certain native organisms not previously regarded as pests to damage their hosts or invade new ones. Climate change can permit expansion of the outbreak range of several forests insectsworldwide. It can modify the natural synchronization between the host plant and insects (Ewelina, 2012).

2.1.2Altitudinal distribution of forest insect pests

The pest status and host range of the forest insect pests generally varies from low altitude to high altitude. Altitudinal distribution of an insect species is controlled by its environmental tolerances, with maximum population size being achieved at some optimum elevation and population density declining withaltitude above and below the optimum (Hodkinson, 2005). Many studies on the distribution and population dynamics of forest insects suggest that climatic variations, such as drought and heat waves may cause insect outbreaks, these climatic factors influencing both directly on the insect populations and indirectly on the health of the host trees. Flinte*et al*. (2011) reported that insect species distributions are influenced by abiotic factors (e.g. rainfall, humidity and temperature), biotic (e.g. host plants, natural enemies) and by their physiology. Researchers recently focus on how climatic change affects insect species distribution particularly the role of temperature (Battisti*et al*., 2006). Increasing altitude brings lower temperatures, increased precipitation or snow, lower partial pressure of gases, higher wind speed and greater extremes in radiation input. Combination of these factors may produce a general decrease in the structural complexity of insect habitats, as well as variation in the nutritional quality and availability of host plants.

Faccoli and Bernardinelli (2014) reported that with increasing altitude and abiotic factors such as temperature and precipitation can influence physiological and morphological changes in insect populations in the short term (e.g. variations in the life cycle, fecundity and size of individuals) and over evolutionary time. Nihaland Sağlam (2013)found that temperature is a key biotic factor that regulates insect population dynamics, reproduction, mortality and seasonal occurrence of aphids such as adult longevity and fecundity. Alleck*et al*. (2005) found that Cypress aphid populations are strongly influenced by weather conditions. During heavy rains and high temperatures, Cypress aphid populations decline. The pest is present throughout the year with a low population during the warm months (from January to April) and a population rise during the cooler months (from May to September). Temperature affects longevity, development time and fecundity of aphids,all of which influence intrinsic rate of increase (Kairo and Murphy, 1999).Marini *et al*. (2012) clearly showed that trends in insect species richness and abundance of individuals are variable and decreasing with increasing altitude.

Jactel*et al*. (2012) stated that there are many processes which explain how species richness and abundance declines with increasing altitude, including reduction of habitat area at high elevations, reduction of resource diversity, increasingly unfavorable environments and reduction of primary productivity. Erelli*et al*. (1998) stated the distribution of insects along the altitude using two hypotheses; were Temperature and Nitrogen deposition hypothesis. Authors found that mountain tree populations may be more resistant to herbivory if low temperatures constrain growth more than they constrain photosynthesis, resulting in increased secondary metabolism.Alternatively, mountain trees may be fertilized by atmospheric nitrogen deposition and become more palatable to insects (atmospheric deposition hypothesis) and the foliage from plants growing at low altitude would be less palatable to herbivores than the foliage from plants growing at higher altitude.

The climate change might have impact on the relationships between pests, their natural habitats and other elements of the natural ecological chain, like natural enemies and competitors. Bale *et al*. (2002) explained that insect's distribution along the elevationalcan be possibly affected by climate change because their development, reproduction and survival are more sensitive to climatic factors and their changes. Climate change can modify the natural synchronization between the host plant and insects (Ewelina, 2012). Andrew *et al*. (2013) reported five most dominant response variables to climate change were changes in abundance, distribution/range shift, interactions, assemblage composition and phenology. Sambaraju*et al*. (2012) reported that climate change can markedly influence biology, population ecology and spatial patterns of the insects due to the direct influence of temperature on insect development and population success. To a given sensitivity of insect ecological processes to the global climate change could possibly alter the outbreak of forest insects (Andrew *et al*., 2013). Climate change can also affect the geographical range of species (Marin *et al*.,2012). Both theoretical and empirical studies indicate that climate change can permit expansion of the outbreak range of several forests insects (Logan *et al*., 2010). Climate change can cause range shifts of insects by turning climatically unsuitable habitats into suitable ones or vice versa (Marin *et al*., 2012). Tropical insects are predicted to be even more sensitive to climate change than their temperate counterparts (Deutsch,*et al*., 2008). It has been argued that altitudinal range shifts in herbivorous insect species, within the broader distribution range limits of their host plant species, can serve as a sensitive indicator of climate change (Hodkinson and Bird, 1998).

2.1.3 *Cinaracuppressivora*: Host and biology

Cinaracuppressivora is a significant pest of Cupressaceae family (*Cypresses, Cupressus, Juniperus, Thuja, Callitris, Widdringtonia, Chamaecyparis, Austrocedrus*) and has caused serious damage to naturally regenerating and planted forests in Africa, Europe, Latin America, Caribbean and the near East. It is believed to have originated on *Cupressussempervirens* from Eastern Greece (Alleck*et al*., 2005). Watson *et al*. (1999) also reported that much of the information on its biology and ecology has been reported under the name *Cinaracupressi*. O'Neil (1998) stated that, *C. cupressi*are brownish soft-bodied insects, often with a grey waxy coating and adults are winged or wingless. Ciesla (1991) also reported that their bodies are sometimes covered with a powdery wax and typically occur in colonies of 20-80 adults and nymphs on the branches (twigs) of infested trees.

According to Ciesla (1991) the life cycle of the aphid is very complex. Ciesla (2003) reported that *C. cuppressivora* has a high reproductive potential and only female are present during summer months which reproduces parthenogenetically and give birth to live young. At cool weather, both males and females are found and eggs are produced instead of live nymphs. Watson *et al.* (1999); Ciesla (2003) observed that the eggs are deposited in rough areas on twigs and foliage, where they overwinter.

Several generations are produced in a year and adults survive for a period of about fifteen days and the entire lifespan extends over approximately 25 days (Alleck and Seewooruthun, 2002).

2.2 Impact of forest insect pests

A wide range of pests can have negative impact on forestecosystems and the forest products. Outbreaks of forest insects alone damage some 35 million hectares of forests annually, primarily in the temperate and boreal zones (FAO, 2010). The periodic outbreaks of insect pests affect ecosystem structure and function at a variety of temporal and spatial scales. Forest pest insect outbreaks have been leaving distinct fingerprints in the annual growth rings of the trees (Buentgen*et al*., 2009). FAO (2010) reported that indigenous pest species may become a significant problem, mostly when they reach outbreak populations on introduced tree species. However, most of damage is caused by introduced pests, which have been accidentally introduced through trade of forest products, live plants and other forest commodities. Forestry Commission (2011) reported that it is not easy to predict changes to the impact of specific insect pests and tree diseases on woodlands and stressed trees which are more susceptible to insect pests and diseases.

2.2.1 Impact of *Cinaracuppressivora*on trees of *Cupressuslusitanica*

Sap sucking insects like *C. cuppressivora* can cause some local damage resulting in die-back of infested shoots, loss of photosynthetic area and premature shedding of needles (Rolando and Little, 2005). The Cypress aphid feed on green branches to woody stems. The colonies of Cypress aphid settle on the bark of young woody twigs creating a kind of sleeveaffecting tree by piercing the bark and sucking the sap, unfortunately, causing yellowing to browning of the foliage on the affected twigs. They produce saliva which is phytotoxic and leads to necrosis in the phloem resulting subsequently in twig withering (Ciesla, 2003).

Montalva*et al*. (2010) reported that Cypress aphid is done damage trees by inserting its stylet mouth on the tree bark and suck sap from the phloem. Phloem sap is rich in sugars and low in amino acids, thus is why aphids are forced to ingest large quantities of liquid to obtain an adequate amount of food to ensure their survival. After penetration of the stylet, Cypress aphids produce saliva containing enzymes that facilitate penetration between the cells of the plant. Feeding retards new growth and causes desiccation of the stems with a progressive dieback of heavily infested trees have been reported by Alleck*et al*. (2005). Obiri (1994) stated that aphids feed in colonies, producing copious amounts of honey dew which covers the branches and stems. Large amount of honeydew produced favour growth of sooty mould that blanket the foliage and branches which thereby hinders photosynthesis and gas exchange. The overall effect on the tree ranges from partial damage to eventual death of the entire tree depends on the severity and duration of the *C. cuppressivora* infestation (O'Neil, 1998).

Watson *et al*. (1999) reported that *C. cuppressivora* seriously damaged commercial and ornamental plantings and native stands of *Cupressus, Juniperus, Widdringtonia* and other *Cupressaceae* in Africa, Italy, Jordan, Yemen, Mauritius and Colombia. Oktinag’ati and Nangawe (1996) reported that the outbreak of the Cypress aphid attack on *C. lusitanica*can cause widespread damage and disrupt the flow of goods and some ecosystem services from cypress trees.

Cinaracuppressivora caused a loss of commercial plantations in East and South Africa and causing serious effects on the region's supply of domestic wood (Ciesla, 1991). Over 75,000 ha of *C. lusitanica* in Kenya, 15,000 in Tanzania and 4,600 in Uganda were infested by the aphid to variable damage levels ranging from slight to severe (Mwangi, 2002). It was earlier estimated that the aphid has caused an annual loss of growth increment worth USD 13.5 million and killed USD 41 million worth of trees in Africa (Murphy, 1996).

2.2.2 Status of *Cinaracupressivora* in Eastern Africa

The Cypress aphid comes from the temperate regions of Europe and North America. It was first recorded in Africa, from northern Malawi in 1986. It then rapidly spread over the East and Central African countries including Tanzania, Burundi, Rwanda, Uganda and Kenya where it caused severe damage to *Cupressus, Juniperus*and*Widdringtonia* species (Watson *et al*., 1999). According to Murphy *et al*. (1990) the symptoms of damage on Cypress trees by *Cinaracupressivora* in Tanzania were observed earlier in Musoma in 1986, however this record has not been published. The drying of the Cypress trees was formerly reported in June 1987 in two regions in the north of Tanzania i.e. Arusha and Kilimanjaro and three regions in the southern highlands i.e. Mbeya, Iringa and Ruvuma (Ciesla, 1991). Towards the end of 1988 Cypress aphid was observed in almost all Cypress trees growing areas across the country (Ciesla, 1991; Chilima, 1991). In Tanzania, populations of

Cypress aphid of up to 80 aphids/10 cm branch has been recorded and damage appears to be more severe during June to September dry season (Kessy, 1990). Most Cypress growing areas suspended planting *C.lusitanica* in large scale in early 1990's and to date Cypress is grown in very slow pace.

2.3 Control of forest insects

Health of the forest should be a first intention of sound commercial forest management. Keeping forests healthy requires careful planning throughout all of the resource management phases from planting to harvest (FAO, 2010). Historically, a great deal of attention has been given to development of treatments for specific pest problems. Conceptually, these tactics affect insect's reproduction, mortality, immigration and/or emigration. There are several ways used to manipulate the populations of the insect's pests. Current methods of pest and disease management in trees vary greatly. Different control options exist for the Cypress aphid including development of resistant materials, silvicultural techniques (Mwangi, 2002), Chemical treatments (RHA, 2004), Biological control (Mwangi, 2002; Eyles*et al*., 2008; Mutitu, 2012) have been used in different parts of the world to reduce the *Cinaracupressivora* problems. The later has been used very successful in Kenya and Malawi, and has a lot of prospects in Tanzania (Mutitu, 2012).

Mwangi (2002) suggests silvicultural technique such as thinning to reduce the density of trees and resultant shady conditions which the aphid seems to prefer; restricting planting of Cypress to rich, deep soils in cool areas; and planting of alternative species, for example *Grevillearobusta*, which are not attacked by the aphid. Other Silvicultural methods are proper site selection and timely harvesting of the plantations. Ciesla (2003) found that Cypress plantations established on good soils are more tolerant of aphid infestations than those established on shallow, rocky and young soils, however, young growing plantations are more susceptible to damage than mature plantations.

