A REVIEW OF INSECT PESTS AND DISEASES OF MAJOR COMMERCIAL TREE SPECIES IN KENYA

KEFRI - GATSBY AFRICA (KCFP) COMMERCIAL FORESTRY PROJECT

SUMMARY REPORT

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EXECUTIVE SUMMARY

Forestry has been practised in Kenya since the beginning of the British colonial rule in 1895. Information on pests and diseases affecting the planted tree species dates back to 1952 under the East African Agricultural and Forestry Research Organization (EAAFRO). However, the information collected to date by forest pathologists and entomologists is scattered in various sources and therefore there was a need to collate it in a report that can guide and inform forestry practice in the country. There is also insufficient information and in particular on key pests and diseases affecting major commercial tree species in Kenya. Increasing demand for wood and its products has created an impetus for investment in commercial forestry. Over the years a number of investment firms and many small holder farmers have engaged in forest farming to compliment the government's plantation forests. Although the private commercial forestry sector in Kenya is at its nascent stage, the full threats posed by insect pests and diseases and resultant economic losses are being felt. The sector also suffers from lack of policies on forest pests and diseases that hinder the flow of information and management technologies. Furthermore, aspects of insect pests and diseases are inadequately integrated in the planning of forestry activities.

This report describes 11 insect pests and 16 diseases that affect six identified commercial forestry tree species. The report is developed through desktop review of relevant literature and experiences from experts in Kenya and the region. The report provides information on the nature of the insect pests or diseases, symptoms, damage and possible management strategies to help stakeholders identify and mitigate their impacts. From the review some insect pests and diseases were found to be shared between Kenya and its neighbouring countries.

The report has revealed major gaps in insect pest and diseases management in Kenya and the region; identification of insect pest and diseases in forestry is only carried out at at KEFRI whereas the relevant sections are heavily underfunded to undertake diagnostic using state of the art technologies, there is poor collaboration between the private forestry sector players and research and collaboration between regional institutions is poor or lacking.

The report recommends the creation and strengthening of a forest health platform for disseminating information on insect pests and diseases relevant to commercial forestry. Further research on emerging insect pests and diseases should be carried out through joint ventures with all stakeholders. It is also recommended that a forest health centre be established in order to make insect pest and disease diagnosis and management timely and effective.

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1.0 INTRODUCTION

1.1 Major commercial tree species grown in Kenya

Commercial tree planting as an investment offers economic gains in addition to environmental services. In Kenya, commercial planting of exotic plantations for timber started in the early 1920's. The main tree species were *Cupressus lusitanica* Miller, *Pinus radiata* D. Don and *Pinus patula* Schlecht (Mugo *et al*., 2007; Mathu and Ng'ethe, 2011). Available literature shows that between 2010 and 2011, a total of 10,407 ha of woodlots were established with 7,375 ha in high potential areas while 3,032 ha were in the Arid and Semi-arid lands (ASALs) on farms. In the high and medium potential areas, *Eucalyptus grandis*, *E. saligna* and *Grevillea robusta* were most popular species while in the drylands *Melia volkensii* and *E. camaldulensis* were the most preferred species (KFS Annual Report, 2010/2011). Private forestry includes plantations owned by Tea and Tobacco companies which comprise of various Eucalyptus species. Currently the major commercial tree species grown in Kenya are Eucalypts, Pines, Cypress and Grevillea while Casuarina and Melia are emerging as important commercial trees species (National Tree Improvement Strategy, 2018-2043).

Pine species in Kenya comprise of about 21,144 ha in public plantations and are widely planted for pulp and sawn timber. Cypress is widely planted both on-farm as well as in public plantations mainly grown for sawn timber. Those in public plantations are estimated to be about 50,711 ha. Eucalypts are mainly grown for sawn timber, poles and fuelwood both in small-scale woodlots and large commercial plantations. Eucalyptus platations and on farm woodlots are estimated at about 100,000 ha.

The major species of the genus *Casuarina* in Kenya is *C. equisetifolia,* which is most popular and widely planted mainly at the Coast (Narayanan, 1996). *Melia volkensii* is an indigenous tree species with high potential for plantation establishment in the drylands of Kenya and East Africa. KEFRI has embarked on a comprehensive breeding program for *Melia* over the last decade. It's high quality timber, adaptability to arid conditions and tolerance to major pests; including termites has made it a priority species for commercialization in the drylands. *Grevillea robusta* is one of the most important trees for agroforestry in the tropical highlands of Eastern and Central

Africa. It provides economically valuable products including timber, poles and firewood (Njuguna, 2011; Muchiri, 2001; Fact Net, 1998).

1.2 Problem statement

Forestry has been practiced in Kenya since the beginning of British colonial rule in 1895 (Ofcansky, 1984). Information on pests and diseases affecting the planted tree species dates to 1952 under the East African Agricultural and Forestry Research Organization (EAAFRO). However, the information documented to date by forest pathologists and entomologists is scattered in various sources and therefore there was a need to collate it in a report that can guide and inform insect pests and diseases management in forestry practice in the country. There is also insufficient information and in particular on key insect pests and diseases affecting commercial forestry tree species. Increasing demand for wood and its products has created an impetus for investment in commercial forestry. Over the years several investment firms and many small holder farmers have engaged in forest farming to compliment the government's plantation forests. Although the private commercial forestry sector in Kenya is at its nascent stage the full threats posed by insect pests and diseases and resultant economic losses are being felt. The sector also suffers from lack of policies on forest pests and diseases that hinder the flow of information and implementation of management technologies. Furthermore, aspects of insect pests and diseases are inadequately integrated in the forestry management plans.

1.3 Challenges facing management of pests and diseases in commercial forestry in Kenya

In recent times, there has been an increase in the number of invasive pests and diseases attacking most of the exotic commercial tree species. This has prompted research to be undertaken in the development of appropriate mitigation strategies. In Kenya, research in insect pests and diseases management has been carried out largely by the Government institutions such as universities and research organisations. However, the private sector provides suitable areas for the implementation of management technologies. The number of trained and experienced scientists and technical staff specialized in this field is low and their succession as they approach retirement should be planned to replace them with new staff in time for them to acquire necessary experience in the development of mitigation measures.

Lack of quarantine facility and other well equipped laboratories has been a major constraint in hastening the development and implementation of classical biological control programs of these invasive insect pests. The recently constructed quarantine unit at KEFRI Headquarters, Muguga will play a key role in the development of mitigation measures. KEFRI Regional Centres have limited experienced technical staff to deal with insect pests and diseases issues that arise in the regions. Regional Centres require well trained research personnel to support Integrated Pest Management (IPM) research related to commercial forestry in Kenya. There is weak or lack of linkages with national and international institutions on insect pests and diseases in commercial forestry.

1.4 Purpose and methodology

The purpose of this document is to collate the available information on insect pests and diseases of major tree species for commercial forestry. The information focuses on major commercial forestry tree species identified in Kenyan forestry systems namely; *Pinus* spp, *Eucalyptus* spp, *Cupressus lusitanica*, *Grevillea robusta*, *Casuarina* spp and *Melia volkensii*. Information provided in this document is a review of insect pests and diseases; identification, origin, biology, causal agent, damage symptoms, distribution, host range, and management options. The information provided will play a key role in guiding tree growers and foresters on issues of insect pests and diseases in commercial forestry. The document is also an inventory of insect pests and diseases of commercial tree species in Kenya and the neighbouring countries. The collated information will therefore be disseminated to a wide range of stakeholders ranging from tree growers, foresters/forest managers, researchers, and institutions of higher learning. The gap analysis identifies key research areas that need to be addressed in the future focusing on tree insect pests and diseases in Kenya.

The report was compiled through a desktop review of current information. It includes information from various sources such as journal papers, technical reports, guidelines, inventories, and consultation with regional experts. A review of grey literature such as unpublished reports was undertaken. It also includes expert's field experiences in the areas of tree insect pests and diseases. This documentation is also in tandem with the objectives of the KEFRI's National Forest Health Research Strategy 2018-2033.

2.0 MAJOR INSECT PESTS OF COMMERCIAL TREE SPECIES

2.1 Insect pests of Eucalypts

Eucalypts in Kenya are attacked by a wide range of insect pests. These include; Borers, Sap suckers, Defoliators and Gall formers.

2.1.1 Borers

2.1.1.1 Termites

Damage symptoms

Although termites have been considered to be of ecological importance and even lead to increased yields (Hausberger & Korb, 2015), some families cause considerable damage to growing trees. The roots of the young trees can be severely damaged by termites, leading to death. Termites also cause ring-debarking at the soil level causing destruction of the vascular bundles leading to withering of affected trees and eventual death. Exotic hosts such as *Eucalyptus* spp. and *Grevillea robusta* are prone to attack during the early stages of establishment in the field. The four genera in the family Termitidae are widespread throughout Kenya but damage is especially common in arid and semi-arid areas on moisture-stressed trees.

Management

In Kenya, termites are effectively managed by application of chemicals whose registration as termiticides is regulated by the Pest Control Products Board (PCPB). One can review the list of registered chemical products for various uses by visiting the PCPB Website. Termiticides that are currently available include those whose active ingredients are permethrin, cypermethrin, bifenthrin, fenvalerate, imidachloprid, fipronil, chlortraniliprole and chlorfenapyr, which are formulated as soluble concentrates or granules and registered under various trade names. Pyrethroids such as permethrin, cypermethrin, bifenthrin and fenvalerate repel the termites from treatment barriers, whereas other termiticides such as fipronil, imidacloprid and chlortraniliprole prevent termite invasion by lethal contact. Contact termiticides are transferred from termite to termite by poisoned individuals via grooming behaviour, resulting in colony collapse.

The insecticides described above are available in the market for use in commercial forestry, when termites pose a threat to tree establishment especially exotic species. Granules are formulated for pre-planting application while soluble concentrates are for post planting application by soil drenching.

Breeding and planting tolerant tree species such as *Melia volkensii*, is an option for afforestation in termite prone areas for incorporation of indigenous tree species of desired qualities in the expansion of forestry in ASAL's.

2.1.2 Sap suckers

2.1.2.1 Blue gum psyllid, **Ctenarytaina eucalypti**

Damage symptoms

Infested host plants display leaf distortion, wilting of foliage at the tips and leaf drop may follow. Dieback of twigs and branches can occur during heavy infestations and young plants may have reduced growth due to foliage loss. Adults and nymphs feed on succulent new growth of susceptible host plants producing honeydew that lead to growth of black sooty mould (Hodkinson, 1999).

Juvenile plants parts high in epicuticular waxes are preferred for oviposition and supports the development of the insects (Brennan *et al*., 2001). This indicates that host plants are susceptible as seedlings, coppices, and ornamental hedges.

Host range and Distribution

The insect has a narrow host range. The pest has been observed attacking *Eucalyptus globulus*, *E. maideni*, *E. nitens*, *E. gunnii*, and *Corymbia citriodora* (De Little *et al*., 2008). In Kenya, this pest has only been reported damaging *E. globulus* in Eastern region (Embu and Machakos) and Naivasha. It became established on *E. globulus* and *E. maideni* plantings in Portugal and Spain (Starr *et al*., 2007).

