STATUS OF PINE WOOLLY APHID (*Pineus boerneri?*) IN SAO-HILL FOREST PLANTATION, SOUTHERN HIGHLANDS, TANZANIA

BY

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ABSTRACT

The study on the status of Pine Woolly Aphid, (*Pineus boerneri?*) in Sao-Hill forest plantation, Southern Highlands of Tanzania was carried out between November and December 2007. The major objectives of the study was; to determine distribution and abundance of pine woolly aphid (PWA) affecting main plantation species (*Pinus patula* and *P. elliottii*) in the plantation, to assess intensity of damage between different age classes and to determine the parts of the tree crown mostly damaged and the extent of damage. The main findings of the study were; the population densities of adult PWA did not differ significantly ($P > 0.05$) for both *P. patula* and *P. elliottii* among the three Divisions studied. However, Division one was more affected by aphids than other Divisions with the mean total adult population number of 17.4, 16.5 and 13.6 for *P. patula* and 6.7, 6.3 and 6.1 for *P. elliottii* for Divisions I, II and III respectively. The mean total adult aphid population was found to be 10.1, 20.2 and 17.3 for *P. patula* for young, middle and old age classes respectively. In *P. elliottii* where only old class was observed, the mean total adult aphid was 19.1. In old age class, *P. elliottii* was more affected than *P. patula*. The middle part of the tree crown was more damaged, followed by lower crown part and upper crown was the least damaged. There was a strong relationship between aphid abundances and damage among Divisions and age classes with coefficient of determination (R^2) of 99.7% and 99.9% respectively. Generally the intensity of attack of aphids at Sao Hill forest plantation was low compared to the intensity of attack as reported by other authors in the early 1990s. This was probably due to the effect caused by predators like *Tetraphleps raoi*, a natural enemy which was released at Sao Hill in 1970s. Resistance of the pines as a result of adaptation to Sao Hill could also have contributed to the recorded low intensity of attack. It is recommended that; silvicutural operations should be regularly conducted in order to prevent any outbreak and spread of forest pests. The Government should initiate regular insect survey and monitoring programmes in the forest plantations and take prompt measures whenever the pests are observed. A study has to be done to determine the population dynamics of the pine woolly aphid. Both regional and international cooperation should be intensified in dealing with pine conifer aphids.

DECLARATION

I, Revocatus Petro, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has not been submitted or concurrently being submitted for a higher degree award in any other University.

27.08.2009

Revocatus Petro,

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Date

The above declaration confirmed

29/08/2009

Professor S.S. Madoffe

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Date

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DEDICATION

This work is dedicated to my late father and mother who laid the foundation of my education with a lot of sacrifice.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BTC	Belgian Technical Cooperation
FAO	Food and Agriculture Organization of the United Nations
FBD	Forestry and Beekeeping Division
Ha	Hectare
m.a.s.l	metres above sea level
MNRT	Ministry of Natural Resources and Tourism
PWA	Pine Woolly Aphid
SAS	Statistical Analysis System
SE	Standard error
SHFP	Sao Hill Forest Plantation
SUA	Sokoine University of Agriculture
TAFORI	Tanzania Forestry Research Institute
URT	United Republic of Tanzania

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Trees in plantation forests, like many other plants, suffer from attack by insect pests and diseases which could cause serious damage, thus resulting in poor tree growth, poor pole and timber quality and in some cases, complete destruction and reduction of forest cover. This has both economic and environmental implications. Thus, trees and forests need to be protected from these agents of destruction (NAFORRI, 2005).

Food and Agriculture Organisation (FAO) of United Nations with the cooperation of experts from member countries, has been compiling data for a global information system on the impact of insect pests and disease outbreaks on natural and planted forests, trees outside forests and other wooded lands. By year 2002, more than 300 outbreaks had been recorded, including 113 insect taxa comprising 38 families, 79 genera and 90 species (Cock, 2002). Between 1980 and 2002, more than 52 million hectares of forests in 37 countries (developing and countries in transition) were reported to have been damaged by pests (Cock, 2002).

Examples of significant recent outbreaks include *Lymantria dispar* in the Balkan Peninsular which affected more than two million hectares of predominantly *Quercus* species between 1997 and 1999 and in Mongolia more than 480 thousand hectares of valuable forests have been damaged by defoliators including *Dendrolimus sibiricus,* infesting mainly larch (Allard *et al.*, 2003). Also a total of more than 150,000 hectares of conifers have been infested by the bark beetle, *Dendroctonus frontalis* in Belize, El Salvador, Guatemala, Honduras and Nicaragua, between 2000 to 2002 (Cock, 2002). In

Switzerland, several outbreaks of the European spruce bark beetle (*Ips typographus*) have been occurring during the past 25 years. The devastating storm "Lothar" of 1999 felled 12.7 million m^3 of timber comprising 82% conifers, mostly spruce. This triggered an outbreak of *I. typographus* that eventually lead to the highest volume of infested timber recorded during the past 200 years in Switzerland (Gugerli *et al.*, 2008).The Asian longhorned beetle, *Anoplophora glabripennis* (Coleoptera: Cerambycidae), an exotic pest of Asian origin was first discovered in New York City and Chikago in North America in 1996 (Sawyel, 2006). The potential tree resources which were found at risk to Asian longhorned beetle attack ranges from 12-61% of the city tree population, with an estimated value of $72 million - $2.3 billion per city (Nowak *et al.*, 2001). The infestation has now spread to Quees, Manhattan, Long Island, Jersey City and Toronto (Sawyel, 2006).

An insect pest Blue gum chalcid, *Leptocybe invasa* has recently been reported on *Eucalyptus* species in several countries. It was first recorded in Middle East in 2000, in Uganda and Kenya in 2002, in Tanzania in 2005 and in South Africa in 2007 (Roux and Slippers, 2007). *Sirex noctilio* an insect vector was first recorded in Australia in 1952, in Uruguay in 1980, in Northern Argentina in 1985, in Southern Brazil in 1988, in South Africa in 1994 and Chile in 2000. Most recently, in 2005, an established population of *S. noctilio* was confirmed in the United States of America and Canada (Hurley *et al.*, 2007). Infestations were mainly in *Pinus taeda* and *P. elliottii* plantations in Brazil, Northern Argentina and Uruguay and *P. radiata* plantation in Chile and *P. patula* and *P. radiata* in South Africa (Hurley *et al.*, 2007). In Brazil 300 thousand out of a total two million hectares of pines plantations were damaged and an estimated US$ 6.6 million would be lost each year if an integrated pest management programme were not in place. The estimated mortality reported was 5 trees/ha/year. For this reason an intensive programme of biological control of the pest was developed, using the nematode *Deladenus siricidicola* (Cock, 2002). In Kwazulu Natal Province, South Africa it is estimated that approximately 35,000 hectares of pine in the Eastern Cape and Kwazulu Natal are infested to a mean level of 6%, with a total estimated value of damage being R300 million (approximately $ 45 million) per annum (Hurley *et al.*, 2007).

Although aphids have a world-wide distribution there are fewer species in the tropics than in temperate regions. This could be due to the harsh environment of the tropics and subtropics and it is difficult to understand why aphids have not flourished as a group on the rich tropical and subtropical floras (Aloo, 1996). Primack (2006) reported that in the tropics and subtropics where floral diversity is very high, few species of plants are apparent, enough to sustain an aphid species and that is why more aphids are polyphagous in the tropics than in the temperate regions. The greater number of aphids in the temperate regions can be due to the fact that in the temperate regions there are fewer plant species than in the tropics and the commonest ones are, apparently enough to sustain one or more species of aphids. This is combined with the greater niche diversity produced by seasonal changes in habitat quality in temperate regions (Aloo, 1996).

It is generally believed that outstanding initial performance of exotic tree species in the areas of introduction is attributed to good edaphic factors together with the absence of pests and diseases. However, with time, diseases and or pests tend to follow (sometimes through accidental introductions) those species in their areas of introduction and hence assume economic importance. A graphic illustration is offered by the experience gained from introductions of some exotic trees in Tanzania. *Pinus insignis* (*P. radiata*) is believed to be one of the first pine species to be introduced to Tanzania (Schabel, 1990). For about

60 years no pests or diseases were reported for the species. In the 1960's most areas planted with *Pinus radiata* had to be clearfelled following incidences of *Dothistroma* needle blight at Shume Forest Project, Tanga Region in 1958: and *Cercospora* needle blight at Sao-Hill, Iringa Region (Etheridge, 1965). As a control measure the planting of *P. radiata* was banned and *Pinus elliottii* and *P. patula* were introduced as an alternative species. The species and most pine plantation in Tanzania soon proved to be susceptible to pine woolly aphid, (*Pineus boerneri*?) infestations. Biological control of the aphid relying on a predator *Tetraphleps raoi, Leucopis* species and native predators has minimised the spread of infestation (Madoffe, 1989).

In Tanzania, some epidemics of forest insect outbreak have been recorded, though in small scale. The most common ones include defoliators: *Gonometa podocarpi, Lechriolepsis basirufa, Orgyia mixta, O. basalis, Icerya purchasi, Dasychira georiana, Chromothericles* sp., *Plagiotriptus pinivorus* and *Heteronygmi dissimilies* (Madoffe, 1989). These insects are all natives living on indigenous host plants but have adapted to the exotics. *Pineus boerneri?* (Pine woolly aphid), *Eulachnus rileyi* and *Cinara cupressivora* are introduced sap sucking insects and are posing a great threat to our forests, particularly the exotic conifers (Madoffe, 1989). Following the global movement of insects and plant materials and the conditions of our forests, there is no reason to believe that other pests may not adapt to the exotics. In 1989 nearly all pine plantations in Tanzania were affected by Pine woolly aphid (PWA) only with varying degree of attack (Madoffe, 1989). Today, 2008, it is not clearly known to what extent forest insect pests are affecting Tanzanian forest plantations.

Pine woolly aphid (*Pineus boerneri?)* is attacking *Pinus* species at Sao Hill (Madoffe, 1989; Madoffe and Austarå, 1993). At present, the infestation at Sao Hill has given concern to the Forest and Beekeeping Division of Tanzania, foresters and other forest stakeholders. In spite of this concern, the mode of attack, spread and the population dynamics within the plantation is not well studied and Madoffe (1989) recommended that in order to prevent spread of attack and contain the forest pest problems continuous pest survey should be undertaken. Furthermore, breeding programmes for resistance, biological control and silvicultural practices should be taken concurrently. It is from these recommendations that the current study is proposed.