Chemical control method including application of the behavioral chemicals compounds that resulting in attraction and dispersal of the insects has been used widely particularly at nursery stage. Phenolic compounds such as stilbenes, flavonoids, lignans and tannins are a major class of inducible defencechemical compounds in many woody species (Eyles*et al*., 2008). However, due to the economic and environmental constraints, chemicals are not well applied in sufficient level to reduce population density and spreading of exotic pests.RHA (2004) identified chemical treatments containing Pirimicarb (Pyrimor) to combat *C.cuppressivora* which has a low toxic level for humans and other insects. The treatment depends on the presence of the aphid and spraying should be done on all foliages (Mwangi, 2002). Nyeko*et al*. (2007) reported that chemical treatment is not feasible for many pests and diseases in large plantations, though more suitable in nurseries. It may lead to problems associated with environmental contamination, health safety and the possibility of resistance development in the pest (Alleck*et al*., 2005).

Classical biological control consists of controlling non-indigenous pests by importing natural enemies (parasitoids or predators or pathogens) (FAO, 2010).

According to Montalva*et al*. (2010) the term biological control is the use of living organisms as agents for pest control. Worldwide have been identified and used classical biological control to control impacts of forest pest insects as well as agricultural pest insects. It is considered as one of the best possible solutions for the control of forest insect pests because it is most effective and successful method in various areas to reduce the population density and spread of its outbreak but also can be used as part of integrated pest management (IPM)(Mutitu, 2012; Cross and Poswal, 2013).

The advantages of using this method is that there is little or no collateral , rare cases of resistance, long-term control adverse effects , the benefit / cost ratio is very favorable and can be used as part of integrated pest management (IPM) (Cross and Poswal, 2013).The same authors found that exotic nature of the pest and its outbreak in the absence of its natural enemy would indicate that it would be an ideal candidate for classical biological control. This would involve the introduction of one or more of the natural enemies primarily responsible for its control. A number of natural enemies have been identified attacking the Cypress aphids such as *Pauesiajuniperunum*, *P. antennata,* Spider mites and Ladybird beetles(Mutitu, 2012; Cross and Poswal, 2013)**,** but it is proposed that the host specific parasitoid *P. juniperunum* should be given priority for controlling of Cypress aphid. For accidently introduced pests, classical biological control has frequently proven to be a very efficient and cost effective pest management strategy in many countries in East Africa e.g. Malawi, Kenya and Uganda. Information from different projects on the classical biological control of Cypress aphids indicates that *P. juniperunum* play an important role in reducing population density and spread of Cypress aphid (Mutitu, 2012; Cross and Poswal, 2013). Biological control using *P. juniperunum* is considered as the best possible solutions for the control of Cypress aphid globally. Biological control agents of *C. cuppressivora*such as *Pauesiacupressobii*and *P. juniperunum* (Hymenoptera: Braconidae) and *Aphidus* species parasitoid have been used successfully in different parts of the world (Mwangi, 2002; Mutitu, 2012). The parasitic wasp, *P. juniperunum* which showed good performance was introduced in Kenya, Malawi and other Eastern African countries on the Cypress aphid (Chilima, 1995; Day *et al*., 2003). Biological control has several advantages that are little or no collateral, rare cases of resistance, long-term control adverse effects, the benefit/cost ratio is very favorable (Cross and Poswal, 2013). Alleck*et al*. (2005) argued that classical biological control is the most suitable option for controlling Cypress aphid under Integrated Pest Management which is environmentally friendly, economically viable and socially acceptable option.

Genetic resistance to *C. cuppressivora*in *C. lusitanica* has been found and investigated in Kenya (Kamunya*et al*., 1999; Orondo and Day, 1994). Variation in resistance against this pest has been observed both among the genera and within the species of the Cupressaceae family (Claude and Faustin, 1991). This trend is important in selecting for resistance breeding as the species and individual trees showing a high combining ability for disease resistance provide a basis for a viable hybridization programme (Marini *et al*., 2012).

The most effective way to deal with forest pests is integrated pest management (IPM) in which variety of tactics can be used simultaneously to manage insect pest population. IPM systems consist of a combination of decision-making and pest management tools directed against a pest and are in various stages of development. These suppression measures can be ecologically and economically efficient and sociallyacceptable, in order to maintain pest populations at a suitable level (FAO, 2010). An example of an evolving IPM system is the approach being taken to manage the European wood wasp, *Sirexnoctilio*, in pine plantations in southern Brazil (Cross and Poswal, 2013).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of study area

3.1.1 Location

Sokoine University of Agriculture Training Forest (SUATF) Olmotonyi is located on the slopes of mount Meru between latitude 3º15'-3º18'S and longitude 36º41'-36º42'E at about between 1740 to 2320 meters above sea level. The forest is about 15 km north ofArusha Municipal and is accessible byall weather road which branches at Ngaramtoni township about 10 km from Arusha- Nairobi highway. It covers a total area of about 840 hectares and is bordered by Meru Forest Plantation to the East and West, Arusha National Park (ANAPA) to the North and some villages to the South (Figure 1).

3.1.2 Climate

The climate of SUATF is typically tropical with two main rain seasons. The first season (long rain season) lasts for about three months starting from March to May and the second (short rain season) is from November to December. The mean annual rainfall varies from 800-1200 mm per year and humidity is high, nearly 98-100% during the long rains. The temperature varies between 15^0C and 28^0C depending on the season and altitude, July and August being to the coldest months (SUATF, 2011).

3.1.3Topography and hydrology

Most parts of the Training forest are mountainous with slopes ranging from gentle to steep slope at an altitude of about 1740 to 2320 meters above sea level. Areas with gentle slope are utilized for plantation forest while very steep sloped areas remain protected by natural vegetation cover. Seliani and Engare-Narok are the main permanent rivers flowing through the Training Forest (SUATF, 2011).

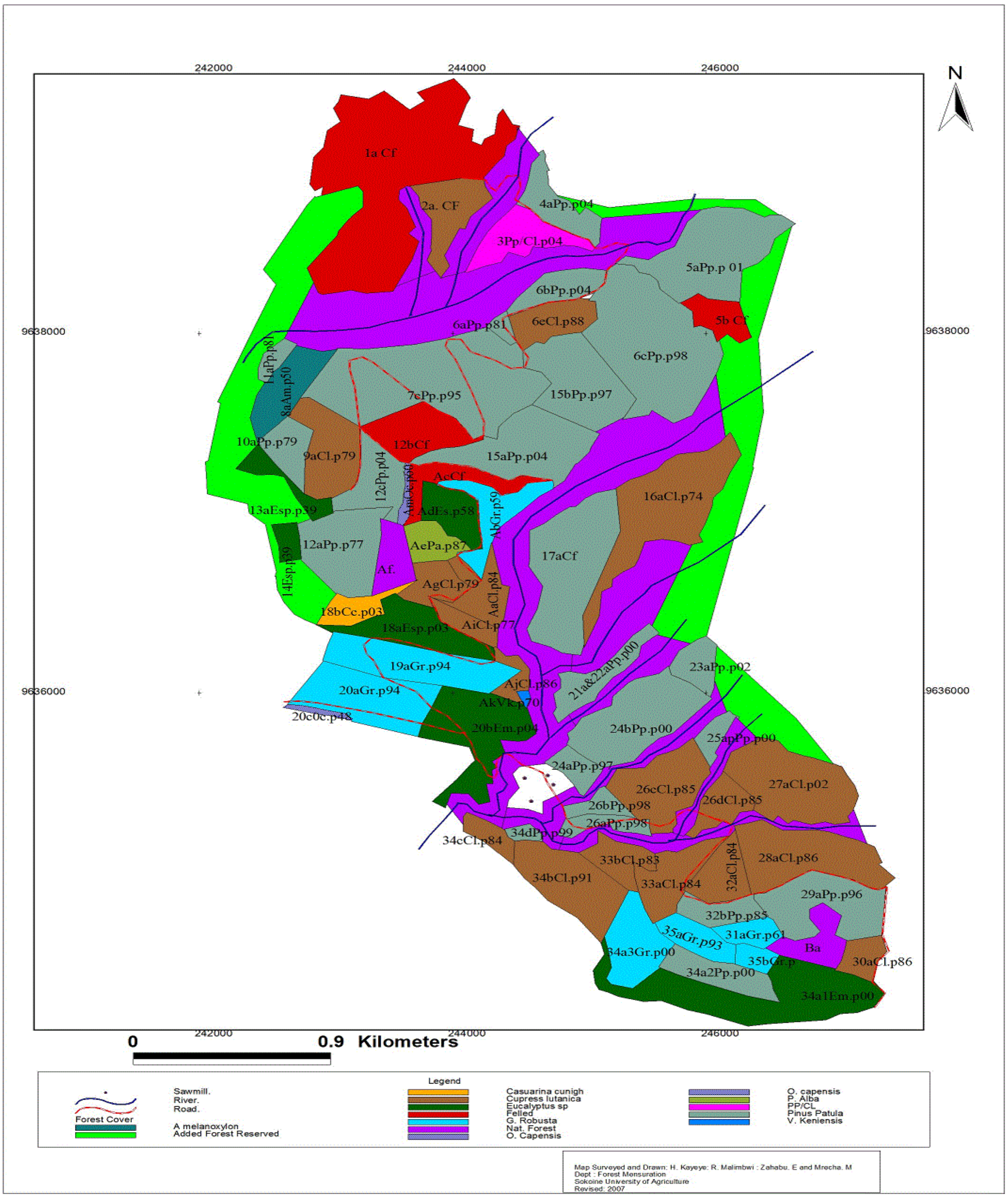

Figure 1: Map of Sokoine University of Agriculture Training Forest, Olmotonyi, Arusha. Source: SUATF (2011).

3.1.4 Vegetation

The Forest is comprised of two main vegetation blocks; plantation forests and natural vegetations. In the natural forest there is a lot of brambles and brushes but *Ulticamasaica* (the Masai nettle) is the commonest natural under growth. Also many wood species such *as Entandrophragmaexcelsum, Croton megalocarpus, Cordiaabbyssinica, Diosyposlspp, Syzygiumguineense, Myrianthusholstii*and *Albiziagumifera* are common in this area. In most open areas, the most dominant species are *Neoboutoniamacrocalyx, Rauvolviaabyssinica, Albiziaschimperiana*and *Dombeyagoetzeii*. *Podocarpusgracilior, Juniperusprocera, Croton macrostachyus*and *Oleacapensis*occur widely in the mid-latitude. Above 1700m of altitude *Prunusafricana*and *Podocarpusmillanjianus* occur with patches of bamboo-*Arundinariaalpina* at greater altitudes. Above 2500m the higher forest degenerates into Cricaseous woodland with *Stoebekilimandscharica, Hageniaabyssinica, Rapanearhododendroides, Erica aroborea,* and*Philippiatrimera*. Plantation forest is dominantly comprised of *Pinuspatula, Eucalyptus spp, Grevillearobusta*and*Cupressuslusitanica*(SUATF, 2011).

3.2 Methodology

3.2.1 Sampling frame

SUA Training forest covers an area of about 840 hadivided into 667.8 ha as a plantation forest, 159.2 ha a protection forest and 13 ha anon-forested area. The plantation has 63 registered compartments, 10 compartments are planted with *C. lusitanica* which covers about 96.6 ha and the remaining areas are planted with *P.patula, G. robusta* and *Eucalyptus* species(SUATF, 2011).

Purposive sampling was employed to select all *C. lusitanica*compartments along the gradients ensuring that each altitudinal range with *C. lusitanica*and age classes are covered. Before embarking in the field work, reconnaissance was conducted to capture the general pattern of *C.cuppressivora* distribution and damage in compartments. In each selected compartment, 50 trees were selected systematically whereby every 5th tree along the row was considered as a candidate. The selected trees were marked and geo-referenced using GPS to facilitate future measurement and monitoring. The first tree was established randomly at any of the corners of the compartment at least 50m from the boundary. The distance between transects were at every 10th row from the starting point. A total of six transects were considered in each compartment, distributed systematically at the middle and two edges oriented along the contours.