Management

Attempts to use chemicals for management of the insect has not borne fruit in several countries (Chauzat *et al*., 2002; Hodkinson, 1999). Maintaining adequate soil moisture and reduced application of nitrogen fertilizers in Eucalyptus nurseries and plantations can reduce their susceptibility to psyllid (Paine & Hanlon, 2010). A parasitoid of Australian origin, *Psyllaephagus pilosus* has been imported into different parts of the world where it has established and managed the pest (Chauzat *et al*., 2002; Costanzi *et al*., 2003; Hodkinson, 1999). Syrphid and hemerobiid predators have been reported to reduce the population of this invasive insect (Pinzón *et al*., 2002) and are probably responsible for checking the population in Kenya.

2.1.2.2 ***Red Gum Lerp Psyllid,*** *Glycaspis brimblecombei*

Damage symptoms

Glycaspis brimblecombei feeds by sap-sucking which involves the secretion of saliva and ingestion of plant sap (Sullivan *et al*., 2006). Heavily infested leaves are readily noticeable because of the large numbers of white lerps encrusting the leaf. Heavy infestations result in chlorosis, leaf drop and twig dieback which may lead to plant death. Black sooty mould development is observed on the lerps as they get older. The honey-dew provide a medium for the development of sooty moulds on heavily infested trees (Murphy *et al*., 1991). Heavy infestations occlude the surface of light required for photosynthesis or reduce the leaf surface area and hence retarded growth in young saplings.

Host range and Distribution

In its original habitat in Australia, *G. brimblecombei* mostly prefers to feed on *Eucalyptus camaldulensis* Dehn (Myrtaceae). Other host species susceptible to attack include *E. globulus*, *E. maidenii*, *E. punctata*, *E. robusta*, *E. smithii* and *E. viminalis* (European and Mediterranean Plant Protection Organization. Data sheets on quarantine pests, 2019).

Currently, the pest has been observed attacking *E. camaldulensis* in the Central, Eastern and Western regions of Kenya. Unpublished data have indicated that in Central Highlands of Kenya, RGLP has been found in Murang'a, Embu and drier parts of Kirinyaga counties.

Management

The main natural enemy from Australia, the parasitoid *Psyllaephagus bliteus* Riek (Hymenoptera: Encyrtidae), have been studied to manage this insect pest in infested regions outside endemic areas (Paine *et al*. 2006). However, low parasitism (0.2–11%) has been observed, in Brazil where classical biological control program has been implemented (Ferreira-Filho *et al*., 2015). Natural enemies of RGLP observed in Kenya include Chrysomelidae and

Coccinelidae beetles which are generalists but their potential towards sustainable control of RGLP has not been investigated.

2.1.2.3 Winter Bronze Bug, **Thaumastocoris peregrinus**

Damage symptoms

Typical symptoms of host infestation by Bronze bug include initial reddening of the canopy leaves which subsequently changes to a reddish-yellow or yellow-brown colour (Nadel *et al*., 2010,). The symptoms are due to the bug feeding habitat that results in puncturing the leaves and twigs to suck sap, causing chlorosis (Wilcken *et al*., 2010). Some leaf loss can be observed as well as an abundance of adults, nymphs and black egg capsules usually clustered in high numbers (Nadel *et al*., 2010). During severe infestations, leaf loss leads to severe canopy thinning, and this sometimes results in branch dieback or tree mortality (Wylie & Speight, 2012).

Host range and Distribution

About 30 species of *Eucalyptus* and associated hybrid clones are known to be hosts of *T. peregrinus* (Nadel *et al*., 2012; Noack *et al*., 2011). In Kenya, *E. grandis* x *E. camaldulensis* (GC) hybrid clones have been found to be more susceptible than the local land races such as *E. grandis* (Mutitu *et al*. 2018). It has been shown that there are both intra-specific and inter-specific differences in susceptibility and this can be used in the development of host plant resistance.

It has spread to Africa, South America, and Europe (Laudonia & Sasso, 2012; Nadel and Noack, 2012). It was first recorded outside its native range in 2003 in South Africa and in 2005 it was reported in South America (Mutitu *et al*., 2016; Noack *et al*., 2011). In September 2011 it was reported for the first time in the Northern hemisphere (Europe).

It was first reported in Kenya in November 2009 infesting both clonal hybrids and other *Eucalyptus* species in Kajiado County that borders Tanzania. It spread from Tanzania through livestock grazing across the borders into Kenya (Mutitu *et al*., 2013; Nadel *et al*., 2010). In Kenya it has spread to all major host tree growing areas of Kenya (Mutitu *et al*., 2018)

The winter bronze bug has been recorded in all major host growing areas of Kenya (Mutitu *et el*., 2018). It has also been reported in neighbouring countries of Uganda, Tanzania, Ethiopia, and Rwanda. Understanding the population dynamics and spread of this pest is a key step in developing an effective management strategy to reduce its impact. A study carried out in Kenya by Mutitu *et al*., 2018 revealed there were consistent annual population fluctuations with peak and off-peak seasons. During the dry spell the population increased compared to the rainy wet season leading to more damage on the host trees (Nadel *et al*., 2010; Mutitu, 2016). The bug population is present throughout the year, but its abundance varied on host species and in different areas (Mutitu *et al*., 2018).

Management

Systemic insecticides have been found to be an effective tool for the control of *T. peregrinus*, but this approach is generally not feasible for large scale application such as plantations due to cost implications (Noack *et al*., 2007). Sustainable management of such exotic pests can be achieved by use of exotic natural enemies (classical biological control). The parasitic wasp *Cleruchoides noackae* (Mymaridae: Hymenoptera) has been identified as a potential biological control agent, but its field effectiveness to control *T. peregrinus* is yet to be confirmed (Mutitu *et al*., 2013).

2.1.3 Defoliators

2.1.3.1 Eucalyptus snout beetle, Gonipterus scutellatus

Damage symptoms

Young larvae feed on tender leaf tissues, mostly between leaf veins, on both upper and lower leaf epidermis leaving the leave intact. Older larvae chew on leaf edges, creating highly irregular notches. They also injure the sides and tips of soft shoots. Apical buds are often killed by these feeding, forcing dormant lateral buds to break, which are fed upon. Intensive damage can kill larger branches, cause the branches to stop growing, or force stubby growth in a “witches broom” (Cowles & Downer, 1995).

Adult weevil feed along the leaf edges while the larva stage feed on the leaf epidermis (Hanks *et al*., 2000). During peak weevil population period, heavy destruction of young soft twigs and debarking of branches is experienced. This kind of damage lowers productivity through compromised photosynthetic surface area leading to retardation of tree growth.

Host range and Distribution

Eucalyptus species are commonly susceptible to Eucalyptus snout beetle damage and the most susceptible species are *E. globulus, E. viminalis, E. camaldulensis, E. robusta, C. citriodora, E. saligna* and *E. tereticornis* (Silva *et al*., 1968). Narrow-leaved species such as *E. pulchella* are not normally attacked. *Gonipterus scutellatus* is native to Australia and it was introduced into South Africa in 1916 (Tooke, 1955). The weevil dispersed from South Africa to Mozambique, Malawi (1938) and Kenya (1940).

The weevil is wide spread in Kenyan highlands which has a wide range of eucalyptus germplasms which are heavily attacked by ESB including; *E. globulus spp. globulus, E. maidenii, E. robusta* and *E. smithii* (FAO, 2007).

Management

Various management options have been attempted. In 1930's aerial spray of affected host trees with pesticides was attempted in Kenya, but due to the environmental hazards and non-economic feasibility associated with this kind of management option it was found not to be sustainable (OEPP/EPPO, 1980).

In 1945, a biological control programme was implemented through the introduction of an egg parasitoid, *Anaphes nitens* (Hymenoptera: Mymaridae) (Tooke, 1955). This egg parasitoid originates from Australia and its release in Kenya was conducted after importation from S. Africa where it had been released earlier (Cowles & Downer, 1995). Releases were carried out in Rift Valley province in Timboroa area. Further monitoring indicated that the parasitoid had establishment and satisfactory impact achieved (Cowles & Downer, 1995).

2.1.4 Gall formers

2.1.4.1 *Blue Gum Chalcid, Leptocybe invasa*

Damage symptoms

Leptocybe invasa oviposits on apical buds and young leaves of *Eucalyptus* species leading to formation of galls on susceptible hosts. Galls induced on *Eucalyptus* shoots by *L. invasa* either appear singly or coalesce with neighbouring galls into a series of bumps along the leaf petiole, midrib or young shoot of the plant (Mendel *et al*., 2004). On infested plant tissue the ovipuncture marks are well observed.

In some host plants, the leaves appear twisted and heavily attacked saplings may display stunted growth mainly attributable to challenged water transport and loss of apical dominance of the plant (Tong *et al*., 2016). Leaves with reduced sizes may be profusely produced in some plants, resulting in compacted canopy. Mortality may occur in heavily infested seedlings. Reduction in height by up to 39% and yield volume by up to 23% has been observed on infested host plants (Petro *et al*., 2015).

Host range and Distribution

After escaping from the endemic areas within a period of only 15 years, the wasp had spread to over 35 countries and become a serious insect pest of *Eucalyptus* species grown outside Australia. The invasion is currently reported in all continents. The infestation is more severe in dry low altitude areas than in cooler high altitude (>800 masl) areas (Nyeko *et al*., 2010).
The wasp has a broad host range mainly restricted to the genus *Eucalyptus* (Mendel *et al*., 2004; Quang *et al*., 2009). Several studies have reported variable susceptibility of *Eucalyptus* species and their hybrids against damage by the wasp (Mendel *et al*., 2004; Pham *et al*., 2009). This could result from the widespread variability in the *Eucalyptus* species and even within the species (Burley *et al*., 1971; Farrow *et al*., 1994). Hybrids of the major commercial species have also displayed variable levels of resistance hence selection of planting material need to be guided by research.

Management

Planting of resistant genotypes to alleviate the losses associated to infestation by the wasp has been proposed by several authors (Dittrich-Schröder *et al*., 2012; Nyeko *et al*., 2010; Zhu *et al*., 2012). However, resistant eucalypt genotypes might only be restricted to certain ecological conditions for optimal performance.

Several parasitoids from Australia including *Quadrastichus mendeli*, and *Selitrichodes kryceri* (Kim *et al*., 2008), *S. neseri* (Hurley, 2012), *Megastigmus zvimendeli* and *M. lawsoni* (DoĞAnlar, 2015; Doganlar & Hassan, 2010) have been introduced to various regions. While earlier attempts to introduce biocontrol agent in Kenya were not successful, *Selitrichodes kryceri* has been identified from galls collected from Turbo. Unidentified species of *Megastigmus* has been found associated with *L. invasa* in Kenya.

Rampant use of pesticides has been reported (Nyeko *et al*., 2007) despite only a few studies on the efficacy of pesticide in the management of *L. invasa*. In the absence of such testing, current pesticide practices may be inappropriate for managing this wasp due to environmental concerns emanating from their use.

