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Eucalypt pests and diseases: growing threats to plantation productivity

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Plantations of eucalypts (species of *Eucalyptus* and *Corymbia*), particularly in the tropics and Southern Hemisphere, have expanded dramatically during the course of the last 100 years. The nature of these plantations has changed substantially as selection, breeding, hybridisation, vegetative propagation and other innovative techniques have been introduced to improve planting stock. Although there are various examples of diseases and pests damaging early plantations, it is clear that separation of the trees from their natural enemies has resulted in exceptional performance. Not surprisingly, both the incidence and impact of diseases and pests in eucalypt plantations has increased over time. This has been due to the accidental introduction of pests and pathogens from areas where the trees are native to new environments. There are also growing examples of host-specific pathogens native to areas where eucalypts have been planted as non-natives, which have undergone sometimes surprising host jumps. These 'new pathogens' threaten not only plantation forestry based on non-natives, but also eucalypts and their relatives in areas where they grow naturally. There is little question that pests and pathogens are set to challenge eucalypt plantation forestry worldwide, more than ever before. In order to sustain profitable businesses based on eucalypt plantations, forestry companies will need to invest substantially in technologies enabling management of these pests and diseases.

Keywords: enemy escape, host jumps, invasives, plantation health, tree diseases, tree pathogens, tree pests

Introduction

Together with species of *Pinus* and *Acacia*, eucalypts (species of *Eucalyptus* and *Corymbia*) are among the trees most widely utilised to establish intensively managed plantations, particularly in the tropics and Southern Hemisphere. On suitable sites, these trees grow rapidly and are remarkable for the wide variety of environments to which different species are adapted. Consequently, as eucalypt plantation forestry has grown in many countries of the world, an increasing number of species have been tested for planting. Selections have thus been made from taxa trials leading to the evolution of local land races. As technologies have developed, hybrids have been artificially made to capitalise on specific characteristics of species and vegetative propagation of the most desirable genotypes has become common practice (Denison and Kietzka, 1993).

Plantations of eucalypts have displayed remarkable growth in many parts of the world. They have consequently come to represent one of the most important and fastest growing sources of fibre, particularly for the worldwide pulp and paper industry. Pulpwood rotations have been reduced to as few as five years and the opportunity to replace planting stock with new and improved clones has become increasingly feasible. The rapid growth and success of eucalypts in plantations can be attributed to various factors. It is, however, widely accepted that one of these factors has been the absence of debilitating damage to the trees due to pests and diseases.

The greater number of eucalypt species are native to Australia, with only a few species found naturally outside that country. As these trees have been moved to new environments, they have been separated from the pests and diseases that naturally infest them. Separation of organisms from their natural enemies, or the so-called enemy escape hypothesis (Jeffries and Lawton, 1984; Keane and Crawley, 2002; Mitchell and Power, 2003), is a key factor leading to rapid growth and also the emergence of weediness. This is certainly also one of the primary reasons for the exceptional growth and development of eucalypts in their new environments (Wingfield, 2003).

Gradual arrival of pests and pathogens

While newly established eucalypt planting programmes in most parts of the world have typically been relatively free of pests and diseases, such problems have gradually appeared with time. Analyses of arrivals of pests and pathogens specific to eucalypts grown as non-natives in plantations show interesting and important trends. Where these data are available, the trends are also generally the same for most countries of the world. Overall these depict a worrying trend showing a steady increase in the arrivals of new pests and pathogens, as is shown for South Africa (Tables 1 and 2).

In the case of countries such as South Africa, commercial planting of *Eucalyptus* species has been operational for more

Table 1: Important *Eucalyptus* pathogens recorded in South Africa*

Disease (pathogen)	Date recorded	Reference to first record	Possible origin
Fairmaniella leaf spot (*Fairmaniella leprosa*)	1928	Doidge *et al*. (1953)	Australia
Mycosphaerella leaf blotch (*Mycosphaerella nubilosa*)	1935	Doidge *et al*. (1953)	Australia
Corky leaf spot (*Aulographina eucalypti*)	1950	Doidge *et al*. (1953)	Australia
Phytopthora root rot (*Phytophthora cinnamomi*)	1980	Wingfield and Knox-Davies (1980)	Indonesia
Phaeophleospora leaf spot (*Kirramyces epicoccoides*)	1988	Crous *et al*. (1988)	Australia
Cryphonectria canker (*Chrysoporthe austroafricana*)	1989	Wingfield *et al*. (1989)	South Africa
Cylindrocladium blight (*Cylindrocladium pauciramosum*)	1991	Crous *et al*. (1991)	South America
Endothia canker (*Holocryphia eucalypti*)	1993	van der Westhuizen *et al*. (1993)	Australia
Quambalaria leaf and shoot blight (*Quambalaria eucalypti*)	1993	Wingfield *et al*. (1993)	Australia
Pink disease (*Erythriceum salmonicolor*)	1993	Nicol *et al*. (1993)	Unknown
Botryosphaeria canker (*Botryosphaeria* spp.)	1994	Smith *et al*. (1994)	Unknown
Pythium root rot (*Pythium splendens*)	1994	Linde *et al*. (1994)	South Africa
Coniothyrium canker (*Kirramyces zuluense*)	1997	Wingfield *et al*. (1997)	Unknown
Bacterial canker (*Ralstonia solanacearum*)	2000	Coutinho *et al*. (2000)	Unknown
Bacterial blight (*Pantoea* spp.)	2001	Coutinho *et al*. (2002)	Unknown