3.2.2 Data collection

3.2.2.1 Altitudinal distribution and abundance of Cypress aphid on *Cupressuslusitanica*of different age classes.

Stratified sampling was adopted whereby the entire study area was arbitrarily divided into three strata based on altitudinal ranges. The lower stratum was (1700-1930 m.a.s.l), middle (1931-2125 m.a.s.l) and upper stratum (2126- 2300 m.a.s.l). Three age classes, young trees (1-10years), middle (11-25) and old trees (>25 years) were considered in each stratum. Tree age was obtained from the Training forest management plan. The crown of the selected trees was divided into three whorls (lower, middle and upper) and five shoots in each whorl were randomly cut and quickly put in labeled zipped plastic bags to avoid insect jump which was later put in a refrigerator to reduce insect decomposition . Each shoot was then carefully (with a help of fine brash) washed with alcohol (70% ethanol) in a Petri dish to remove the aphids (eggs, nymph and adults). The separate morphs (eggs, nymphs and adults) were counted and recorded accordingly. Occurrences of natural enemies were recorded in the field to capture their diversity and abundance. Identification of the natural enemies was done either in-situ or collected for laboratory identification. Diversity and abundance of natural enemies were assessed from the same twigs used for Cypress aphid assessment.

3.2.2.2 Damage of *Cupressuslusitanica* by *Cinaracupressivora*

Visual observation on the crown was used to determine the level of damage in different altitudinal ranges and age classes. Level of damage was determined using the extent of browning/death of the crown of the selected trees used to study the distribution and abundance and a five-point subjective scale developed by Petro and Madoffe (2011) was used (Table 1).

Table 1: Damage scale of Cypress aphid on Cypress trees

Percentage of crown attacked	Damage score	Remarks
0	1	Healthy tree. No symptoms associated with Cypressaphid.
1-25	2	Light infestation. Yellowing to browning of branches and twigs limited to bottom of the crown.
25-49	3	Moderate infestation. Yellowing/brown over the bottom of the crown extending to half of the crown.
50-74	4	Heavy infestation. Yellowing to browning and death of branches and twigs affecting up to 75% of the crown.
75-100	5	Severe infestation. Yellow to browning and death of twigs and branches extending to the entire crown.

3.2.2.3 Historical trend of occurrence and control of Cypress aphid

The historical trend of occurrence and control measures of Cypress aphid were obtained from different projects documents and interviews. The later was administered to the manager, former managers and forest officers/field officers with outstanding experience in the training forest.

3.3 Data analysis

Data wasanalysedwith help of Microsoft excel Software. Analysis of Variance (ANOVA) at 5% level of significance was adopted to compare differences in abundance and damage intensity between altitudinal ranges and age classes. Logistic regression modelwas used to determine the relationship between the abundance of *Cinaracupressivora* and damage intensity. Similarly, regression model was run to determine the relationship between abundance of natural enemies and Cypress aphid. The most abundantnatural enemies with >10 individuals per twigs were considered for the regression.

CHAPTER FOUR

4.0 RESULTS AND DISSCUSION

4.1 Altitudinal distribution and abundance of Cypress aphid in SUATF

The results revealed that mean number of Cypress aphid was 25.8aphids/twig distributed un-equally throughout thealtitudinal rangesand age classes. The mean number of adult Cypress aphid per twig was 19.6, 25.1 and 33.7 for lower, middle and upper altitude respectively (Table 2). The mean number of nymph followed similar trend as adults with 9.8, 12.5 and 19.0 individuals per twigs at lower, middle and higher altitude respectively. The abundance was however, reversed for the eggs. Ciesla (1991) reported that Cypress aphid typically occurs in colonies of 20-80 adults and nymphs on the branches (twigs) of infested trees. The higher altitude had more Cypress aphid than lower and middle altitude and the abundance was statistically significant ($p<0.05$, *df*=2, F=6.57) (Table 3).

Table 2: Mean number of eggs, nymphs and adults Cypress aphid per twigs for different altitudinal ranges at SUATF

Altitudinal range (m.a.s.l)	Mean number		
	Eggs	Nymph	Adults
Lower (1700-1930)	3.8±2.2(1.08)	9.8±2.9(1.47)	19.6±5.9(2.92)
Middle (1931-2125)	3.2±0.8(0.39)	12.5±1.7(0.87)	25.1±2.9(1.48)
Upper (>2126)	1.4±0.1(0.59)	19.0±5.8(2.91)	33.7±8.2(4.13)
Mean Total	3.0±0.6(0.45)	13.3±1.6(1.34)	25.8±2.6(1.07)

Mean±Confidence Level (95%) and (Standard error)

Table 3: Analysis of Variance to compare population density of adults Cypress aphid between altitudinal ranges at SUATF

Source of variation (Altitudinal ranges)	*df*	F-ratio	*P-value*
Between lower, middle and Upper altitude	2	6.57	0.05**
Between lower and upper altitude	1	21.14	0.04**
Between lower and middle altitude	1	1.33	0.36*
Between middle and upper altitude	1	3.68	0.19*

df= Degree of freedom *= Not significant (p>0.05) and **= Significant (p<0.05) at 5% level of significance

This difference in Cypress aphid between upper, middle and lower altitudinal rangesmight have been caused by a number of possible reasons such as; heterogeneity of abiotic factors such as temperature and precipitation experienced along elevation which can influence physiological and morphological changes in insect populations (Flinte*et al*., 2011). Temperature is the most important abiotic factor affecting development and reproduction of aphids. Geographically separated populations of aphids may differ with respect to the influence of temperature on development and population growth. Temperature influences both aphid development and mortality and is a fundamental feature of its life history (Nihal and Sağlam, 2013). Similarly,Faccoli and Bernardinelli (2014) reported that temperature influences almost all aspects of insect life history, population level processes such as development rate, seasonality, voltinism and range. Hodkinson (2005) reported that extreme heterogeneity over relatively short distances in montane regions influences insect distribution, morphology, physiology and their behavior.This is because of their sensitivity to anthropogenic disturbances, habitat loss, pollution and climate change. Many insect taxa are used as indicators of global change (Brown and Gange, 1990;Menendez and Gutierrez, 1996).

Another probable reason for this difference wasatmospheric nitrogen deposition (nitrogen deposition hypothesis) which affects palatability of the host trees. Erelli*et al*. (1998) found that the nitrogen deposition hypothesis shows that high elevation trees tended to have higher leaf nitrogen, lower leaf tannins and support higher insect growth performance than trees from lower elevations. Atmospheric nitrogen deposition could produce phenotypic changes in tree allocation patterns similar to those typically associated with fertilization i.e., increased plant growth, increased leaf nitrogen, decreased concentrations of secondary metabolites which are used in defensive mechanism to herbivoryand increased suitability for herbivores (Herms and Mattson, 1992).Hodkinson (2005) reported that secondary compounds and defensive chemicals are varying with altitudinal gradient. The concentrations of condensed tannins in mature trees at lower altitude were around twice compared to those at higher altitude. Plants which are growing in more stressful conditions, like in the upper parts of the mountains, invest less in producing defensive compounds (Erelli*et al*., 1998).

Additional reason is the effect of CO_2 enrichment on tree species, related to climate change and global warming, also affects changes in host plant quality and consequent effects on plant palatability to insects related to varying of CO_2 levels with elevations (Peacock, 1998).The same authorreported that the partial pressure of atmospheric gases including oxygen and carbon dioxide decreases with increasing altitude and lower partial pressure influence the occurrence of a number of the forest insect at the higher altitude than lower altitude.Chen *et al*. (2011) reported that climate change may cause shifting of insects from low altitude to upward by turning climatic variable from unsuitable habitats into suitable ones for tropical montane insects.

The results further showed that adultCypress aphid were more abundantthan nymphs and eggs (Table 2). The differences in number of the three developmental stages could have been caused by complex model of reproduction of Cypress aphid**.** Ciesla (2003) reported that *C. cuppressivora* has a high reproductive potential and only female present during summer months which reproduces parthenogenetically and give birth to live young. At cool weather between 15^0C -20^0C, both males and females are found and eggs are produced.Three nymphal instars occur, lasting for about eleven days. Adults survive for a period of about fifteen days and the entire lifespan extends over approximately 25 days (Alleck and Seewooruthun, 2002).However, the number of adultCypress aphid was high probably due to the adult life span being longer than nymph life span which always makes the population number of adultCypress aphid higher than nymph and eggs.Kamunya*et al*. (1997) also argued that immature stages are more sensitive to abiotic factors changes than adults.

Additionally, Figure 2 shows that mean population density of adultCypress aphid increases with elevation. It is evidently shown that the population density of the

Cypress aphid increased toward the slope at SUATF with coefficient of determination of R^2=92.9showing a very strong relationship between variation of the adult Cypress aphid with elevation. The results are similar toFlinte*et al*. (2011) that abundance of *Plagiometrionaspaeth* increased with altitude up to 1800 m, where the highest mean host plant density was found. The increasing of adultCypress aphid along the gradient atSUATFwas probably caused by climate change that influences the changes of climatic factors such as temperature and precipitation. Climate change is having a noticeable effect on terrestrial ecosystems, as evidenced by poleward and elevational shifts in the distributions of many species of plants and animals (Bale *et al*., 2002; Hickling*et al*., 2006). Climate change cause range shifts of insects by turning climatically unsuitable habitats into suitable ones for tropical montane insects along the elevation (Chen *et al*., 2011).

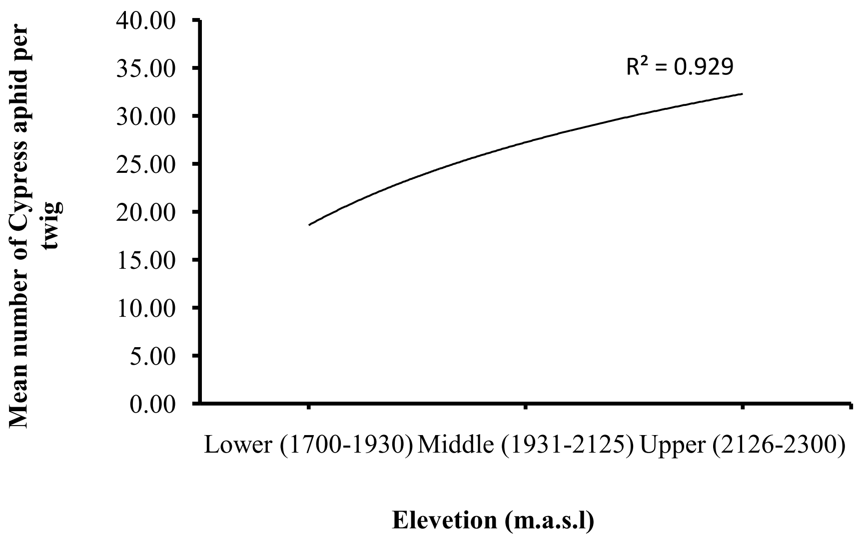

Figure 2: Mean population density of adultCypress aphid per twig along the slope at SUATF

Tropical ectotherms are responding to changes in climate because they exhibit a narrow range of physiological tolerance and live at or near their thermal optimum (Deutsch *et al*., 2008). Tropical insects are predicted to be even more sensitive to climate change than their temperate counterparts (Deutsch *et al*., 2008). It has been argued that altitudinal range shifts in herbivorous insect species, within the broader distribution range of the host plant species, can serve as a sensitive indicator of changing climate (Hodkinson and Bird, 1998). The climatic shifts are predicted to be greater in the uplands (mountains) than in the lowlands (Deutsch *et al*., 2008). Upslope shifts are more likely than poleward shifts in the tropics due to the shallow latitudinal temperature gradient (Colwell *et al*., 2008). Root *et al*. (2003) found that climate change has strongly altered insect species distributions, causing range retractions and extinctions. For example, in Britain, rising temperatures causing butterflies and other taxa to move poleward and upward (Hickling*et al*., 2006). Species extinctions in the mountains are primarily expected to occur due to the loss of high elevation species that have to move upwards (mountaintop extinctions) and the local loss of species from the lower portion of their elevational range (Wilson *et al*., 2007).Recent studies suggest that the conditions in the upper elevation and higher latitude became more suitable for organisms particularly insects, because global warming exceeded threshold of tolerance (heating and aridity) in lowlands. The uphill became refuges for escaping organisms from lowlands (Hardy *et al*., 2010).

The results contrary with Alonso (1999) stated that several insects declined densities with increasing altitude, including the *Yponomeutamahalebella* and the

Ditropispteridis. Increasing altitude brings lower temperatures, increased precipitation (rain or snow), lower partial pressure of gases, higher wind speed and turbulence and greater extremes in radiation input (Flinte*et al*., 2011). Combination of these factors may produce a general decrease in the structural complexity of insect habitats, as well as variation in the nutritional quality and availability of host plants.

