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REVIEW

Pests and diseases of trees in Africa: A growing continental emergency

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Societal Impact Statement

The increasing occurrence of native and non-native pests and diseases of trees in Africa is impacting rural livelihoods, economic development, and biodiversity across the continent. Here we provide an updated and comprehensive overview of insect pests and pathogens targeting natural and planted forests in Africa, and raise awareness of this growing emergency. Data availability and limited biosecurity of some countries are limiting the ability to tackle this invasion. An improved knowledge of taxonomy, distribution, and damage caused by these organisms will be crucial for developing continent-wide strategies to manage this emergency and enhance country-level intervention capacity.

Summary

An increasing multitude of insect pests and pathogens is targeting indigenous trees of natural forests, agroforestry systems, and exotic trees in planted forests in Africa. This is raising major concerns for a continent already challenged by adaptations to climate change, as it threatens a vital resource for food security of rural communities, economic growth, and ecosystem conservation. The accidental introduction through trade of non-native species in particular is accelerating, and it adds to the damage to tree-based landscapes by native pests and diseases. Old-time and new invaders heavily impact planted forests of exotic eucalypts, pines, and acacias, and are spreading quickly across African regions. But many non-native pathogens are recently found affecting important indigenous trees. We describe the threat to African trees by providing an overview of highly relevant insect pests and diseases of indigenous and exotic trees in Africa, and discuss implications for management and future research. The implementation of an integrated and globally coordinated approach based on improved biosecurity, biological control, and tree resistance would contribute to mitigate the potentially devastating impact of these invasions on African natural resources.

KEYWORDS

Africa, agroforestry, forest health, integrated pest management, invasive species

1 | TREES ARE CRUCIAL FOR AFRICA'S FUTURE

Natural and agroecosystems of the African continent are expected to be intensely vulnerable to climate change (Wheeler & Von Braun, 2013). This may impact particularly Sub-Saharan countries, with negative cascading effects for land management and ecosystem health, food availability, and rural livelihoods (Müller, Waha, Bondeau, & Heinke, 2014; Schlenker & Lobell, 2010; Wheeler & Von Braun, 2013).

Trees, both in forests and on cropland in agroforestry settings, will play a pivotal role in the resilience and adaptation of African landscapes to these changes. Forests and tree cover on agricultural land have a vital function for the mitigation of climatic variations and carbon storage (Albrecht & Kandji, 2003; Bonan, 2008; Zomer et al., 2016). The overall forest cover in Africa is shrinking at the rate of almost 0.5% annually, due to deforestation of natural forests (FAO, 2015). Planted forests, which include production plantations, afforestation, and agroforestry, are however growing 1.3% annually, thus helping to partially reduce the overall loss of tree cover and carbon stock (FAO, 2015). The ecological and socioeconomic benefits from natural and planted forests will be increasingly crucial for Africa's capacity to face ecological and socioeconomic changes (Evans & Turnbull, 2004; Shackleton, Shackleton, Buiten, & Bird, 2007). In particular, agroforestry provides a variety of ecosystem services to smallholders in marginal lands. Planting trees moderates the effects of climatic extremes and plant pests on crops, reduces soil degradation and deforestation, and provides farmers with food, firewood, and timber (Mbow et al., 2014; Verchot et al., 2007).

In addition to trees in natural forests, both indigenous and introduced tree species are widely planted in forestry and agroforestry settings, and are crucial for the preservation of tree cover in Africa (Bennet & Kruger, 2013; Leakey et al., 2012). *Eucalyptus*, *Pinus*, *Cupressus*, and *Acacia* spp. are among the non-indigenous trees dominating industrial plantation forestry across the continent (Evans & Turnbull, 2004), while the silk tree *Grevillea robusta* (Proteaceae) is an example of an important non-indigenous tree used in small plantations and farms (Booth & Ekeleme, 2002). Indigenous African trees contribute immensely to the continent, and global, biodiversity. Africa counts some 4,500–6,000 tree species, of which 800 are documented to contribute significantly to food security (Linder, 2014; Slik et al., 2015; UNEP, 2008). The conservation of these resources will be crucial for Africa's future.

2 | BIOLOGICAL INVASIONS AND THE THREAT TO AFRICAN ECOSYSTEMS

The introduction and establishment of non-native invasive organisms are increasing globally, showing no saturation (Seebens et al., 2017), facilitated by accelerating global trade and amplified by climatic variations (Hellmann, Byers, Bierwagen, & Dukes, 2008; Meyerson & Mooney, 2007; Westphal, Browne, MacKinnon, & Noble, 2008). The spread of invasives in newly colonized regions reduces habitat biodiversity, disrupts ecosystem functioning, and harms economic development (Simberloff et al., 2013; Walsh, Carpenter, & Vander Zanden, 2016). Invasive plant pathogens and herbivorous arthropods in particular pose a devastating threat to the integrity of natural habitats, the productivity of agricultural commodities, and the sustainability of rural economies (Fisher et al., 2012; Lovett et al., 2016).

The global spread of tree pests and diseases of both natural and planted forests is also on the rise (Boyd, Freer-Smith, Gilligan, & Godfray, 2013; Wingfield, Brockerhoff, Wingfield, & Slippers, 2015). In the United States, for instance, around 400 forest insect pests were detected during 1860 to 2006 (Aukema et al., 2010). In Europe, over 100 non-native tree pathogens were introduced in the period 1800 to 2009 (Santini et al., 2013). These introductions have the potential to trigger deep effects on ecosystem functioning and services linked to tree-based landscapes (Boyd et al., 2013; Ghelardini et al., 2017; Kenis et al., 2009). Major recent examples are the unprecedented devastation of ash trees in the North American natural and urban forests by the non-native emerald ash borer *Agrilus planipennis* (Herms & McCullouhg, 2014), the widespread mortality of European ash *Fraxinus excelsior* by the ash dieback fungus *Hymenoscyphus fraxineus*, that is threatening to functionally remove the tree from landscapes (Burokiene et al., 2015), and the wave of native and non-native arthropods and pathogens that are compromising the productivity of eucalypt plantations in its non-native range, particularly in Africa (Burgess & Wingfield, 2016; Hurley et al., 2016; Wingfield et al., 2008).

Africa is increasingly susceptible to biological invasions (Paini et al., 2016; Pratt, Constantine, & Murphy, 2017). Due to vulnerable agroecosystems, weak cross border biosecurity, and limited intervention capacity, low-income countries are more prone to suffering serious impacts from biological invasions (Early et al., 2016). The accelerating introduction and spread of non-native and highly destructive arthropods and pathogens are triggering economic emergencies and local food crises. The newly introduced fall armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae), for example, is devastating maize resources in numerous African countries just 2 years following detection (Nagoshi et al., 2018). The cumulative economic impact of invasives in Africa is expected to exceed 1.2 billion dollars per year (Pratt et al., 2017). Considering recent and imminent introductions this prediction may be underestimated, and the total invasion cost as proportion of gross domestic product (GDP) for many African countries is among the highest globally (Paini et al., 2016). This raises the stakes for developing locally appropriate management strategies across the continent.

Cultivation of important indigenous and introduced tree species in Africa is being increasingly targeted by new and old-time invaders, which are locally disrupting the sustainability of plantation forestry, frustrating the benefits of agroforestry, and threatening the continent's biodiversity (Crous et al., 2017; FAO, 2009a; Nair, 2001; Schroth, Krauss, Gasparotto, Aguilar, & Vohland, 2000; Speight, 2014; Wingfield et al., 2008). This highlights the urgency for coordinating efforts to limit accidental introduction of these organisms and

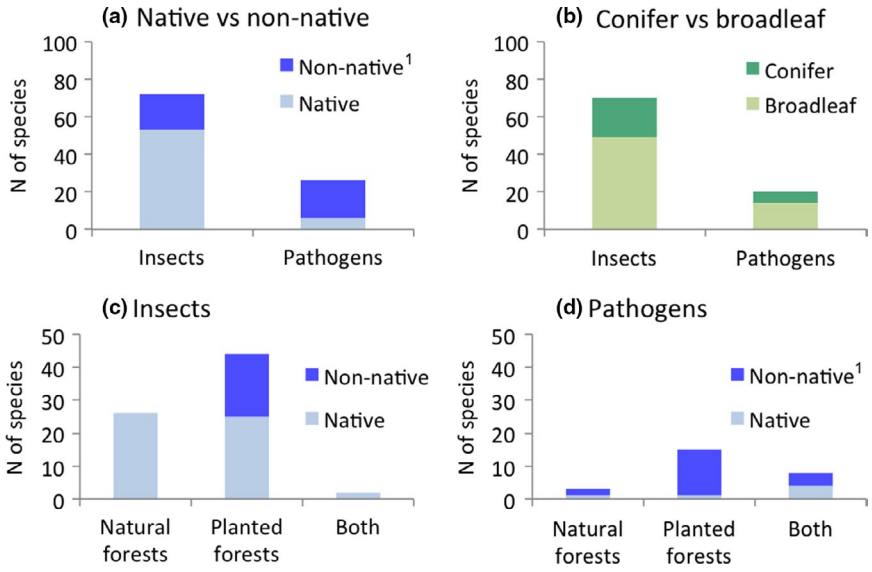

FIGURE 1 Overview of pests and diseases of natural and planted forests reported in Africa: (a) native and non-native insects and pathogens; (b) native and non-native insects and pathogens affecting conifer and broadleaf tree host; (c) native and non-native insects; and (d) pathogens targeting natural or planted forests, or both types FAO (2009a), FAO (2009b). [1]Includes pathogens of unknown origin. (Source: FAO (2009a, 2009b))

mitigate their impact (Wingfield et al., 2015). We sought to provide an overview of emerging insects and pathogens targeting trees in Africa, discuss implications for further studies and management, and raise awareness about this threat for the conservation of indigenous and introduced trees in Africa.