1.2 Problem Statement and Justification

Limited numbers of studies on the status of pine woolly aphid (PWA) have been initiated in Tanzania. This includes population dynamics, the impact on tree growth and biological control of PWA (Madoffe, 1989; Madoffe and Austarå, 1990; Massawe, 1991; Madoffe and Austarå, 1993; Madoffe, 2006; Nsolomo *et al.*, 2006). Survey carried out at Sao Hill revealed that tree mortality and growth loss was associated with heavy attacks of PWA, especially in young stands grown on inferior sites (Madoffe and Austarå, 1993). Pests cause significant commercial losses if going uncontrolled. Infested trees become stunted in growth, poor forms and poor quality timber which fetch very low prices in the market. Tanzania and Sao-Hill in particular has suffered from PWA attacks due to lack of control and monitoring of the outbreaks. The Government does not have a regular insect survey and monitoring programmes in her forest plantations. Similarly there is no regular pest management budget. Most entomological studies are short term studies for either a donor funded project or for thesis/dissertation requirements (Example Madoffe, 1989; Madoffe and Day, 1995). Specifically in Sao-Hill, no study has been conducted in the last twenty years to determine the status (population abundance, density and distribution) of PWA in the plantation. There are contradicting reports which indicate that the PWA situation has stabilized while others report on worsening of the situation. This study was therefore initiated to generate valuable information on the status of pine woolly aphid in Sao-Hill which will be useful to forest managers, protectionists and conservationists in the country to find ways of managing the pest situation accordingly.

1.3 Objective of the Study

1.3.1 Overall objective

The main objective of this study was to assess the status of Pine Woolly Aphid in Sao-Hill forest plantation, Southern Highlands, Tanzania.

1.3.2 Specific objectives

i. To determine distribution and abundance of pine woolly aphid affecting main plantation species (*P. patula* and *P. elliottii*) in Sao Hill forest plantation.

ii. To assess the intensity of damage between different tree age classes.

iii. To determine the parts of the tree crown mostly damaged and the extent of damage.

1.4 Hypotheses of the Study

H_{01}: Pine woolly aphid is not widely distributed in Sao-Hill forest plantation and has no serious effects on the health of the plantation.

H_{02}: The abundance and intensity of damage of Pine woolly aphid to pines is fairy low and has no serious effects on the health of the plantation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Forest Plantations in Tanzania

Tanzania has a total area covering about 945 000 km^2 of which 35 257 000 hectares or 40% of total land area is covered by forests and woodlands (TEP, 2006). In order to supplement wood supplies from natural forests, pioneering attempts to establishment of forest plantations in Tanzania started in the 1890's (Nshubemuki *et al.*, 2001). This was followed by large scale industrial forest plantations establishment between 1920-1961. These plantations are dominated by exotic tree species which are fast growing and are easy to manage. To date, Tanzania has industrial plantations which cover about 150 000 hectares or about 0.4% of total forests cover (TEP, 2006). Earlier Nshubemuki *et al.* (1996) reported that softwoods and hardwoods cover (84.7%) and (15.3%) of the total plantation area in Tanzania respectively. Most of these forests are in poor condition because of poor management and use of inferior seeds.

At least 12 exotic tree species have been planted in industrial plantations, among which five dominate. *Pinus* is the most widely planted genus in Tanzania as it accounts for 56% of the planted area. *Pinus patula* is the most widely planted species accounting for 85% of the area under pines, *P. caribaea* accounts for about 14% while other pines notably *P. elliottii* and to a lesser extent *P. kesiya* account for about one per cent of the planted area (Mbwana, 1991). *Cupressus lusitanica* accounts for 13% of the area under plantations, *Eucalyptus maidenii/E. saligna* and *Tectona grandis* occupy 4.3% and 3.3% respectively.

2.2 Status of Forest Insect Pests in Tanzania

The few tree species which have been grown successfully are subjected to attack firstly by many non-host-specific indigenous insects and secondly by a few exotic insects which have been introduced along with their host plants (Perry and Maghembe, 1989). Until the recent expansion of forestry, exotic tree plantations were relatively free of insect pest problems. This situation has, however, changed markedly from mid 1960's with the accidental introduction of several serious insect pests originating from other continents (Ciesla, 1991). The following is a review of some selected exotic pests in which their major hosts, type of damage and other vital information are given. While the identification of the pests and the nature of the damage are well known, little is known of the extent of damage and its impact (Madoffe and Day, 1995).

2.2.1 *Cinara cupressivora* (Lachnidae: Homoptera): Cypress aphid

This is the most serious insect pest in Eastern Africa (socially and economically). This pest is native to Southern Europe, and was accidentally introduced to Malawi in 1986. During the following year, the insect was discovered in Tanzania. It attacks members of the family Cuppressaceae, including *Juniperus, Cuppressus, Thuja. Chamaecyparis, Callitris* and *Widdringtonia nodiflora,* Malawi's national tree (Ciesla, 1993). *Cupressus lusitanica* which is widely used for timber production, fuel wood, living fences and wind breaks is more susceptible to attack than indigenous species (Odera, 1991). In East Africa the pest was estimated to cause losses in annual growth of *Cupressus lusitanica* of US $ 17.5 million, not counting the widespread death of trees which it has caused (Ciesla, 1991). In Meru forest plantations in Tanzania, it was found that about 30% of trees were dead through infestation, representing a loss in volume of 350 000 m^3 valued at 289.5 million Tanzanian shillings based on 1992 prices (O'Kting'ati and Nangawe, 1996). In Kenya damage to *C. lusitanica* plantations has been as high as 90% (Owuor, 1991). Threat from this pest forced the Tanzanian Government to stop planting *C. lusitanica* in the Government plantations while most of the mature plantations were clearfelled in 1970's and 1980's (Madoffe, 2006). The pest can be controlled by silviculture methods e.g. thinning, proper site selection and selection of resistant trees. Chemical control is only feasible on small areas such as hedges (Madoffe and Day, 1995). Classical biological control using a parasitoid, *Pauesea sp* has shown some positive results in Kenya and Uganda under the sponsorship of Food and Agriculture Organisation (FAO) (Allard *et al.*, 1994). The release of the parasitoid was done in early 1990's and records show that in the late 1990s it had spread and established in northern Tanzania (Kilimanjaro and Arusha) where *C. lusitanica* is widely planted. In spite of lack of a systematic survey to evaluate the status of the pest, a general observation is that the severity of the attack is diminishing and the Government has relaxed its ban on replanting of Cypress, while many individuals have continued planting the species (Madoffe, 2006).

2.2.2 *Pineus boerneri*? (Homoptera: Adelgidae): Pine woolly aphid

This pest is native to Europe, where it has been reported to cause a lot of serious damages to various species of pines. It has about 50 hosts of pine species in Africa of which 41 species have been introduced in Eastern and Southern Africa and nearly 30 species are recorded as furnishing food for the pine woolly aphid (Madoffe, 1989). Towards the end of 1984 nearly all pines plantations in Tanzania had been infested, showing varying degrees of attack (Madoffe and Day, 1995). In East Africa the most planted pines are *Pinus patula*, *P. elliottii* and *P. kesiya* of which *Pinus kesiya* and *P. patula* appear more susceptible to attack than other pines grown (Odera, 1991). Studies have been undertaken on the biology, ecology and economic importance of this pest in Kenya, Zimbabwe and South Africa

(Barnes *et al.*, 1976; Zwolinski, 1989). In Tanzania, studies were reported to be confined to ecology (Madoffe and Austrå, 1990; 1993). It was reported in Zimbabwe by Mazodze *et al.* (1990) that the pine plantations seemed to be very safe from serious damage of pine woolly aphid and the aphid was no longer causing economic damage. No current information about the pest has been reported from Kenya and South Africa.

The commonest control method of PWA is by practicing proper silviculture e.g. sites amelioration and use of resistant pines. Biological control has also been used successfully for example in Tanzania, native predators such as the Coccinellids sp., Chaelemens sp., Chilocorus sp. and Rodolia sp. have been found keeping down the aphid population in some pine plantations in the Sao Hill, West Kilimanjaro and Meru Forest projects (Kisaka, 1990). Various exotic predators which have been evaluated for control of PWA include *Leucopis nigraluua, L. manii, L. tapiae, Ballia eucharis, Scymnus* species and *Tetraphleps raoi* (Hemiptera: Anthocoridae). Most of these predators have been found feeding on the aphids, hence helping in suppression of the pest. However, Kisaka (1990) reported that *T. raoi* predator was not very effective as it did not reduce the population sufficiently to prevent tree growth reduction and occasional tree mortality. Conversely, Madoffe (2006) considered the predator to contribute to the reduced numbers and damage of the pine woolly aphid in Sao Hill forest plantation. Similarly some chemicals have been reported to suppress the pest though they are expensive and not environmentally friendly.

2.2.3 *Phoracantha semipunctata* and *P. recurva* (Coleoptera: Cerambycidae): Eucalyptus bark beetles

These two longicorn beetles are native to Australia and were accidentally introduced in many parts of the world including South Africa and East Africa where *Eucalyptus* are widely grown (Bubala *et al.*, 1989). It attacks both growing trees and green logs (Annecke and Moran, 1998). Attacks can cause considerable damage to physiologically stressed trees sometimes killing them. *Phoracantha semipunctata* is a serious pest in Zimbabwe, Malawi, and Zambia and to a lesser extent in Southern part of Tanzania (Annecke and Moran, 1998). In 1989 the beetles were widely distributed in Zambia. Out of the 54 plantations inspected during 1980-1983, they were present in 32 plantations corresponding to 94% of the area of 25,000 hectares under eucalypts in Zambia (Bubala *et al.*, 1989). All Eucalyptus species grown in Zambia are susceptible to the attack by *P. semipunctata* whereby in South Africa, host plants of phoracantha beetles are *E. grandis, E. saligna, E. diversicolor, E. paniculata and E. maculata.* Control of phoracantha beetles includes stripping the bark and destroying the infested branches of felled trees. Trees felled for firewood should be similarly treated to prevent the beetles from breeding and to stop them from being spread in firewood (Annecke and Moran, 1998).

2.2.4 *Eulachnus rileyi* (Homoptera: Lachnidae): Pine needle aphid

This needle infesting aphid of European and North America origin was for the first time discovered in Zambia, Zimbabwe and South Africa in the late 1970's but the species has subsequently spread to Tanzania, Kenya and Malawi where pines are grown (Katerere, 1984). Like the pine woolly aphids, *P. patula* and *P. elliottii* seem to be particularly more susceptible. The infested needles turn yellow and could be lost prematurely and the aphids produce copious quantities of honeydew, which induce a cover of sooty moulds on heavily infested trees (Madoffe, 2006). In Tanzania, the pest is found in most pine growing plantations and Sao Hill forest plantation has the most serious attacks (Madoffe, 1989).

However, there is no available information about the quantitative effect of the pine needle aphid on its pine host in Tanzania, Kenya, South Africa and the actual damage to pines is slight than that caused by the pine woolly aphid. Mazodze *et al.* (1990) reported in Zimbabwe that the pine plantations were very safe from serious damage of *E. rileyi* and no economic loss was reported. Combined attack of *P. boerneri?* and *E. rileyi* especially towards the end of the dry season could have much more serious consequents. *Tetraphleps raoi*, which was specifically introduced to Tanzania to control pine woolly aphid, appear also to be effective against pine needle aphid. Massawe (1991) described *T. raoi* as the most important predator of *Pineus* species. *Leucopis tapeae* could also have some prospects for management of this pest. Proper site selection, proper silvicultural practices and use of resistant pine species could also reduce ravages from this pest.