Furthermore, themean numbers of adultCypress aphid were 33.7, 16.6 and 18.8 per twig for the young, middle and old age classes respectively (Table 4). Analysis of variance showed that the abundance of aphids between age classes was significantly different (p<0.05, *df*=2 and f=10.82) (Table 5).

Table 4:The mean numbers of eggs, nymphs and adults Cypress aphid per twig at different age classes at SUATF

	Mean number		
Age classes in years	Eggs	Nymph	Adults
Young (0-10)	2.7±0.9(0.43)	18.1±2.8(1.41)	33.7±4.5(2.32)
Middle (11-25)	2.9±1.2(0.63)	8.5±2.1(1.12)	16.8±3.7(1.91)
Old (>25)	3.5±1.4(0.71)	8.3±1.4(0.71)	18.8±2.7(4.49)
Mean Total	**3.0±0.6(0.32)**	**13.3±1.6(0.8)**	**25.8±2.6(1.34)**

Mean±Confidence Level (95%) and (Standard error)

Table 5:Analysis of variance (ANOVA) to compare population density of adult Cypress aphid between Age classes at SUATF

Source of variation (Age)	*Df*	F-value	*P-value*
Between young, middle and old trees	2	10.82	0.02**
Between young and middle trees	1	16.12	0.05**

Between young and old trees	1	9.04	0.03**
Between middle and old trees	1	0.13	0.75*

df= Degree of freedom *= Not significant (p>0.05) and **= statistically significant (p<0.05) at 5% level of significance

Observation showed that the young age class was more attacked by Cypress aphid than middle and old age classes. The result was similar to Madoffe (1989)who reported that young *Pinuspatula* were vulnerable to Pine woolly aphid (*Pineus? Boerneri*) infestation than old trees. This is probablydue to the host tree resistance variation between tree age classes (ontogenetic) resistanceand nutritional value of the young age class (Develey-Riviere and Galiana, 2007). Plant resistance can be described on several mechanistic levels including basal resistance, parasite- and race-specific resistance (Jones and Dangl, 2006), age-related (ontogenetic) resistance (Develey-Riviere and Galiana, 2007), organ-specific resistance (Blodgett *et al*., 2007) and acquired or induced resistance (Kiraly*et al*., 2007). Develey-Riviere and Galiana (2007) found that young trees have low resistance against insect pests than old trees.Blodgett *et al*. (2007) reported that tree bark is a first line of ontogenetic (age-related) resistance against insects and pathogens. It contains not only chemical means to combat insect attacks but also anatomical structures (Franceschi*et al*., 2005). Bark texture was historically hypothesized to be an ant insectdefence that operates by reducing the ability of insectspiercing tree stems for sap sucking. Young age class supported a higher number of Cypress aphid because of large proportion of the smooth and tender bark texture which iseasily for pierced by.

Another possible reason is nutritional value of the young age class that influences insect preference and performance (Zehnder, 2006). Nutritional value and quality of young trees influence and create a fouvarable condition for Cypress aphid survival and development. Ciesla (2003) reported that Cypress aphid prefers more feeding on the young trees because the phloem sap of the young age classes is rich in sugars that is why aphids are forced to ingest large quantities of liquid in young age to ensure their survival. Therefore, mature trees have high resistance against insect pests because of large proportion of rough bark texture, low quality of nutritional value and high ability of producing chemicals resistance (Eyles*et al*., 2008).

Although, the results show that there was considerable variation in number ofCypress aphid eggs between ages classes,old age classes had high number of eggs than young and middle age classes. The mean number of eggs per twigs was 2.7, 2.9 and 3.5 for young, middle and old age classes respectively. On the other hand, the mean numbers of nymph were 18.1, 8.5 and 8.3 per twig for young, middle and old age classes respectively. The variability in number of eggs may be attributed by variation of male reproductive Cypress aphid. Ciesla (2003) reported that at cool weather, Cypress aphids reproduce eggs instead of live nymph when both male and female are found. However, young age class had high number of nymphs of Cypress aphid followed by middle and lastly by old age classes. The difference may be attributed by number of reproductive female in young age classes which is experienced with high number of adult Cypress aphid. Only female Cypress aphids present during summer reproduce parthenogenetically and give birth to live young rather than eggs (Ciesla, 2003).

Table 6 shows that total mean number of adult Cypress aphid were6.8, 12.5 and 6.5 per twig for lower, middle and upper part of the crown respectively. The resultsclearly showed that the middle part of the crown of all age classes of *C.lusitanica*supported higherabundance of adult Cypress aphids than lower and upper part of the crown. Analysis of variance showed that abundance of the Cypress aphids differ significantly between the crown parts ($p<0.05$,*df*=2 and f=43.8) (Table 7).

Table 6:The mean number of adult Cypress aphid in three crown part of the *C.lusitanica* at SUATF

Age classes	Mean number of Cypress aphid in crown parts		
	Lower	Middle	Upper
Young	9.2±1.4 (0.73)	15.7±2.3 (1.14)	8.8±1.4 (0.71)
Middle	4.4±1.6 (0.81)	8.2±1.7 (0.87)	4.0±1.8 (0.89)
Old	4.3±0.8 (0.43)	10.1±1.5 (0.76)	4.3±0.8 (0.39)
Mean Total	**6.8±0.8 (0.43)**	**12.5±1.3 (0.66)**	**6.5±0.8 (0.43)**

Mean±Confidence Level (95%) and (Standard error)

Table 7:Analysis of variance (ANOVA) to compare the abundance of adults Cypress aphid between three crown parts of the *C.lusitanica* at SUATF

Source of variation (Crown)	*Df*	F-value	*P-value*
Between lower, middle and upper part	2	43.8	0.002**
Between lower and middle part	1	40.49	0.024**
Between lower and upper part	1	4.18	0.177*
Between middle and upper part	1	48.52	0.019**

df= Degree of freedom *= Not significant ($p>0.05$) and **= statistically significant ($p<0.05$) at 5% level of significance

This difference might be caused by phototacticresponse to aphid against light as reported byPetro and Madoffe (2011) that aphids respond positively to light but do not settle onto surface exposed to strong light. They appear negatively to phototactic response and strong light and consequently tend to settle in hidden and light fissures. Petro and Madoffe (2011) reported that middle crown part of the *P.patula* and *P.elliottii* had higher total mean number of Pine Woolly Aphid followed by lower crown part and upper crown part. The middle crown part receives lower amount of sunlight owing to shade from the upper branches, this would tend to encourage aggregation of aphid where there is less strong sun light consequently contributing to high extent of damaging (Petro and Madoffe, 2011). Madoffe(1989) argued that insect distribution on the tree is mainly affected by light, temperature and wind and so the insects could attain the favourable microclimatic sites. Therefore, there is a considerable variation in severity of attack on individual tree within a crown of affected tree for the reason thatcreate microclimate variation within a crown cover of the tree by making a shelter against light, wind and other environmental factorsaffecting Cypress aphid development and performance.

4.2 Altitudinal distribution and abundance of natural enemies in SUATF

In the current study the main natural enemies for Cypress aphid detected in affected twigs of *C.lusitanica* at SUATF were; *Pauesiajuniperunum*, Hoverfly larvae and Spider mites.Natural enemies were un-equally distributed throughout thealtitudinal rangesand age classes of*C.lusitanica*. The mean number of natural enemies was 3.1, 2.7 and 2.3 per twig for *Pauesiajuniperunum,* Spider mites and Hoverfly larvae respectively.The former is introduced and the later two are native species. The middle age class appears to have supported higher number of the natural enemies than young and old age classes (Figure 3). The abundance of natural enemies was lower compared with abundance of Cypress aphid found at SUATF.

The mean number of natural enemies was 2.5, 2.7 and 2.1 per twig for lower, middle and higher altitudinal range respectively. The middle altitudinal range had higher mean number of natural enemies followed by lower altitudinal range and higher altitudinal range had lowest mean number of natural enemies(Figure 4). This indicates that natural enemies increase with altitude up to a certain point and then decreasing again. The result is similar to Flinte*et al*. (2011) who reported that the species richness did not vary clearly with altitude, but abundance of *Plagiometrionaspaeth* increased with altitude up to 1800m and then decreased again. The presence of these natural enemies to some extent might have kept the population of Cypress aphid on check in SUATF. The results likewise tothe field observations conducted by Alleck*et al*. (2005) revealed the presence of several natural enemy predators including *Pauesiajuniperunum*(Hymenoptera*:* Braconidae),Coccinellid beetles (Coleoptera: Coccinellidae), Syrphid flies (Diptera: Syrphidae), *Chrysopids* (Neuroptera: Chrysopidae) and Spiders (Arachnida). *Pauesiajuniperunum*is a solitary endoparasitoid which has a narrow host range restricted to *Cinaraspp* (Kairo and Murphy, 1993).It is natural enemies which can be used as potential biological agents of *Cinaracupressivora* to regulate the pest population to a certain extent (Mwangi, 2002).

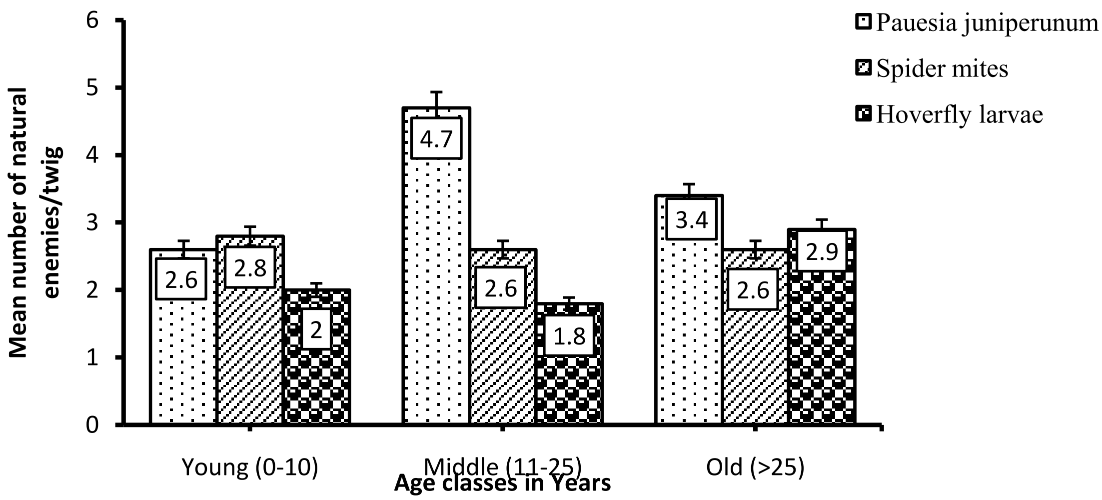

Figure 3:Mean number of natural enemies in different age classes of *C.lusitanica* at SUATF

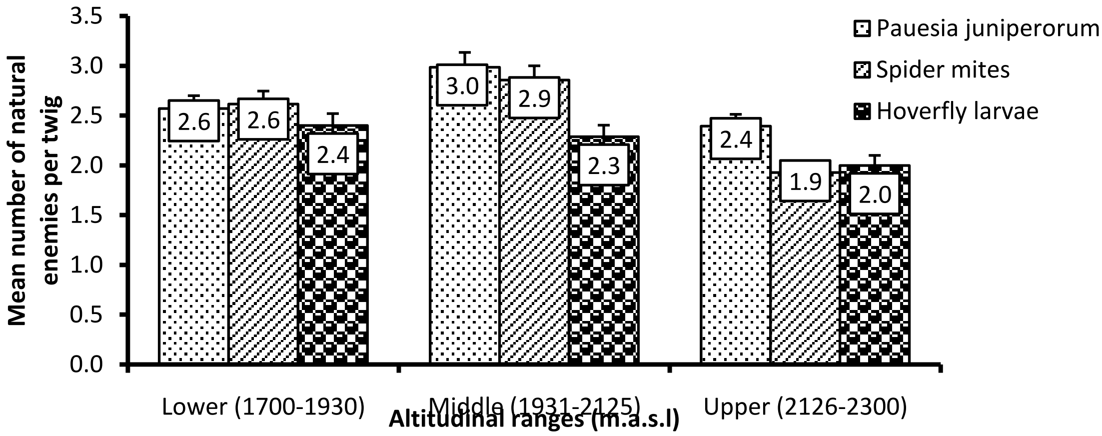

Figure 4:Mean number of natural enemies in different altitudinal ranges at SUATF

The relationship between abundance of natural enemies and abundance of Cypress aphid attacking *C. lusitanica* at SUA Training Forest plantation was represented bythe below equation and figure 5.

$$Y = -1.9428X + 29.501$$

Where, Y is abundance of natural enemies

Xrepresentsabundance of adult Cypress aphid

The result showed that the relationship betweenthe number of natural enemies and abundance of Cypress aphid was not very strong (R^2=35.9), which means that the presence of these natural enemies had mild contribution in keeping the population of Cypress aphid low. The coefficient of determination (R^2) explains that 35.9% of the variation of the number of Cypress aphid was caused by presence of the native natural enemies even though they are fewin number compared to the abundance of Cypress aphid attacking *Cupressuslusitanica* at SUATF.