3 | INSECT PESTS AND PATHOGENS OF AFRICA'S TREES

Numerous native and non-native species of herbivorous insects and pathogenic microorganisms are reported to be harming indigenous and exotic trees in plantations, natural forests, and agroforestry systems across Africa. The Food and Agriculture Organization of the United Nations (FAO) (2009a, 2009b) report approximately 100 species of insects and pathogens affecting trees in planted and natural forests across northern, western, eastern, central, and southern African countries (Ghana, Kenya, Malawi, Mauritius, Morocco, South Africa, Sudan). Only half of these species are identified as native organisms, while over one third are non-native invaders, and 15% are of unknown origin. Non-native species represent over one third of insects known to damage trees, while almost two thirds of pathogens are non-native or of unknown origin (Figure 1). Broadleaf trees are affected the most, with only one third of insect and pathogen species attacking conifers. This pattern reflects the composition of native flora, constituted for the majority of broadleaves and with numerous conifers introduced as exotic plantation trees (Craib, 1947). Introduced pests and diseases are targeting for the majority planted forests, with approximately 90% of pathogens of plantation forestry being non-native or of uncertain origin. In the last few decades, new invaders have become established and spread across African landscapes, adding to the damage caused by old invaders and natives to natural and planted forests, and to indigenous and introduced tree species. The number of pests and diseases targeting plantation forestry is substantial. Over 47 native and 19 non-native defoliators, sap-feeders, wood, and shoot borers are harming *Acacia mearnsii* (Fabaceae), *Eucalyptus* spp. (Myrtaceae), *Pinus* spp. (Pinaceae) and teak tree, *Tectona grandis* (Lamiaceae), plantations (Hurley, Slippers, Sathyapala, & Wingfield, 2017), while 15 species of pathogens are described to cause major damage to eucalypts (Wingfield et al., 2008).

We collected information on native and non-native insect pests and pathogens of trees reported in Africa using available reviews (FAO, 2009a, 2009b; Hurley et al., 2017; Nair, 2001; Roux et al., 2005; Wingfield et al., 2008), recent reports (Gichora, Kojwang, & Bosu, 2017), and invasive species compendiums to determine geographical distribution and to access additional literature (CABI, 2018; EPPO, 2014). We seek to present here a near-exhaustive updated overview of highly significant arthropods and microorganisms affecting trees in Africa based on ecological or economic impact, widespread occurrence, or recent detection.

3.1 | Native insects

An updated list of relevant native insect pests reported on indigenous and exotic trees is presented in Table 1. Coleopteran stem and seed borers, lepidopteran defoliators, stem and shoot borers, and sap-feeding hemipterans are the major groups of native pests, with several taxa affecting important indigenous trees. Among coleopterans, the seed borer *Bruchidius uberatus* (Coleoptera: Bruchidae) is a relevant pest of *Vachellia* (=*Acacia*) species (Fabaceae), and the stem borer *Sphenoptera chalcichroa* (Coleoptera: Buprestidae) is damaging *Vachellia nilotica*, an important tree of South African savannah (Atta, 1988; Delobel, 2015). The productivity of West African indigenous timber trees *Triplochiton scleroxylon* (Malvaceae), and African teak *Milicia excelsa* and *M. regia* (Moraceae), is affected by native psyllids *Diclidophlebia eastopi*, *Phytolyma fusca* (African teak gall bug), and *P. lata* (Iroko gall bug) (Hemiptera: Psyllidae), respectively (Bosu, Cobbinah, Nichols, Nkrumah, & Wagner, 2006; Ugwu & Omoloye, 2014; Wagner, Cobbinah, & Bosu, 2008a; Youmbi, Yana, & Tamesse, 2014). Among lepidopterans, the shoot borer *Orygmophora mediofoveata* (Lepidoptera: Noctuidae) is

TABLE 1 Native insect pests of indigenous and exotic trees in natural and planted forests (including agroforestry) reported in Africa

Species	Common name	Damage[a]	Tree host[b]	Host	Distribution[c]
Coleoptera					
Bruchidius uberatus	Seed beetle	SE	I	*Vachellia* spp.	Widespread
Sphenoptera chalcichroa	Silver tree borer	ST	I	*Vachellia nilotica*, *V. arabica*	SU
Analeptes trifasciata	Long-horned beetle	ST	I, N	*Tectona grandis*, *Adansonia digitata*, *Eucalyptus* spp.	W Africa
Apate monachus	Black borer	ST	I, N	*Azadirachta indica*, *Terminalia* spp., others	Widespread
Apate terebrans	Shot hole borer	ST	I, N	*Tectona grandis*, *Terminalia*, *Khaya*, *Eucalyptus* spp.	BE, GH, ZM
Caryedon serratus	Tamarind seed beetle	SE	I, N	*Vachellia*, *Acacia*, *Tamarindus* spp., others	Widespread
Ellimenistes laesicollis	(Weevil)	DE	I, N	*Eucalyptus* spp., *Grevillea robusta*, *others*	SA
Hypopholis sommerii	Wattle chafer	DE	I, N	*Acacia mearnsii*, *Eucalyptus*, *Pinus* spp.	SA
Platypus cylindrus	Cork oak ambr. beetle	ST	I, N	*Quercus suber*	AL
Sphenoptera fulgens	Root-boring beetle	ST	I, N	*Prosopis chilensis*, others	SU
Chaetastus tuberculatus	(Ambrosia beetle)	ST	N	*Eucalyptus* spp.	GH
Colasposoma spp.	(Leaf beetle)	D	N	*Acacia mearnsii*, *Eucalyptus*, *Pinus* spp.	SA
Doliopygus spp.	(Ambrosia beetle)	ST	N	*Tectona grandis*, *Eucalyptus* spp.	GH
Hypothenemus spp.	(Bark beetle)	ST	N	*Tectona grandis*	GH
Monochelus calcaratus	Wattle chafer	DE	N	*Acacia mearnsii*	SA
Oemida gahani	(Long-horned beetle)	ST	N	*Cupressus*	W Africa, KE
Platypus lintzi	(Ambrosia beetle)	ST	N	*Eucalyptus* spp.	GH
Xyleborus perforans	Island pinhole borer	ST	N	*Eucalyptus* spp.	GH
Hemiptera					
Diclidophlebia eastopi	(Psyllid)	SP	I	*Triplochiton scleroxylon*	W Africa
Phytolyma fusca	African teak gall bug	SP	I	*Milicia excelsa*	W Africa
Phytolyma lata	Iroko gall bug	SP	I	*Milicia regia*	W Africa
Helopeltis anacardii	(Mirid)	SP	N	*Eucalyptus spp.*	MW
Lygidolon laevigatum	Black wattle mirid	SP	N	*Acacia mearnsii*	SA
Parasaissetia nigra	Black scale	SP	N	*Eucalyptus spp.*	GH
Planococcoides njalensis	Cocoa mealybug	SP	N	*Tectona grandis*	GH
Saissetia coffeae	Hemispherical scale	SP	N	*Eucalyptus* spp.	GH
Isoptera					
Various Isoptera spp.	Termites	WO	I, N	*Acacia*, *Eucalyptus*, *Cupressus* spp.	SU, others
Lepidoptera					
Anaphe venata	African silk moth	DE	I	*Triplochiton scleroxylon*	GH, NI
Lamprosema lateritialis	Leaf tying moth	DE	I	*Pericopsis elata*	GH, MW
Operophtera brumata	Winter moth	DE	I	*Quercus afares*	AL, TU
Orygmophora mediofoveata	Shoot borer	SH	I	*Nauclea diderrichii*	W Africa
Diacrisia spp.	(Tiger moth)	DE	I, N	*Tectona grandis*, *Eucalyptus* spp., *others*	GH
Gonometa podocarpi	Wild silkmoth	DE	I, N	*Podocarpus*, *Cupressus*, *Pinus*, *Acacia*, *Eucalyptus*	E Africa

(Continues)

TABLE 1 (Continued)

Species	Common name	Damage[a]	Tree host[b]	Host	Distribution[c]
Hypsipyla robusta	Mahogany shoot borer	SH	I, N	*Khaya*, *Entandrophragma*, *Eucalyptus* spp.	E Africa, W Afr.
Thaumetopoea pityocampa	Processionary moth	DE	I, N	*Pinus* spp.	N Africa
Achaea lienardi	(Erebid moth)	DE	N	*Acacia mearnsii*	SA
Ascotis selenaria	Giant looper	DE	N	*Eucalyptus* spp., *Tectona grandis*	GH, NI
Biston (*Buzura*) spp.	(Looper)	DE	N	*Eucalyptus* spp.	S Africa
Chaliopsis junodi	Wattle bagworm	DE	N	*Acacia mearnsii*	SA
Cleora herbuloti	Pine looper	DE	N	*Eucalyptus*, *Pinus* spp.	SA
Coryphodema tristis	Quince borer	ST	N	*Eucalyptus nitens*, *Malus domestica*, others	SA
Euproctis spp.	(Tussock moth)	DE	N	*Acacia mearnsii*, *Eucalyptus*, *Pinus* spp.	GH, SA
Gynanisa maia	Speckled emper. moth	DE	N	*Acacia mearnsii*	SA
Holocerina smilax	(Emperor moth)	DE	N	*Pinus* spp.	SA
Imbrasia spp.	(Emperor moth)	DE	N	*Acacia mearnsii*, *Eucalyptus*, *Pinus* spp.	SA
Narosa viridana	(Slug caterpillar moth)	DE	N	*Eucalyptus* spp.	ZM
Neocleosa spp.	(Looper)	DE	N	*Eucalyptus* spp.	S Africa
Orgyia basali	(Tussock moth)	DE	N	*Tectona grandis*, *Eucalyptus* spp.	GH, NI
Eutricha capensis	Cape lappet moth	DE	N	*Acacia mearnsii*, *Eucalyptus*, *Pinus* spp.	SA
Pseudobunaea irius	(Emperor moth)	DE	N	*Acacia mearnsii*, *Eucalyptus*, *Pinus* spp.	SA
Strepsicrathes rhothia	(Tortricid moth)	DE	N	*Eucalyptus* spp.	GH
Thaumetopoea wilkinsoni	Processionary moth	DE	N	*Pinus*, *Cedrus* spp.	N Africa
Xanthisthisa tarsispina	Pine looper	DE	N	*Pinus* spp.	MW
Orthoptera					
Anacridium melanorhoden	Sahelian tree locust	DE	I	*Acacia senegal*; *Balanites aegyptiaca*, others	SE
Manowia spp.	(Eumastacidae grass-hop.)	DE	N	*Pinus* spp.	MW
Phymateus kazschi	(Milkweed locust)	DE	N	*Eucalyptus* spp.	GH, NI

Note: Species are arranged by insect order and origin of tree hosts (indigenous, introduced, or both). We included common name of insect species, when available, or common names of species' taxonomic group (subfamily, family, or order), in parenthesis. Sources: Nair (2001), FAO (2009a, 2009b), Gichora et al. (2017), Hurley et al. (2017), and additional sources as included in the text.

[a]Damage: ST = stem borer, SE = seed borer, SP = sap feeder, DE = defoliator, SH = shoot borer, WO = wood feeder.

[b]Tree host: I = indigenous, N = introduced (exotic).