2.2.5 *Leptocybe invasa* (Hymenoptera: Eulophidae): Eucalyptus chalcids

The Blue Gum Chalcid, *Leptocybe invasa* (Hymenoptera: Eulophidae) is a new genus and species that was first recorded in the Middle East in 2000 and has spread to most Mediterranean countries and to many of the Eucalyptus areas in northern and eastern Africa. The wasp has been reported from several countries including Algeria, Iran, Israel, Italy, Jordan, Kenya, Morocco, Spain, Syria, Turkey and Uganda (Mutitu, 2003). It was detected in Uganda and Kenya in December, 2002 and more recently from Tanzania where it is reported to spread fast and cause serious damage to young plantations and nursery seedlings (Roux and Slippers, 2007). Although the wasp is probably native to Australia, its Australian distribution is still unknown.

In Tanzania, first official records were made in Tabora Leaf Tobacco Company Eucalyptus plantation and Shinyanga in early 2005 where young, mostly 4-6 months *Eucalyptus camaldulensis, E. tereticornis* and *E. grands* are grown. Similar observations were made in a one year old *E. grandis* clonal trial from South Africa grown in Kibaha, Coast Region and Mombo and Korogwe in Tanga region. No death has been recorded so far; however, it hinders production of leaves. In Kenya, the area affected with this pest is restricted to Western Kenya region, particularly Kisumu, Vihiga, Busia and Teso districts are heavily infested. The invasion is suspected to have come from eastern Uganda (Mutitu and Mukirae, 2004).

Mutitu and Mukirae (2004) reported that the insect attacks all species of eucalyptus. This insect pest reproduces by parthenogenesis. Each insect is capable of laying eight to one hundred eggs during its short life span. The insect is active and has considerable power of flight and can easily infest very fast large areas within a very short time (Mutitu and Mukirae, 2004). Blue gum chalcid causes formation of galls on twigs and foliage of the host trees. Galls are also found on the leaf petiole. Repeated attacks on growing tips (shoots) lead to gnarled or twisted appearance. This causes the tree to lack terminal leader shoot, leading to umbrella-shaped canopy instead of conical (Nyeko *et al.*, 2007).

Control measures taken in Tabora (Tanzania) so far include application of agrochemicals and application of fertilizers to induce leaf formation. The suggested pest management options in Kenya include; quarantine measures on movement of seedlings in all the districts affected, cultural control methods, the affected seedlings are not sold to farmers to avoid the spread of the pest and Kenya Forestry Research Institute (KEFRI) is thinking of initiating a biological control program as a permanent solution (Mutitu and Mukirae, 2004).

2.3 The Study Insect: Pine Woolly Aphid

The pine woolly aphid, *Pineus boerneri?* (Homoptera: Adelgidae) was originally identified as *Pineus pini* (Macquart) which is indigenous to Europe and possibly some parts of Pakistan and India (Murphy *et al.*, 1991a). It has a number of host species of exotic *Pinus* in Africa and feeds on the bark, shoots and bases of pine needles, producing tufts of white woolly wax (Barnes *et al.*, 1976; Zwolinski, 1989; 1990).

2.3.1 General information on Family Adelgidae

Adelgidae family is one of the three families within the order Homoptera which has 71 species known and one subspecies in the world (Sanyang and Shanchun, 1997). The Adelgidae form a small clade of insects within the Aphidoidea (Hemiptera) that includes some of the most destructive pest species threatening forest ecosystems. Despite their importance, little is known about their evolutionary history and their taxonomy remains unresolved (Havill and Foottit, 2007). It posses short 2-5 segmented antennae, with 2 primary rhinaria in apterae and 3 in alatae; the wings are usually held roof-like in response and the cubitus 1 and 2 remain separated in the fore wing. The adelgids feeds only on Coniferae.

Adelgids are cyclically parthenogenetic and exhibit multigeneration complex life cycles. They can be holocyclic, with a sexual generation and host alternation, or anholocyclic, entirely asexual and without host alternation (Havill and Foottit, 2007). In cyclically parthenogenetic organisms, a holocyclic species or lineage is one that includes a sexual generation in its life cycle. Life cycles that do not include a sexual generation are termed anholocyclic (Havill *et al.*, 2007). Five generations make up the typical adelgid holocycle. Three are produced on the primary host, where sexual reproduction and gall formation occur: two are produced on the secondary host that supports a series of asexual generations. The entire cycle takes two years to complete (Sanyang and Shanchun, 1997; Havill and Foottit, 2007) and Spruce (*Picea* spp.) is always the primary host while another conifer genus (*Abies*, *Larix*, *Pseudotsuga*, *Tsuga*, or *Pinus*) are always the secondary host. Adelgids are highly host specific: A given species can survive and reproduce only on certain tree species within a single primary and secondary host genus. For example, *Pineus orientalis* can alternate between *Picea orientalis* and *Pinus silvestris*, but it cannot survive on *Picea abies*, *Pinus strobus*, or *Pinus cembra* (Havill and Foottit, 2007).

The African *Pineus* species is anholocyclic and autoecious. In Europe, *Pineus* species are cyclically parthenogenetic with host alternating, multiple-generation complex life cycles and are restricted to certain host genera in the Pinaceae (Havill *et al.*, 2007). Adelgid species and populations that are anholocyclic experience only parthenogenetic reproduction on either a primary or secondary host. The anholocyclic life cycle on *Picea* consists of two parthenogenetic generations, fundatrices and gallicolae . The entire cycle is completed within one year. As in the holocycle, fundatrices overwinter as nymphs and galls are formed in the spring. Winged gallicolae can disperse or can stay to lay eggs near the gall from which they emerged (Sanyang and Shanchun, 1997). *Pineus pineoides* is unique among adelgid species in that it is restricted to *Picea* but does not produce galls (Havill and Foottit, 2007). The life cycle consists of only wingless parthenogenetic individuals that reside on the bark. Morphologically they are more similar to exules on secondary hosts than to the fundatrices or gallicolae normally found on spruce (Havill *et al.*, 2007). *Pineus similes* which is anholocyclic on *Picea* is also unique in that gallicolae can sometimes be wingless and can occasionally settle, feed, and even lay eggs inside the gall. The anholocyclic life cycle on a secondary host consists of a simple series of parthenogenetic exulis generations. The number of generations per year ranges from two to six depending on the species and on climate and host condition (Havill and Foottit, 2007). The pest species, balsam woolly adelgid, *Adelges piceae* and hemlock woolly adelgid, *A. tsugae,* have this type of life cycle in their introduced ranges.

Pineus species are too small to be visible by naked eyes and their presence can usually be detected by the presence of white "wool". These small clumps of "wool" appear initially around the base of pine needles on the young shoots. As the number of aphids increases, a solid mass of "wool" is produced which spreads down the branches of the tree and even on the trunk (Madoffe, 1989). The produced white woolly, gives this species its common name (Annecke and Moran, 1998). At high densities, feeding behaviour of the aphid causes a reduction in needle growth, needle drop, shoot death, dieback of branches and, sometimes, death of trees. The injury due to the pine woolly aphid consists of a characteristic die-back of the leading shoots, the young needles then turn yellow to red, the older needles drop off prematurely, and the bark tissues deteriorate, resulting in both stunting and slowing down of growth in thickness of the infested trees. In a final scenario, the tree may die. Death of a tree is gradual, usually progressing from the top to the base and from the outside to the centre of the crown.

2.3.2 Introduction and spread of the pine woolly aphid in southern Africa

The pine woolly aphid was first introduced simultaneously in Kenya and Zimbabwe in 1968 and was probably introduced into Zimbabwe with *Pinus taeda,* scions from Australia in 1962 (Barnes *et al.*, 1976; Massawe, 1991). Since 1968, the aphid has spread throughout African pine plantations and the other countries including Ethiopia, Tanzania, Malawi and South Africa (Murphy *et al.*, 1991b). The pest was not reported from Uganda, Zambia and

Malawi because these countries did not participate in seed orchard planting programmes as Tanzania, Kenya and Zimbabwe did in 1960's (Odera, 1991).

In 1968, the first observation was made in Kenya and the spread was very fast such that in the same year, heavy infestation was found in pines around Muguga (centre of infestation). Initially, the spread was slow in Zimbabwe. However, it picked up in 1968 partly because the condition was very favourable for population build up (Barnes *et al.,* 1976). In Tanzania, the PWA was first found at Sao-Hill and West Kilimanjaro forest plantations in 1968 (Massawe, 1991). Tanzania which was a member of East African Agricultural and Forestry Research Organisation (EAAFRO) and participated in seed orchard planting programme probably got the pest through *P.radiata* nursery planting stock imported from Australia through Kenya in 1964 (Massawe, 1991).

From the seed orchard at Kihanga arboretum in Sao Hill, infestation spread quickly to other pine species in the arboretum and later to the other parts of the plantation. Irregular infestation is common at Sao Hill and the general trend shows east west spread of the aphid, probably following the direction of the monsoon winds. General surveys showed a decrease in this pest in some compartments particularly in the older stands, contrary to what was expected when first reported in the late sixties (Kisaka, 1990).

2.3.3 Host trees and their susceptibility to attack

A wide range of pine species are attacked by the pine woolly aphid (Zwolinski, 1989) but there seems to be a great variation in the susceptibility to attack between species (Barnes *et al.,* 1976; Zwolinski, 1989). Of the main industrial species, *P. kesiya, P. elliottii, and P. radiate* seem to be highly to moderately susceptible, while *P. patula* and *P. taeda* are only slightly susceptible to attack (Murphy *et al.*, 1991b). However, the susceptibility of trees of the same species also differs between individuals planted on the same site and age classes.

Aphid growth rate and fecundity can be significantly different between individual trees of the same conifer species. Some hosts are consistently poor for aphids while other hosts are heavily attacked by aphids. The same host species grown on the same soil type can also have different rate of attack. This state of resistance of some hosts is controlled by genes of the host trees. Evidence of heritable resistance of *Pinus elliottii* to *Pineus sp.* has also been recorded by Barnes *et al.* (1976) in Southern Africa. Further evidence that poor aphid performance can be genetically controlled by the host tree has been shown with *Cinara cronartii* by Shaw (1984) when different clonal trees from the same parental crossings were shown to inherit resistant properties from the resistant parents. Identification of the precise resistance mechanisms of conifer host plants to aphids have yet to be made, but Nichols (1987) has shown a negative relationship between aphid performance and the concentration of certain phenolic and terpene compounds in the foliage of spruce.