The result clearly showed that the number of Cypress aphid decreased as the number of natural enemies increased (Figure 5). This indicates that natural enemies play some role in reduction of number of Cypress aphid attacking *Cupressuslusitanica*. Montalva*et al*. (2010) reported that because of the potential risk to protected native species, it was considered important to use natural enemies to combat Cypress aphid in Chile. An important fact about the natural enemies particularly, *Pauesiajuniperunum*is that despite the low number of individual parasitoids released in southern Chile territory it has remarkably dispersed making it a complementary agent undoubtedly decrease the number of observed aphids in field populations. It is also possible that natural enemies had a larger impact on aphid population growth than did plant productivity (Muller *et al*., 2001).

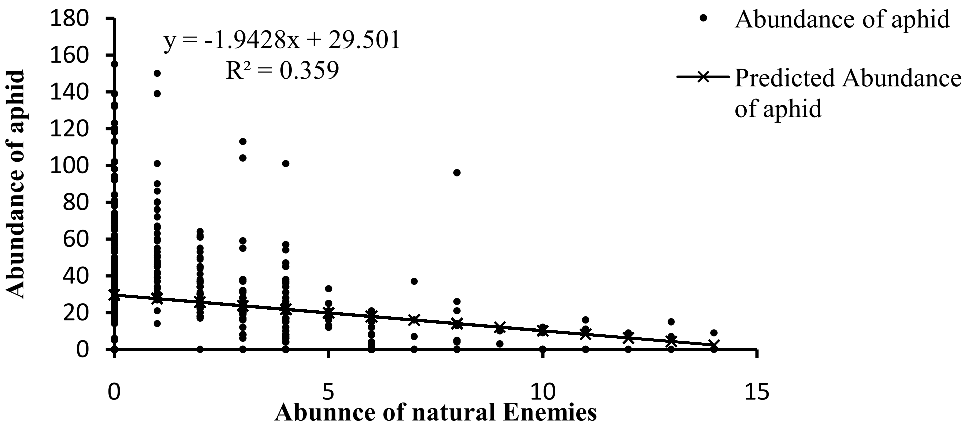

Figure 5:The relationship between the abundance of Cypress aphid and native natural enemies in*Cupressuslusitanica* at SUATF

4.3 Damage intensity of *Cupressuslusitanica* of different age classes along altitudinal ranges

The damage intensity of *C. lusitanica*between altitudinal ranges and age classes as a result of Cypress aphid attack was determined using the extent of the browning/death of the crown. The percentage mean intensity of damage was moderate infestation (25-49%) for young and old age and light infestation (1-25%) for middle age class (Figure 6 and 7). Plates 1, 2 and 3, show intensity of damage on Cypress by *C. cupressivora* for young, middle and old trees respectively.Attack was moderate (25-49%) along the altitude with higher altitude sustaining the heaviest attack (37.63%) followed by middle altitude (30.61%) and least was in the lower altitude (27.12%). Thehigher altitude and young age class had more damage by Cypress aphid, which may have been contributed by the higher abundance of Cypress aphids detected on higher altitude and young age classes at SUATF. Flinte*et al*. (2011) reported that plant damage intensity is generally a function of insect population level. Populations with higher rates of increase have greater potential for causing plant injury.The abundance of Cypress aphid corresponds perfectly with the damage intensity of the attacked tree (high abundance higher damage). Similarly,Nihaland Sağlam (2013) reported that younger trees are the most vulnerable to the insect and disease, and are rapidly killedthan old trees.

Table 8 shows the abundance of the Cypress aphid and percentage mean of damage intensity for different compartments of *C. lusitanica*in SUATF. It is evidently shown that compartment Ad and 8a had higher number of aphids per twig(50.72±12.58 and 37.88±10.83) with a percentage mean of damage intensity of 52.82% and 41.64% respectively than other compartments. The recorded higher number of aphids could be due to the fact that these compartments are dominated by young ageclass trees and planted at higher altitude which together supported large number of the Cypress aphid. The total mean numbers of Cypress aphid were found to be higher in young age classes than in old age classes and middle age class. This corresponds to the intensity of damage, which was recorded to be greater in young age class than old age class and middle age class.

On the other hand, compartment 32a, 27a and 34b had lower number of Cypress aphids per twigs 15.48± 4.19, 16.18± 5.07 and 17.38± 5.59 with low level of damage intensity of 26.12±6.84, 21.92±5.67 and 22.22±6.83 respectively. The lower number of Cypress aphid in these compartments probably due to the fact that they are dominated with old age trees and planted at lower and middle altitudes. However, appendix 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 show the number of adult Cypress aphid and damage intensity of the individual tree, the results clearly showing that some of the Cypress trees might be resistant to aphids attack. Kamunya*et al*. (1999) found that there is considerable variation in severity of attack on individual trees within affected Cypress stand and it is common to find a completely healthy tree adjacent to, and with branches intermingled with a heavily infested neighbour. This is due to the fact that resistance to Cypress aphid may be subject to genetic variation.

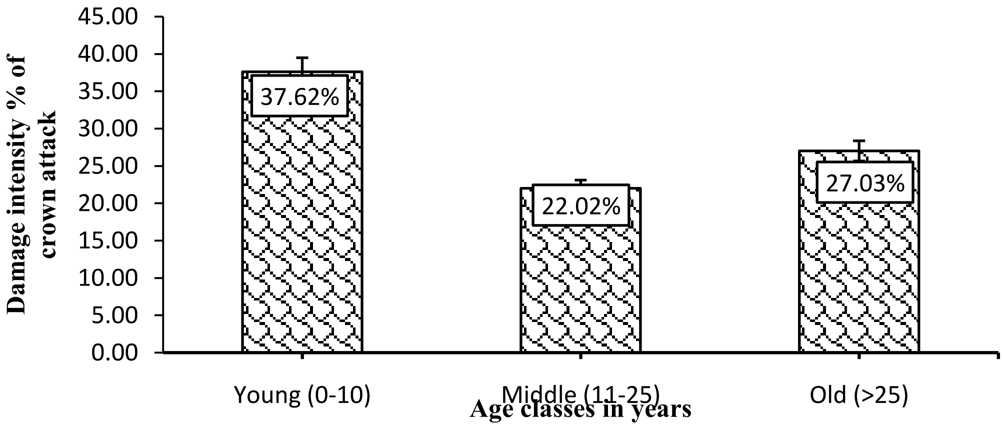

Figure 6:Mean damage intensity caused by Cypress aphid between different age classes of *Cupressus lusitanica*at SUATF, Arusha

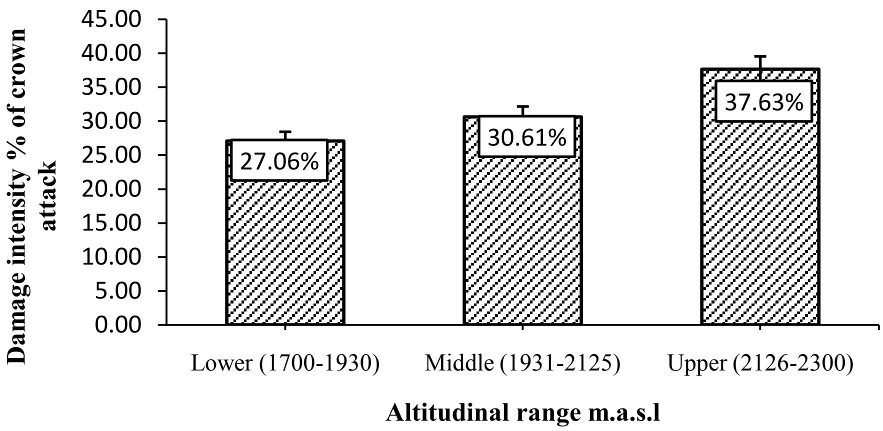

Figure 7:Mean damage intensity caused by Cypress aphid on*Cupressus lusitanica* at different altitudinal range in SUATF, Arusha

Table 8:The abundance of the Cypress aphid and percentage mean of damage intensity for different compartments of *Cupressuslusitanica* in SUATF

Compartments	Age(Years)	Mean number of Cypressaphid/twig	SE	Mean damage % of crown attack	SE
26c	29	20.50±4.92	1.05	24.70±5.67	2.82
27a	12	16.18±5.07	2.53	21.92±5.67	2.82
28a	28	20.46±4.87	2.42	30.26±6.07	3.02
30a	4	22.04±6.52	3.24	25.82±6.11	3.04
32a	30	15.48±4.19	2.08	26.12±6.84	3.40
34b	23	17.38±5.59	2.77	22.22±6.83	3.39
8a	2	37.88±10.83	5.39	41.64±9.75	4.85
Ab (2013)	1	28.76±10.63	5.29	29.80±8.97	4.46
Ab (2009)	5	28.92±8.57	4.26	38.00±9.02	4.48
Ad	2	50.72± 12.58	6.26	52.82±10.32	5.13
Mean Total		25.85±2.10	2.31	31.35±6.34	3.00

Mean±Confidence Level (95.0%), SE= Standard Error

Plate 1: Crown damage intensity of young age class trees (0-10 years) at SUATF

Plate 2: Crown damage intensity of Middle age class trees (11-25 years) at SUATF

Plate 3:Crown damage intensity of old age class trees (>25 years) at SUATF

4.4The relationship between Cypress aphid abundance and damage intensity

Figure 8shows the relationship between abundance of Cypress aphid and percentage mean damage intensity for *Cupressuslusitanica* at SUATF. This relationship is represented by the following regression equation:

$$Y = 7.9928 + 0.9029X$$

Where, X represents the abundance of adult Cypress aphid

Y representsthe mean percentage of damage intensity

The results showed that the relationship was statistically significant ($P<0.05$ and R^2=87.8%), which means that the abundance of Cypress aphid significantly contributed to damage intensity of the attacked trees.The relationship between the abundance of Cypress aphid and percentage mean damage intensity in three age classes separately was regressed and results shown in Figures 9, 10 and 11 for young, middle and old age classes respectively. The results followed similar trend as general/overall relationship between the abundance of Cypress aphid and percentage mean damage intensity for *Cupressuslusitanica* at SUATF with R^2=89.9, R^2=94 and R^2= 82.7 for young, middle and old age classes respectively. The results showed that the damage intensity of attacked trees increased with the abundance of the Cypress aphid. Petro and Madoffe (2011) argued that the damage intensity of *Pinuspatula* corresponds with number of pine woolly aphid, meaning that damage intensity increased with an increasing number of pine woolly aphids attacking *Pinuspatula.*