[c]Distribution: C Africa = Central Africa, E Africa = Eastern Africa, N Africa = Northern Africa, S Africa = Southern Africa, W Africa = Western Africa, widespread = present in Northern, Eastern, Western, Central and Southern Africa, AL = Algeria, BE = Benin, GH = Ghana,, MW = Malawi, NI = Nigeria, SA = South Africa, SE = Senegal, SU = Sudan, TU = Tunisia, ZM = Zambia.

a significant pest that complicates cultivation of West African timber tree *Nauclea diderrichii* (Rubiaceae), targeting young trees and seedlings in nurseries (Bosu, Acquah, & Boamah, 2018). The defoliator *Lamprosema lateritialis* (Lepidoptera: Pyralidae) is a major forest pest in Ghana and Malawi, where it causes seedling mortality on *Pericopsis elata* (Fabaceae), an endangered tree species (Atuahene & Doppelreiter, 1982; IUCN, 2018; Wagner, Cobbinah, & Bosu, 2008b).

Numerous native insect species known as pests of indigenous trees are reported to widen their host range and cause damage to exotic trees. Long-horned beetles such as stem girdlers *Analeptes* and *Paranaleptes* spp. (Coleoptera: Cerambycidae) can cause severe damage to a wide range of indigenous trees including baobab *Adansonia digitata* and *Bombax costatum* (Malvaceae), as well as non-indigenous teak tree *T. grandis*, eucalypts, and cashew, *Anacardium occidentale* (Anacardiaceae) (Asogwa, Ndubuaku, & Hassan, 2011; Jones, 1961; Lyimo, 2017). Another native coleopteran, *Apate monachus* (Coleoptera: Bostrichidae), is a common borer affecting indigenous *Terminalia* spp. (Combretaceae) and

exotic neem tree *Azadirachta indica* (Meliaceae), while congeneric *A. terebrans* inflicts severe damage to African mahogany *Khaya* spp. (Meliaceae), and cultivated teak and eucalypts (Agboton et al., 2017; Becker, 1980). The quince borer *Coryphodema tristis* (Lepidoptera: Cossidae) is a wood borer with a wide range of native hosts, but has recently become a major pest of eucalypt plantations in South Africa (Adam, Mutanga, & Ismail, 2013). The wattle mirid *Lygidolon laevigatum* (Hemiptera: Miridae) is a major pest of the exotic black wattle, *Acacia mearnsii* (Fabaceae) in forestry plantations in South Africa, where it causes irregular branching and defoliation (Govender, 2002; Ingham, Samways, & Govender, 1998). Termites feed on wood within the wood-soil interface, and various species can locally cause severe damage to young plantings of several indigenous and exotic trees (Ambele, Bisseleua Daghela, Babalola, & Ekesi, 2018).

3.2 | Non-native insects

Numerous non-native tree pests of plantation forestry trees have invaded Africa in the past 100 years, and the accumulation of invaders has progressively increased in the last few decades (Table 2). Eucalyptus long-horned borers *Phoracantha semipunctata* and *Phoracantha recurva* (Coleoptera: Cerambycidae) are two stem borers introduced in the early 1900s in South Africa, and currently impacting eucalypt production in northern and southern African countries (Paine, Steinbauer, & Lawson, 2011). The Eucalyptus snout beetle *Gonipterus scutellatus*, the deodar weevil *Pissodes nemorensis* (Coleoptera: Curculionidae), and the teak defoliator *Hyblaea puera* (Lepidoptera: Hyblaeidae) are also historic invaders; detected in South Africa in the first half of the 20th century quickly established as important pests for eucalypts, pines, and teak, respectively (Gebeyehu & Wingfield, 2003; Hurley et al., 2017; Newete, Oberprieler, & Byrne, 2011). Non-native aphids are major pests of exotic conifers in Africa (Hemiptera: Aphididae). The pine woolly aphid *Pineus pini* and the pine needle aphid *Eulachnus rileyi* where introduced several decades ago and then spread to most regions of the continent, while the distribution of black pine aphid *Cinara cronartii* is still limited to southern Africa (Day et al., 2003; Odendaal, 1980; Zwolinski, 1990). The cypress aphid *Cinara cupressi* was introduced some 30 years ago and currently occurs in all the main cypress-growing areas, reducing the productivity of exotic cypress plantations, but also affecting native African cedar *Juniperus procera* (Cupressaceae), which natural populations in native range are declining (IUCN, 2018; Watson, Voegtlin, Murphy, & Foottit, 1999).

The wood borer *Sirex noctilio* (Hymenoptera: Siricidae), a global pest of *Pinus* spp. native to Europe, Asia, and Mediterranean Africa, was accidentally introduced and detected in South Africa in 1994, where it caused a major outbreak and tree mortality in pine plantations (Tribe & Cillié, 2004). Five new non-native pests feeding on eucalypt leaves, which included three hemipterans and two hymenopteran gall makers, were introduced from Australia to South Africa since 2002 (Bush et al., 2016). The shell lerp psyllid *Spondyliaspis* cf. *plicatuloides* (Hemiptera: Psyllidae) is the most recent of those invaders, and is currently reported in other countries (Bush et al., 2016). Following detection, the red gum lerp psyllid *Glycaspis brimblecombei* and the bronze bug *Thaumastocoris peregrinus* (Hemiptera: Thaumastocoridae) spread quickly, colonizing other countries in southern and northern Africa the former, and in southern and Eastern Africa the latter (Attia & Rapisarda, 2014; Ndela, Manyangadze, Sachisuko, Lingen, & Makowe, 2018; Saavedra, Avila, Withers, & Holwell, 2015). A similar pattern of invasion is observed for the gall makers blue gum chalcid *Leptocybe invasa* and Eucalyptus gall wasp *Ophelimus maskelli* (Hymenoptera: Eulophidae). Within a few years from first introduction to the continent, *O. maskelli* was detected in Algeria, Morocco, and Tunisia, and *L. invasa* spread to several countries in northern and Eastern Africa (Asfaw, 2018; Nyeko, Mutitu, Otieno, Ngae, & Day, 2010).

3.3 | Pathogens

Microbial pathogens of trees are increasingly affecting the health of natural and planted forests in the continent, with well-known diseases and multiple recent detections of new species in the continent (Table 3). While in many cases it is not always possible to determine the geographic origin of these organisms due to their cryptic nature, non-native pathogens have a long history in the continent. *Armillaria* root rot pathogens were introduced by early settlers in South Africa with potted plants from Europe in the 1600s (Coetzee et al., 2001). The disease was first observed decimating planted pine and eucalypt in the early 1900s and later in Eastern Africa, but is now impacting native plants in woody landscapes in South Africa and Ethiopia (Coetzee, Wingfield, & Wingfield, 2018; Gezahgne, Coetzee, Wingfield, Wingfield, & Roux, 2004; Gibson, 1960). Eucalypts are hosts of several global plant pathogens. Anthracnose caused by *Colletotrichum* spp., including widespread *C. gloeosporioides*, are a problem in eucalypt plantations and nurseries as they have wide host ranges including several fruit trees for which they are known to cause post harvest disease (Mangwende, Aveling, & Chirwa, 2018). Root rots and blights caused by *Phytophthora* spp. are an important group of emerging pathogens, as they are one of the major sources of damage to plantations and can affect indigenous trees. *Phytophthora cinnamomi* causes root rot of eucalypts in South Africa and Kenya, and basal canker of *A. mearnsii* in South Africa, but also impacts natural vegetation, such as native Proteaceae of South Africa (Brasier, 2000; Nagel, Gryzenhout, Slippers, & Wingfield, 2013). Recent surveys show an incredible diversity of *Phytophthora* taxa in the country, suggesting an imminent threat to natural ecosystems (Oh, Gryzenhout, Wingfield, Wingfield, & Burgess, 2013).

Following a similar trend to the one described for some insect pests, many pathogens of *Eucalyptus* spp. are discovered and described in important eucalypt producing countries, then are later found in other African countries. The canker causing pathogen *Teratosphaeria zuluense* was detected in South Africa and later reported also from East Africa (Gezahgne, Cortinas, Wingfield, &

TABLE 2 Non-native insect pests of indigenous and exotic trees in natural and planted forests (including agroforestry) reported in Africa

Species	Common name	Damage[a]	Year detection	Tree host[b]	Host	Distribution[c]
Coleoptera						
Hylurgus ligniperda	Red-haired p. bark beetle	ST	1885	N	*Pinus* spp.	SA
Phoracantha semipunctata	Eucalyptus long-horn. bor.	ST	1906	N	*Eucalyptus* spp.	N Africa, S Africa
Phoracantha recurva	Lesser Euc. long-horn. bor.	ST	1906	N	*Eucalyptus* spp.	N Africa, S Africa
Gonipterus scutellatus	Eucalyptus snout beetle	DE	1916	N	*Eucalyptus* spp.	E Africa, S Africa
Hylastes angustatus	Pine bark beetle	ST	1930	N	*Pinus* spp.	SA
Pissodes nemorensis	Deodar Weevil	DE	1942	N	*Pinus* spp.	SA
Orthotomicus erosus	Mediterr. pine engraver	ST	1968	N	*Pinus* spp.	SA
Trachymela tincticollis	Eucalyptus tortoise beetle	DE	1982	N	*Eucalyptus* spp.	SA
Hemiptera						
Ctenarytaina eucalypti	Blue gum psyllid	SP	1958	N	*Eucalyptus* spp.	KE, SA
Pineus pini	Pine woolly aphid	SP	1960s	N	*Pinus* spp.	E, N, S Africa
Pineus boerneri	Pine woolly aphid	SP	1960s	N	*Pinus* spp.	E Africa, S Africa
Eulachnus rileyi	Pine needle aphid	SP	1970s	N	*Pinus* spp.	C, E, N, S Africa
Cinara cronartii	Black pine aphid	SP	1974	N	*Pinus* spp.	SA
Aonidiella orientalis	Oriental yellow scale	SP	1985	N	*Azadirachta indica*	W Africa
Cinara cupressi sensu lato	Cypress aphid	SP	1986	I, N	*Cupressus*, *Juniperus* spp.	C, E, N, S Africa
Heteropsylla cubana	Leucaena psyllid	SP	1992	N	*Leucaena*, *Mimosa* spp.	E, N, S, W Africa
Thaumastocoris peregrinus	Bronze Bug	SP	2003	N	*Eucalyptus* spp.	E, S Africa
Blastopsylla occidentalis	Eucalyptus psyllid	SP	2006	N	*Eucalyptus* spp.	SA
Glycaspis brimblecombei	Red gum lerp psyllid	SP	2012	N	*Eucalyptus* spp.	N, S Africa
Spondyliaspis cf. plicatuloides	Shell lerp psyllid	SP	2014	N	*Eucalyptus* spp.	SA
Hymenoptera						
Sirex noctilio	Sirex Woodwasp	WB	1994	N	*Pinus* spp.	N Africa, S Africa
Leptocybe invasa	Blue gum chalcid	GM	2000	N	*Eucalyptus* spp.	E, N, S Africa
Ophelimus maskelli	Eucalyptus gall wasp	GM	2002	N	*Eucalyptus* spp.	N, S Africa
Lepidoptera						
Hyblaea puera	Teak defoliator	DE	Old invader	N	*Tectona grandis*	E Africa, S Africa

Note: Species are arranged by insect order and then chronologically by year of detection. Sources: Nair (2001), Wingfield et al. (2008), FAO (2009a, 2009b), Gichora et al. (2017), Hurley et al. (2017), CABI (2018) and EPPO (2014), and additional sources as included in the text.