2.2 Insect pests of Cypress

The major insect pest for Cypress in Kenya is Cypress aphid (*Cinara cupressivora*) which is a sap sucker.

Damage symptoms

The cypress aphid can cause severe damage resulting in dieback and sometimes death of host conifers with associated economic, environmental and aesthetic costs. The saliva they produce is phytotoxic (toxic to the plant) and leads to necrosis in the phloem which subsequently results in the twig withering. The impact on the plant depends on tree stress and weather factors. Growth of sooty mould in the foliage on inner and lower parts, which develops near colonies of the aphids can be seen as signs of infestation. The aphids themselves are extremely difficult to see because their brown bodies are like that of the tree bark.

Host range and Distribution

In Africa, *C. cupressivora* attacks a wide range of Cupressaceae species, including indigenous species such as Mulanje cedar, *Widdringtonia cupressiodes* (the national tree of Malawi) and African pencil cedar, *Juniperous procera* a key tree species in water catchment areas in Kenya. In East Africa it attacks the Mexican Cypress, *Cupressus lusitanica*, a tree that is widely planted for commercial purposes in the region (Day *et al*., 2003: FAO, 1991).

The cypress aphid was considered one of the world's 100 worst invasive alien species according to the criteria used by the international Union for the Conservation of Nature (FAO, 1991). It occurs in Europe, Asia, Africa, and the Americas. This insect pest was first reported in Kenya in the 1990 and has spread to all host tree growing areas (Mills, 1990; Day *et al*., 2003).

Management

Host-plant Resistance can be harnessed since a wide range of tolerance in different host species and even individuals within species has been reported (Kamunya *et al*., 1999). According to Orondo and Day (1994), the degree of aphid damage varies from one tree to another. *Thuja* spp. and *C. leylandii* are most tolerant, whereas *Widdringtonia* and *Callitris* species were least tolerant. In the genus Cupressus, the most tolerant species are *C. torulosa*, *C. funebris* and *C. arizonica*, whereas the most susceptible were *C. benthamii* and *C. lusitanica*.

A biological control agent, *Pauesia juniperorum*, was introduced to Malawi from Europe (Chilima, 1995) and was subsequently introduced to Kenya and Uganda (Day *et al*., 2003). This has established well in Kenya with significant reduction in population of the aphids with only sporadic outbreaks reported. Local natural enemies such as Sryphids and lace wings play a role in its management. In Kenya, there were unsuccessful attempts at the beginning of the infestations to contain this menace through chemical application (active ingredients: pirimicard, diazinone).

2.3 Insect pests of Pines

In Kenya Pines are infested by 3 major sapsuckers; Pine Woolly Aphid (*Pineus pini*), Pine needle aphid (*Eulachnus rileyi*), and Black pine aphid (*Cinara cronatii*)

2.3.1.1 *Pine Woolly Aphid*, Pineus pini

Entry into Kenya is thought to be accidental in 1962 through scions of *Pinus taeda*, with the initial area of infestation being Muguga (Odera, 1974). The first sighting of the insect in the African continent was 1968 in Kenya and Zimbabwe (Barnes *et al*.,1976). The insect most likely originated from Australia (Barnes *et al*., 1976; Blackman *et al*., 1995).

Damage symptoms

Loses have been reported to occur both in plantations and in nursery seedlings. Stunted needles and abortion of buds occur after infestation while deformity and stunting in growth of trees occur in heavy and repeated infestations (Mailu *et al*., 1978; Odera, 1972). In infested trees, losses in diameter at breast height (up to 63%) and height (up to 65%) were reported on *P. pinaster* (Zwolinski, 1990). Loss in growth of both diameter (12.2%) and height (14.1%) have also been reported on seedlings of susceptible pine species (Madoffe & Austarå, 1990). Mortality has also been recorded of highly damaged plants (McClure, 1989; Odera, 1974; Zwolinski, 1990). Seed production of infested trees has also been affected with losses of up to 71.1% reported to occur due to deformation, cracking and flow of resins from the cones (Zwolinski *et al*., 1989).

Host range and Distribution

Variability in susceptibility has been reported by many authors, highly susceptible are those of the group Silvestres while the sub-section Oocarpae are resistant to *P. pini* (Barnes *et al*., 1976). The most susceptible host species include *Pinus massoniana, P. elliottii*, *P. contorta*, *P. radiata*, *P. pinaster* (Odera, 1974; Zwolinski, 1990), *P. halepensis*, *P. pinea* (Mendel *et al*., 1994), *P. kesiya* (Chilima & Leather, 2001), *P. resinosa* (McClure, 1982) while *P. ayacahuite and P. strobus* var. *chiapensis* (Odera, 1974) were resistant to attack. Although *Pinus patula* generally showed tolerance to the attack, stands of the species may have some resistant trees (Mailu *et al*., 1982; Odera, 1974).

The insect has been reported to attack pines in different parts of Africa with remarkable yield losses to pine plantations. The countries infested include Kenya (Odera, 1974), South Africa (Zwolinski, 1989), Tanzania (Madoffe & Austarå, 1990), Malawi (Chilima & Leather, 2001) among others. The insects have also been reported in countries outside the African continent: Jordan (Mendel *et al*., 1994), Brazil (Lazzari & Cardoso, 2011), Britain (Carter, 1971), Soviet Georgia (Saradzhishvili, 1985).

Management

Biological control has remained the key management option. In Kenya, *Tetraphleps raoi* introduced in May 1975 remarkably reduced the population of the pest but was not sufficient to avert tree mortality due to infestation (Karanja & Aloo, 1990). Several other biocontrol agents have been introduced for management of the invasive pest. These include *Leucopsis species* in Hawaii (Nakao *et al*.; 1981Greathead, 1995). Resistant species have been identified and heritability of resistance confirmed (Zwolinski, 1990). This can be harnessed by encouraging planting of resistant genotypes.

2.3.1.2 Pine needle aphids, Eulachnus rileyi

Damage symptoms

Eulachnus rileyi feeds on mature or senescing needles throughout the crowns of host trees (Chilima, 1991). Infestation causes needles of host pines to turn yellow (leaf chlorosis) and the aphids produce copious amounts of honeydew. According to Murphy *et al*. (1996), the honeydew provides a medium for development of sooty moulds on heavily infested trees. Feeding by *E. rileyi* causes a characteristic mottling and yellowing of the crowns of infested trees. Black sooty mould forms on the needles and branches, while ants are observed tending the aphid colonies.

Host range and Distribution

Pine needle aphid attacks a wide range of pine species that include*; Pinus caribaea* (Caribbean pine), *Pinus elliottii* (slash pine), *Pinus kesiya* (Khasya pine), *Pinus merkusii* (Tenasserim pine), *Pinus michoacana* (Michoacan pine), *Pinus mugo* (mountain pine), *Pinus nigra* (black pine), *Pinus oocarpa* (Ocote pine), *Pinus palustris* (longleaf pine), *Pinus patula* (Mexican weeping pine), *Pinus pinea* (stone pine), *Pinus ponderosa var. scopulorum*, *Pinus sylvestris* (Scots pine) and *Pinus taeda* (loblolly pine).

Although not invasive, *Eulachnus rileyi* was first reported in Kenya, Tanzania, and Uganda in 1988 according to Kanturski *et al*., (1991). In Kenya, about half of the approximately 150,000 ha of plantation forests is pines species and therefore, this aphid poses a considerable threat to the timber industry (Orondo & Day, 1994). Data are being collected to assess the extent of damage and any correlations with climatic factors in eastern and southern Africa (Chilima, pers. comm.).

In Zambia, in 1978 and 1979, the build-up of pine needle aphid populations was rapid in May-June after the rains ceased, and the onset of the rains caused a drastic decrease in the population density from November to December (Loyttyniemi, 1979). The cypress aphid was first reported in Malawi in 1986 (Chilima, 1991), by 1990, it had spread to several countries, including Kenya (Owuor, 1991).

Management

Parasitoid known to attack *E. rileyi* is *Diaeretus leucopterus* and has been studied as a potential biological control agent for *Eulachnus sp*. (Murphy and Völkl, 1996). Parasitism levels are relatively low and the biocontrol agent is subjected to high levels of hyperparasitism. Studies suggest that this parasitoid is not an effective biological control agent unless used in combination with other complementary natural enemies (Murphy and Völkl, 1996).

2.3.1.3 *Black pine aphid,* Cinara cronatii

Damage symptoms

Low to moderate numbers of leaf feeding aphids are not usually damaging in gardens or on trees. However, large populations can turn leaves yellow and stunt shoots. Aphids can also produce large quantities of a sticky exudate known as honeydew, which often turns black with the growth of sooty mold fungus.

Host range and Distribution

Black pine aphid attacks conifers in particular pines *Pinus* spp. Its distribution closely follows that of fusiform rust disease caused by the fungus *Cronartium fusiforme* Hedge and N.R Hunt ex Cummins (Cronartiaceae), a destructive disease that causes stem canker on pine trees. The black pine aphid is not considered to be a pest in North America and lives almost exclusively in canker formed by this disease where it is guarded by various ant species (Pepper & Tissot, 1973).
This insect pest was first reported in Kenya 1998 in Uasin Gishu County in Turbo tree nursery attacking young *Pinus patula.* This pest has been reported in Uganda in pine plantations (Prof. Nyeko *pers com.*) and in South Africa (Kfir & Van Rensburg, 2003).

Management

Chemical control can be applied by use of soil-applied imidacloprid products that are often diluted with water in a bucket and poured around the base of the tree or plant. Professional applicators can use soil injectors, which provide better control with less runoff potential. In natural habitats, generalist natural enemies such as lady beetles, lacewings, syrphid fly larvae predate on the aphid. In 1983, a parasitoid described as *Pauesia cinaravora* was discovered to parasitize *C. cronatii* colonies and its biology studied by Kfir & Kirsten (1991).

2.4 Insect pests of *Grevillea robusta*

Grevillea robusta has been reported to be attacked by a Shot-hole borer (*Apate indistincta*)

Damage symptoms

The insects bore in dry and seasoned wood destroying the sapwood. Bostrichid beetles are also found under bark and in dead branches which have been debarked. *Apate* spp. usually attack living but unhealthy trees species which are moisture stressed. The damage occurs during feeding which is associated with sexual maturation. This occurs on another host other than the one associated with laying of eggs or larval feeding. The host tree produces resin from frass injection holes as a defence mechanism against further insect attack. Gum exudation kills the adults that are stuck on the resin.

Young trees have been found to be very susceptible to shot-hole borer attack. Active boring is indicated by presence of frass (saw-dust like substance) at the tree base and point of entry. The attack starts from the bottom of the stem and spread upward the crown. Weak crown is prone to break when it is windy. The borers are most active during the dry season and on dry trees.

Host range and Distribution

Apate species are generally polyphagous. Adult usually attack living but likely unhealthy trees while larvae have only been found in dead wood. They attack a wide range of both exotic and indigenous tree species. Exotic hosts include *Acacia mearnsii*, *Callistemon lanceolatus, Coffea sp, Eucalyptus maculata, E. camaldulensis, Grevillea robusta and Casuarina sp.* while the indigenous hosts include *Albizia* species, *Blighia unijugata, Ekebergia capensis, Fagaropsis angolensis, Diospyros scabra, Olea spp., Rhus spp,* and *Vangueria spp*.