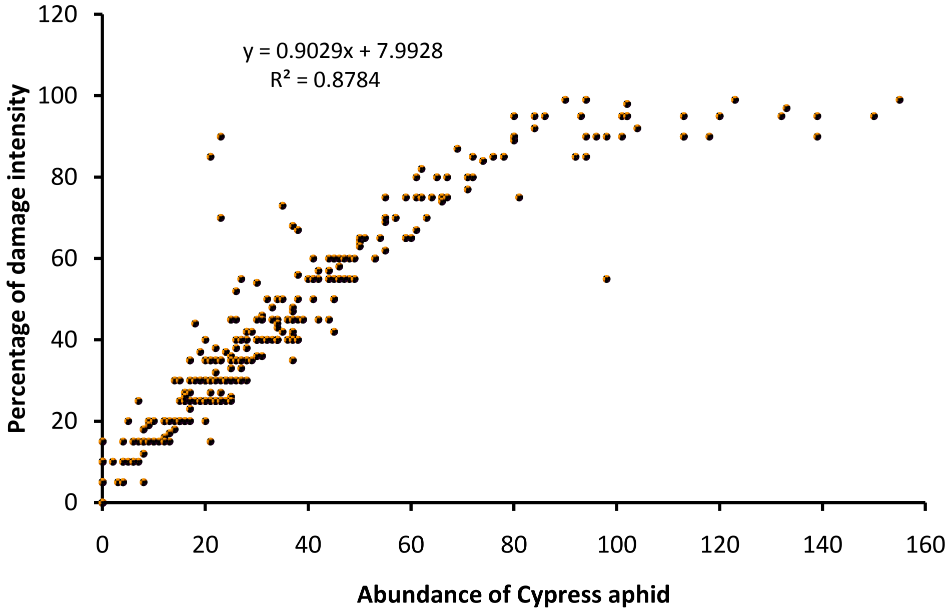

Figure 8:The relationship between the abundance of Cypress aphid and percentage mean damage intensity of*Cupressuslusitanica* in SUATF

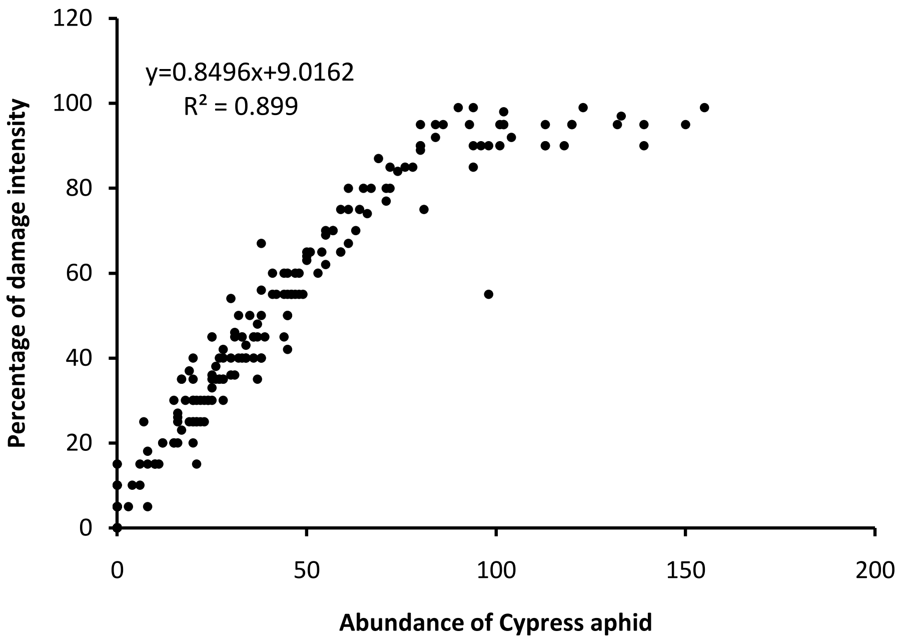

Figure 9:The relationship between the abundance of Cypress aphid and percentage mean damage intensity ofyoung age class of *Cupressuslusitanica*

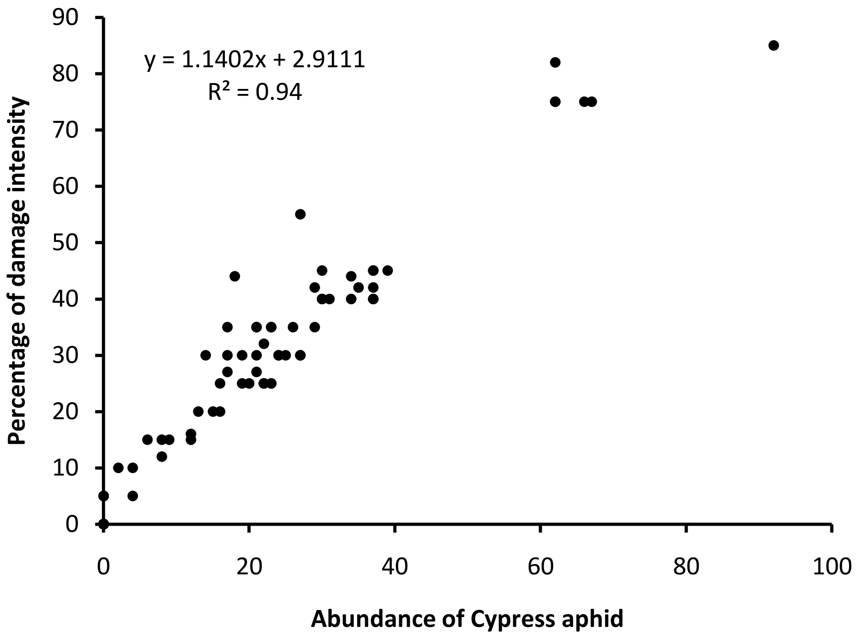

Figure 10:The relationship between the abundance of Cypress aphid and percentage mean damage intensity of middle age class of *Cupressuslusitanica*

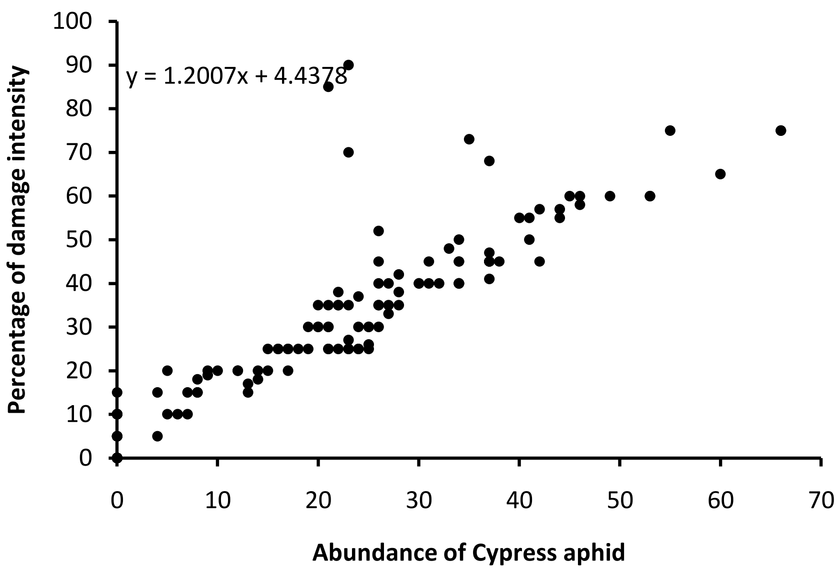

Figure 11: The relationship between the abundance of Cypress aphid and percentage mean damage intensity of old age class of *Cupressuslusitanica*

4.5 Historical trend of Cypress aphid infestation and control measures in SUATF.

In SUATF, species trials started in 1940's when the area was under Meru Forest plantation and the emphasis was put on Pines and Cypress species. Then large scale planting started from early 1950's starting with *Pinuspatula*, *Pinusradiata* and *Cupressuslusitanica*. The main exotic forest insect pests for these species were; *Pineuspini* (L) originated from Europe attacking *P. Patula*and *P. radiata*(Massawe, 1991) and *Cinaracupressivora* native to Southern Europe affecting *C. lusitanica* (Ciesla, 1991). The former was reported in 1978 and the later in 1990 (Madoffe, 1989).Cypress aphid appeared to have slowedgrowth of the*C.lusitanica*than usual as the apical shoots are affected consequently resulting to extendedrotation age.Extension of the rotation age of *C.lusitanica*lead toincreasing of investment and management cost from TZS 2.04 to 5.24 million per hato the final product. The SUATF management estimated that, from 2002 up to 2013 Cypress aphid killed trees worthTZS11.9millionper ha.

The SUATF management reported that*Cupressuslusitanica*damage by Cypress aphid was at highest peak during dry and cool season from June to September similar to what was earlier reported byKessy (1990). Similarly,Alleck*et al*. (2005) reported that the aphidpopulation builds to a peak during the dry winter season and is remarkedly reduced during summer and rainy season.Cypress aphid populations are strongly influenced by weather conditions. During heavy rains and high temperatures, Cypress aphid populations decline to the minimum level. This is because; temperature affects longevity, development time and fecundity of the

Cypress aphid (Kairo and Murphy, 1999). It is believed that natural enemies play important role in keeping population of the insect pests to minimum level. The commonest and abundantly recorded native natural enemies are;*Pauesiajuniperunum*, *Hoverfly larvae*, *Spider mites* and *Coccinellids*.

It was reported that SUATF has not conducted any project to combat the problem of *C.cupressivora*. Thinning and pruningof Cypress is done according to the technical order but not for the control of Cypress aphid. Biological control is one of the possible solutions to reduce and eliminate the problem of the Cypress aphid as has been reported from Kenya Forestry Research Institute (KEFRI). *Pauesiajuniperunum* was selected as a potential agent and well established in African countries for the biological control programme against *C.cupressivora*. This parasitoid was introduced in Africa in the 1990's from UK and France and released in Kenya, Malawi and Uganda. A decline in the severity of damage and the aphid population has been observed since the introduction of the parasitoid in Kenya, Malawi and Uganda (Day *et al*., 2003). The same authors reported that the introduction of *Pauesiasp* in Kenya and Malawi has significantly reduced the impact and spread of *C.cupressivora* in the entire plantation. In spite that Tanzania was not a release site of *P. juniperunum*, this parasitoid has spread in most Cypress growing areas in the country. Decision makers need to carry out a thorough survey to determine the status of this parasitoid in all Cypress growing areas and consider incorporating it in Integrated Pest Management (IPM).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Thefindings from this study can lead to the following conclusions:

- *Cinaracupressivora*is widely distributed throughout the altitudinal ranges and age classes of *C.lusitanica*growing areas at SUATF plantation.
- The study showed that mean number of Cypress aphid was 25.8 per twig and distributed un-equally throughout the altitudinal ranges and age classes of the *C.lusitanica*. The higher altitude had more adults Cypress aphid of about 33.7 individuals per twig than lower and middle altitude with 19.6 and 25.1 individuals per twig respectively, but also young age class was more attacked by Cypress aphid and had about 33.7 aphids per twig than middle and old age classes with 16.8 and 18.8 aphids per twig respectively. This shows that the young age classes are more vulnerable to Cypress aphid than middle and old age classes.Therefore, from these findingsit is evidently shown that the distributions of Cypress aphid appear to be influenced by altitude and age of the trees.
- Natural enemies were un-equally distributed throughout the altitudinal ranges and age classes of *C.lusitanica*. The mean number of natural enemies per twig was 3.1, 2.7 and 2.3 for *Pauesiajuniperunum, Spider mites* and *Hoverfly larvae* respectively. The abundance of natural enemies was lower compared with abundance of Cypress aphid found at SUATF.

- The percentage mean intensity of damage was moderate infestation (25-49%) for young and old age and light infestation (1-25%) for middle age class. The percentage mean intensity of damage was 27.0%, 30.61% and 37.63% for lower, middle and higher altitudes respectively. Therefore, the higher altitude and young age class are highly vulnerable to Cypress aphid damage than the rest.
- Furthermore, the results revealed that there is strong relationship between abundance of the Cypress aphids and damage intensity with coefficient of determination (R^2) of 87.8%, but there is weak relationship between abundance of natural enemies and the number of Cypress aphids attacking *C. lusitanica* with coefficient of determination (R^2) of 35.9%.

5.2 Recommendations

Based on the results from this study and experience from elsewhere, the following recommendations are made.

- In order to deal with the problem of the Cypress aphids at SUATF, broadly control measures should be intensified starting with young age classes and at higher altitude.
- Harvesting of mature Cypress should start immediately in order to reduce the damage intensity and spreading of the Cypress aphid beyond the current areas.
- Tending operations and schedule i.e. thinning, weeding and pruning must be followed in order to reduce favourable microclimate for growth development and reproduction of Cypress aphid.

- The SUATFmanagement should introduce and release*P. juniperunum* bio-control agent as part of Integrated Pest Management and/or rear the existing stock and release them over large area.The management should consider introducing rearing stock of *P. juniperunum*from Kenya and Malawi to increase the current stock of the natural enemies.
- Provision of public education on the impact of Cypress aphid to the *C.lusitanica* growing communities adjacent to the plantation and advise these communities to harvest their mature Cypress trees and participate in all pest management activities including bio-control and IPM as advocated by the Training Forest Management.