[a]Damage: ST = stem borer, SE = seed borer, SP = sap feeder, DE = defoliator, WB = wood borer, GM = gall maker.

[b]Tree host: I = indigenous, N = introduced (exotic).

[c]Distribution: C Africa = Central Africa, E Africa = Eastern Africa, N Africa = Northern Africa, S Africa = Southern Africa, W Africa = Western Africa, SA = South Africa.

Roux, 2005). The agent of pink disease *Erythricium salmonicolor* was first described in Ethiopia on Eucalypt, then appeared in South Africa where it is now infecting indigenous forest trees including native conifer *Podocarpus* spp. (Podocarpaceae), and *Ekebergia capensis* (Meliaceae) (Roux & Coetzee, 2005). Similarly, the canker pathogen *Chrysoporthe* spp. was first reported on Eucalyptus in South Africa, now are occurring in many countries, also affecting indigenous *Syzygium* trees (Nakabonge, Roux, Gryzenhout, & Wingfield, 2006).

Africa is also affected by global pathogens of *Pinus* spp. (Burgess & Wingfield, 2001). The agent of Sphaeropsis blight and cankers *Diplodia sapinea* was reported some 100 years ago, but is still a major threat to pine health, and able to infect other *Cupressus* spp. (Bihon, Slippers, Burgess, Wingfield, & Wingfield, 2012; Linde, Kemp, & Wingfield, 1997; Swart, Knox-Davies, & Wingfield, 1985). The agent of pitch canker *Fusarium circinatum* is among the recent invaders: detected in South Africa in 1990 affecting pine seedlings in nurseries, it caused an outbreak in pine plantation 10 years ago, and is now spreading in the country (Coutinho, Steenkamp, Mongwaketsi, Wilmot, & Wingfield, 2007). The white rot fungus *Amylostereum areolatum* is a symbiont of the wood wasp *S. noctilio*, and was introduced with its insect vector to South Africa, where it causes extensive damage to pine stands in combination with the wood wasp (Slippers, Wingfield, Coutinho, & Wingfield, 2001).

The ascomycete family Botryosphaeriaceae contains a group of relevant emerging diseases in the continent, with several species involved in novel disease complexes. *Lasiodiplodia theobromae* is a long-time known native pathogen, producing cankers on many indigenous species and eucalypts (Mohali, Burgess, & Wingfield, 2005; Roux, Coutinho, Byabashaija, & Wingfield, 2001). Non-native Botryosphaeriaceae species are causing stem cankers of *Eucalyptus* (Gezahgne, Roux, Slippers, Wingfield, & Hare, 2004; Roux et al., 2005; Slippers et al., 2004) and two other species are associated with stem cankers and major dieback to the silk tree *G. robusta* in East Africa (Njuguna et al., 2011). Some Botryosphaeriaceae species are latent pathogens infecting a wide range of hosts from planted *Pinus* spp. to indigenous Acacia and others, thus raising concerns on imminent diseases of important indigenous species caused by Botryosphaeriaceae (Jami, Slippers, Wingfield, & Gryzenhout, 2012; Jami, Wingfield, Gryzenhout, & Slippers, 2017). Dieback of large baobab trees was recently reported from southern Africa: various microorganisms were described to be associated with symptoms, but the causes are still uncertain (Cruywagen, Crous, Roux, Slippers, & Wingfield, 2015; Cruywagen, Slippers, Roux, & Wingfield, 2017).

4 | IMPLICATIONS, MANAGEMENT, AND FUTURE DIRECTIONS

Indigenous and exotic trees in Africa are affected by a multitude of native and non-native insect pests and microbial pathogens, with detrimental consequences for African natural and planted forests, agroecosystems, and rural communities (Crous et al., 2017; FAO, 2009a; Gichora et al., 2017; Hurley et al., 2017; Roux et al., 2005; Wingfield et al., 2015). The rate of introduction of non-natives is increasing (Figure 2). This should be considered as an emergency that adds to the effects of climate change on the continent, and calls for strategies that provide smallholders and land managers with tools to mitigate such impact quickly, and ultimately preserve the productivity of natural resources (Challinor, Wheeler, Garforth, Craufurd, & Kassam, 2007; Lobell et al., 2008). The effects of climate change on

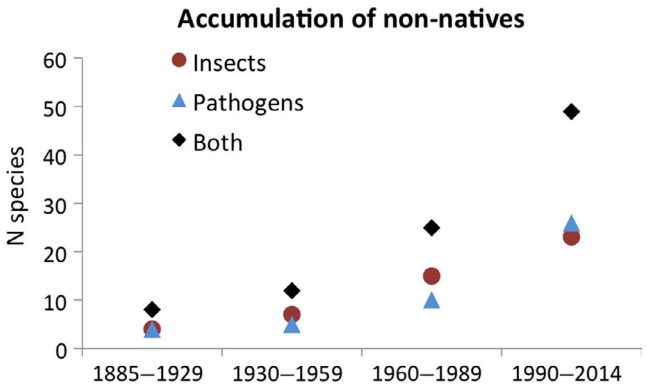

FIGURE 2 Cumulative detections of established non-native pests and diseases (and both) of natural and planted forests in Africa for the years 1900–2013. We considered detections of non-native species (or species of unknown origin) presented in Tables 2 and 3

non-natives' introduction and spread, pests and disease ecology, and ecosystem vulnerability will challenge the ability to predict their impact and implement management programs on the continent (Allen et al., 2010; Anderson et al., 2004; Dukes et al., 2009; Ramsfield, Bentz, Faccoli, Jactel, & Brockerhoff, 2016).

Invasion pathways are shaping the pattern of introduction and spread on the continent and determining taxonomy of plant hosts affected by non-native organisms. South Africa is a major port of entry for many arthropods and pathogens targeting exotic *Eucalyptus*, *Pinus*, and *Acacia* spp. in planted forests. Some non-native Eucalyptus pests are initially established in the southern and then northern part of Africa, but are now colonizing other regions as a result of accidental intracontinental introductions and spread. For instance, the number of Eucalyptus pests introduced to South Africa from other biogeographic regions surpasses the number of Eucalyptus pests introduced elsewhere in Africa (Faulkner, Hurley, Robertson, Rouget, & Wilson, 2017). Faulkner et al. (2017) found that eucalypt pests introduced to South Africa and then spread elsewhere in the continent are more numerous than predicted, and significantly more numerous compared to the number of pests introduced elsewhere in Africa which then spread to South Africa.

The geographic distribution of non-native pests and pathogens detection (Figure 3) may be explained by two main factors. First, the higher capacity of some country-level national plant protection organizations to detect introductions and track the spread of invasives. Secondly, the activity of local plantation forestry sectors might facilitate introductions of pests and diseases of non-indigenous trees through international exchange of improved plant material. This highlights the risk of introducing invasives through forestry and the consequences for management (Burgess & Wingfield, 2016; Wingfield et al., 2015; Wingfield, Roux, Coutinho, Govender, & Wingfield, 2001; Wingfield, Slippers, Roux, & Wingfield, 2001).

Local economic growth and increasing global trade with African countries will likely accelerate the rate of invasions further, while climate change could exacerbate invasibility and impact (Hulme, 2009; Paini et al., 2016). In this scenario, we emphasize the urgent need

TABLE 3 Pathogens of indigenous and exotic trees in natural and planted forests (including agroforestry) reported in Africa

Species	Common name	Damage[a]	Year detection	Tree Host[b]	Host species	Distribution[c]
Ascomycota						
Lasiodiplodia theobromae	-	SB, CA	-	I	*Boswellia*, *Eucalyptus* spp., other	ET, SA, UG
Diplodia sapinea	Sphaeropsis blight	FD, SB, CA	1912	N	*Pinus* spp.	E, S Africa
Aulographina eucalypti	Corky Leaf Spot	FD	1928	N	*Eucalyptus* spp.	KE, SA, ZM
Fairmaniella leprosa	Fairmaniella leaf spot	FD	1928	N	*Eucalyptus* spp.	SA
Mycosphaerella spp.	Mycosphaerella leaf blotch	FD	1935	N	*Eucalyptus* spp.	E, S Africa
Kirramyces epicoccoides	Phaeophleospora leaf spot	FD	1988	N	*Eucalyptus* spp.	KE, SA
Teratosphaeria zuluense	Coniothyrium stem canker	CA	1988	N	*Eucalyptus* spp.	ET, MA, MZ, SA, UG
Chrysoporthe spp.	Chrysoporthe canker	CA	1989?	I, N	*Eucalyptus* spp, *Syzygium cordatum*	KE, MA, MZ, SA
Colletotrichum spp.	Anthracnose	FD	1980s	I, N	*Eucalyptus* spp., Proteaceae, other	ET, SA
Fusarium circinatum	Pitch canker	CA, RR	1990	N	*Pinus* spp.	SA
Cylindrocladium spp.	Cylindrocladium leaf blight	FD	1991	N	*Eucalyptus* spp.	KE, CO, SA
Botryosphaeriaceae spp.	Euc. Botryosphaeria canker	CA	1994	N	*Eucalyptus* spp.	ET, KE, SA, UG
Holocryphia eucalypti	Endothia canker	CA	1993	N	*Eucalyptus* spp.	SA, UG
Ceratocystis fimbriata	Ceratocystis wilt	CA, WI	1998	N	*Eucalyptus* spp.	CO, CT, SA, UG
Ceratocystis spp.	Wattle wilt	CA, WI	1990s	I, N	*Eucalyptus* spp., *Acacia mearnsii*	CO, E, S Africa
Botryosphaeriaceae spp.	Botryosphaeria cankers	CA	2000s	I, N	*Pinus*, *Acacia* spp.	SA
Botryosphaeriaceae spp.	Grevillea stem canker	CA	2001	N	*Grevillea robusta*	KE, UG
Teratosphaeria gauchensis	Eucalyptus stem canker	CA	2013	N	*Eucalyptus* spp.	KE
Basidiomycota						
Armillaria spp., *A. mellea*	Armillaria root rot	RR	1900s	I, N	*Eucalyptus*, *Pinus* spp., other	ET, KE, MA, SA, TA
Erythricium salmonicolor	Pink disease	CA	1993	I, N	*Eucalyptus*, *Acacia*, *Podocarpus*	ET, SA
Quambalaria eucalypti	Quambalaria blight	FD, SB	1993	N	*Eucalyptus* spp.	SA
Amylostereum areolatum	(symbiont of *Sirex noctilio*)	WR	1994	N	*Pinus spp.*	SA
Phakopsora myrtacearum	Eucalyptus rust	FD	2009	N	*Eucalyptus* spp.	KE, MZ, SA
Puccinia psidii	Eucalyptus rust	FD	2013	N	*Eucalyptus* spp., Myrtaceae	KE