Apate indistincta was first reported in Kenya in 1950 in Central highlands region on *Grevillea robusta*. In Kenya this pest has been reported in several counties: Kiambu, Nyeri, Mombasa, Kwale, Laikipia, Kericho, Nakuru, Vihiga, Meru, Kakamega, Baringo, Nairobi, Kitui, Siaya, Embu, Nyandarua, Homa Bay, and Isiolo. It also occurs in South Africa, Zambia, Uganda, and Tanzania.

Management

The borers on living trees can be controlled using chemicals where cotton wool tab is soaked in pesticides such as Chlorpyrifos (Dimethoate®), Permethrin (Ambush®), phosphorothioate (Diazinon®) and inserting into the frass injection holes where the borer is feeding. The borer suffocates and eventually dies. Borers are also killed manually by inserting sharp pieces of wire into such holes and pierce the insect inside. Silvicultural practices such as pruning of affected tree branches breaks the life cycle of the pest and hence control the spread of the pest.

2.5 Insect pests in the neighbour countries

Most of the insect pests of commercial trees planted in Kenya have also been found in the neighbouring countries and beyond (Table 1). The neighbouring countries are likely to get invasion through trade, travel and tourism. These proliferating economic activities within the region provides suitable avenues for dispersal mechanisms of these invasive insect pests within the region. The presence of almost uniform genetic material/similar species planted across the region in a mosaic pattern and close to each other provides suitable spread of the invasive insect pests within the trees planted areas. The similarities of climate in the region also favour the establishment of these invasive species. The spread of these insect pests in the region creates a platform of sharing research results through networking and regional approach to implementation of management strategies such as classical biological control programme for exotic insect pests.

Table 1. Records of Insect pests of trees in countries neighbouring Kenya

Host tree species	Insect pest species	Damage group	Reported country
Eucalypts	*Leptocybe invasa*, Blue gum pysllid	Sap-sucker	Uganda, (Nyeko *et al*., 2007), Tanzania and Ethiopia (Starr *et al*., 2007)
	Thaumastocoris peregrinus, Winter bronze bug	Sap-sucker	Tanzania, and Uganda (Nadel *et al*., 2010 ; Mutitu *et al*., 2018)
	Ctenarytaina eucalypti, Blue gum psyllid	Sap-sucker	Tanzania and Ethiopia (Starr *et al*., 2007).
	Termites	Borers	All countries in East Africa (KEFRI Insect Collection Reference)
	Gonipterus scutellatus, Eucalyptus snout beetle	Defoliator	Uganda (EPPO, 2017)
	Glycaspis brimblecombei, Red gum lerp psyllid	Sap sucker	Ethiopia EPPO Reporting Service (2019/049)

Pines	*Pineus pini*, Pine wooly aphid	Sap-sucker	Tanzania (Madoffe & Austarå, 1990)
	Eulachnus rileyi, Pine needle aphid	Sap-sucker	Tanzania (Masewe & Kisaka, 1995) and Uganda (Kiwuso, 2004)
	Cinara cronatii, Black pine aphid	Sap-suckers	Uganda (Day *et al*., 2003; Kfir and Van Rensburg., 2003)
Cypress	*Cinara cupressivora*, Cypress aphid	Sap-sucker	Uganda, Tanzania, and Ethiopia (Demeke 2018)
Grevillea robusta	Termite	Borer	Uganda, Tanzania, and Ethiopia (Nyeko, pers com.)

2.6 Gap analysis on insect pests of commercial importance and mitigation strategies

This identified key research gaps and mitigation measures were proposed. The proposed mitigation measures are also in tandem with the KEFRI's National Forest Health Research Strategy 2018-2033. The identified research gaps and their mitigation strategies are shown in Table 2.

Table 2 Identified Insect Pests Research gaps and their mitigation measures

Insect pest	Identified gap	Mitigation strategy
Termites	1. Narrow active ingredient termiticide range 2. Biological control agent of termites not known 3. Limited number of termiticide application methods 4. Host plant resistance range is not known 5. Limited knowledge on termite phylogeny in Kenya 6. Guideline on termite management is lacking	1. Increase efficacy trials of new termiticides for registration 2. Studies to determine biological control agents for termites e.g effects of Bacteria, Fungi etc. 3. Undertake studies to develop more application methods of termiticides e.g bait application 4. Studies on host plant susceptibility levels undertaken to increase host plant resistance range 5. Studies of termite species diversity using molecular techniques. 6. Development of a termite management guideline
Blue gum psyllid, *Ctenarytaina eucalypti*	1. Population dynamics and damage status not known 2. Impact of local natural enemies not known	1. Undertake countrywide studies of the psyllid 2. Undertake local natural impact studies
Red Gum Lerp Psyllid, *Glycaspis brimblecombei*	1. Host specificity and efficacy studies of *P. bliteus* not known 2. Lack of biocontrol agent, *P. bliteus* in Kenya 3. Host plant susceptibility of the psyllid not determined	1. Carry out host specificity test and efficacy tests 2. Import and release *P. bliteus* into Kenya 3. Undertake both laboratory and field host plant studies

Winter bronze bug, *Thaumastocoris peregrinus*	1. Lack of biocontrol agent, *C. noackae* in Kenya 2. Host plants resistance germplasm not known.	1. Import *C. noackae* into Kenya and implement classical biological control programme for Winter bronze bug 2. Undertake host plant resistant studies
Eucalyptus snout beetle, *Gonipterus scutellatus*	1. Cause(s) of sporadic upsurge of Snout beetle not known 2. Species complex of Snout beetle not known 3. Economic loss and impact of the Snout not determined. 4. Host plant resistance of the snout beetle not known	1. Undertake studies to determine causes of population upsurge 2. Use molecular techniques to determine the species identity 3. Undertake economic loss and impact studies 4. Undertake host plant resistant studies to determine host plant susceptibility levels
Blue Gum Chalcid (BGC), *Leptocybe invasa*	1. Annual seasonal population variability not known 2. Impact of local natural enemies not known 3. Biological control agent not in Kenya 4. Host plant resistance of BGC not known	1. Undertake BGC ecology and population studies 2. Undertake studies on impact of local natural enemies 3. Import and release the biocontrol agent *S. neseri* 4. Undertake studies to determine susceptibility levels of BGC on Eucalyptus germplasm
Cypress aphid, *Cinara cupressivora*	1. Impact assessment of released *P. juniperorum* has not been undertaken 2. Host plant resistance not known	1. Undertake impact assessment studies of *P. juniperorum* in the field. 2. Undertake host resistance studies
Pine Woolly Aphid, *Pineus pini*	Host plant resistance not known	Undertake host plant susceptibility of the different pine genotypes to *P. pini*
Pine needle aphids, *Eulachnus rileyi*	1. Impact of local natural enemies not understood. 2. Biological control *Leucopis tapie* in Kenya.	1. Undertake studies on local natural enemies' impact 2. Import and release biocontrol agent into Kenya

Black pine aphid, *Cinara cronatii*	1. Effective pesticide not known 2. Distribution and population dynamics of *C. cronatii* not known 3. Economic impact and damage levels on the host not known. 4. Host plant resistance not known 5. Suitable biological control agent not identified	1. Undertake pesticide efficacy studies as a management tool 2. Undertake studies on distribution and population dynamics of *C. cronatii* 3. Undertake studies on economic impact and damage level 4. Host susceptibility studies to be undertaken 5. Undertake exploration studies and efficacy studies to identify a suitable biocontrol agent
Apate indistincta	1. Distribution, incidence levels and economic impact of *A. indistincta* not known 2. Local natural enemies and their impact not known	1. Undertake national survey to determine the distribution, incidence levels and economic impact. 2. Undertake studies on identification of local natural enemies and their impact

3.0 MAJOR DISEASES OFCOMMERCIAL TREE SPECIES IN KENYA

3.1 Nursery diseases

3.1.1 Damping-off

Introduction

Damping-off is a disease that affects seeds, germinating and young seedlings of many species including commercial trees such as *Eucalyptus, Pines, Cypress, Melia, Grevillea* and *Casuarina* species. There are two types of damping off; pre-emergence and post-emergence. Pre-emergence damping-off affects seeds and germinating seedlings before they emerge causing them to decay. Post-emergence damping-off affects young seedlings before their stems become woody causing soft rot. Both types occur in bare root nursery beds t and container grown seedlings in nurseries.

Damping-off pathogens may be endemic in nursery soil without causing damage but can cause disease when environmental conditions are favourable. The main environmental factors influencing damping-off are soil pH, moisture and temperature. The effect of these factors varies with the predominant pathogen and the tree species. Damping-off pathogens grow and reproduce when the pH of the soil or growth medium is slightly acidic and therefore not optimal for seedling growth (pH of 5.2-5.8). Nitrogen fertilizers applied to emerging seedlings can increase seedling losses. Within the same seed bed, the soil environment can be variable leading to sporadic seedling damage occurring in pockets of the seedbed.

Nurseries throughout Kenya have experienced losses due to damping off. Research carried out in the early fifties to late sixties in Kenya showed that damping off was common in coniferous nurseries (Odera, J.A. and Arap Sang, F.K., 1975): Since the disease is caused by a variety of pathogens with differing environmental conditions it is difficult to establish bare root nursery beds or container nursery beyond the reach of spores of the fungi.

Causal organisms

Damping-off disease is caused by different species of fungi. These pathogens survive in the soil, plant debris, or seed as dormant spores. They include species of *Pythium*, *Fusarium*, *Botrytis*, *Rhizoctonia* and *Alternaria* (Hocking, 1968). Seed borne pathogens *Aspergillus flavus* and *Rhizopus stolonifer* are associated with post-germination seedling mortality of *Melia volkensii*

(Mulanda *et al*., 2013). Damping-off is a common disease in Casuarina nurseries worldwide and can cause heavy loss of seedlings. It is caused by some species of *Pythium, Phytophthora, Fusarium* and *Rhizoctonia*.

Cool and wet soils slow down germination and extend the time seeds and germinating seedlings are exposed to existing pathogens in the planting medium. Excessive soil moisture and moderate temperatures favour development of some pathogens such as *Pythium*. Soil texture, organic amendments and nutrients enhance damping-off by providing substrates for competing fungi.

Symptoms and damage

Damping-off affects seeds and seedlings during germination and emergence. Pre-emergence damping-off occurs where seeds are affected before their hypocotyl breaks through the soil surface. This type of damping-off is difficult to diagnose because affected seeds are not visible and consequently the losses are attributed to poor germination. If germinating seedlings have not emerged after a reasonable time the seed should be excavated and examined for fungal mycelium and rotting.

Post emergence damping-off occurs shortly after emergence while tissues are still succulent. To check for this type of damping-off in the seedlings of Melia, Grevillea and Casuarina one can look for necrotic areas at or below the ground line where infected seedlings wilt and die. Post emergence damping-off in Pines occurs between emergence and development of primary needles. Infection in Pines occurs at or slightly below the ground line and results in water soaked discoloured brownish areas that rapidly become sunken or constricted. Affected seedlings fall over (damping-off).