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APPENDICES

Appendix 1: Number of Cypress aphidson 5 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment Ab)at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1941	10	8	10	0	0	Middle
2	1957	45	3	0	0	37	Middle
3	1958	0	0	0	0	0	Middle
4	1860	20	6	40	0	12	Middle
5	1941	85	1	0	66	72	Middle
6	1958	35	4	30	6	20	Middle
7	1956	35	0	28	3	26	Middle
8	1957	69	0	0	50	55	Middle
9	1953	5	0	0	0	0	Middle
10	1954	0	0	0	0	0	Middle
11	1955	25	7	0	8	7	Middle
12	1958	55	0	20	16	45	Middle
13	1956	50	2	0	16	45	Middle
14	1956	45	0	10	9	36	Middle
15	1960	0	4	0	0	0	Middle
16	1958	37	0	6	7	19	Middle
17	1958	5	3	0	0	0	Middle
18	2025	0	0	0	0	0	Upper
19	1963	45	0	8	4	25	Middle
20	1962	67	3	0	23	38	Middle
21	1960	0	0	0	0	0	Middle
22	2004	89	1	0	41	80	Upper
23	1967	45	0	0	22	33	Middle
24	1966	99	1	0	41	90	Middle
25	1954	75	0	0	64	59	Middle
26	1960	80	0	0	66	72	Middle
27	1955	54	0	0	0	30	Middle
28	1987	70	3	0	50	55	Middle
29	1992	60	4	20	17	45	Middle
30	1956	35	5	0	16	17	Middle
31	1991	0	0	0	0	0	Middle
32	2008	10	0	0	0	0	Upper
33	2000	90	1	0	129	80	Upper
34	1956	5	0	0	0	0	Middle
35	2004	95	0	0	50	120	Upper
36	2004	46	0	0	0	31	Upper
37	2025	95	0	0	41	84	Upper
38	1958	15	6	0	0	0	Middle
39	1941	0	0	0	0	0	Middle
40	1957	36	0	0	5	25	Middle
41	1958	10	6	0	0	0	Middle
42	2025	80	0	0	45	61	Upper
43	2004	5	0	0	0	0	Upper
44	2023	43	0	0	6	34	Upper
45	1956	0	0	0	0	0	Middle
46	1955	0	0	0	0	0	Middle
47	2022	35	4	8	4	25	Upper

48	1954	50	0	0	20	35	Middle
49	2022	0	0	0	0	0	Upper
50	2019	45	5	0	22	33	Upper

Appendix 2: Number of Cypress aphids on 29 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment 26C) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1920	35	1	0	6	27	Middle
2	1869	45	3	0	14	31	Middle
3	1864	0	6	0	0	0	Middle
4	1864	0	0	0	0	0	Middle
5	1858	60	0	0	33	49	Middle
6	1858	45	2	0	11	38	Middle
7	1847	10	4	0	0	7	Lower
8	1840	40	0	6	8	31	Lower
9	1833	30	0	0	5	21	Lower
10	1858	20	9	20	10	10	Middle
11	1840	10	8	10	0	5	Lower
12	1840	5	0	0	0	0	Lower
13	1851	0	6	0	0	0	Middle
14	1846	20	6	0	13	12	Lower
15	1866	0	0	0	0	0	Middle
16	1872	30	2	0	3	20	Middle
17	1875	75	0	0	25	66	Middle
18	1863	0	0	0	0	0	Middle
19	1870	0	0	0	0	0	Middle
20	1876	30	5	0	13	25	Middle
21	1852	0	0	0	0	0	Middle
22	1884	30	0	0	0	24	Middle
23	1853	30	0	0	13	25	Middle
24	1879	17	8	38	4	13	Middle
25	1855	25	0	0	0	24	Middle
26	1873	25	0	34	7	21	Middle
27	1846	40	1	0	15	34	Lower
28	1893	26	3	0	13	25	Middle
29	1838	0	0	0	0	0	Lower
30	1879	25	0	0	0	24	Middle
31	1833	25	4	0	17	23	Lower
32	1871	40	2	0	15	34	Middle
33	1837	60	1	12	7	53	Lower
34	1849	20	4	2	3	17	Lower
35	1845	0	0	0	0	0	Lower
36	1868	25	0	0	17	23	Middle
37	1893	30	0	21	8	26	Middle
38	1870	65	1	0	23	60	Middle
39	1878	60	0	12	7	53	Middle
40	1869	45	0	0	19	42	Middle
41	1859	25	5	0	25	25	Middle
42	1854	57	0	0	9	44	Middle
43	1839	18	0	0	3	14	Lower
44	1851	0	0	0	0	0	Middle
45	1849	15	8	38	4	13	Lower
46	1938	25	0	34	7	21	Middle
47	1836	0	0	0	0	0	Lower

48	1850	27	0	0	8	23	Middle
49	1831	25	0	2	6	22	Lower
50	1829	0	0	0	0	0	Lower

Appendix 3: Number of Cypress aphids on 12 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment 27a) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1884	25	0	20	7	20	Middle
2	1892	5	6	10	2	0	Middle
3	1898	35	3	0	3	26	Middle
4	1898	0	0	0	0	0	Middle
5	1901	0	0	0	0	0	Middle
6	1925	15	3	0	0	8	Middle
7	1909	12	4	18	0	8	Middle
8	1990	25	0	0	19	23	Middle
9	1914	0	0	0	0	0	Middle
10	1936	40	2	15	19	34	Middle
11	1901	40	0	0	5	34	Middle
12	1902	0	0	0	0	0	Middle
13	1930	45	2	0	6	37	Middle
14	1902	20	0	0	30	15	Middle
15	1905	30	0	0	13	24	Middle
16	1914	25	2	0	3	22	Middle
17	1930	10	6	15	0	2	Middle
18	1937	85	0	0	36	92	Middle
19	1933	25	0	0	3	23	Middle
20	1899	0	0	0	0	0	Middle
21	1921	30	0	10	17	25	Middle
22	1986	30	1	0	16	21	Middle
23	1936	15	10	0	6	9	Middle
24	1912	25	0	10	8	22	Middle
25	1888	0	0	0	0	0	Middle
26	1885	.	8	0	15	21	Middle
27	1890	15	0	0	0	6	Middle
28	1909	30	0	12	23	19	Middle
29	1914	35	4	0	0	17	Middle
30	1937	0	0	0	0	0	Middle
31	1932	42	1	22	24	29	Middle
32	1937	0	0	0	0	0	Middle
33	1924	5	0	0	0	0	Middle
34	1892	0	0	0	0	0	Middle
35	1873	30	2	20	0	17	Middle
36	1880	0	0	0	6	0	Middle
37	1867	35	0	0	10	23	Middle
38	1913	0	0	0	0	0	Middle
39	1860	5	0	0	0	0	Middle
40	1903	0	0	0	0	0	Middle
41	1912	55	0	0	22	27	Middle
42	1925	40	0	0	14	30	Middle
43	1930	35	4	0	5	21	Middle
44	1936	0	0	0	0	0	Middle
45	1935	75	1	16	53	67	Middle
46	1932	35	0	0	15	23	Middle
47	1913	0	0	0	0	0	Middle
48	1930	40	0	0	10	30	Middle
49	1912	35	3	25	4	21	Middle

50	1887	20	5	0	22	13	Middle

Appendix 4: Number of Cypress aphids on 28 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment 28a) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1866	60	2	0	13	45	Middle
2	1857	30	6	0	8	19	Middle
3	1888	0	8	0	0	0	Middle
4	1872	40	2	0	14	30	Middle
5	1873	0	0	0	0	0	Middle
6	1877	42	2	0	6	28	Middle
7	1873	0	0	0	0	0	Middle
8	1873	45	0	0	21	37	Middle
9	1877	25	7	0	3	16	Middle
10	1879	0	0	0	0	0	Middle
11	1891	57	0	20	5	42	Middle
12	1878	5	0	0	0	0	Middle
13	1868	10	0	21	3	0	Middle
14	1862	25	5	0	19	16	Middle
15	1859	33	1	20	0	27	Middle
16	1865	0	0	0	0	0	Middle
17	1873	45	0	0	8	26	Middle
18	1866	0	0	0	0	0	Middle
19	1883	0	0	0	0	0	Middle
20	1898	75	1	0	35	55	Middle
21	1887	55	0	0	34	44	Middle
22	1888	15	13	0	0	7	Middle
23	1872	38	3	0	10	28	Middle
24	1873	10	11	0	0	0	Middle
25	1877	40	0	0	6	27	Middle
26	1873	35	5	25	4	21	Middle
27	1873	20	12	0	23	9	Middle
28	1956	50	0	0	19	34	Middle
29	1855	47	0	0	6	37	Middle
30	1856	35	3	27	4	22	Middle
31	1862	10	8	0	16	0	Middle
32	1856	45	2	10	29	34	Middle
33	1872	45	0	0	6	37	Middle
34	1863	35	0	0	17	26	Middle
35	1861	0	0	0	0	0	Middle
36	1873	20	10	0	13	12	Middle
37	1880	0	0	0	0	0	Middle
38	1882	35	4	0	3	20	Middle
39	1890	75	0	0	25	66	Middle
40	1860	10	0	0	16	0	Middle
41	1870	40	0	10	19	34	Middle
42	1876	68	0	0	6	37	Middle
43	1884	52	2	15	17	26	Middle
44	1872	15	0	0	16	0	Middle
45	1875	45	4	11	19	34	Middle
46	1863	41	2	0	6	37	Middle
47	1852	35	4	0	17	26	Middle

48	1853	38	4	0	16	22	Middle
49	1855	19	14	0	6	9	Middle
50	1846	48	0	20	26	33	Lower

Appendix 5: Number of Cypress aphids on 4 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment 30a) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1877	25	3	15	9	20	Middle
2	1977	0	4	0	21	0	Middle
3	1842	85	0	0	36	94	Lower
4	1859	0	0	0	0	0	Middle
5	1872	65	1	0	20	59	Middle
6	1867	30	2	0	1	18	Middle
7	1866	36	2	0	12	30	Middle
8	1872	15	4	15	6	21	Middle
9	1853	40	0	0	42	27	Middle
10	1871	0	0	0	0	0	Middle
11	1880	5	10	20	0	0	Middle
12	1860	30	4	10	0	15	Middle
13	1870	0	0	0	0	0	Middle
14	1876	30	0	0	11	23	Middle
15	1842	5	7	0	0	0	Lower
16	1884	20	0	12	2	15	Middle
17	1879	5	8	0	5	0	Middle
18	1873	55	2	22	21	44	Middle
19	1869	74	1	0	47	66	Middle
20	1893	26	0	25	20	16	Middle
21	1879	0	0	0	0	0	Middle
22	1871	30	2	13	13	25	Middle
23	1868	40	1	2	6	34	Middle
24	1878	0	0	0	0	0	Middle
25	1859	40	0	0	33	38	Middle
26	1871	40	0	0	21	32	Middle
27	1869	35	0	0	7	27	Middle
28	1886	5	6	20	0	0	Middle
29	1896	55	2	0	31	49	Middle
30	1854	25	2	0	11	20	Middle
31	1889	25	4	0	4	20	Middle
32	1887	30	0	0	13	24	Middle
33	1883	5	4	0	0	0	Middle
34	1879	30	2	0	6	22	Middle
35	1880	25	2	0	13	23	Middle
36	1839	60	1	0	25	47	Lower
37	1874	0	6	20	0	0	Middle
38	1877	0	0	0	0	0	Middle
39	1877	30	0	0	16	24	Middle
40	1880	55	0	0	12	41	Middle
41	1878	0	6	0	0	0	Middle
42	1878	15	3	0	0	6	Middle
43	1882	20	4	0	0	15	Middle
44	1894	15	3	0	2	0	Middle
45	1874	35	0	0	16	37	Middle
46	1880	10	4	10	0	6	Middle
47	1879	20	2	0	4	20	Middle
48	1888	5	6	0	3	8	Middle