(Continues)

TABLE 3 (Continued)

Species	Common name	Damage[a]	Year detection	Tree Host[b]	Host species	Distribution[c]
Oomycota						
Phytophthora cinnamomi	Phytophthora root rot	RR	1980	I, N	*A. mearnsii*, *Eucalyptus*, Proteaceae	KE, SA
Pythium splendens	Pythium root rot	RR	Native[d]	N	*Eucalyptus* spp.	SA
Proteobacteria						
Ralstonia solanacearum	Bacterial canker	CA	2000	N	*Eucalyptus* spp.	SA
Pantoea spp.	Bacterial canker	CA	2001	N	*Eucalyptus* spp.	SA

Note: Organisms are arranged by taxonomic group and then chronologically by year of detection. Sources: Roux et al. (2005), Wingfield et al. (2008), FAO (2009a, 2009b), Gichora et al. (2017), CABI (2018) and EPPO (2014), and additional sources as included in the text.

[a]Damage: CA = canker, DI = dieback, FD = foliar disease (leaf spot, foliar blight, blotch or rust), SB = shoot blight, RR = root rot, WI = wilt, WR = white rot.

[b]Tree host: I = indigenous, N = introduced (exotic).

[c]Distribution: C Africa = Central Africa, E Africa = Eastern Africa, N Africa = Northern Africa, S Africa = Southern Africa, W Africa = Western Africa, widespread = present in Northern, Eastern, Western, Central and Southern Africa, CO = Republic of Congo, CT = Côte d'Ivoire, ET = Ethiopia, KE = Kenya, MA = Madagascar, MZ = Mozambique, SA = South Africa, TA = Tanzania, UG = Uganda, ZM = Zambia.

[d]Detected in 1994.

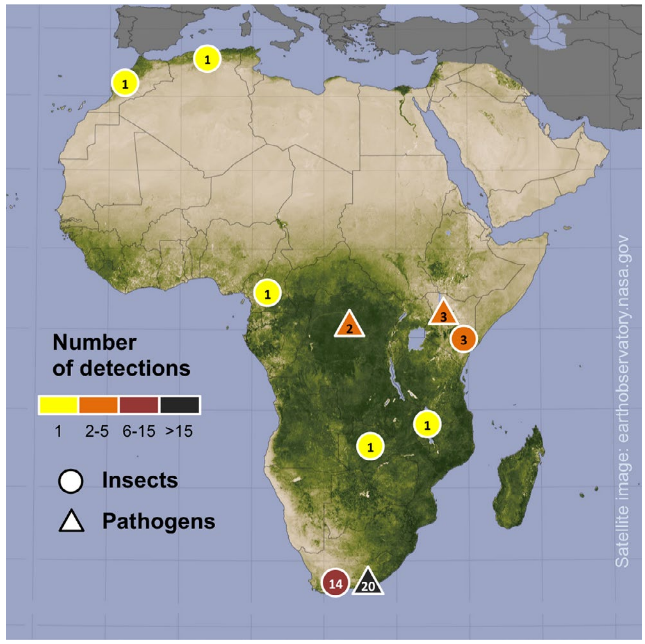

FIGURE 3 Geographic distribution of detections of non-native pests and diseases invading natural and planted forests in Africa. We considered first detections in the African continent of non-native species (or unknown origin) presented in Tables 2 and 3. (Satellite image: Africa vegetation map 2004, https://www.earthobservatory.nasa.gov)

for improving plant biosecurity in Africa and developing effective control options for managing invasives, but efforts require coordination at regional and international level (Burgess, Crous, Slippers, Hantula, & Wingfield, 2016; Wingfield et al., 2015). The reinforcement of phytosanitary barriers at country and regional level through improved diagnostic tools, updated plant exchange regulations, and renewed trade policies will be the key in reducing accidental introduction and spread of invasives, (Mumford, Macarthur, & Boonham, 2016; Robert, Orden, & Josling, 2004; Roy et al., 2014; Wingfield et al., 2015). Because of their cryptic nature and variable lag times, and the limited detection capacity of some countries, numerous non-native pathogenic microorganisms may have been introduced and established without discovery.

Highly efficient and long-term effective management options such as biological control, innovative silviculture practices, and selection of resistant trees could be the answer for mitigating the impact of biotic threats (Garnas, Hurley, Slippers, & Wingfield, 2012; Sollars et al., 2017; Wingfield et al., 2015; Wingfield & Swart, 1994). Biological control has been used successfully against several non-native insects (Garnas et al., 2012), and development of resistant exotic tree clones for forest plantations is promising (Oates, Külheim, Myburg, Slippers, & Naidoo, 2015; Wingfield et al., 2015). Furthermore, the opportunity for managing resistance of indigenous African tree species is worthy of attention. Relevant programs for the conservation of tree germplasm and domestication of indigenous species in Africa have been implemented, and numerous field gene banks of high-priority indigenous trees have

been deployed across African eco-regions (Dawson et al., 2014; ICRAF, 2013). Such programs offer the opportunity to evaluate the susceptibility of multiple provenances of indigenous taxa to pests and pathogens, and represent a very valuable resource for selecting resistant trees. As domestication of indigenous trees for use in agroforestry progresses, resistant varieties could be the right tool to manage emerging pests and pathogens in small plantings and farm settings.

The invasion of African natural and planted forests by biotic threats is a growing emergency of continental scale, with pervasive and long-lasting harmful effects on livelihoods and ecosystems. This is calling for action. There is a compelling need for coordinated responses at continent and international level that aim to reduce the gap in intervention capacity among African countries, consider region-specific ecological differences, and integrate innovative policy, management, and knowledge dissemination tools.

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AUTHORS CONTRIBUTION

I.G. planned and designed the manuscript, prepared tables and images, and led the manuscript preparation, I.G., M.T., J.K. and A.M provided information included in the manuscript and contributed to writing.

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REFERENCES

Adam, E., Mutanga, O., & Ismail, R. (2013). Determining the susceptibility of *Eucalyptus nitens* forests to *Coryphodema tristis* (cossid moth) occurrence in Mpumalanga, South Africa. *International Journal of Geographical Information Science*, *27*(10), 1924–1938. https://doi.org/10.1080/13658816.2013.772183

Agboton, C., Agboton, C., Onzo, A., Korie, S., Tamò, M., & Vidal, S. (2017). Spatial and temporal infestation rates of *Apate terebrans* (Coleoptera: Bostrichidae) in cashew orchards in Benin. *West Africa*. *African Entomology*, *25*(1), 24–36. https://doi.org/10.4001/003.025.0024

Albrecht, A., & Kandji, S. T. (2003). Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems & Environment*, *99*(1–3), 15–27. https://doi.org/10.1016/S0167-8809(03)00138-5

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., … Cobb, N. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management*, *259*(4), 660–684. https://doi.org/10.1016/j.foreco.2009.09.001

Ambele, F. C., Bisseleua Daghela, H. B., Babalola, O. O., & Ekesi, S. (2018). Soil-dwelling insect pests of tree crops in Sub-Saharan Africa, problems and management strategies—A review. *Journal of Applied Entomology*, *142*(6), 539–552. https://doi.org/10.1111/jen.12511

Anderson, P. K., Cunningham, A. A., Patel, N. G., Morales, F. J., Epstein, P. R., & Daszak, P. (2004). Emerging infectious diseases of plants: Pathogen pollution, climate change and agrotechnology drivers. *Trends in Ecology & Evolution*, *19*(10), 535–544. https://doi.org/10.1016/j.tree.2004.07.021

Asfaw, B. A. (2018). First Record of Eucalyptus Gall Wasp (EGW) (*Ophelimus maskelli*) (Ashmead) on *Eucalyptus camaldulensis* in Ethiopia. *International Journal of Agriculture and Forestry*, *8*(2), 112–117.

Asogwa, E. U., Ndubuaku, T. C. N., & Hassan, A. T. (2011). Distribution and damage characteristics of *Analeptes trifasciata* Fabricius 1775 (Coleoptera: Cerambycidae) on cashew (*Anacardium occidentale* Linnaeus 1753) in Nigeria. *Agriculture and Biology Journal of North America*, *2*(3), 421–431. https://doi.org/10.5251/abjna.2011.2.3.421.431

Atta, H. E. (1988). *Sphenoptera chalcichroa arenosa* Ob. (Col., Buprestidae) associated with the die-back of *Acacia nilotica* (L. Willd. ex Del.) in the Sudan. *Journal of Applied Entomology*, *106*(1–5), 350–355. https://doi.org/10.1111/j.1439-0418.1988.tb00603.x

Attia, S. B., & Rapisarda, C. (2014). First record of the red gum lerp psyllid, *Glycaspis brimblecombei* Moore (Hemiptera Psyllidae), in Tunisia. *Phytoparasitica*, *42*(4), 535–539. https://doi.org/10.1007/s12600-014-0391-8

Atuahene, S. K. N., & Doppelreiter, H. (1982). Histopathological observations on *Beauveria bassiana* in larvae of *Lamprosema lateritialis* (Lepid., Pyralidae). *Zeitschrift Für Angewandte Entomologie*, *93*(1–5), 456–463. https://doi.org/10.1111/j.1439-0418.1982.tb03620.x

Aukema, J. E., McCullough, D. G., Von Holle, B., Liebhold, A. M., Britton, K., & Frankel, S. J. (2010). Historical accumulation of nonindigenous forest pests in the continental United States. *BioScience*, *60*(11), 886–897. https://doi.org/10.1525/bio.2010.60.11.5

Becker, G. (1980). Wood damage by *Apate monachus* F. and other bostrichid species in West Africa and its prevention. *Material and Organismen*, *15*(3), 245–249.