Management

Excessive high soil pH can be lowered by adding Sulphur compounds that include granular Sulphur or Ammonium sulphate. Watering must be regulated to avoid overwatering in both bare root and container nurseries. High quality seed with low fungal contamination reduces the susceptibility to damping off. Reusable containers are cleaned and disinfected to prevent fungal inoculum from being carried to the next crop. Low density sowing leads to strong germinating that are more tolerant to damping off. Regulate shading when experiencing damp conditions in sowing beds or pots.

Some of the fungi responsible for damping-off are seed-borne thus necessitating seed treatment with respective fungicides before sowing. Other seed treatments include standing water soaks, running water rinses and chemical treatments with bleach (Sodium hypochlorite) and Hydrogen peroxide.

When growth medium is suspected to harbor the pathogens then chemical fumigation or pasteurization is undertaken. Fungicidal drenches are applied after disease symptoms become evident. However, this practice is rarely curative since most of the damage has already been done by the time the chemical is applied. Nevertheless, these can stop secondary spread of the disease. Drenches have been found to be effective against damping-off but are expensive and hazardous to the environment. Fungicide sprays on seedlings after emergence applied at intervals of 3-4 days over 14 days using combinations of recommended fungicides could help.

3.1.2 Powdery Mildew

Causal organism

The disease is caused by several species of fungi from the order Erysiphales with the most common genera being Erysiphe. The mildew fungi belong to the family Erysiphaceae (the true mildews). The conidial stage belongs to the form genus Acrosporium (formerly oidium) and Sphaerotheca both in the family Erysiphaceae. The causal organisms are quite host specific but usually causing the same symptoms and are often confused one for the other. *Erysiphe cichoracearum* has been recorded as causing mildew on most *Eucalyptus* species.

Symptoms and damage

Powdery mildew is associated with poor growth, necrosis, and leaf fall in seedlings. It is characterized by the appearance of white powdery spots on leaves buds and stems of plants. The most affected parts are the lower leaves and the disease is more severe on young leaves. The white powdery appearance of mildew is caused by microscopic chains of spores on the affected plant parts. The infection blocks the leaves from receiving sunlight hence reducing photosynthesis and causing chlorosis. The leaves become distorted causing them to curl and in severe cases leaves drop prematurely. The disease also causes etiolation in young shoots causing weak stems and fewer leaves. It also causes yellowing/browning, premature leaf drop, blemished or aborted flowers. Young plants in heavy shade are most affected by the disease. Branch tip dieback on highly susceptible species is common but not usually lethal. The disease affects seedlings in the nursery and saplings but is hardly found on mature trees.

Management

Powdery mildews rarely kill plants but can be controlled by planting resistant varieties. Conifers have been found to be resistant to powdery mildew. Susceptible plants should be placed in adequate sunlight and good air circulation to prevent growth of the fungus by controlling humidity. Watering should be controlled to reduce the relative humidity in the greenhouse or nursery and inhibit the fungus from growing.

Allow proper plant spacing and avoid over sowing to aid in good flow of air. Prune when necessary to reduce shaded leaves which are susceptible to the disease. All infected plants and plant parts should be removed as they are a source of inoculums in the nursery. Overhead watering has been used to protect plants as the fungus does not germinate where there is water but this should be done with caution as it can lead to increased relative humidity making conditions favourable for the fungi. Affected plant debris should not be composted as the spores overwinter and can cause new infections in the new season. Affected plants should be removed from excess shading and put in direct sunlight for recovery.

In severe cases chemical control is done using sulphur and copper-based fungicides. They can be controlled using fungicides such as Benlate, Milraz, Kocide. Biopesticides such as neem oil have also been found effective in the control of the disease. Biocontrols such as Trichoderma spp. have been tested on Powdery mildews for efficacy but still have not been used widely and only reduce the severity of the disease. Nitrogen fertilizers should be applied with caution as they cause shoots of plants to be succulent making them susceptible to the disease.

3.1.3 Gray mold

Causal organism

Grey mold is caused by the fungus *Botrytis cinerea* which is pathogenic and saprophytic on plant tissues. Spores are dark ellipsoid to oval. The fungus produces small, black sclerotia, which provide a means by which the fungus can infect over winter. The sexual state of the fungus (*Botryotinia fuckeliana*), is produced on the sclerotia. Moisture is often a more limiting factor in disease development than temperature because the spores require free water to germinate. The disease is favoured by cultural practices, such as high planting densities or and shading that limit air movement and raise the humidity around the seedlings.

Symptoms and damage

During periods of high humidity, the fungus can be seen as a thin gray web of mycelium on infected plant parts. Tufts of dark conidiophores grow from the mycelium and from infected tissue. The conidiophores produce clusters of spores. If they are not present on infected tissues the spores will develop when the seedling is placed in a moist chamber. Once established on a branch, it moves downward into the stem killing the tissues it infects. In succulent 1-year-old stem tissue there are black sunken cankers usually low on the stem which finally girdles the stem. The portion of the seedlings above the girdled area dies. Grey mold is often confined to pockets of seedlings but can cause heavy mortality in highly susceptible species.

Management

Modify the environment to increase aeration and decrease humidity around the seedlings. This will reduce spore germination and growth of the fungus. Other practices include reducing seedling density for adequate spacing, improving air circulation and irrigating less frequently or early in the morning. Keep seedlings healthy and vigorous and avoid injuring the foliage.

Botrytis has developed strains resistant to some fungicides especially the systemic benzimidazole such as Benomyl® that make it difficult to control the disease chemically (Landis, 1989). Use different fungicides, preferably with different modes of action in rotation. Surfactant fungicides are more effective since the fungus is not systemic. The timing of protective fungicide application is important and should be done to ensure chemicals cover susceptible plant tissue before the spores germinate and penetrate the foliage.

3.1.4 Calonectria diseases

Causal organism

In Kenya, vegetative propagation of cuttings of some clones can be affected by cankers and mortality with profuse sporulation of *Calonectria spp*. on the canker surfaces (Roux *et al*., 2005). A *Calonectria* species was found attacking *E. glandis* X *E. Camuldulensis* cuttings during rooting and causing cankers on young seedlings of *E. grandis*. In most cases, the disease was associated with high humidity.

Symptoms and damage

Calonectria infection also causes leaf disease and stem cankers. Several species of the genus are known to cause leafs pots, seedling blights, cutting rot and stem cankers, especially in nurseries (Crous *et al*., 1991). *Calonectria* shoot blight and damping-off is common in nurseries in Kenya.

Management

Calonectria disease can be controlled by planting disease-free seedlings. Use sterile soil mix when potting. Propagate from only healthy stock plants since the disease spreads rapidly in most propagation beds. Destroy infected plants to prevent re-infection and spread. Apply a copper-based fungicide to protect healthy plants.

3.2 Plantation diseases of Eucalyptus

3.2.1. Botryosphaeria canker disease

Causal organism

Botryosphaeriaceae is a very diverse group of fungi that includes pathogens, endophytes or saprobes, occurring largely on woody hosts across a wide range of geographical and climatic areas of the world (Pillay *et al.,* 2013). Members of the Botryosphaeriaceae are latent and opportunistic pathogens occurring as endophytes in asymptomatic plant tissues but often cause rapid disease development when such plants are exposed to environmental stress such as drought or insects and animal damage (Slippers and Wingfield, 2007). While these fungi are often not as aggressive as some primary pathogens, the die-back and canker diseases they cause on *Eucalyptus* are economically serious and amongst the most common in some environments.

Symptoms and damage

Symptoms of Botryosphaeria disease include formation of stem cankers, production of gum and stunted growth. This causes cracking of the stem and production of black/brown gum (Kino). In some cases, sections of infected stems show a brown ring in the sapwood. This is mainly at the base of stems but can also extend up the stem. Infected young trees can become stunted and finally die. Infection on the upper part of the stem leads to dieback on the trees. Infection can also occur on lateral branches leading to branch die-back. The fungus can also penetrate the wood rendering it unacceptable for sawn timber production. Infected trees are not suitable for pulp production, as this would require heavy bleaching using chemicals. They can only be used as fuelwood. Some infected trees produce epicormic shoots.

Management

Botryosphaeriaceae cankers are mainly managed through cultural practices. These include: removal of infected trees for use as fuel wood, use of appropriate pruning techniques to prevent unnecessary wounding of trees and proper species-site matching to avoid planting trees in unsuitable site where they are likely to be stressed. Currently there is no documented chemical control for Botryosphaeriaceae canker. Use planting material that is resistant to Botryosphaeriaceae canker.

3.2.2 Teratosphaeria canker disease

Causal organism

Teratosphaeriaceae canker is caused by fungal pathogens in the family Teratosphaeriaceae. The family was recognized in 2007 as distinct from the genus Mycosphaerella where it had previously been placed based on DNA phylogenies. Many fungi in the Mycosphaerellaceae and Teratosphaeriaceae are thought to be widespread, yet little is known about their individual distributions or the range of hosts that they inhabit. After the family was formally split from Mycosphaerella in 2007, many new species have been described in this family including a number of causal agents of leaf diseases and stem cankers of Eucalyptus. In Kenya symptomatic bark samples were collected from Muranga and Nanyuki areas and the associated fungus isolated and identified using DNA sequence analyses of multiple gene regions. The pathogen was identified as *Teratosphaeria gauchensis* (Machua *et al*., 2016).

Symptoms and damage

The symptoms of Teratosphaeria stem canker include dark brown circular lesions that sometimes coalesce to give rise to larger measles-like lesions, sub-epidermal dark tiny pycnidia on the lesions, kino exudation and epicormic shoots.

Management

To stop further spread, a lot of awareness is necessary and all infected material should be destroyed by fire. Keen border phytosanitary control for seed and clonal imports should be undertaken to prevent import of contaminated material.

3.2.3 Chrysoporthe canker disease

Causal organism

Previous described species of *Chrysoporthe cubensis* have been shown to contain both *Chrysoporthe cubensis, C. austroafricana* and to some extent *Chrysoporthe deuterocubensis.* Collectively all these were known as *Cryphonectria cubensis* in the past. Species in the genus Chrysoporthe are important fungal pathogens of Eucalyptus spp. worldwide where it causes basal and upper stem cankers. The fungus is also known on many other hosts all residing in the order Myrtales. Five species of Chrysoporthe, including *C. austroafricana, C. cubensis, C. deuterocubensis, C. syzygiicola* and *C. zambiensis* are known in Africa where they occur on trees in the Myrtales including native Syzygium spp. and Eucalyptus spp. (Chen *et al*., 2013).

Symptoms and damage

Chrysoporthe canker disease on young trees causes wilt and dieback of foliage due to the girdling of the stem by the pathogen. Symptoms on older trees include the swelling, cracking, and splitting of the bark at the bases of trees or the formation of sunken, target shaped cankers higher up the stems. These can be associated with branch stubs. The disease on Eucalyptus species is most serious and common in hot, humid regions mainly at the Coast. Yellowish brown pycnidia may form on the bark and black perithecia may be visible with the naked eye and at low magnification.