Fluid feeding insects like aphids depend entirely on soluble organic nutrients metabolized by the host plant. The inability of tree roots to take up nutrients, due to physical limiting factors, such as soil temperature and water availability influences host quality. Periods of plant stress in conifers, such as a sublethal drought, which is visibly difficult to recognize, has a profound effect on aphid fecundity and hence population increase (Major, 1990). Soluble carbohydrates from photosynthesis are the aphids' energy source and are usually in plentiful supply; but it is the soluble amino-acids necessary for growth, which are at a relatively low concentration that can greatly influence aphid growth rate and fecundity. Seasonal changes in amino acid composition in conifer foliage significantly influences population increase and decline of the green spruce aphid (Carter and Watson 1991). An imbalance of major plant nutrients, especially nitrogen and potassium ratios, can significantly alter both the quality and quantity of available amino-acids and hence influence the growth rate of aphids (Carter and Watson, 1991).

2.3.4 Economic importance of conifer aphids

A number of studies have been conducted to determine the impact of the pine woolly aphid on wood production in Africa. In Kenya, Mailu *et al.* (1980) showed that 6% of the plantations of medium-aged *P. patula*, a major species grown for industrial purposes, were infested with the aphid and trees were losing approximately 5% of their volume over a six year period. The study conducted by Kisaka (1990) at Sao Hill in Tanzania showed that increment in basal area of the attacked tree was 1.14% less than that of unaffected trees. It was also shown that uninfested trees grow faster in height by 1.14% than that of infested trees. Moreover, Madoffe and Austarå (1990) showed from studies in Tanzania, that the shoots and stems of seedlings of *P. patula* lost 20.9% of their dry weight after 24 weeks.

Other studies were reported from the southern Cape region of South Africa in the early eighties whereby 31.8% of *P. pinaster* cones were heavily infested and showed deformation, cracks and resinous outflow; the total number of seeds obtained from affected cones was reduced by 71.7% (Zwolinski *et al.*, 1989). Zwolinski (1990) also reported that 89.2 % of *P. pinaster*, 54.2% of *P. elliottii*, and 27.2 % of *P. radiata* were infested with the aphid. *P. pinaster* was the most susceptible of the three pines and infested trees lost 19.5% of the annual increment in volume. Similarly in Malawi, it was recorded that approximately 2 – 5% of annual growth was lost in young *Pinus* species due to *P. boerneri* infestation (Chilima and Leather, 2001). Murphy *et al.* (1991a) reported that the most damaging attacks of aphid are generally on young trees and seedlings. For example, heavy infestations of the spruce aphid, *Cinara piceae*, (Panzer), reduces tree growth by up to 60 - 70% in young spruce plantations in Japan and the grey pine aphid, *Schizolachnus pineti* reduces growth of Scots pine to similar extent (Furuta and Takai, 1983). While no studies have been conducted on lachnid impact on older softwood trees, the sycamore aphid, *Drepanosiphum platanoide* (Schr.), reduces annual growth of mature sycamore by as much as 77 % (Straw *et al.*, 2000). It is probable; therefore, that loss of growth is broadly equal in both young and older trees while the younger and seedlings may be less able to survive this growth stress.

2.3.5 Aphids and conifers interactions

Nutritionally modified conditions of the host plant can be brought about by an aphid of the same or even another species, a simple example being a delay in bud burst in trees following heavy aphid attacks the previous growing season (Carter, 1988). Chlorosis of *Picea* caused by the green spruce aphid, *Elatorium abietinum*, improves the growth rate of the subsequent aphid generation by providing a better quality food source (Fisher, 1987). Similarly in clustered aggregations of *Schizolachnus pineti* or *Cinara pini*, there is a temporary increase in amino acids concentration to 47% at their feeding sites, which then results in a 31% increase in nymphal growth rates. *Eulachnus agilis* favours senescing pine needles; its growth rate has been shown to increase when feeding on the same needles as *Schizolachnus pineti* (Kidd *et al.*, 1985).

Aphids are also capable of inducing chemical changes in the tissue of their conifer hosts which may be their detrimental. After a while, highly infested sites on the tree become unfavourable and the colonies decamp to another site (Larsson, 1985). With *Cinara* *cupressi* and *Cinara fresai* on *Juniperus virginiana*, this behaviour is quite conspicuous, as small branchlets of foliage discolour and are shut down in response to feeding (Carter and Watson, 1991). This phenomenon is less obvious with *Cinara pini* on *Pinus sylvestris*: but anatomical inspection of the plant tissue beneath the aphid colony has shown extensive lignification developments with the cortex parenchyma cells as a result of aphid feeding (Smith, 1991).

2.3.6 Insects population estimation

World wide, the most diverse group of organisms appears to be insects, with about 750 000 species described already which is about half the world's total species (Primack, 2006). Various entomologists have tried to estimate number of insects by sampling entire insect communities in tropical forests using insecticidal fogging of whole trees and intensive hand collection. Using the results of such intensive collecting, entomologists have attempted to calculate the number of insect species (Novotny *et al*., 2002). The counting of total populations' abundances of insects is usually measured by an index which is relatively easy to estimate and related to insect numbers over the whole tree. Madoffe (1989) reported some methods which have been used to estimate some defoliators, but the commonest one is the use of insect density in the middle part of the tree. Simple visual estimation of defoliation accompanied by examination of tree crown foliage and estimating the percent of foliage removed was reported to be cheap and relatively sufficient method. The length of the needle on the host tree and percentage of twig covered with wool has been used to estimate the population of *Pineus* (Mailu *et al*., 1982).

Other two methods used in estimating abundance of aphids are Biomass and Subjective methods. These two methods were used in a seasonal study (1975-1978) of the aphidophagous Australian ladybird, *Scymnodes lividgaster* at Chinaman's Beach Reserve near Sydney. The abundance of a prey species *Aphis eugeniae* on the cheese tree, *Glochidion ferdinandi* was estimated in order to analyse the relationship between aphid and ladybird. These two simple methods were used concurrently to estimate *A. eugeniae* abundance which could have application in integrated pest control procedures. *Aphis eugeniae* was the main food present in the reserve (Anderson, 1981).

2.3.7 Insects population dynamics

In particular, analysis of distribution pattern is an essential first step for better understanding of insect pest population dynamics. Aloo (1996) reported that the impact of aphid attack on newly planted trees is severe and lessens as trees grow, therefore, the time of initial invasion and spread of aphids within a plantation is very important. Understanding of the dispersal distance of *Cinara todocola* is important for prediction of outbreaks and for determination of the range of direct control by the use of synthetic sex pheromone, chemical or silvicultural methods (Aloo, 1996).

The population dynamics of insects with different types of seasonal development depends on peculiarities in insect seasonal development and in particular, on weather conditions of the region. In Zimbabwe and Kenya, population studies have indicated that the pine woolly aphid is most abundant during the dry season and tends to be reduced by rainfall during the wet season (Barnes *et al.*, 1976; Mailu *et al.*, 1980). Mailu *et al.* (1980) also reported that nine species of indigenous predatory insects were found attacking the aphid and that together these predators were removing approximately 12% of the aphid population. The most common predators were *Exochomus sp.* (Coleoptera: Coccinellidae). In another study done on pine needle aphids in Zimbabwe Katerere (1984) suggested that, in that country, there are two peaks of aphids each year; in July and November. In July the greatest densities are found on *P. taeda* and in November on *P. patula*. In 1978 and 1979 in Zambia, the build up of populations was rapid in May-June after the rains caused a dramatic decrease in population density in November and December (Löttyniemi, 1979). For insect species which hibernate in the egg state (*Tortrix viridana, Neodipriana sertifer, Lymantria dispar*), the initiation of outbreaks occurs more often in years when larval feeding begins early. Outbreaks of insect species that hibernate in the larval stage (*Deudrolimus pini, Euproctis chrysorrhoea*) often follow years when dry and hot weather occours during the period when young larvae are feeding at the end of the summer. Outbreaks of insects species that hibernate in the pupal stage begin in the years following after the occourence of an early spring (*Panolis flammea*) or a dry and hot June (*Bupalus piniarius*) and are associated with conditions that promote the rapid development of young larvae (Mashkova, 2003). The occurrence of outbreaks of insect species whose feeding takes place at the end of the dry season are also associated with warm and dry weather during the feeding period which promotes synchrony in the completion of their seasonal development with completion of the period of vegetation by the host tree.

2.4 Management of Forest Aphids

2.4.1 Chemicals control

Chemical insecticides have played important and beneficial roles in the control of agricultural pests and the reduction of insect borne disease for many years. Their use will remain essential for many more years. Nonetheless, insecticides also pose real hazards. Some leave undesirable residual in food, water, and the environment. Low doses of many insecticides are toxic to humans and other animals, and some insecticides are suspected to be carcinogens (Weinzieri and Henn, 2001). As a result, many researchers, farmers, and homeowners are seeking less hazardous alternatives to conventional synthetic insecticides.

Several chemical insecticides have been tried against *Pineus pini* in East Africa. For example, spraying of thiodan and teepol 1% solution and propoxur (Baygon E.C) used to control PWA at Sao Hill and was found to be effective (Kisaka, 1990). In Uganda, pesticides such as Lemdacyhalothrin (karate), Deltamethrin (decis) and Fenitrothion (sumithion) were found to be effective against *Cinara cupressivora* (Kiwuso, 1991). Chilima (1991) reported that several insecticides such as LC 50 of 1.5 ppm followed by fenitrothion with an LC 50 of 1.8 ppm were the most effective against *C. cupressivora* in Malawi. Rao (1994) suggested that the use of systematic and broad spectrum insecticides such as dimethoate, cypermethrine, cyhalothrine and carbofuran are the most effective for 2-3 week against Leucaena psyllid (*Heteropsylla cubana*) in Kenya and Tanzania.

2.4.2 Biological control

Pineus boerneri?, like other adelgids is attacked by a range of aphidophagous predators including chamaemyiids, syrphids, coccinellids and hemerobiids but unlike lachnids which is not attacked by hymenopterous parasitoids (Murphy *et al.*, 1991b). The predatory groups include both relatively host-specific and more generalist species but it is the former group which is of interest for biological control work. Of particular interest are the various species of *Leucopis* (Diptera: Chamaemyiidae) as some of these species, for example, *L. tapiae* are specific to *Pineus* species and have already been successfully used for the control of *P. boerneri?* and *P. laevis* in other regions of the world (Murphy *et al.*, 1991b).