Bennett, B. M., & Kruger, F. J. (2013). Ecology, forestry and the debate over exotic trees in South Africa. *Journal of Historical Geography*, *42*, 100–109. https://doi.org/10.1016/j.jhg.2013.06.004

Bihon, W., Slippers, B., Burgess, T., Wingfield, M. J., & Wingfield, B. D. (2012). Diverse sources of infection and cryptic recombination revealed in South African *Diplodia pinea* populations. *Fungal Biology*, *116*(1), 112–120. https://doi.org/10.1016/j.funbio.2011.10.006

Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science*, *320*(5882), 1444–1449. https://doi.org/10.1126/science.1155121

Booth, T. H., & Ekeleme, F. (2002). Identifying climatically suitable areas for growing particular trees in Africa: An example using *Grevillea robusta*. *Agroforestry Systems*, *54*(1), 41–49.

Bosu, P. P., Acquah, E., & Boamah, R. O. (2018). Evaluation of four insecticides to protect *Nauclea diderrichii* (Rubiaceae) seedlings against *Orygmophora mediofoveata* (Lepidoptera: Noctuidae) shoot borer damage. *International Journal of Tropical Insect Science*, *38*(1), 39–45. https://doi.org/10.1017/S1742758417000236

Bosu, P. P., Cobbinah, J. R., Nichols, J. D., Nkrumah, E. E., & Wagner, M. R. (2006). Survival and growth of mixed plantations of *Milicia excelsa* and *Terminalia superba* 9 years after planting in Ghana. *Forest Ecology and Management*, *233*(2–3), 352–357. https://doi.org/10.1016/j.foreco.2006.05.032

Boyd, I. L., Freer-Smith, P. H., Gilligan, C. A., & Godfray, H. C. J. (2013). The consequence of tree pests and diseases for ecosystem

services. *Science*, *342*(6160), 1235773. https://doi.org/10.1126/science.1235773

Brasier, C. M. (2000). The role of *Phytophthora* pathogens in forestsand semi-natural communities in Europe and Africa. In E. M. Hansen and W. Sutton (Eds.), *Phytophthoradiseases of forest trees* (pp. 6–13). Corvallis, OR: Forest Research Laboratory, Oregon State University.

Burgess, T. I., Crous, C. J., Slippers, B., Hantula, J., & Wingfield, M. J. (2016). Tree invasions and biosecurity: Eco-evolutionary dynamics of hitchhiking fungi. *AoB Plants*, *8*, plw076. https://doi.org/10.1093/aobpla/plw076

Burgess, T., & Wingfield, M. J. (2001). Exotic pine forestry in the Southern Hemisphere: A brief history of establishment and quarantine practices. *The Southern African Forestry Journal*, *192*(1), 79–83. https://doi.org/10.1080/20702620.2001.10434137

Burgess, T. I., & Wingfield, M. J. (2016). Pathogens on the move: A 100-year global experiment with planted eucalypts. *BioScience*, *67*(1), 14–25. https://doi.org/10.1093/biosci/biw146

Burokiene, D., Prospero, S., Jung, E., Marciulyniene, D., Moosbrugger, K., Norkute, G., … Schoebel, C. N. (2015). Genetic population structure of the invasive ash dieback pathogen *Hymenoscyphus fraxineus* in its expanding range. *Biological Invasions*, *17*(9), 2743–2756. https://doi.org/10.1007/s10530-015-0911-6

Bush, S. J., Slippers, B., Neser, S., Harney, M., Dittrich-Schröder, G., & Hurley, B. P. (2016). Six recently recorded Australian insects associated with Eucalyptus in South Africa. *African Entomology*, *24*(2), 539–544. https://doi.org/10.4001/003.024.0539

CABI. (2018). *Invasive Species Compendium*, *Open access online resource*. *Centre for Agriculture and Bioscience International*. Retrieved from https://www.cabi.org/ISC/ (accessed 1 Oct 2018).

Challinor, A., Wheeler, T., Garforth, C., Craufurd, P., & Kassam, A. (2007). Assessing the vulnerability of food crop systems in Africa to climate change. *Climatic Change*, *83*(3), 381–399. https://doi.org/10.1007/s10584-007-9249-0

Coetzee, M. P., Wingfield, B. D., Harrington, T. C., Steimel, J., Coutinho, T. A., & Wingfield, M. J. (2001). The root rot fungus *Armillaria mellea* introduced into South Africa by early Dutch settlers. *Molecular Ecology*, *10*(2), 387–396. https://doi.org/10.1046/j.1365-294x.2001.01187.x

Coetzee, M., Wingfield, B., & Wingfield, M. (2018). Armillaria root-rot pathogens: Species boundaries and global distribution. *Pathogens*, *7*(4), 83. https://doi.org/10.3390/pathogens7040083

Coutinho, T. A., Steenkamp, E. T., Mongwaketsi, K., Wilmot, M., & Wingfield, M. J. (2007). First outbreak of pitch canker in a South African pine plantation. *Australasian Plant Pathology*, *36*(3), 256–261. https://doi.org/10.1071/AP07017

Craib, I. J. (1947). The silviculture of exotic conifers in South Africa. *Journal of the South African Forestry Association*, *15*(1), 11–45. https://doi.org/10.1080/03759873.1947.9630547

Crous, C. J., Burgess, T. I., Le Roux, J. J., Richardson, D. M., Slippers, B., & Wingfield, M. J. (2017). Ecological disequilibrium drives insect pest and pathogen accumulation in non-native trees. *AoB Plants*, *9*(1). https://doi.org/10.1093/aobpla/plw081

Cruywagen, E. M., Crous, P. W., Roux, J., Slippers, B., & Wingfield, M. J. (2015). Fungi associated with black mould on baobab trees in southern Africa. *Antonie Van Leeuwenhoek*, *108*(1), 85–95. https://doi.org/10.1007/s10482-015-0466-7

Cruywagen, E. M., Slippers, B., Roux, J., & Wingfield, M. J. (2017). Phylogenetic species recognition and hybridisation in Lasiodiplodia: A case study on species from baobabs. *Fungal Biology*, *121*(4), 420–436. https://doi.org/10.1016/j.funbio.2016.07.014

Dawson, I. K., Leakey, R., Clement, C. R., Weber, J. C., Cornelius, J. P., Roshetko, J. M., … Jamnadass, R. (2014). The management of tree genetic resources and the livelihoods of rural communities in the tropics: Non-timber forest products, smallholder agroforestry practices and tree commodity crops. *Forest Ecology and Management*, *333*, 9–21. https://doi.org/10.1016/j.foreco.2014.01.021

Day, R. K., Kairo, M. T., Abraham, Y. J., Kfir, R., Murphy, S. T., Mutitu, K. E., & Chilima, C. Z. (2003). Biological control of homopteran pests of conifers in Africa. *Biological Control in IPM Systems in Africa*, 101–112. https://doi.org/10.1079/9780851996394.0101

Delobel, A., Le Ru, B., Genson, G., Musyoka, B. K., & Kergoat, G. J. (2015). Molecular phylogenetics, systematics and host-plant associations of the *Bruchidius albosparsus* (Fåhraeus) species group (Coleoptera, Chrysomelidae, Bruchinae) with the description of four new species. *Zootaxa*, *3931*(4), 451–482. https://doi.org/10.11646/zootaxa.3931.4.1

Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N., … Ehrenfeld, J. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research*, *39*(2), 231–248. https://doi.org/10.1139/x08-171

Early, R., Bradley, B. A., Dukes, J. S., Lawler, J. J., Olden, J. D., Blumenthal, D. M., … Tatem, A. J. (2016). Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature Communications*, *7*, 12485. https://doi.org/10.1038/ncomms12485

EPPO (2014). *PQR database*. Paris, France: European and Mediterranean Plant Protection Organization. Retrieved from http://www.eppo.int/DATABASES/pqr/pqr.htm (accessed 20 Sept 18).

Evans, J., & Turnbull, J. W. (2004). *Plantation forestry in the tropics: The role, silviculture, and use of planted forests for industrial, social, environmental, and agroforestry purposes*, 3rd ed. Oxford, UK: Oxford University Press.

FAO (Food and Agriculture Organization of the United Nations). (2015). *Global Forest Resources Assessment 2015: How are the world's forests changing?* 2nd ed. Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations). (2009a). Global review of forest pests and diseases. FAO Forestry Paper, 156, 222 pp, ISBN 978-92-5-106208-1.

FAO (Food and Agriculture Organization of the United Nations). (2009b). Global review of forest pests and diseases. Annex 1: Pest species distribution in the selected countries by region. Retrieved from http://www.fao.org/docrep/011/i0640e/i0640e00.htm

Faulkner, K. T., Hurley, B. P., Robertson, M. P., Rouget, M., & Wilson, J. R. (2017). The balance of trade in alien species between South Africa and the rest of Africa. *Bothalia-African Biodiversity & Conservation*, *47*(2), 1–16. https://doi.org/10.4102/abc.v47i2.2157

Fisher, M. C., Henk, D. A., Briggs, C. J., Brownstein, J. S., Madoff, L. C., McCraw, S. L., & Gurr, S. J. (2012). Emerging fungal threats to animal, plant and ecosystem health. *Nature*, *484*(7393), 186. https://doi.org/10.1038/nature10947

Garnas, J. R., Hurley, B. P., Slippers, B., & Wingfield, M. J. (2012). Biological control of forest plantation pests in an interconnected world requires greater international focus. *International Journal of Pest Management*, *58*(3), 211–223. https://doi.org/10.1080/09670874.2012.698764

Gebeyehu, S., & Wingfield, M. J. (2003). Pine weevil *Pissodes nemorensis*: Threat to South African pine plantations and options for control. *South African Journal of Science*, *99*(11–12), 531–536.

Gezahgne, A., Coetzee, M. P. A., Wingfield, B. D., Wingfield, M. J., & Roux, J. (2004). Identification of the Armillaria root rot pathogen in Ethiopian plantations. *Forest Pathology*, *34*(3), 133–145. https://doi.org/10.1111/j.1439-0329.2004.00352.x

Gezahgne, A., Cortinas, M. N., Wingfield, M. J., & Roux, J. (2005). Characterisation of the *Coniothyrium* stem canker pathogen on *Eucalyptus camaldulensis* in Ethiopia. *Australasian Plant Pathology*, *34*(1), 85–90.