Management

The selection and breeding of disease tolerant hybrid clones has proven highly successful in the management of disease caused by Chrysoporthe species. This has in the past been done through artificial inoculation trials.

3.2.4 Mycosphaerella leaf disease

Causal organism

The Mycosphaerella leaf disease is caused by pathogens in the fungal family Teratosphaeriaceae. Two species of Mycosphaerella (*M. keniensis*) on *E. grandis* and *M. juvenis* (*Teratosphaeria nubilosa*) on leaves of *E. globulus* have been identified in Kenya on older leaves (Crous, 1998). In Kenya leaf spots are also common on most GC clones. The fungi causing MLD produce conidia which enable them to spread the disease. Mycospherella asexual spores are usually elongate, elliptical, and septate conidia.

Symptoms and damage

Symptoms of Mycosphaerella leaf disease (MLD) include: leaf spot formation, leaf blotch, defoliation, shoot die-back and stem cankers. The disease may also cause blackish appearance on the underside of leaves and purplish or brown spots on the upper side.

Management

In Kenya there are no known management strategies of Mycosphaerella and Teratosphaeria in place. This is despite that species such as *E. globulus* is mainly attacked by the pathogens in highland sites. The options for management should therefore focus on tree improvement to increase host resistance or tolerance to pathogen infection. However, clones derived from hybridization can differ markedly in their resistance to disease (Gavin *et al*., 2011). Seed that is transferred between countries should be subjected to quarantine. Care should be taken to restrict movement of infected nursery seedlings. Chemical control using copper-based fungicides in nurseries may also be an option for severe infections.

3.2.5 Ceratocystis wilt

Causal organism

Ceratocystis wilt disease is caused by the ascomycete fungus in the genus *Ceratocystis* (Microascales, Ceratocystidaceae). *Ceratocystis fimbriata* which is the type species produces ascospores that are found atop of fruiting body (perithecia). In Kenya, Ceratocystis wilt caused by *Ceratocystis albifundus* has been found infesting *Eucalyptus grandis* (Roux *et al*., 2005).

Symptoms and damage

Ceratocystis species infect wounds on trees and hence artificial stem wounding can be used to determine the presence of the pathogen. During disease development, white, fuzzy mycelia with long black perithecia grow out from the lesions. Symptoms on Eucalyptus present as stem cankers, black canker stains and vascular wilts. The infection leads to death of trees.

Management

Management of Ceratocystis disease involves mainly cultural practices. This involves good forestry management practices such as cleaning all equipment especially pruning to prevent disease spread. However, Thiabendazole and difenoconazole are known to be effective on *C. fimbriata* (Scruggs *et al*., 2017). Attacked trees should be removed to prevent the spread of the disease.

3.2.6. Armillaria root rot

Causal organism

The predominant species found on Eucalyptus is *A. heimii*. The pathogen is prevalent at high altitudes in Kenya where Eucalypts are grown in plantation and farms.

Symptoms and damage

Symptoms include dying of whole trees and presence of white mycelial mat of the fungus between the bark and the wood. It spreads through root to root contact with healthy plants. *Armillaria* occasionally attacks roots and the base of trees of any age causing death or slow decline. The fungus may survive in the soil or on stumps and roots of various trees for many years. This is particularly important in agroforestry systems where susceptible trees and crops are grown together since other species could be susceptible.

Management

Root rots can be controlled by removal of dead plants including the roots by excavation or digging them up. The material should then be burnt. Avoid planting susceptible trees in disease prone sites.

3.3 Diseases of Pines

3.3.1 Dothistroma needle blight

Causal organism

Multigene phylogenies reveal that red band needle blight of Pinus is caused by two distinct species of *Dothistroma* namely*: D. septosporum* and *D. pini* (Barnes *et al.,* 2004). The latter fungus has a worldwide distribution and is the causal agent of the red band needle blight that has damaged exotic plantations of *Pinus radiata* in the Southern Hemisphere.

Symptoms and damage

The most characteristic symptom of this disease is brick-red bands that appear on the needles. The blight first appears in groups of trees three to five years old. Later, the spots and bands turn brown to reddish brown and fall. Needles may develop extensive necrosis (browning) 2 to 3 weeks after the first appearance of symptoms. Infection is typically most severe in the lower crown. Conidia are borne in stromata (fruiting bodies), which develop below the epidermis of needles. The disease spreads primarily by means of splash-dispersed asexual conidia (Gibson *et al.,* 1964). This is favoured by rain and misty conditions. A variety of the fungus with intermediate conidia size was named by Ivory as *Dothistroma pini* var. *keniensis* (Ivory, 1967). The spread of the blight over long distances is not understood, but it is likely that wind, cloud and diseased materials aid its spread (Gibson, 1974). In 1962 the planting of *P. radiata* was stopped in Kenya due to the severity of the disease and lack of effective control measures. In Kenya in 1963, over 1500 hectares of *P. radiata* aged 1-5 years were cut down and replanted with *Pinus patula* as alternative tree species.

Management

The main method of control is spraying with copper oxychloride fungicides. Aerial spray trials in Kenya demonstrated that copper fungicides had the potential to provide economically beneficial control of DNB (Gibson *et al*., 1966). Large-scale spraying in East Africa was largely discontinued due to problems with difficult topography of the forests and a shortage of suitable airstrips and aircraft (Gibson, 1974). Some pine species, such as *P. radiata* and *P. muricata*, develop resistance with age and maturity (usually at 15 years). This is a feature of the whole tree in that resistance is seen even on new needles of mature trees (Ivory, 1972). Due to its superior qualities, breeding for resistance programmes were started. Ivory and Paterson (1969) demonstrated that it was possible to select resistant *P. radiata* based on phenotype and this was transmissible. Resistant material was collected from Kenya and others imported from New Zealand to set up trials in the Rift valley province where the disease is more prevalent. The main phytosanitary risk is in the export/import of diseased plant material between countries.

3.3.2. Pine tip blight disease (Diplodia Blight)

Causal organism

Sphaeropsis sapinea produces fungal spores from fruiting bodies during wet weather and they are spread to trees by wind, splashing rain, animals, and pruning equipment. They infect and colonize green, succulent stems of newly expanding shoot tips and young needles. Spores can also infect more mature branch tissue through wounds, such as pruning cuts or hail injury. Sometimes, the invading fungus may not kill stems or needles right away, but instead survive within the tree with delayed symptom development (latent infection). Often, the pathogen will only produce symptoms after trees have been exposed to environmental stresses such as drought.

Symptoms and damage

The disease occurs on trees from 5 years or older (Roux *et al*., 2005). Damage to trees includes shoot blight and branch and stem cankers. Infections are usually scattered. The cankers exude copious amount of resin from stems and branches. Dead brown needles at the tip of branches are the most common symptom. The blight starts on the lower branches of the tree. Damage is usually severe on pines that are stressed. The lowest branches of old, well established trees are the first to show disease, and dieback gradually spreads upward.

Management

Cultural control measures include provision and conservation of water during drought. Tree branches with blight may be pruned. Managing tip blight in landscapes is challenging, and no single treatment is highly effective. Reduce tree stresses that enhance disease through proper species site matching and water to reduce moisture stress. Prune away and destroy dead twigs and branches to improve the affected tree's appearance. Remove and destroy diseased needles, twigs, and cones on the ground under the tree as they become a source of inoculum. Resistant species should be planted to reduce the chances of the disease affecting the trees.

3.3.3. Armillaria root rot

Causal organism

The predominant Armillaria species attacking pines is *A. heimii* (Mwangi *et al*., 1994).

Symptoms and damage

The production of resin at the root collar is a common response in pines. Spectacular fans of thick white mycelium are found in the roots and root collar and may extend several feet up the trunk. In most cases the infection originates from previously infected stumps of both hardwoods and conifers which can retain the inoculum for many years. Although the disease can also spread from infected trees as secondary inoculum through root contact most infections have however been found to originate from primary inoculum. In forest plantations the incidence of Armillaria is confined to localized infection centers usually around infected trees or stumps of indigenous trees or conifer species. These can subsequently enlarge depending on the frequency of root contact. Gibson, 1960 noted that highest mortality occurred in plantations between the ages of 5 – 10 years.

Management

There are currently no fungicide treatments available. However, infected trees should be removed including the stumps and large roots. Removal of infected material from infested sites will reduce the impact of the disease in subsequent plantings.

3.3.4 Stereum rot disease

Causal organism

The fruit body of *Stereum sanguinolentum* manifests itself as a thin (typically less than 1mm thick) leathery crust on the surface of the host wood. Often, the upper edge is curled to form a narrow shelf (usually less than 10mm thick). When present, these shelves can be fused to or overlap neighboring shelves. The surface of the fruit body consists of a layer of fine felt-like hairs, sometimes pressed flat against the surface. The color ranges from beige to buff to dark brown in mature specimens; the margins are lighter-colored. Fresh fruit bodies that are injured exude a red juice, or will bruise a red color if touched. The fruit bodies dry to a greyish-brown color. The spores are ellipsoid to cylindrical, amyloid and typically measure 7–10 by 3–4.5 µm.
Comparative studies by Griffin, (1969) found that the fungus was the same as that found in the Northern Hemisphere and that fruit bodies were most abundant on *P. patula* and *P. radiata*. The author also found that *P. insularis, P. montezumae, P. oocarpa* and *P. pinaster* hosts to the fungus.

Symptoms and damage

Stereum sanguinolentum causes red heart rot, a red discoloration on conifers, particularly spruces or Douglas-firs. Fruit bodies are produced on dead wood, or sometimes on dead branches of living trees. They are a thin leathery crust of the wood surface. Fresh fruit bodies will bleed a red-colored juice if injured, reflected in the common names bleeding Stereum or the bleeding conifer parchment. It can be the host of the parasitic jelly fungus *Tremella encephala*.

Management

Protection from game damage has been recommended to reduce infection. Pruning of pine plantations should be done during the dry season.

3.4 Plantation diseases of *Cupressus lusitanica*

3.4.1 Cypress canker

Causal organism

Cypress canker is caused by *Lepteutypa cupressi* (Monochaetia unicornis Cooke & Ellis) The pathogen survives in infected bark tissue. During wet weather, spores are released and spread to nearby hosts or healthy branches. These spores are spread by splashing and water runoff. They can also be carried longer distances by contaminated pruning tools and movement of infected plants. Since the fruiting bodies needed for identification are found near oozing cankers, it is important to include the entire branch when sampling. The branch can be cut into several smaller lengths (1 ft pieces) and all sections should be included when submitting a sample for diagnostic testing.