A devastating outbreak of *P. pini* in Hawaii, which occurred in the 1960's, was successfully controlled by the introduction of two chamaemyiids, *Leucopis obscura* from

Europe and *L. nigraluna* from Pakistan (Zondag and Nuttall, 1989). *Tetraphleps raoi* was successfully introduced into Kenya from Pakistan for biological control of *P. pini* and established in pine plantation. The establishment of *T. raoi* was followed by a decline in field populations of *P.pini* (Aloo and Karanja, 1986). The nematode *Deladenus siricidicola* and various parasitic wasp species have been introduced as biological control agents in all southern hemisphere countries where *Sirex noctilio* has been introduced (Hurley *et al.*, 2007; Villacide and Corley, 2008). Ciesla (1991) reported that six families of insects, representing four orders (Diptera, Coleoptera, Hymenoptera and Neuroptera) have been observed as natural enemies of *Cinara cupressivora* in Tanzania. Larvae of the family Sirphidae (Diptera) were commonly seen feeding on colonies of *C. cupressivora* in Kenya. Parasitoids are an important part of the natural control complex of aphids of the family Lachnidae. According to Mills (1990), these offer the greatest potential for biological control.

During the early 1970's, the black pine aphid, *C. cronartii*, was discovered damaging plantations of *Pinus taeda, P. patula,* and *P. elliotii* plantations in South Africa. This aphid is native to the southeastern United States where it is found in or near bark lesions or cankers caused by fusiform rust, *Cronartium fusiforme* (Mills, 1990). An unidentified species of *Pauesia* was discovered to be a parasitoid of *C. crontartii* and was introduced and established in South Africa. The parasitoid has been identified as *Pauesia bicolor* and resulted to the collapse of the aphid population (Mills, 1990). Two species of *Pauesia; P. cupressobii,* and *P. juniperorum* have been recorded from *Cinara juniperi*, an aphid closely related to *C. cupressivora* which infests *Juniperus communis*. These two parasitoids are considered to be specific to *Cinara* sp. which feed on plants of the family Cupressaceae. In Tanzania, *Psyllaephagaus yaseeni* and *Tamarix leucaenae* parasitoids which are natural enemies of Leucaena psyllid, *Heteropsylla cubana* were imported from Trinidad and Tobago and released in Tanga, Morogoro and Tabora regions respectively in late 1990s. Madoffe *et al.* (2000) reported that these species are well established and distributed to most *Leucaena* growing sites in Tanzania and that there was an indication of reduced host population and damage probably as a result of these parasitoids.

2.4.3 Cultural control

Cultural tactics are designed to create conditions inhospitable for the development of damaging numbers of pests. These include matching tree species selected for planting to suitable growing sites, controlling stocking through intermediate harvests to maintain tree vigor and timely harvesting of plantations when they reach maturity. A drastic but sometimes necessary cultural approach is to simply eliminate a tree species from a plantation programme because of its high susceptibility to certain pests. The silvicultural practices may have profound effects on the population levels and species composition of various groups of forest organisms and they have sometimes been suggested as a means of controlling forest pests. Veteli *et al.* (2006) reported that control of forest pests by silvicultural practices is a potentially attractive approach because, in contrast to temporary suppressive measures such as insecticide treatments, it is preventive, long-lasting and has a low environmental impact. There is considerable evidence to suggest that the correct proper management practices of pine species are important silvicultural factors in the control of *Pineus* (Chilima and Leather, 2001). Several beetle pests have been reduced to a tolerable level by simple silviculture operations (Bubala *et al.*, 1989). For example thinning is recommended as mean for reducing stand susceptibility to attack by southern pine beetles (*Dendroctonus frontalis*). Cultural practices have been used in *Leucaena psyllid*, particularly the destruction of infested plants seems to be the most important means of controlling the pest in Mozambique by individual farmers (Svensson, 1987). Silvicultural practices as described by Hurley *et al.* (2007) have been used to control *Sirex noctilio* in Australia and New Zealand. After the outbreak of S. *noctilio* in New Zealand between 1946 and 1951, improvements in silviculture, kept *S. noctilio* population low.

2.4.4 Resistant control

Generally the production of plants resistant to particular insect pests is accomplished by selective breeding for resistance traits. Selecting and breeding for host plant resistance can be an extremely effective means of controlling pest insects. For example Welty and Murphy (1991) reported that resistant varieties were used to prevent underground infestations of woolly apple aphid, *Eriosoma lanigerum*, which infests apple trees in Ohio. The Malling-Merton (MM) rootstock series provide resistance to woolly apple aphid attack. Some apple varieties such as Northern Spy are resistant to this pest. Propagation and planting of resistant genotypes of *Cupressus lusitanica* could be a means of managing *Cinara cupressivora* (Mwangi, 2001). Another possibility is the use of species which are less sensitive to cypress aphid attacks. For example, *Cupressus torulusa* (Don.), a species native to the Himalayas, appears to be more tolerant to attack when planted in Africa (Ciesla, 1991). However, these approaches require testing and evaluation before they can be recommended for application on a wide scale.

Hanks *et al.* (1995) reported the use of eucalyptus species that are well adapted to each location and provide them with proper cultural care as a one way of controlling longhorned borers in California. Certain species of eucalyptus are more resistant to longhorned borers for example hybrid, *E. trabutii*, lemon gum, *E. citriodora,* swamp mahogany, *E. robusta*, etc. Most eucalyptus species that are adapted to wetter growing conditions are more susceptible to longhorned borers, while the more resistant eucalyptus often are species adapted to drier conditions. However, most eucalyptus can be attacked if they are heavily stressed, for example by being planted in poor soils or deprived of sufficient water. A well-maintained tree of a susceptible species may be at less risk of infestation than a neglected tree of a resistant species. Trees with some resistance to these wood borers may produce copious amounts of resin in response to an attack. Genetic control in Australia as reported by Heidelberg (2001) is the most chance of success and it involves the selection of eucalypt material displaying inherent resistance to psyllid attack in psyllid infested plantations. Some eucalypt species hybridise, into genotypes with a marked resistance to insect attack example the hybrid cross between *E. torquata* and *E. woodwardi* is a tree displaying pronounced resistance to gum leaf skeletoniser. Heidelberg (2001) further reported that *E. camaldulenis* also hybridises well with a range of eucalypt species, although it is not known whether any of these hybrids are manifestly resistant to psyllids or other insect pests. Furthermore, insect resistance in a hybrid may be obtained at the expense of such characteristics as good form, growthrate and desirable wood properties. The use of insect-resistant material is advantageous as it provides an alternative means of controlling pests such as psyllids without having to resort to pesticide applications.

2.4.5 Integrated pest management (IPM)

Integrated pest management (IPM) is an approach which combines different pest control techniques and integrates them into the overall farming systems. It relies on host plant resistance, biological control and cultural practice with pesticides introduced only when these non-chemical control methods fail to maintain pest populations below economically damaging level (Kiss and Meerman, 1995). The concept of (IPM) was developed in the late 1950s and early 1960s in response to problems of insecticide resistance and insecticide-induced pest resurgence, plus growing concerns of environmental contamination (Gullan and Cranston, 2005). It was conceived as a means to reduce the use of pesticides, and to encourage the more "ecologically friendly" use of pest natural enemies via biological control (Mariau, 1999).

Integrated pest management systems consist of a combination of decision-making and pest management tools directed against a pest or pest complex and are in various stages of development. An example of an evolving IPM system is the approach being taken to manage the European wood wasp, *Sirex noctilio*, in pine plantations in South America and South Africa (Iede and Ciesla, 1993). Early detection of this insect is accomplished by baiting suppressed trees in plantations with a herbicide, a procedure that attracts attacking wasps. Infestations are treated either through inoculation of a parasitic nematode, *Daladenus siricidola* and *Beddingia siricidicola*, which render the female wood wasps incapable of producing eggs, or thinning plantations to reduce stocking and maintain tree vigor (Iede and Ciesla 1993; Elliott *et al.*, 1998). Recent successful IPM projects in forestry include control of *Heteropsylla cubana (Leucaena psyllid)* in East Africa through use of biological methods, resistance species like *Leucaena deversiflora, L. pallida, L. collinsi*, cultural methods and alternative species such as *Gliricidia* and *Calliandra* species (Madoffe, 2006). Similar programmes have been used successful in Asia (Napompeth, 1994). Other examples include *C. cupressivora* and other conifer aphids in Eastern and Southern Africa, *Sirex noctilio* in New Zealand, and South America, *Lymantria dispar* in the United States and Europe (Allard *et al.*, 2003) and *Ips grandicollis* (Coleoptera: Scolytidae) in Australia which comprises silvicultural techniques, quarantine and biological control (Wylie *et al.*, 1999). Cook *et al.* (2007) described the use of Push-Pull strategies as one of the IPM strategies. Push-Pull strategies involve the behavioral manipulation of insect pests and their natural enemies via the integration of stimuli that act to make the protected resource unattractive or unsuitable to the pests (push) while luring them toward an attractive source (pull) from where the pests are subsequently removed. The push and pull components are generally nontoxic. Therefore, the strategies are usually integrated with methods for population reduction, preferably biological control. Push-pull strategies maximize efficacy of behavior manipulating stimuli through the additive and synergistic effects of integrating their use. By orchestrating a predictable distribution of pests, efficiency of population-reducing components can also be increased. The strategy is a useful tool for integrated pest management programs reducing pesticide input. Some examples of stimuli for push components include visual distraction, non-host volatiles, anti-aggregation pheromones, alarm pheromones, oviposition deterrents, antifeedants and examples of stimuli for pull components also includes visual stimulants, host volatiles. aggregation pheromones, sex pheromones, oviposition stimulants and gustatory stimulants.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Sao-Hill Forest Plantation (SHFP) is the largest forest plantation in the country with planted area of about 43 000ha out of total gazetted area of 95 000ha. The plantation is managed by the Forest and Beekeeping Division of the Ministry of Natural Resource and Tourism. This forest is the main supplier of raw materials (round wood) to Sao Hill Saw Mills Ltd and Southern Paper Mills Ltd (now Mufindi Paper Mills Ltd), the largest paper mill in the country. It is also a source of raw material for about 140 small sawmills and two transmission poles plants (Mlowe, 2007). For managerial convenience, SHFP is divided into four divisions each with a divisional manager reporting to the Plantation manager.

Sao Hill Forest Plantation is located at 8°18'S to 8°33'S and 35°6'E to 35°20'E at an altitude ranging between 1 700 m to 2 000 m.a.s.l. in Mufindi district, Iringa region in the southern highlands of Tanzania. The area is a rolling plateau with low hills and wide flat-bottomed valleys. The plantation headquarter is 15 km from Mafinga township, which is the district headquarters. This study was conducted in three locations namely Division I, II and III.

3.1.2 Climate and soils

The rainfall pattern in Mufindi district and at SHFP and nearby villages is unimodal with single rain season from November through May and a dry season during the rest of the year. The area receives between 600 and 1 300 mm of rainfall annually (Mgeni, 1986).

Temperatures are fairly cool, reaching close to freezing point between June and August. The mean monthly minima and maxima temperatures are 10°C and 23 °C respectively. The soils are relatively homogenous and are mainly dystric nitosols in association with orthic acrisols (Ngegba, 1998). These are sandy clay loam soils with relatively uniform physical structure in undisturbed state, colour ranging from very dark brown to yellow orange. The clay minerals are mainly of the kaolitic type with low cation exchange capacity, low base saturation and high acidity with pH less than 6 (Malisa, 1992).