Gezahgne, A., Roux, J., Slippers, B., Wingfield, M. J., & Hare, P. D. (2004). Identification of the causal agent of *Botryosphaeria* stem canker in

Ethiopian Eucalyptus plantations. *South African Journal of Botany*, *70*(2), 241–248. https://doi.org/10.1016/s0254-6299(15)30241-6

Ghelardini, L., Luchi, N., Pecori, F., Pepori, A. L., Danti, R., Della Rocca, G., … Santini, A. (2017). Ecology of invasive forest pathogens. *Biological Invasions*, *19*(11), 3183–3200. https://doi.org/10.1007/s10530-017-1487-0

Gibson, I. A. S. (1960). Armillaria root rot in Kenya pine plantations. *Empire Forestry Review*, 94–99.

Gichora, M., Kojwang, H., & Bosu, P. (2017). The status and trends of forest and tree pests and diseases management in Africa. *African Forest Forum Working Papers*, *3*(3), 1–33.

Govender, P. (2002). Management of insect pests: Have the goalposts changed with certification? *The Southern African Forestry Journal*, *195*(1), 39–45. https://doi.org/10.1080/20702620.2002.10434602

Hellmann, J. J., Byers, J. E., Bierwagen, B. G., & Dukes, J. S. (2008). Five potential consequences of climate change for invasive species. *Conservation Biology*, *22*(3), 534–543. https://doi.org/10.1111/j.1523-1739.2008.00951.x

Herms, D. A., & McCullough, D. G. (2014). Emerald ash borer invasion of North America: History, biology, ecology, impacts, and management. *Annual Review of Entomology*, *59*, 13–30. https://doi.org/10.1146/annurev-ento-011613-162051

Hulme, P. E. (2009). Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *Journal of Applied Ecology*, *46*(1), 10–18. https://doi.org/10.1111/j.1365-2664.2008.01600.x

Hurley, B. P., Garnas, J., Wingfield, M. J., Branco, M., Richardson, D. M., & Slippers, B. (2016). Increasing numbers and intercontinental spread of invasive insects on eucalypts. *Biological Invasions*, *18*(4), 921–933. https://doi.org/10.1007/s10530-016-1081-x

Hurley, B. P., Slippers, B., Sathyapala, S., & Wingfield, M. J. (2017). Challenges to planted forest health in developing economies. *Biological Invasions*, *19*(11), 3273–3285. https://doi.org/10.1007/s10530-017-1488-z

ICRAF. (2013). *Agroforestry tree genetic resources strategy 2013–2017*. ICRAF (World Agroforestry Centre) online document. Retrieved from http://www.worldagroforestry.org/products/grunew/downloads/ICRAFGeneticResourcesStrategy2013.pdf (accessed 15 Oct 2018).

Ingham, D. S., Samways, M. J., & Govender, P. (1998). Monitoring the brown wattle mirid, *Lygidolon laevigalum* Reuter (Hemiptera: Miridae). *African Entomology*, *6*(1), 111–116.

IUCN. (2018). *The IUCN Red List of Threatened Species. Version 2018-2*. Retrieved from http://www.iucnredlist.org

Jami, F., Slippers, B., Wingfield, M. J., & Gryzenhout, M. (2012). Five new species of the Botryosphaeriaceae from *Acacia karroo* in South Africa. *Cryptogamie, Mycologie*, *33*(3), 245–266. https://doi.org/10.7872/crym.v33.iss3.2012.245

Jami, F., Wingfield, M. J., Gryzenhout, M., & Slippers, B. (2017). Diversity of tree-infecting Botryosphaeriales on native and non-native trees in South Africa and Namibia. *Australasian Plant Pathology*, *46*(6), 529–545. https://doi.org/10.1007/s13313-017-0516-x

Jones, T. (1961). A Note on *Analeptes Trifasciata* Fabr. and *Paranaleptes Reticulata* Thoms. (Coleop. Lamiinae) two tree girdling beetles of Tropical Africa. *East African Agricultural and Forestry Journal*, *27*(1), 36–39. https://doi.org/10.1080/00128325.1961.11661744

Kenis, M., Auger-Rozenberg, M. A., Roques, A., Timms, L., Péré, C., Cock, M. J., … Lopez-Vaamonde, C. (2009). Ecological effects of invasive alien insects. *Biological Invasions*, *11*(1), 21–45. https://doi.org/10.1007/s10530-008-9318-y

Leakey, R. R., Weber, J. C., Page, T., Cornelius, J. P., Akinnifesi, F. K., Roshetko, J. M., … Jamnadass, R. (2012). *Tree domestication in agroforestry: Progress in the second decade (2003–2012). In Agroforestry-the future of global land use* (pp. 145–173). Dordrecht, the Netherlands: Springer.

Linde, C., Kemp, G. H. J., & Wingfield, M. J. (1997). First report of Sphaeropsis canker on cypress in South Africa. *European Journal of Forest Pathology*, *27*(3), 173–177. https://doi.org/10.1111/j.1439-0329.1997.tb00858.x

Linder, H. P. (2014). The evolution of African plant diversity. *Frontiers in Ecology and Evolution*, *2*, 38. https://doi.org/10.3389/fevo.2014.00038

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science*, *319*(5863), 607–610. https://doi.org/10.1126/science.1152339

Lovett, G. M., Weiss, M., Liebhold, A. M., Holmes, T. P., Leung, B., Lambert, K. F., … Weldy, T. (2016). Nonnative forest insects and pathogens in the United States: Impacts and policy options. *Ecological Applications*, *26*(5), 1437–1455. https://doi.org/10.1890/15-1176

Lyimo, P. J. (2017). A tree girdling beetle in Korogwe District: Its potential risk to Eucalyptus plantations and woodlots in Tanzania. *Tanzania Journal of Forestry and Nature Conservation*, *86*(2), 27-34.

Mangwende, E., Aveling, T. A. S., & Chirwa, P. W. (2018). Seed-borne *Colletotrichum* spp.: Implications for Eucalyptus nurseries. *South African Journal of Botany*, *115*, 321. https://doi.org/10.1016/j.sajb.2018.02.164

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A., & Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability*, *6*, 61–67. https://doi.org/10.1016/j.cosust.2013.10.014

Meyerson, L. A., & Mooney, H. A. (2007). Invasive alien species in an era of globalization. *Frontiers in Ecology and the Environment*, *5*(4), 199–208. https://doi.org/10.1890/1540-9295(2007)5[199:IASIAE]2.0.CO;2

Mohali, S., Burgess, T. I., & Wingfield, M. J. (2005). Diversity and host association of the tropical tree endophyte *Lasiodiplodia theobromae* revealed using simple sequence repeat markers. *Forest Pathology*, *35*(6), 385–396. https://doi.org/10.1111/j.1439-0329.2005.00418.x

Müller, C., Waha, K., Bondeau, A., & Heinke, J. (2014). Hotspots of climate change impacts in sub-Saharan Africa and implications for adaptation and development. *Global Change Biology*, *20*(8), 2505–2517. https://doi.org/10.1111/gcb.12586

Mumford, R. A., Macarthur, R., & Boonham, N. (2016). The role and challenges of new diagnostic technology in plant biosecurity. *Food Security*, *8*(1), 103–109. https://doi.org/10.1007/s12571-015-0533-y

Nagel, J. H., Gryzenhout, M., Slippers, B., & Wingfield, M. J. (2013). The Occurrence and Impact of Phytophthora on the African Continent. *Phytophthora: A Global Perspective*, *2*, 204.

Nagoshi, R. N., Goergen, G., Tounou, K. A., Agboka, K., Koffi, D., & Meagher, R. L. (2018). Analysis of strain distribution, migratory potential, and invasion history of fall armyworm populations in northern Sub-Saharan Africa. *Scientific Reports*, *8*(1), 3710. https://doi.org/10.1038/s41598-018-21954-1

Nair, K. S. S. (2001). *Pest outbreaks in tropical forest plantations: Is there a greater risk for exotic tree species?* Bogor, Indonesia: CIFOR.

Nakabonge, G., Roux, J., Gryzenhout, M., & Wingfield, M. J. (2006). Distribution of Chrysoporthe canker pathogens on *Eucalyptus* and *Syzygium* spp. in eastern and southern Africa. *Plant Disease*, *90*(6), 734–740. https://doi.org/10.1094/pd-90-0734

Ndlela, S., Manyangadze, T., Sachisuko, A., van der Lingen, S., & Makowe, I. A. (2018). The distribution and management of two invasive pests of Eucalyptus: The red gum lerp psyllid, *Glycaspis brimblecombei* (Hemiptera: Psylloidae), and the blue gum chalcid wasp, *Leptocybe invasa* (Hymenoptera: Eulophidae). *Zimbabwe. African Entomology*, *26*(1), 104–115.

Newete, S. W., Oberprieler, R. G., & Byrne, M. J. (2011). The host range of the Eucalyptus Weevil, *Gonipterus "scutellatus"* Gyllenhal (Coleoptera:

Curculionidae) in South Africa. *Annals of Forest Science*, *68*(5), 1005–1013. https://doi.org/10.1007/s13595-011-0108-9

Nyeko, P., Mutitu, K. E., Otieno, B. O., Ngae, G. N., & Day, R. K. (2010). Variations in *Leptocybe invasa* (Hymenoptera: Eulophidae) population intensity and infestation on Eucalyptus germplasms in Uganda and Kenya. *International Journal of Pest Management*, *56*(2), 137–144. https://doi.org/10.1080/09670870903248835

Oates, C. N., Külheim, C., Myburg, A. A., Slippers, B., & Naidoo, S. (2015). The transcriptome and terpene profile of *Eucalyptus grandis* reveals mechanisms of defense against the insect pest. *Leptocybe Invasa*. *Plant and Cell Physiology*, *56*(7), 1418–1428. https://doi.org/10.1093/pcp/pcv064

Odendaal, M. (1980). *Eulachnus rileyi*: A new pest on pines in Zimbabwe. *South African Forestry Journal*, *115*(1), 69–71. https://doi.org/10.1080/00382167.1980.9629994

Oh, E., Gryzenhout, M., Wingfield, B. D., Wingfield, M. J., & Burgess, T. I. (2013). Surveys of soil and water reveal a goldmine of *Phytophthora* diversity in South African natural ecosystems. *nIMA Fungus*, *4*(1), 123–131.