49	1877	55	0	0	40	98	Middle
50	1877	40	0	0	22	38	Middle

Appendix 6: Number of Cypress aphids on 30 years old *Cupressuslusitanica* in different altitudinal ranges (Compartment 32a) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1888	25	3	2	8	19	Middle
2	1875	50	2	0	10	41	Middle
3	1871	58	1	0	22	46	Middle
4	1876	35	0	10	10	28	Middle
5	1877	25	0	0	7	17	Middle
6	1869	25	13	0	20	15	Middle
7	1876	40	3	0	6	32	Middle
8	1871	5	0	0	0	0	Middle
9	1868	45	0	0	27	37	Middle
10	1842	55	0	0	24	41	Lower
11	1872	0	0	0	0	0	Middle
12	1842	10	0	0	0	0	Lower
13	1873	5	7	20	2	0	Middle
14	1843	10	10	20	2	0	Lower
15	1880	0	0	0	0	0	Middle
16	1868	0	0	0	0	0	Middle
17	1837	0	0	0	0	0	Lower
18	1860	30	4	0	12	20	Middle
19	1830	0	0	0	0	0	Lower
20	1868	25	2	16	11	18	Middle
21	1842	40	0	0	10	30	Lower
22	1879	37	0	0	0	24	Middle
23	1859	60	0	0	22	46	Middle
24	1882	20	8	0	7	14	Middle
25	1854	25	3	0	7	17	Middle
26	1890	10	4	0	0	6	Middle
27	1848	20	6	0	20	15	Lower
28	1867	73	0	0	15	35	Middle
29	1853	0	0	0	0	0	Middle
30	1868	18	6	0	0	8	Middle
31	1848	90	2	0	4	23	Lower
32	1887	45	4	0	27	37	Middle
33	1841	70	0	0	23	23	Lower
34	1853	0	0	0	0	0	Middle
35	1849	30	5	12	16	21	Lower
36	1859	0	0	0	0	0	Middle
37	1884	5	4	35	2	0	Middle
38	1866	35	0	0	6	22	Middle
39	1859	35	0	0	5	23	Middle
40	1892	0	0	0	0	0	Middle
41	1854	85	0	0	4	21	Middle
42	1898	55	0	0	15	40	Middle
43	1848	0	0	0	0	0	Lower
44	1898	15	3	0	0	8	Middle
45	1853	15	6	0	0	4	Middle
48	1901	0	0	0	0	0	Middle
47	1853	20	0	0	0	5	Middle
49	1909	5	4	0	0	4	Middle
46	1846	40	0	0	10	26	Lower

50	1990	15	6	0	0	8	Middle

Appendix 7: Number of Cypress aphids on 23 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment 34b) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1847	75	0	0	24	66	Lower
2	1990	42	1	0	15	37	Middle
3	1866	25	4	0	7	16	Middle
4	1914	10	6	0	3	4	Middle
5	1956	0	0	0	0	0	Middle
6	1901	0	10	0	0	0	Middle
7	1855	30	2	0	11	24	Middle
8	1856	20	3	0	2	16	Middle
9	1862	0	0	0	0	0	Middle
10	1902	0	0	0	0	0	Middle
11	1856	0	0	0	0	0	Middle
12	1901	32	0	0	6	22	Middle
13	1872	45	7	0	15	37	Middle
14	1902	0	0	0	0	0	Middle
15	1863	5	4	0	3	4	Middle
16	1902	40	2	0	26	37	Middle
17	1861	0	0	0	0	0	Middle
18	1905	16	3	0	9	12	Middle
19	1861	0	0	0	0	0	Middle
20	1939	0	0	0	0	0	Middle
21	1852	25	4	0	6	22	Middle
22	1814	0	0	0	0	0	Lower
23	1850	0	4	0	0	0	Middle
24	1829	30	0	15	20	27	Lower
25	1856	40	0	0	24	37	Middle
26	1836	0	0	0	0	0	Lower
27	1853	15	5	0	9	12	Middle
28	1990	0	0	0	0	0	Middle
29	1842	0	0	0	0	0	Lower
30	1914	40	2	10	22	31	Middle
31	1853	0	0	0	0	0	Middle
32	1863	0	0	0	0	0	Middle
33	1845	30	2	15	20	27	Lower
34	1901		0	0	0	0	Middle
35	1842	75	0	0	29	62	Lower
36	1902	82	0	0	18	62	Middle
37	1842	0	0	0	0	0	Lower
38	1902	0	0	0	0	0	Middle
39	1843	25	0	0	12	19	Lower
40	1856	30	1	0	12	14	Middle
41	1837	35	0	10	14	29	Lower
42	1853	45	2	2	11	30	Middle
43	1830	44	2	10	14	34	Lower
44	1842	44	2	10	28	18	Lower
45	1842	27	4	0	11	17	Lower
46	1838	0	0	0	0	0	Lower
47	1939	42	0	20	4	35	Middle
48	1814	45	1	0	22	39	Lower
49	1902	75	2	0	29	62	Middle

50	1902	0	0	0	0	0	Middle

Appendix 8: Number of Cypress aphids on 2 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment 8a) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	2010	45	2	10	11	25	Upper
2	2010	15	6	0	0	8	Upper
3	2019	42	2	0	20	28	Upper
4	2002	55	1	0	35	42	Upper
5	2000	5	0	0	0	0	Upper
6	1997	0	0	0	0	0	Middle
7	2023	40	0	0	27	28	Upper
8	1995	20	11	0	10	16	Middle
9	1988	63	2	0	40	50	Middle
10	1986	95	0	0	29	113	Middle
11	1979	0	0	0	0	0	Middle
12	1987	65	4	0	8	54	Middle
13	1992	0	0	0	0	0	Middle
14	2004	50	0	0	12	32	Upper
15	2022	98	0	0	46	102	Upper
16	1989	95	0	0	52	93	Middle
17	1995	60	0	0	31	48	Middle
18	1997	15	10	0	0	10	Middle
19	1996	5	0	0	0	0	Middle
20	2025	90	0	0	53	113	Upper
21	2007	25	0	0	8	16	Upper
22	2020	15	4	0	0	10	Upper
23	2029	95	0	0	46	102	Upper
24	2029	90	3	0	52	113	Upper
25	2034	0	0	0	0	0	Upper
26	2019	5	6	0	0	0	Upper
27	2023	5	0	0	0	0	Upper
28	2053	5	0	30	0	0	Upper
29	2054	90	8	0	36	96	Upper
30	2050	35	0	0	42	27	Upper
31	2041	0	3	0	0	0	Upper
32	2037	0	0	0	0	0	Upper
33	2036	60	1	0	21	41	Upper
34	2031	5	0	0	0	0	Upper
35	2026	30	5	0	11	20	Upper
36	2021	55	4	0	25	47	Upper
37	2022	45	1	0	12	39	Upper
38	2036	48	1	0	16	37	Upper
39	2038	90	0	0	49	98	Upper
40	2022	27	0	20	0	16	Upper
41	2043	80	0	0	47	67	Upper
42	2049	50	0	0	24	38	Upper
43	2054	70	4	0	26	57	Upper
44	2031	85	0	0	36	78	Upper
45	2067	0	0	0	0	0	Upper
46	2067	5	4	0	0	0	Upper
47	2067	0	0	0	0	0	Upper
48	2075	92	3	0	50	104	Upper
49	2091	75	0	0	51	81	Upper

50	2079	42	1	0	26	45	Upper

Appendix 9: Number of Cypress aphids on 1 year old *Cupressuslusitanica*in different altitudinal ranges (Compartment Ab) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1966	40	1	0	25	33	Middle
2	1967	0	0	0	0	0	Middle
3	1969	0	0	0	0	0	Middle
4	1969	99	0	0	61	155	Middle
5	1974	5	12	10	0	0	Middle
6	1975	25	4	4	11	21	Middle
7	1976	77	0	0	20	71	Middle
8	1976	10	8	0	0	4	Middle
9	1985	55	0	0	16	46	Middle
10	1984	45	0	12	19	44	Middle
11	1989	0	0	0	0	0	Middle
12	1985	40	2	0	3	30	Middle
13	1985	0	0	0	0	0	Middle
14	1990	25	6	0	23	21	Middle
15	1992	60	2	0	22	53	Middle
16	1998	40	2	0	10	36	Middle
17	1994	5	9	0	0	3	Middle
18	1991	65	1	0	24	51	Middle
19	2001	25	4	20	19	22	Upper
20	2001	0	0	0	0	0	Upper
21	2004	23	0	0	13	17	Upper
22	1991	0	0	0	0	0	Middle
23	1996	15	11	0	0	11	Middle
24	2002	25	0	20	0	19	Upper
25	2002	64	1	0	26	50	Upper
26	2001	0	0	0	0	0	Upper
27	1989	55	1	10	31	48	Middle
28	1990	5	13	12	0	0	Middle
29	1992	84	0	0	31	74	Middle
30	1987	95	1	0	70	150	Middle
31	1992	62	2	0	50	55	Middle
32	1991	50	1	20	17	45	Middle
33	2009	0	0	0	0	0	Upper
34	2002	0	0	0	0	0	Upper
35	2004	90	1	0	129	80	Upper
36	2004	95	0	0	50	120	Upper
37	2004	36	4	0	0	31	Upper
38	2003	0	0	0	0	0	Upper
39	2008	33	3	0	5	25	Upper
40	2011	0	0	0	0	0	Upper
41	2024	67	2	0	45	61	Upper
42	2018	0	0	0	0	0	Upper
43	2015	0	0	0	0	0	Upper
44	2020	40	2	0	6	34	Upper
45	2016	0	0	0	0	0	Upper
46	2015	0	0	0	0	0	Upper
47	2022	0	10	0	0	0	Upper
48	2017	35	3	0	30	28	Upper
49	2016	0	0	0	0	0	Upper

50	2018	0	4	0	0	0	Upper

Appendix 10: Number of Cypress aphids on 2 years old *Cupressuslusitanica*in different altitudinal ranges (Compartment Ad) at SUATF

Tree No.	Elev	Percentage of attack	Natural Enemies	Eggs	Nymph	Adults	Altitudinal ranges
1	1988	10	7	20	0	0	Middle
2	1982	45	1	10	10	31	Middle
3	1982	70	1	0	28	63	Middle
4	1980	30	4	10	13	28	Middle
5	1985	80	0	0	37	71	Middle
6	1987	65	3	0	42	59	Middle
7	1982	30	3	0	20	21	Middle
8	1979	18	4	0	0	8	Middle
9	1976	60	0	0	33	44	Middle
10	1970	20	4	30	10	12	Middle
11	1971	0	0	0	0	0	Middle
12	1977	0	0	0	0	0	Middle
13	1973	90	0	0	67	94	Middle
14	1978	75	2	0	52	64	Middle
15	1983	95	1	0	34	86	Middle
16	1983	95	1	0	71	101	Middle
17	1984	90	0	0	64	139	Middle
18	1985	95	0	0	83	102	Middle
19	1969	55	0	0	27	46	Middle
20	1970	80	0	0	36	65	Middle
21	1966	0	0	0	0	0	Middle
22	1961	99	0	0	69	123	Middle
23	1952	5	0	0	0	0	Middle
24	1968	0	0	0	0	0	Middle
25	1960	5	2	0	0	0	Middle
26	1970	0	0	0	0	0	Middle
27	1977	97	0	0	44	133	Middle
28	1972	56	4	0	0	38	Middle
29	1970	90	4	0	72	101	Middle
30	1969	70	0	0	27	57	Middle
31	1972	99	0	0	50	94	Middle
32	1985	38	8	12	39	26	Middle
33	1975	45	4	0	30	36	Middle
34	1983	92	0	0	49	84	Middle
35	1985	5	12	0	0	0	Middle
36	2014	30	3	0	16	20	Upper
37	2015	75	2	2	25	61	Upper
38	1975	90	0	0	59	118	Middle
39	1976	95	0	0	91	132	Middle
40	1978	5	11	20	0	0	Middle
41	1960	40	0	20	3	20	Middle
42	1965	0	0	0	0	0	Middle
43	1960	65	0	0	30	50	Middle
44	1965	95	1	0	65	139	Middle
45	1957	35	3	0	4	28	Middle
46	1948	85	1	0	37	76	Middle
47	1948	95	0	0	46	80	Middle
48	1952	5	14	15	0	0	Middle
49	1948	87	0	0	34	69	Middle
50	1955	35	2	0	10	17	Middle