Symptoms and damage

The pathogen causes cankers, branch deformation, branch and twig dieback (FAO, 2007). The first symptom of the disease is the production of resin. As the pathogen progresses it interferes with the sap-conducting system, eventually causing death of the branch or main trunk above the wound. Branches die rapidly, yellowing almost overnight as the foliage is starved of sap. Sunken cankers, with a reddish tinge, form at the entry point of the fungus, and resin often exudes from the edges of the cankers or through cracks in the bark. Individual cankers are long and thin and may be numerous along a branch. Spore-producing structures of the fungus can be seen on the bark surface as small, circular, black dots. Spores are carried on the wind, in water droplets or by insects and birds. New infections develop when spores are washed down the tree or splashed from tree to tree by rain or overhead irrigation. They can also be transferred from plant to plant on pruning tools, or through the transport of infected cuttings or plants.

Management

Any infected branches can be pruned 10 cm below the canker to prevent infection from spreading to the main stems. All tools should be sterilized before and after use with alcohol or domestic bleach (Sodium hypochlorite). Severely diseased plants should be removed and destroyed. No fungicides are effective in controlling the disease once infection has occurred. Selection and breeding for disease tolerance and resistance has been undertaken in Kenya. In the 1960s an epidemic of cypress canker rendered the planting of *C. macrocarpa* uneconomical. The planting of *C. macrocarpa* was abandoned and *C. lusitanica* which is more resistant was introduced. This was combined with selection of plus trees for plantation establishment. However, the disease still occurs on ornamental Cypress tree species such as *C. sempervirens* var. *sempervirens* and *C. sempervirens* var. *pyramidalis* in Kenya.

3.4.2 Armillaria root rot

Causal organism

Armillaria root rot is caused by several species of the fungus *Armillaria*. However, *A. heimii* is by far the major causal species on *Cupressus lusitanica* (Mwangi *et al.,* 1994). This can easily be grown on artificial media.

Symptoms and damage

The production of resin at the collar is a common response of Abietaceae, especially pines, attacked by *A. ostoyae* or *A. heimii* (Gibson, 1960). Infection of a root system does not immediately result in the appearance of symptoms on the aerial part. These only begin to show when the collar is attacked or when several large roots are destroyed. Attacked trees appear brownish which progress until the tree dies. The main symptom is the presence at the level of the cambium of white, thick, mycelial fans, sometimes constituting a continuous mycelial tube. Clusters of mushrooms form at the base of the infected tree, indicating attack. Fruit bodies though rare occur in clusters at the base of infected stumps and dead trees especially on *C. lusitanica*. Most of the fruit bodies that were found seem to correspond to the species *A. heimii* although they vary in size and some are often larger than those described by Pegler (1977) for *A. heimii*. Trees can die in patches as the fungus spreads through root to root contact. In a survey conducted in Cypress plantations, it was found that 23.5% of *C. lusitanica* were infected. A high mortality of 12.6% occurred on *C. lusitanica* plantation in Sabatia compartment 9E. (Mwangi *et al*, 1994).

Management

Control of Armillaria root rot is extremely difficult, because the inoculum is found in the soil, in the form of masses of mycelium enclosed in important volumes of wood and often protected by the 'zone lines' within this wood. The most drastic method of reducing inoculum potential consists of the total removal of the stumps. The most effective ways of management is limiting the spread of the fungus by planting resistant species and removing infected material. A decrease of 32% in mortality of trees was recorded in a plantation of *C. lusitanica* by removal of dead trees and stumps (Mwangi *et al*., 1994). This indicates that this method could be effective to some extent in the control of the disease. Removal of diseased trees, stumps and roots was recommended as a method of controlling Armillaria (Shaw & Roth, 1978).

3.5 Diseases of *Casuarina equisetifolia*

3.5.1 Casuarina wilt (Bark blister disease)

Causal organism

Wilt or blister bark disease is caused by *Trichosporium vesiculosum* Butler (now *Subramanianospora vesiculosa*) and is the most destructive disease of this species. The pathogen multiplies rapidly over the main stem of the tree.

Symptoms and damage

It produces fruiting bodies beneath the necrotic lesions pushing the bark outwards and forming numerous blisters. The blisters rupture and release sooty black spores which are deposited all over the tree giving the tree a black appearance. Infected trees develop vertical cracks and splits in the main stem and die resulting in economic losses.

Discoloration of tree foliage is one of the initial symptoms of blister bark disease. As the disease advances, necrotic lesions appear all over the main stem and branches. Subsequently, all affected trees exhibit symptoms of wilting and drying. During the final stages of the disease, the pathogen produces black sooty spores beneath the necrotic lesions. Due to excessive production of spores beneath the lesions, the bark is pushed outward forming numerous blisters. Such blisters of varying size and shape can be located all over the main stem and branches of affected trees. Later the blisters rapture and release black sooty spores which become deposited all over the tree, imparting a black appearance to trees as if burnt by fire. The spores can also be detected on the roots.

Management

Seeds collected from healthy trees in a diseased plantation have the potential to carry viable spores of the pathogen. Quarantine procedures need to be implemented during seed collection and exchange from localities with disease outbreaks to avoid pathogen spread into new regions. Pruning infected and healthy trees with the same tool should be avoided and tools should be disinfected. Seeds should not be collected from infected plantations. Infected trees should be removed and burnt to stop the disease from spreading. Research findings from an International provenance trial at Malindi showed a positive correlation between genetic variation and disease resistance among provenances of *C. equisetifolia* (Narayanan *et al*., 2003). Selection and breeding strategies targeting existing trees resistant to the disease is a recommended long term management option.

3.6 Diseases of Grevillea robusta

3.6.1 Botryosphaeria Canker on *Grevillea robusta*

Causal organism

The most commonly isolated family was Botryosphaeriaceae from symptomatic and healthy tissue. The three most abundant species isolated are: *Neofusicoccum parvum, Lasiodiplodia theobromae,* and *Diplodia seriata*.

Symptoms and damage

Canker symptoms include dark sunken pits that are usually found on the trunk, twigs and branches of trees. They can be followed by gum exudation or oozing around the lesions and dieback of shoots and twigs reducing photosynthetic area and causing gradual death of the tree. The fungi cause dieback of shoots and twigs leaving the tree bare at the top progressing to the stem. On injuring the bark, a red stained wood of the *G. robusta* is revealed and in severe infections the stain is brown oozing gum.

The fungi enter plants through wounds or leaf openings in healthy plants. Endophytic fungal species are found present on healthy tissue. Spores produced are dispersed in masses through air, oozes and water during humid seasons causing new infections and re-infections. All plant parts including seeds have been found to be host to latent Botryopshaeriaceae The dieback and canker symptoms become more severe in hot conditions leading to death from loss of xylem tissue and reduced photosynthesis. On onset of infection the trees flower prolifically in an attempt to fight infection. Flowering may also come late or earlier than expected.

Management

The endophytic nature of Botryosphaeria canker fungi requires that tree vigor and growth be promoted to reduce stress since physiological stress has been shown to exacerbate the disease. Grevillea should be cultivated in humid and higher altitudes. Timely weeding and pruning of the established trees will ensure that the trees grow optimally reducing chances of infection. Pruning tools should be disinfected and the wounds sprayed with fungicides to reduce chances of infection. Any symptomatic trees or plant part should be removed as soon as possible to eliminate the source of inoculum from the plantation. It is recommended to use disease free seed and seedlings when establishing plantations.

3.7 Diseases of *Melia volkensii*

3.7.1 Botryosphaeria canker

Causal organism

The species that occur were mainly from two genera namely; Neofusicoccum and Lasiodiplodia causing canker and dieback on the trees and rots on the fruits. *Neofusicoccum parvum, Lasiodiplodia crassispora* and *Lasiodiplodia theobromae* were isolated from *Melia volkensii* trees in agro-ecological zones IV and V of Kenya. The colonies are adapted for quick spread in large masses at the onset of stress to the plant. Conidial infections are most common and are spread by splashing water during the rains and dispersed by air and water during high humidity. The disease is also spread through contaminated pruning tools. Leaves may also be infected through stomatal openings. Sporulation may take place immediately after infection but the incubation period depends on the species. Colonies grow rapidly under high temperatures making species in drylands highly susceptible to Botryosphaeriaceae species.

Symptoms and damage

Trees affected by the canker disease die gradually from the lead shoot downwards as leaves wilt producing lesions and cankers on the stems and branches. Gummosis is common on affected stems with canker formation and wood staining. Lesions expand causing discoloration of the wood beneath the canker. Botryosphaeriaceae species presents reproductive structures as pycnidia or ascomata on colonized barks and leaves.

Management

Botryosphaeriaceae cankers noticed on a KEFRI orchard were controlled through application of an epoxy resin. Other control mechanisms include disinfecting pruning tools, use of systemic fungicides, mechanical removal of infected material and correct species site matching.

3.7.2 Root collar rot and stem canker

Causal organism

Root collar rot and stem canker are caused by *Fusarium* or *Botryosphaeria* which can result into wilting and death of trees.

Symptoms and damage

The disease initially starts as root collar rots which form cracks around the base of the tree which develop into cankers. The root collar rots can extend from the base of the tree up the stem. However, stem cankers can develop in the upper parts of the stem.

Management

Use of available commercial fungicides and removal of infected trees

3.8 Reported diseases of commercial trees in neighboring countries

Trees in plantations or in woodlots on farms are susceptible to attack by exotic diseases which have pursued them from outside the region. Diseases hamper the productivity and sustainability of most trees and some also affect product quality. Diseases are favored by the extensive monocultures which can create a large resource base for harmful micro-organisms. The narrow range of common tree species grown at national and regional levels has transboundary dimensions. The free movement of goods and people around the globe has increased the pace at which diseases can spread globally. This movement of plant materials is a potential avenue for spread of pests and diseases. Incidences of diseases of trees are also influenced by a combination of biotic and abiotic factors. Trees in eastern Africa have been reported to suffer from different types of diseases in the various countries. The various diseases found in the neinghbouring countries of Uganda (Table 3), Tanzania (Table 4) and Ethiopia (Table 5) have been included in this report. Successful transboundary management of diseases requires common efforts of the concerned countries since the causal agents have no respect for territorial boundaries. More can be done to share experiences and information in the affected region and beyond especially when the matter involves exotic and introduced diseases.