3.1.3 Vegetation

The natural vegetation is characterized by mosaic of open grassland with scattered trees and shrubs dominated by species such as *Brachystegia* and *Julbernadia* spp (MNRT, 1989). The main species planted in the plantation are *Pinus patula, P. elliotii, P. caribaea* and *P. kesiya*. All pines together cover about 83% of the plantation area. Other species planted include *Cupressus lusitanica* and *Eucalyptus spp.* which cover about one percent and nine percent of the plantation area respectively and remaining seven percent is occupied by other species namely; *Erythrina, Parinari, Cussonia, Apodytes* and *Albizia* (Malimbwi, 2001). Common grass species are *Themeda triandra, Pennisetum schimperi* and *Exotheca abysinica* (Mhando *et al.*, 1993).

3.2 Methodology

3.2.1 Data collection

Data were collected from two main plantation species *Pinus patula* and *P. elliottii*. Stratified sampling was adopted whereby three Blocks/Divisions with the study tree species with different age classes were selected. In each block, three compartments with different age classes were picked for each tree species. Trees were grouped into three age

Temperatures are fairly cool, reaching close to freezing point between June and August. The mean monthly minima and maxima temperatures are 10°C and 23 °C respectively. The soils are relatively homogenous and are mainly dystric nitosols in association with orthic acrisols (Ngegba, 1998). These are sandy clay loam soils with relatively uniform physical structure in undisturbed state, colour ranging from very dark brown to yellow orange. The clay minerals are mainly of the kaolitic type with low cation exchange capacity, low base saturation and high acidity with pH less than 6 (Malisa, 1992).

3.1.3 Vegetation

The natural vegetation is characterized by mosaic of open grassland with scattered trees and shrubs dominated by species such as *Brachystegia* and *Julbernadia* sp*p* (MNRT, 1989). The main species planted in the plantation are *Pinus patula, P. elliotii, P. caribaea* and *P. kesiya*. All pines together cover about 83% of the plantation area. Other species planted include *Cupressus lusitanica* and *Eucalyptus spp*. which cover about one percent and nine percent of the plantation area respectively and remaining seven percent is occupied by other species namely; *Erythrina, Parinari, Cussonia, Apodytes* and *Albizia* (Malimbwi, 2001). Common grass species are *Themeda triandra, Pennisetum schimperi* and *Exotheca abysinica* (Mhando *et al.*, 1993).

3.2 Methodology

3.2.1 Data collection

Data were collected from two main plantation species *Pinus patula* and *P. elliottii*. Stratified sampling was adopted whereby three Blocks/Divisions with the study tree species with different age classes were selected. In each block, three compartments with different age classes were picked for each tree species. Trees were grouped into three age groups i.e. young (0 – 10 years), middle age (11 – 25 years) and old age (>25 years). Visual observation on the crown was used to determine the intensity of damage. This was expressed in percentage of attack/damage. On the other hand the intensity of attack was ranked into four subjective levels namely low, mild, high and very high with percentage attack and scores of (0% – 15%) (1 score), (16% – 30%) (2 score), (31% -- 49%) (3 scores) and (> 50%) (4 score) respectively.

Trees were selected systematically from sampled plots whereby every fourth tree along the row was considered as a candidate. Three boarder rows were excluded from the sampling to avoid boarder effect. From the tree crown, five twigs in each crown were cut by climping randomly at lower/middle/upper crown of tree (Plate 1a & b) and put in a polythene bags for laboratory insect counting. *Pinus elliottii* trees were difficult to climb due to lack of strong lower branches and therefore twenty three trees were felled down for sample (twigs) collection which were also put in polythene bags. The polythene bags containing twigs were put in a refrigerator and PWA (eggs, nymph and adult) counted at a later stage. The insects (eggs, nymph and adult) were washed with a help of brush and ethanol (70%) to a Petri-dish and counted under microscope.

(a) Pruning twigs for observation from *Pinus patula* of 0 – 10 years

(b) Pruning twigs for observation from *Pinus patula* of 11 – 25 years

Plate 1: Clipping pine twigs for recording aphid infestation at Sao Hill forest plantation

3.2.2 Data analysis

Data were analyzed using Statistical Analysis System (SAS) software. Two ways Analysis of Variance (ANOVA) was used to compare the differences in abundance and damage between blocks, tree species, upper/middle/lower crown and age classes. Regression analysis was run to determine the relationship between the abundance of pine woolly aphids and intensity of damage.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Distribution of *P. patula* and *P. elliottii* According to Age Classes in Different Compartments in Sao Hill Forest Plantation

A total of 1 114 trees (628 in Division I 292 in Division II and 194 in Division III) were sampled (Table 1). Few *P. elliottii* (23 trees in total) were sampled compared to *P. patula* because the former had to be felled for sample collection due to difficulties in climbing the trees.

Table 1: Number of trees sampled within compartments for the three Divisions in Sao Hill forest plantation

Division/Block	Compt. No.	Tree spp	Age classes (years)	Area (Ha)	No. of trees sampled	Total
I	ID/2B	*P. patula*	Young (<10)	120.40	262	
	ID/1A	*P. patula*	Middle (11-25)	119.24	214	
	ID/1B	*P. patula*	Old (> 25)	67.84	143	
	ID/5B-1	*P. elliiottii*	Old (> 25)	112.93	9	628
II	S16/10	P. patula	Young (<10)	37.73	97	
	S15B/5	*P. patula*	Middle (11-25)	4.96	47	
	MT1/17	*P. patula*	Old (> 25)	66.42	141	
	S15A/1	*P. elliiottii*	Old (> 25)	19.11	7	292
III	3/T3/20	P. patula	Young (<10)	5.55	53	
	3/T3/19	*P. patula*	Middle (11-25)	14.33	81	
	3/NU1/8	*P. patula*	Old (> 25)	8.94	53	
	3/NU1/3	*P. elliiottii*	Old (> 25)	12.21	7	194

The plantation had no *P. elliottii* stands below 25 years since the species had not been planted for the last 25 years now as a result of unavailability of seeds, loss of market due to poor elasticity of timber (easily broken) and free falling down of trees in the plantation because of unknown reasons.

4.2 Distribution and Abundance of Pine Woolly Aphid in Sao Hill Forest Plantation

The Pine Woolly Aphid was not uniformly distributed between the tree blocks (Table 2). The mean number of adult aphid per twig at Sao Hill was 17.4, 16.5 and 13.6 for *P. patula* and 6.7, 6.3 and 6.1 for *P. elliottii* for Division I, II and III respectively. Division one had more adult aphids than other Divisions for both tree species although the difference was not statistically significant (P > 0.05). The insignificant difference observed might have been caused by relative homogeneity of the soil present within the plantation (Ngegba, 1998). The presence or absence of macro and micro elements in the soil within the plantation does not vary much which probably makes the abundance of aphid to be relatively similar to all blocks. Another possible reason for insignificant difference in abundance of aphid for all blocks might be due to the similarity of silvicultural operations carried out within the plantation. Tending operations like thinning and pruning are done almost equally throughout the plantation which makes the plantation to have almost the same microclimates hence no block is more preferable to aphid.

The results further showed that nymph were found in highest numbers, followed by adults and eggs the least. The population difference of the three stages could have been caused by predators present at the study site because some aphid predators (e.g. *Tetraphleps raoi*) are host specific, they usually prefer adults, but may feed on eggs and rarely on nymph (Mailu *et al.*, 1980). Similarly, the total number of nymph was high probably because the nymph life span is longer than adult life span which always makes the population densities of nymph higher than that of adults (Mailu *et al.*, 1980). This result is in agreement with

Table 2: Mean ($\bar{X}$) and Standard error (SE) of Pine Woolly Aphid population per twig for various Divisions/Blocks in Sao-Hill forest plantation

Division/ Block	Tree species	PWA Growth stage	$\bar{X}$ SE	Age classes in years			Total
				Young (0-10)	Middle (11-25)	Old (>25)	
I	*P. p*	Egg	$\bar{X}$	2.00	5.25	4.70	11.95
			SE	0.47	0.74	0.57	1.78
		Nymph	$\bar{X}$	5.56	7.67	5.15	18.38
			SE	0.67	0.98	1.11	2.76
		Adult	$\bar{X}$	4.78	6.25	6.40	17.43
			SE	0.65	0.66	0.24	1.55
	P. e	Egg	$\bar{X}$			5.17	5.17
			SE			0.77	0.77
		Nymph	$\bar{X}$			6.34	6.34
			SE			1.29	1.29
		Adult	$\bar{X}$			6.66	6.66
			SE			0.97	0.97
II	*P. p*	Egg	$\bar{X}$	3.40	7.10	3.56	14.06
			SE	1.50	1.23	0.48	3.21
		Nymph	$\bar{X}$	4.83	5.09	4.44	14.36
			SE	0.58	0.91	1.67	3.16
		Adult	$\bar{X}$	2.44	8.46	5.63	16.53
			SE	0.50	1.13	0.47	2.10
	P. e	Egg	$\bar{X}$			4.99	4.99
			SE			0.58	0.58
		Nymph	$\bar{X}$			4.83	4.83
			SE			0.67	0.67
		Adult	$\bar{X}$			6.34	6.34
			SE			0.91	0.91
III	*P. p*	Egg	$\bar{X}$	2.00	2.28	5.83	10.11
			SE	1.00	0.57	1.09	2.66
		Nymph	$\bar{X}$	5.58	6.22	6.17	17.97
			SE	0.62	1.16	0.24	2.02
		Adult	$\bar{X}$	2.88	5.44	5.27	13.59
			SE	0.69	1.26	0.24	2.19
	P. e	Egg	$\bar{X}$			6.00	6.00
			SE			1.19	1.19
		Nymph	$\bar{X}$			6.79	6.79
			SE			0.47	0.47
		Adult	$\bar{X}$			6.13	6.13
			SE			1.12	1.12

P. p – Pinus patula
P. e – Pinus elliottii

observations made in Kenya that branch whorls of the crown had 11%, 18% and 6% of the total population of adults, nymph and egg respectively (Mailu *et al.*, 1982). In contrast, Madoffe (1989) whose data collection was done from September to January when the *Pineus* experienced a good balance between the highest activity during the dry period and the period of fluctuations during the rain season, found that in all cases eggs were the most abundant, followed by adults and crawlers (nymph) were the least. Similarly, in the study done by Bruzas (1983) in South Africa, whose study took one year, experienced higher number of eggs than nymph or adult PWA in all cases. The fluctuations in number of aphids could be a result of changes in the weather or tree physiology.