Paine, T. D., Steinbauer, M. J., & Lawson, S. A. (2011). Native and exotic pests of Eucalyptus: A worldwide perspective. *Annual Review of Entomology*, *56*, 181–201. https://doi.org/10.1146/annurev-ento-120709-144817

Paini, D. R., Sheppard, A. W., Cook, D. C., De Barro, P. J., Worner, S. P., & Thomas, M. B. (2016). Global threat to agriculture from invasive species. *Proceedings of the National Academy of Sciences*, *USA*, *113*(27), 7575–7579. https://doi.org/10.1073/pnas.1602205113

Pratt, C. F., Constantine, K. L., & Murphy, S. T. (2017). Economic impacts of invasive alien species on African smallholder livelihoods. *Global Food Security*, *14*, 31–37. https://doi.org/10.1016/j.gfs.2017.01.011

Ramsfield, T. D., Bentz, B. J., Faccoli, M., Jactel, H., & Brockerhoff, E. G. (2016). Forest health in a changing world: Effects of globalization and climate change on forest insect and pathogen impacts. *Forestry*, *89*(3), 245–252. https://doi.org/10.1093/forestry/cpw018

Roberts, D., Orden, D., & Josling, T. (2004). Sanitary and phytosanitary barriers to agricultural trade: Progress, prospects and implications for developing countries. *Agriculture and the New Trade Agenda - Creating a Global Trading Environment for Development*, 329–358. https://doi.org/10.1017/cbo9780511550676.016

Roux, J., & Coetzee, M. P. A. (2005). First report of pink disease on native trees in South Africa and phylogenetic placement of *Erythricium salmonicolor* in the homobasidiomycetes. *Plant Disease*, *89*(11), 1158–1163. https://doi.org/10.1094/pd-89-1158

Roux, J., Coutinho, T. A., Byabashaija, D. M., & Wingfield, M. J. (2001). Diseases of plantation Eucalyptus in Uganda: Research in action. *South African Journal of Science*, *97*(1–2), 16–18.

Roux, J., Meke, G., Kanyi, B., Mwangi, L., Mbaga, A., Hunter, G. C., … Wingfield, M. J. (2005). Diseases of plantation forestry trees in eastern and southern Africa. *South African Journal of Science*, *101*(9–10), 409–413.

Roy, B. A., Alexander, H. M., Davidson, J., Campbell, F. T., Burdon, J. J., Sniezko, R., & Brasier, C. (2014). Increasing forest loss worldwide from invasive pests requires new trade regulations. *Frontiers in Ecology and the Environment*, *12*(8), 457–465. https://doi.org/10.1890/130240

Saavedra, M. C., Avila, G. A., Withers, T. M., & Holwell, G. I. (2015). The potential global distribution of the Bronze bug *Thaumastocoris peregrinus* Carpintero and Dellapé (Hemiptera: Thaumastocoridae). *Agricultural and Forest Entomology*, *17*(4), 375–388. https://doi.org/10.1111/afe.12117

Santini, A., Ghelardini, L., De Pace, C., Desprez-Loustau, M. I., Capretti, P., Chandelier, A., … Stenlid, J. (2013). Biogeographical patterns and determinants of invasion by forest pathogens in Europe. *New Phytologist*, *197*(1), 238–250. https://doi.org/10.1111/j.1469-8137.2012.04364.x

Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, *5*(1), 014010. https://doi.org/10.1088/1748-9326/5/1/014010

Schroth, G., Krauss, U., Gasparotto, L., Aguilar, J. D., & Vohland, K. (2000). Pests and diseases in agroforestry systems of the humid tropics. *Agroforestry Systems*, *50*(3), 199–241.

Seebens, H., Blackburn, T. M., Dyer, E. E., Genovesi, P., Hulme, P. E., Jeschke, J. M., … Essl, F. (2017). No saturation in the accumulation of alien species worldwide. *Nature Communications*, *8*, 14435. https://doi.org/10.1038/ncomms14435

Shackleton, C. M., Shackleton, S. E., Buiten, E., & Bird, N. (2007). The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *Forest Policy and Economics*, *9*(5), 558–577. https://doi.org/10.1016/j.forpol.2006.03.004

Simberloff, D., Martin, J.-L., Genovesi, P., Maris, V., Wardle, D. A., Aronson, J., … Vilà, M. (2013). Impacts of biological invasions: What's what and the way forward. *Trends in Ecology & Evolution*, *28*(1), 58–66. https://doi.org/10.1016/j.tree.2012.07.013

Slik, J. W. F., Arroyo-Rodríguez, V., Aiba, S.-I., Alvarez-Loayza, P., Alves, L. F., Ashton, P., … Venticinque, E. M. (2015). An estimate of the number of tropical tree species. *Proceedings of the National Academy of Sciences*, *USA*, *112*(24), 7472–7477. https://doi.org/10.1073/pnas.1423147112

Slippers, B., Fourie, G., Crous, P. W., Coutinho, T. A., Wingfield, B. D., Carnegie, A. J., & Wingfield, M. J. (2004). Speciation and distribution of *Botryosphaeria* spp. on native and introduced Eucalyptus trees in Australia and South Africa. *Studies in Mycology*, *50*(2), 343–358.

Slippers, B., Wingfield, M. J., Coutinho, T. A., & Wingfield, B. D. (2001). Population structure and possible origin of *Amylostereum areolatum* in South Africa. *Plant Pathology*, *50*(2), 206–210. https://doi.org/10.1046/j.1365-3059.2001.00552.x

Sollars, E. S., Harper, A. L., Kelly, L. J., Sambles, C. M., Ramirez-Gonzalez, R. H., Swarbreck, D., … Buggs, R. J. A. (2017). Genome sequence and genetic diversity of European ash trees. *Nature*, *541*(7636), 212. https://doi.org/10.1038/nature20786

Speight, M. (2014). Insects and Other Animals in Tropical Forests. *Tropical Forestry Handbook*, 1–43.

Swart, W. J., Knox-Davies, P. S., & Wingfield, M. J. (1985). *Sphaeropsis sapinea*, with special reference to its occurrence on *Pinus* spp in South Africa. *South African Forestry Journal*, *135*(1), 1–8. https://doi.org/10.1080/00382167.1985.9629601

Tribe, G. D., & Cillié, J. J. (2004). The spread of *Sirex noctilio* Fabricius (Hymenoptera: Siricidae) in South African pine plantations and the introduction and establishment of its biological control agents. *African Entomology*, *12*(1), 9–17.

Ugwu, J. A., & Omoloye, A. A. (2014). Biology of Iroko Gall Bug, *Phytolyma lata* Scott. (Homoptera; Psylidae) on *Milicia excelsa* (Welw) CC Berg. *Journal of Entomology*, *11*(1), 34–41.

UNEP (United Nations Environment Programme). (2008). *Africa: Atlas of Our Changing Environment*. Nairobi, Kenya: Division of Early Warning and Assessment (DEWA).

Verchot, L. V., Van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., … Palm, C. (2007). Climate change: Linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change*, *12*(5), 901–918. https://doi.org/10.1007/s11027-007-9105-6

Wagner, M. R., Cobbinah, J. R., & Bosu, P. P. (2008a). Sap-feeding insects. In: *Forest Entomology in West Tropical Africa: Forests Insects of Ghana* (pp. 41–57) Dordrecht, the Netherlands: Springer.

Wagner, M. R., Cobbinah, J. R., & Bosu, P. P. (2008b). Defoliating insects. In: *Forest Entomology in West Tropical Africa: Forests Insects of Ghana* (pp. 23–40). Dordrecht, the Netherlands: Springer.

Walsh, J. R., Carpenter, S. R., & Vander Zanden, M. J. (2016). Invasive species triggers a massive loss of ecosystem services through a

trophic cascade. *Proceedings of the National Academy of Sciences, USA*, *113*(15), 4081–4085. https://doi.org/10.1073/pnas.1600366113

Watson, G. W., Voegtlin, D. J., Murphy, S. T., & Foottit, R. G. (1999). Biogeography of the *Cinara cupressi* complex (Hemiptera: Aphididae) on Cupressaceae, with description of a pest species introduced into Africa. *Bulletin of Entomological Research*, *89*(3), 271–283. https://doi.org/10.1017/S0007485399000395

Westphal, M. I., Browne, M., MacKinnon, K., & Noble, I. (2008). The link between international trade and the global distribution of invasive alien species. *Biological Invasions*, *10*(4), 391–398. https://doi.org/10.1007/s10530-007-9138-5

Wheeler, T., & Von Braun, J. (2013). Climate change impacts on global food security. *Science*, *341*(6145), 508–513.

Wingfield, M. J., Brockerhoff, E. G., Wingfield, B. D., & Slippers, B. (2015). Planted forest health: The need for a global strategy. *Science*, *349*(6250), 832–836. https://doi.org/10.1126/science.aac6674

Wingfield, M. J., Roux, J., Coutinho, T., Govender, P., & Wingfield, B. D. (2001). Plantation disease and pest management in the next century. *The Southern African Forestry Journal*, *190*(1), 67–71.

Wingfield, M. J., Slippers, B., Hurley, B. P., Coutinho, T. A., Wingfield, B. D., & Roux, J. (2008). Eucalypt pests and diseases: Growing threats to plantation productivity. *Southern Forests: A Journal of Forest Science*, *70*(2), 139–144. https://doi.org/10.2989/SOUTH.FOR.2008.70.2.9.537

Wingfield, M. J., Slippers, B., Roux, J., & Wingfield, B. D. (2001). Worldwide movement of exotic forest fungi, especially in the tropics and the southern hemisphere. *AIBS Bulletin*, *51*(2), 134–140.

Wingfield, M. J., & Swart, W. J. (1994). Integrated management of forest tree diseases in South Africa. *Forest Ecology and Management*, *65*(1), 11–16. https://doi.org/10.1016/0378-1127(94)90253-4

Youmbi, E. N., Yana, W., & Tamesse, J. L. (2014). Population Dynamic of *Diclidophlebia eastopi* Vondracek and *Diclidophlebia harrisoni* Osisanya, Psyllids Pest of *Triplochiton scleroxylon* (K. Schum) (Urticales: Sterculiaceae) in Yaounde. *Cameroon. Journal of Entomology*, *11*(4), 182–197.

Zomer, R. J., Neufeldt, H., Xu, J., Ahrends, A., Bossio, D., Trabucco, A., … Wang, M. (2016). Global Tree Cover and Biomass Carbon on Agricultural Land: The contribution of agroforestry to global and national carbon budgets. *Scientific Reports*, *6*, 29987. https://doi.org/10.1038/srep29987

Zwolinski, J. B. (1990). Preliminary evaluation of the impact of the pine woolly aphid on condition and growth of pines in the southern Cape. *South African Forestry Journal*, *153*(1), 22–26. https://doi.org/10.1080/00382167.1990.9629028

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