Table 3 Diseases of trees in Uganda

Tree species	**Pathogen**	**Disease type**	**Reference**
Eucalyptus spp	*Lasiodiplodia theobromae* (Botryodiplodia	stem cankers & die-back	Roux *et al*, 2001, Nakabonge 2002

	theobromae)		
	*Mycosphaerell*a spp.,	Leaf spots	Nyeko & Nakabonge, 2008
	Cryptosporiopsis eucalypti	Leaf spots	Roux *et al*. 2001
	Oidium	Powdery mildew	Roux *et al*. 2001, Nyeko & Nakabonge, 2008
	Fusarium, Pythium & *Rhizoctonia spp*	Damping off	Maiteki *et al.* 1999
	Botryosphaeria	Canker	Nyeko & Nakabonge, 2008, Roux *et al*. 2001
Eucalyptus grandis	*Ceratocystis fimbriata*	Wilt disease	Roux *et al*. 2001
	Teratosphaeria zuluensis	Stem canker	Jim *et al*., 2014
	T. gauchensis	Stem canker	Jim *et al*., 2014
	Armillaria mellea	Root rot	Gibson 1975
	Ralstonias olanacearum,	Bacterial wilt	Roux *et al*., 2001
	Cytospora eucalypticola	Canker	Gibson1975, Roux *et al*. 2001
	Botryosphaeria spp.	Canker	Nyeko, 2008, Nakabonge, 2002
	Pantoea ananatis	Bacterial blight	Nakabonge, 2002
Eucalyptus Clones (GC 796 GU 609, GU 607) (GC78, GC784,GC796,GU7, GU8 GC 578)	Bacterial leaf spot	Leaf spot disease	Nyeko & Nakabonge, 2008

<table>
<tr><td>GC796, GU8, GC578, GU7, GU609</td><td>Powdery mildews Nursery</td><td>Powdery mildews disease</td><td>Nyeko & Nakabonge, 2008</td></tr>
<tr><td>E. grandis</td><td>Cytospora eucalypticola</td><td>Canker</td><td>Roux et al. 2001</td></tr>
<tr><td rowspan="2">E. urophylla</td><td>Chrysoporthe</td><td>Canker</td><td>Roux, 2005</td></tr>
<tr><td rowspan="2">Fusarium solani& Fusarium oxysporum</td><td rowspan="2">necrotic lesions</td><td rowspan="2">Nakabonge, 2002</td></tr>
<tr><td rowspan="2">Pinus spp</td></tr>
<tr><td>Armillaria mellea</td><td>Root rot</td><td>Gibson 1975</td></tr>
<tr><td rowspan="2">P. radiata</td><td>Dothistroma septosporum</td><td>Needle bright</td><td>Gibson 1975</td></tr>
<tr><td>Sphaeropsis sapinea</td><td>Blue stain</td><td>Roux et al. 2001</td></tr>
<tr><td rowspan="2">P. caribaea</td><td>Fusarium spp.</td><td>Wilt disease</td><td>Nyeko & Nakabonge, 2008</td></tr>
<tr><td>Fusarium spp.</td><td>Wilt disease</td><td>Nyeko & Nakabonge, 2008</td></tr>
<tr><td>P. oocarpa, P. patula</td><td>Sphaeropsis sapinea</td><td>Blue stain</td><td>Roux et al. 2001</td></tr>
</table>

Table 4 Diseases of trees in Tanzania

Species	**Pathogen**	**Disease type**
Casuarina montana	*Armillaria mellea*	root rot
Cuppressus arizona	*Rhynchosphaeria cupressi*	stem canker
C. lindley	*Rhynchosphaeria cupressi*	stem canker
C. lusitanica	Armillarias	butt rot
	Fusicocum tingens	Death of young tees
	Coriolus versicolor	brown cubical rot
	Peniophora cerebela	butt rot
	Poria victa var. *cinerea*	root rot
	Poria vaillanti	white rot
	Rhynchosphaeria cupressi (*Lepteutypa cuppresii*, *Monochaetia unicornis*)	stem canker

Eucalyptus maidenii	*Mycosphaerella molleriana* (*Sphaeropsis molleriana*)	leaf spot
Eucalyptus spp	Armillaria	root rot
Grevillea robusta	*Armillaria mellea*	root rot
Pinus spp	Alternaria spp.	tip dieback
	Armillaria mellea	root rot
	Botryodiplodia theobromae	needle blotch
	Cercospora pini densiflora	needle blight
	Cladosporiums spp	seedling browning & tip blight
	Fusarium oxysporium Fusarium spp.	damping off
	Fusicocum tingens (*Botryospheria ribis*)	Dieback
(*P. radiata,P.patula, P. caribaea*)	Mycosphaerella pini (Dothistroma pini)	needle blight
(*P. radiata, P. caribaea. P.montezumae*)	Mycophaerella pinicola	needle blight
	Naemacyclus niveus	needle cast
	Pestalotiopsis cruenta	needle blotch and cast
	Phytophthora spp	damping off
	Pythium spp	damping off
	Sphaeropsis sapinea (*Diplodia pinea*)	shoot dieback
	Stereum sanguinolentum	stem and log decay
	Thanatephorus scucumeris (*Rhizoctonia solani)*	damping off

List adopted from Nsolomo & Venn (1994).

Table 5 Diseases in Trees in Ethiopia

Host species	***Pathogen***	***Disease type***	***Reference***
Eucalyptus spp	*Erythricium salmonicolor*, (Syn *Corticium salmonicolor*)	pink disease	Alemu *et al*., 2003
	Pseudocerospora eucalyptorum	leaf spot	Crouss, 1988
E. globulus	Botryosphaeria species	Stem cankers	Alemu *et al*. 2003
	Mycosphaerella species (*M. nubilosa, M. marksii, M. parva*)	Leaf blotch	Alemu, *et al*. 2003,
	Phaoeophleospra epicocoides	leaf spot	Alemu *et al*. 2003
E. grandis	Botryosphaeria	Stem canker	Alemu *et al*. 2003
E. saligna	Botryosphaeria species	Stem cankers	Alemu *et al*. 2003
	Phaoeophleospra epicocoides	leaf spot	Walker *et al*., 1992
	Cytospora species	Canker	Alemu *et al*. 2003
E. citriodora.	Botryosphaeria species	Stem cankers	Alemu *et al*. 2003
E. camaldulensis	*Teratosphaeria gauchensis*	Stem canker	Alemu *et al*., 2003
Pinus species	*Sphaeropsis sapinea*	Dieback	Alemu *et al*., 2003
	Armillaria spp	Root rot	Alemu *et al*., 2003
Pinus radiata	*Dothistroma pini* (*Dothistroma septospora*)	needle blight	Gibson 1972
Pinus patula	*Sphaeropsis sapinea*	found on cones	Alemu *et al*., 2003
	Armillaria	Root rot	Mengistu, 1992
Grevillea robusta	Armillaria	root rot	Dagne, 1998

3.9 Gap analysis and mitigation strategies

A review was done to evaluate the current activities and compared to expected performance based on the strategic goals of the National Forest Health Strategy 2018-2033. From the review, gaps were identified and described based on the current status of the diseases. Strategies were developed and activities proposed to address them (Table 5). These strategies and respective activities would ensure effective forest health management for commercial forestry.

Table 6 Gap analysis for diseases of tree species for commercial forestry

Disease	**Identified gap**	**Mitigation strategy**
Damping off	**1.** Causal species not identified 2. Prevalence levels not known	1. Undertake studies on species identification 2. Undertake studies on prevalence
Powdery mildews	Causal species not identified	Undertake studies on species identification
Grey mold	1. Causal species is based on old literature 2. Management options not known	1. Undertake new studies to update species identity 2. Undertake studies on management
Calonectria	1. Causal species not identified 2. Management options not known	1. Undertake studies for species identification 2. Study management options
Botryosphaeria canker	1. Causal species not identified 2. Management options needed	1. Undertake studies for species identification 2. Study management options
Teratosphaeria canker	1. National prevalence of disease unknown 2. Management options needed	1. Undertake a national prevalence survey 2. Develop management options
Chrysoporthe canker	1. National prevalence unknown 2. Only one species identified so far	1. Undertake a national prevalence survey 2. Undertake species identification
Mycosphaerella leaf disease	1. National prevalence unknown 2. Only 2 species identified so far	1. Undertake a national prevalence survey 2. Undertake species identification

Ceratocystis wilt	1. National prevalence unknown 2. Only one species identified so far	1. Undertake a national prevalence survey 2. Undertake species identification
Dothistroma needle blight	Management unknown	Develop management options
Diplodia pinea blight	none	none
Armillaria root rot	1. Species identification incomplete 2. National prevalence unknown	1. Complete species identification 2. Undertake prevalence survey
Stereum rot disease	none	none
Cypress canker	Species not fully identified	Undertake molecular identification
Bark blister disease	1. Causal species not fully identified 2. Prevalence unknown	1. Undertake studies on species molecular identification 2. Undertake prevalence survey
Root collar rot and stem canker	1. Causal species unknown 2. Prevalence unknown 3. Management unknown	1. Undertake studies on species identification 2. Undertake prevalence survey 3. Develop management options

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusions

- Eucalyptus species have the majority of the shared insect pests and diseases in the region followed by Pines. *Cupressus lusitanica* and *Grevillea robusta* have one insect pest each that is shared while *Casuarina equisetifolia* and *Melia volkensii* have no reported shared insect pest between the neighbouring countries.
- The report reveals that a wide range of economically important insect pests and diseases have been reported on commercial tree species in Kenya.
- The literature shows that there has been increasing emergence of exotic insect pests in the country and its neighbours over the last two decades.
- The review shows that forestry research and development by KEFRI on tree pests and diseases in Kenya has continued to be undertaken mainly focusing on the increasing number of exotic insect pests and pathogens.
- KEFRI has the state of art technology and equipment for insect pest and pathogen identification.
- The review showed that identification of insect pest and diseases in forestry is carried out only at KEFRI however, the relevant sections are heavily underfunded to undertake diagnostic using state of the art technologies
- From the review, it is evident that identification of insect pests and pathogens to species level though possible at KEFRI, lacks funding.
- In this review it was found out that management strategies such as cultural methods, classical biological control, chemical control and use of resistant host trees have been implemented in Kenya on a number of tree insect pests and diseases.
- The KEFRI team has developed a National Forest Health Research Strategy for 2018-2033 that focuses on research and development on tree pests and diseases.
- The review did not find any documented collaboration between the private forestry sector players and research on insect pests and diseases.
- Although insect pest and diseases is a cross border issue, the review did not find well documented collaboration between relevant regional institutions for cross border prevention and management of invasions.

4.2 Recommendations

- Key stakeholders in the forestry sector should provide impetus to the expansion of commercial forestry in Kenya for the provision of wood products, services, and mitigation of climate change.
- The state agencies in forestry together with key stakeholders should promote information sharing on strategies for effective management of tree insect pests and diseases that will play a key role in increasing tree productivity in commercial forestry.
- KEFRI to develop effective and appropriate management strategies for emerging pests and diseases to mitigate losses.
- KFS and KEFRI to create or strengthen platforms for awareness and information dissemination on insect pests and diseases to stakeholders in commercial forestry. KEFRI to monitor the population dynamics and impact of selected natural enemies introduced to control exotic pests.
- KEFRI to evaluate or introduce resistant tree germplasm against insect pests and diseases.
- KEFRI to conduct field surveys to determine the cause, distribution and/or magnitude of selected pest and disease problems in commercial forestry.
- Implement fully the National Forest Health Research Strategy 2018-2033.
- The private commercial forestry firms to fund research on insect pests and diseases.
- The key stakeholders in the forestry sector and financial institutions to facilitate the establishment of a **National Forest Health Centre** at KEFRI to coordinate Forest Health programs in Kenya.
- The proposed National Forest Health Centre to enhance linkages, partnership and networking with locally and internationally quasi-related institutions and other stakeholders for improved delivery of management strategies of pests and diseases.
- The proposed National Forest Health Centre to introduce known natural enemies for respective pests nationally and regionally after joint studies

- The proposed National Forest Health Centre to operate the tree disease clinic for all players in commercial forestry.
- The proposed National Forest Health Centre to implement joint mitigation measures for the key insect pests and diseases.

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