The mean total numbers of adult aphid which were found to attack pines were 10.1, 20.2 and 17.3 for *P. patula* for the young, middle and old age classes respectively (Table 3). *Pinus elliottii* which was observed only in old class was insignificantly more attacked by aphids than *P. patula* having the mean total adult aphid of 19.1 comparing to 17.3 of *P. patula* of the same class age. The trend on *P. patula* indicated that middle age trees were more preferred by adult aphid than young and old class trees. The mean number of adult aphids observed in young age class differed significantly ($P < 0.05$) with that observed in middle and old age classes but no significant difference was observed between middle and old age class ($P > 0.05$). Adult aphids probably preferred to attack/damage middle age trees because of high foliage quality they have compared to other age classes which always create good rooms for aphid survival. In earlier studies, Ruohomaki *et al.* (2000) found that *Epirrita autumnata* 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. This is in contrary with Madoffe (1989) whose results indicated that young trees were vulnerable to aphid infestation than old trees.

Table 3: Mean total number of Adult Pine Woolly Aphid per tree for different age classes at Sao-Hill forest plantation

Age classes in years	Mean number	
	Pinus patula	*Pinus elliottii*
Young (0-10)	10.1a*	
Middle (11-25)	20.2b	
Old (>25)	17.3b	19.1b

* Values followed by different letters in a given column and row are significantly different ($P < 0.05$).

Similarly, Aloo (1996) reported in contrast that *Cinara todocola* attacks young trees less than 10 years old and the percentage of infested trees often increases in season when no winged females exist. This means that within a plantation the wingless aphids disperse and make colonies. Therefore, dispersal of wingless female seems to be an important factor in the spread of the aphids within plantation. In, forestry, dispersal of wingless aphids between and within trees is of great importance since they attack young trees. These insects are sometimes found crawling on the ground around the host plants. They infest only the branches, stems and sometimes roots of saplings below 2m in height which are less than 10 years old. For some three to four years after planting the aphids feed on almost all parts of the stem and branches of the tree. Thereafter, their feeding places are gradually restricted to the upper part of the stem or a branch as the tree grows.

Kolb *et al.* (2006) also reported in contrast that *Ips pini* were found to select small trees and small stems (young trees) that have thin bark because attacks on stems with thin bark require less expenditure of energy by the insect than an attack on stems with thick bark. Alternatively, attacks on stems with thin bark minimize competition with other phloem-feeding insects that prefer to attack larger diameter stems with thick bark because of the larger cross-sectional area of phloem and hence, food resources inside (i.e. niche partitioning).

This abundance of PWA recorded here is lower than that reported by Madoffe and Austrå (1993) in the same plantation. The population decrease recorded during this study could have been caused by availability of predators like *Tetraphleps raoi*, natural enemy which was imported to Tanzania from Pakistan in 1974 and released at Sao Hill. Indigenous natural enemies such as playmate, ladybird beetles (Cocinellidae), ants and dragon flies could also have contributed to the declined population. During the study, playmates, ants and dragon flies were seen visiting shoots affected by PWA. In spite of these indigenous natural enemies living in association with aphids, there was no clear evidence that they were feeding on aphids consequently contributing to the declining aphid population. However, Napompeth (1994) reported that, with the exception of ants, the rest are considered as important predators of aphids in South East Asia, Pacific Region and Central America although there is no quantitative evidence for this. Pines are growing as exotics at Sao Hill, an environment different to that of their origin. However, it is now about 50 years since when pines were introduced at the plantation. It is possible that these exotic trees might have adapted to the environment and be able to build resistance to fight against pests like aphids, hence reduction in aphid population. This has been evidenced by Paine (2008), who reported that the capacity of tree to adapt to novel insect species must be considered in relation to the genetic characteristics of the tree population and to the environment in which they live. The environment determines the modalities of the resistance expression. It is a crucial factor, for acclimatizing an exotic tree species facing exotic insects as well as for the resistance of indigenous trees to insect invaders.

Tanzania has faced significant climate variability in the last 20 years and likely to face increased variability and changing climate in future (Paavola, 2004). In areas with stable climatic conditions, insect fluctuations in abundance are usually small. Currently, the climatic factors (temperature, rainfall and wind) have been changing irregularly regardless of the season of the year. Probably these irregular changes could have some effects on the development of aphids at Sao Hill and resulted to decrease in the population. Aloo (1996) reported that aphid population densities are being regulated by environmental factors such as temperature, rainfall and to a lesser extent wind. Temperatures influence fecundity as well as the rate of development of aphids. Weather can also be taken as a disturbing factor and as a major determinant of peak numbers and numbers of fundatrices through egg mortality (Aloo, 1996). Weather through its effect on the aphids' rate of increase and colonization of plants can modify this pattern as can the activity of natural enemies. This is in agreement with Friedenberg *et al.* (2008) who were studying the influence of extreme temperatures on annual southern pine beetle population growth in Eastern Texas. He found that developmental rates of most southern pine beetle life stages decreased above 32°C temperatures. The interaction between temperature and regulation, a potentially common phenomenon in ecology, explains why southern pine beetle outbreaks do not occur at perfectly regular intervals.

On the other hand, in order to simplify management of Sao Hill forest, formal and informal roads have been increased within the plantation which has increased forest fragmentation. Fragmentation leads to a decreasing proportion of interior and an increasing proportion of edge habitat. This habitat results to changes in abiotic and biotic conditions at the edge which lead to the condition called 'edge effects' (Primack, 2006; Niemela *et al.*, 2007). Habitat fragmentation also changes the microenvironment at the fragment edge. Some of the important edge effects include microclimatic changes in temperature, wind, humidity, radiation, predation, parasitism and species interactions. Each of these edge effects can have a significant impact on the vitality and composition of the species in the fragment. Similarly these changes might have played a role in aphid population decrease at Sao Hill plantation. Niemela *et al.* (2007) reported that species requiring interior habitat suffer from edge effects and consequently, such species may be lost if fragments become too small and dominated by edge habitat. Factors other than climate and forest management such as direct suppression, may have contributed significantly to the timing, severity, and eventual reduction of outbreaks since the mid-1990s. It is also possible that this aphid's decrease have been caused by other components still unknown.

4.3 Intensity of Damage of Pine Woolly Aphid in Sao Hill Forest Plantation

The intensity of damage between age classes and blocks for both *P. patula* and *P. elliottii* is given in Table 4. The percentage mean intensity of damage was low (between 0% - 15%) for all Divisions. There was no significant difference in mean intensity damage of aphid either between age classes or blocks ($P > 0.05$). In spite of that, it appears that the middle age class (11-25) was more damaged than old age class (>25) while young age class (<10) was the least damaged and Division I was more damaged than Division II and Division III being least damaged. *Pinus elliottii* was found to be more damaged by PWA than *P. patula* although statistically insignificant ($P > 0.05$). Adult pine woolly aphid feeding preference appears to be for *P. elliottii* than *P. patula*. This shows that *P. elliottii* tree is more suitable host for PWA probably due to composition and quality of volatile substances responsible for orienting the insects toward attacking PWA than *P. patula*. Similarly, Leather *et al.* (1994) reported that some trees emit repellent compounds which could deter insects or the bark of these trees could contain compounds that could kill insects if consumed. Probably this could be the reason as to why *P. patula* was found to be relatively resistant compared to *P. elliottii*.

Table 4: Mean intensity of damage ($\bar{X}$) by Pine Woolly Aphid in percentage and Standard error (SE) for various age classes in Sao-Hill forest plantation

Block	**Treatment**		**Mean Intensity of damage[1] (%) in different age classes (Years)**		
		Mean % ($\bar{X}$) and SE	Young (0-10)	Middle (11-25)	Old age (above 25)
I	*Pinus patula*	$\bar{X}$	11.62	14.53	13.26
		SE	1.11	2.08	1.58
	Pinus elliottii	$\bar{X}$			14.67
		SE			1.58
II	*P.inus patula*	$\bar{X}$	7.45	14.78	14.56
		SE	1.19	2.34	1.44
	Pinus elliottii	$\bar{X}$			14.89
		SE			1.44
III	*Pinus patula*	$\bar{X}$	9.80	12.54	9.88
		SE	2.33	0.14	2.11
	Pinus elliiottii	$\bar{X}$			12.54
		SE			2.11

[1] **Mean Intensity of damage**
- Low (0 -15%)
- Mild (16 – 30%)
- High (31 – 49%)
- Very high (> 50%)

The same differences has been recorded in South Africa where by Zwolinski (1989) reported that *P. kesiya*, *P. elliottii* and *P. radiata* were found to be highly to moderately susceptible while *P. patula* and *P. taeda* are only slightly susceptible to attack than other pine trees. The same results were recorded in Kenya by Mailu *et al.* (1980) that *P. patula* was found to be relatively resistant to *P. boerneri* attack in the highland plantations than other pine species.

The genetic composition of the tree species can be considered as a major important factor for resistance against aphids. The same tree species found on the same site may show different state of infestation. It was observed that trees adjacent to infested ones were sometimes not attacked by aphids and this was thought to be due to tree resistance to attack or nutritional value. These observations suggest that some trees may be resistant to PWA than others. Similar results were reported by Madoffe (1989) that branches of highly infested trees grew side by side with completely uninfected trees. Variation of *Pineus* attack within and between pine stands was also reported in Zimbabwe (Katerere, 1984).

Leahy *et al.* (2007) argued that when no choice could be made between alternative hosts, *Hylastes ater,* a recorded pest on *P. radiata* plantations in New Zealand, showed a clear preference towards the pine species. This was supported by Manlove *et al.* (1997) who studied on feeding habit of large pine weevil, *Hylobius abietis* and found that *P. sylvestris* and *P. nigra* were clearly preferred over *P. abies* and broadleaved trees were completely ignored. Manlove *et al.* (1997) further reported that adult weevils were seen to be attracted by conifers by several volatile compounds. However, it is not known whether the poor consumption level of *P. abies* results from the absence of these attractants or the presence of different compounds. It is also suggested that broad leaved trees could emit repellent compounds to deter insects or the barks of these trees could contain compounds that could kill the weevils if consumed. Similar feeding preferences have also been observed by Mansson and Schlyter (2004).

4.4 Extent of Damage of Pine Woolly Aphid in different Parts of the Tree Crown

The extent of damage of aphids in different parts of the tree crowns which was determined by the available mean number of aphids present in crown parts differed between blocks and age classes. The total mean numbers of aphids recorded (egg, nymph and adults) were 43.4, 47.1 and 43.0 for *P. patula* and 18.1, 19.2 and 15.6 for *P. elliottii* for lower, middle and upper crown respectively (Table 5). The middle crown part for both tree species had higher total mean number of aphids, followed by lower crown part and upper crown part had lowest total mean number of aphids which implies that middle crown part was more damaged than lower crown and upper crown being last in damage. In spite of the differences observed in damage, the damage between crown parts was not significant ($P > 0.05$) for *P. patula* and *P. elliottii.*

The extent of damage within young age class (0 -10 years) was higher in middle crown part having higher total mean number of aphids than other crown parts although the difference was not statistically significant ($P > 0.05$). There was no evidence of preference in damage for any particular levels of the tree canopy. Probably this was caused by the openness of the tree crown. This kind of crown shape receives light relatively equal; no part of the tree where aphids could concentrate more as they do not prefer direct sunrays, hence this would make the distribution of aphids relatively equal.

Table 5: Mean ($\overline{X}$) and Standard error (SE) of Pine Woolly Aphid population per twig for various parts of the tree crown in Sao-Hill forest plantation

Age classes in years	Tree crown parts	$\overline{X}$ SE	Treatments in block							
			Block I		Block II		Block III		Total	
			P.p	*P.e*	*P.p*	*P.e*	*P.p*	*P.e*	*P.p*	*P.e*
Young (0 -10)	Lower	$\overline{X}$	4.40		4.00		3.70		12.10	
		SE	0.58		0.24		0.33		1.15	
	Middle	$\overline{X}$	4.76		4.27		4.18		13.21	
		SE	0.43		0.68		0.46		1.57	
	Upper	$\overline{X}$	5.08		3.50		3.66		12.24	
		SE	0.85		0.22		0.36		1.43	
Middle (11 - 25)	Lower	$\overline{X}$	6.88		6.18		3.50		16.56	
		SE	0.59		0.60		0.73		1.92	
	Middle	$\overline{X}$	6.56		7.08		7.00		20.64	
		SE	0.68		1.01		1.09		2.78	
	Upper	$\overline{X}$	6.44		6.23		5.00		17.67	
		SE	0.89		1.17		0.63		2.67	
Old (>25)	Lower	$\overline{X}$	4.41	6.26	4.23	6.06	6.09	5.71	14.73	18.1
		SE	1.23	1.23	0.76	0.76	0.88	0.88	2.87	2.87
	Middle	$\overline{X}$	4.79	7.20	3.99	6.18	4.49	5.77	13.27	19.2
		SE	1.15	1.15	0.64	0.64	0.68	0.68	2.47	2.47
	Upper	$\overline{X}$	4.45	4.81	4.7	3.88	4.05	6.93	13.20	15.6
		SE	0.89	0.89	0.56	0.56	0.61	0.61	2.06	2.06

P.p – Pinus patula
P.e – Pinus elliotti

These results are supported by Chilima and Leather (2001) who investigated spatial and temporal distribution of pine woolly aphids in 5-year-old *Pinus kesiya* trees in Malawi. They found out that *P. boerneri?* was generally found to settle and reproduce on the outer shoot-end sections of young *P. kesiya* trees and no evidence of preference for any particular levels of the tree canopy was seen. Chilima and Leather (2001) also suggested that the biological performance and, by implication, the pest status of *P. boerneri?* in young *P. kesiya* trees can be influenced by external factors, particularly by the within-tree and seasonal fluctuations in the level of nitrogen in the host trees, total rainfall and canopy structure.

In the middle age class (11-25 years), the number of aphids present differed between blocks, the middle crown harboring the highest number and the lower crown the least, however the difference between crown parts was not statistically significant ($P > 0.05$). Like in other age classes, old age class (above 25 years), the number of aphids present also differed between crown parts. Conversely, the lower crown had the highest number of aphids, followed by middle crown and upper crown being the least. However, the differences in number of aphids/extent of damage between crowns did not differ significantly ($P > 0.05$).

The differences in number of aphids observed in crown parts is probably due to the fact that PWA crawlers are positively phototactic, but do not settle onto surface exposed to strong light. They appear negatively phototactic to strong light and consequently tend to settle in hidden and light crevices. The undersides of lateral branches which receive only moderate light tend to harbour a higher concentration of aphids than the upper surfaces. The middle crown of *P. patula* and *P. elliotti* receives less light of the sun owing to shade of branches above it. This would tend to encourage aggregation of aphids in the middle crown where there is less strong direct light consequently contributing to high extent of damaging of aphid. The result agrees with Madoffe (1989) who reported that the mode of insect distribution on the tree is mainly affected by light, temperature and wind and so the insects could attain the favourable microclimatic sites. To justify about microclimates favouring insects, Norlander *et al.* (2003) reported observations made in the North America on the pine weevil, *Hylobius radicis* and *Hylobius pales*. Weevils were observed crawling faster and probably in more straight lines, as a way of reducing the time spent on pure mineral soil surfaces. Thus, during clear summer days, the conditions for feeding should be better in the shade than on sun-exposed clear-cuttings whereas, on cloudy days with moderate temperatures, the reverse may be true.

In another study, Zwolinski (1989) found aphids to be more abundant on the south side of stems and shaded bottom parts of branches. It was assumed that these locations of insects were better protected from direct sun, dry, northern and north-western winds and rainwater. Mailu *et al.* (1982) reported that in situations where light came from all directions, crawlers tends to move towards those parts of the tree with moderate light. Settlement of one crawler seemed to encourage settlement of others, so that all of them squeezed in one part of a crevice. In contrast, Leahy *et al.* (2007) reported that elevated feeding at increased temperatures is common among forestry pests like *Hylastes abietis*. He proposed the reason to be due to the higher metabolic rates experienced at those temperatures and the effect of temperature, volatile release from the wood, which might stimulate more feeding.

The results of this study agree with Wen *et al.* (2004) whose studies found the need of a shelter of adults *Hylobilus xiaoi* during daytime for mating, oviposition and resting. When the duff and vegetation at the tree base were removed, the weevil population was adversely affected. It is likely that adult shelter was lost and humidity decreased. For other conifer-infesting weevils, such as *H. radicis* are also affected by sunlight since the silvicultural practices such as thinning and pruning have been observed to strongly reduce the weevil damage (Wen *et al.*, 2006). Similar results were observed on *H. warreni* and on *H. abietis* by Nystrand and Granstrom (2000).

Straw *et al.* (2000) on his study found the number of *Drepanosiphum platanoidis* in the upper canopy of sycamore tree which declines dramatically during early summer, and the aphid remains concentrated on lower leaves during mid and late summer. The nutrient quality of leaves in the upper and lower canopy of sycamore tree does not differ greatly during the summer and the aphids appear to move to the lower leaves primarily to avoid high temperatures. It appears that *D. platanoidis* is well adapted to the cooler temperatures of spring and autumn but is intolerant of the high temperatures that occur in the upper canopy during the summer (Straw *et al.*, 2000). This habit implies also to *Elatobium abietinum* which may survive better on older needles deeper in the canopy during the summer, or might move to lower positions, to avoid high temperatures in the upper canopy (Straw *et al.*, 2006). Late-instar larvae of balsam fir sawfly, *Neodiprion abietis* also move to the lower canopy in late summer to avoid high temperatures, and to avoid natural enemies (Anstey *et al.*, 2002).

4.5 Relationship Between Aphid Abundance and Damage

Results from this study indicated a strong relationship between abundance of aphids and mean intensity of damage. A simple linear regression analysis was performed to determine the same relationship. The relationship between aphid abundance and intensity of damage in different Divisions at Sao Hill forest plantation for both *P. patula* and *P. elliottii* was represented by the equation; $y = 0.007 + 0.563x$, whereby x and y represents abundance of aphids in different Divisions and percentage mean of damage respectively. The results showed that the relationship was significant ($P < 0.05$, $R^2 = 99.7\%$), which means that the aphid abundance in different Divisions had a significance contribution to percentage mean of damage. The coefficient of determination (R^2) explains that 99.7% of the variation in percentage mean damage can be explained/ caused by variation in the aphid abundances in different Divisions. It implies that only 0.3% of the variation of percentage mean of damage can be caused by other factors like tree species, tree age class, site/block, tree crown part, season of the year, etc. This indicated that the intensity of damage between Divisions increased with an increase in mean number of adult aphids.

The total mean numbers of adult aphid were found to be higher in middle age class than in old age class and young age class had lowest total mean adult aphids. This corresponds exactly with the intensity of damage which was recorded to be greater in middle class than old age class and young age class being least damage. This relationship is represented by the following regression equation: $y = 5.26 + 0.427x$, whereby x and y represents total mean numbers of adult aphid at different age classes and percentage mean of damage respectively. Results of this regression analysis indicated that the relationship was significant ($P < 0.05$). The R^2 was very high (99.9%) which would indicate that intensity of damage between tree age classes increased with an increase in mean number of adult aphids. Higher number of adult aphid was recorded in *P. elliottii* in old class than that which was recorded in *P. patula* of the same class age although their difference was not statistically different. Likewise, it was recorded that the former tree species was more damaged by aphids than *P. patula*. Therefore it is most likely that the higher the number of aphids attacking pines, the higher the damage they cause.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the results from this study the following conclusions are made;

- The study revealed that all three studied divisions at Sao Hill forest plantation exhibited presence of the aphid. The abundance of adult aphid per twig was found to be 17.4, 16.5 and 13.6 for *P. patula* and 6.7, 6.3 and 6.1 for *P. elliottii* for Division I, II and III respectively. The abundance of aphids did not differ significantly within Divisions although Division one was seen to habour more aphids than other Divisions for both tree species.
- Generally the intensity of attack of aphid at Sao Hill was seen to be low compared to the intensity of attack reported by different authors in the late 1980s and early 1990s. This was probably due to the effect caused by *Tetraphleps raoi*, an exotic predator which was released in the forest in 1970s, local natural enemies and resistant of Pines as a result of being well adapted at Sao Hill.
- There was a very strong relationship between aphid abundances and damage between Divisions and age classes with coefficient of determination (R^2) of 99.7% and 99.9% respectively.
- Among the two tree species studied within the plantation, *P. elliottii* was seen to be more affected by Pine woolly aphid than *P. patula* but not statistically different.
- The middle age class (11–25 years) was seen to be more damaged, followed by old age class (above 25 years) and young age class (0 – 10 years) was seen to be the least damaged.
- It was observed that the middle part of the tree crown was more damaged by

aphids, followed by lower crown part and upper crown was the least damaged. This indicates that the distribution of aphids on the tree is mainly affected by light, temperature and wind.

5.2 Recommendations

Based on the results from this study and experiences from other studies, it is recommended that;

- There must be regular silvicutural operations like thinning and pruning within the forest plantations which could reduce favourable environment for insect pests' reproduction/growth and the Government should initiate regular insect survey and monitoring programmes in forest plantations.
- Study to be done on the ecology of the Pine Woolly Aphid in order to determine the various causes of population fluctuations.
- To conduct inventory of the various natural enemies available within the plantation and determine their effectiveness in controlling Pine Woolly Aphid.
- The problems caused by conifer aphids are not unique to Tanzania, several other African countries are experiencing the same problem, and the search for solution should therefore be a regional effort where activities undertaken by each country complement those of the others. This will not only improve the ties between the national forestry research programs of the affected countries, but it will also save valuable time and resource that would otherwise have been wanted by duplication efforts. Such initiatives could be pursued through Forestry Invasive Species Network for Africa (FISNA).

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