* This list includes only pathogens considered to be relatively important based on damage caused. Many other *Eucalyptus*-infecting fungi have been encountered in South Africa, but these have either not been associated with disease or they are considered relatively irrelevant at present. Where possible origins are noted, these are based on scientific evidence or on some background knowledge indicating an original source

Table 2: Important insect pests recorded on *Eucalyptus* species in South Africa*

Pathogen	Date recorded	Reference	Possible origin
Phoracantha semipunctata and *P. recurva*	c. 1906	Tooke (1935, 1949), Drinkwater (1974)	Australia
Gonipterus scutellatus	1916	Mally (1924)	Australia
Ctenarytaina eucalypti	1958	Stuckenberg (1961)	Australia
Trachymela tincticollis	1982	Tribe and Cillie (1997)	Australia
Thaumastocoris peregrinus	2003	Jacobs and Nesser (2005)	Australia
Coryphodema tristis	2004	Gebeyehu *et al.* (2005)	South Africa
Blastopsylla occidentalis	2006	S Nesser pers. comm.	Australia
Leptocybe invasa	2007	S Nesser pers. comm.	Australia

* This list does not include minor pests, particularly native pests that might be encountered on *Eucalyptus*

than 100 years. In this regard, the number of important insect pests and diseases that have appeared in plantations might be considered to be relatively low. This is at least within the context of the numbers of these organisms that occur on these trees in their native range (Loch and Floyd, 2001; Keane *et al*., 2000) and that might have been introduced. In countries that have established large eucalypt planting programmes more recently, such as those in Indonesia, Thailand, Vietnam and China, the appearance of debilitating pests and pathogens appears to have occurred more rapidly.

There are a number of factors that might account for a more rapid appearance of pests and pathogens in eucalypt plantations being established today, than was perhaps the case for those established a longer time ago. A key driver in this regard must certainly be that larger numbers of people and products are moving around the world than ever before. For example, wood-boring and xylophagous insects commonly cross borders by means of solid wood packing materials (Haack, 2006). However, the greater number of pests and pathogens that have been introduced into plantations of non-native eucalypt species appear to have moved with *Eucalyptus* germplasm (Old *et al*., 2003). Although this also would have been true when the first plantations of non-native eucalypts were established in areas such as South Africa and parts of South America, there are some fundamental differences in the manner in which these programmes have been established.

Massive new eucalypt planting programmes have emerged in various parts of the world, most notably in parts of South and East Asia. In these regions, plantations have been established to provide fibre for large pulp mills. The required furnish for these mills is, in many cases, enormous and this has demanded a high level of urgency to establish very large plantation areas rapidly. Although this might not be uniformly true, the degree of urgency has led to the importation of very large quantities of seed from other parts of the world. In such cases, it would be difficult, if not impossible, to manage the seed in such a way that the concomitant introduction of pests and pathogens would not occur.

In addition to the enhanced risks of introducing very large quantities of seed into new areas, there is good evidence that plant material and particular rooted cuttings have been moved between countries. This is linked to the advent of a eucalypt planting system that relies on vegetatively propagated genotypes having specific and desirable characteristics. Typically, companies planting eucalypts develop and produce suitable clones for plantation establishment. However, the temptation to share or purchase such material is great and is perhaps most likely amongst companies having common ownership. While it may be possible to eliminate the majority of contaminating pests and pathogens from plant material, this is extremely difficult and the risks of moving unwanted organisms are substantial.

Origin of pests and pathogens

The best-known pests and pathogens that have plagued plantations of non-native eucalypts have their origin in the native areas of their host trees. For example, the first *Eucalyptus* species to be used in plantation development in countries such as South Africa was the blue gum, *E. globulus* (Poynton, 1979). Relatively early in the establishment of these trees in South Africa, plantations were severely damaged by *Mycosphaerella* leaf blotch disease, caused by *M. nubilosa* (Hunter *et al*., 2004). At the time, the pathogen was thought to be *M. moleriana* (Doidge *et al*., 1953; Lundquist and Purnell, 1987; Crous and Wingfield, 1997; Crous, 1998). This fungus was first reported in South Africa in 1935 (Lundquist and Baxter, 1985) and it is now known to have originated in Australia (Hunter *et al*., 2008). Likewise, one of the earliest pests affecting *E. globulus* plantations in South Africa was the *Eucalyptus* snout beetle, *Gonipterus scutellatus*, also known to be native to Australia (Mally, 1924).

The most obvious sources of eucalypt pests and pathogens will be areas where these trees are native. However, there are intriguing examples where pests and diseases have originated from native hosts occurring in the environment into which the eucalypts have been introduced. In these cases, the pests or pathogens have shifted host to infest or infect eucalypts. Examples of host shifts amongst eucalypt and other tree pathogens (Slippers *et al*., 2005) also appear to be increasing in number. This is a worrying trend that might be expected to increase in the future.

One of the earliest and best-known examples of a *Eucalyptus* pathogen that jumped from one host to another is that of *Eucalyptus* rust caused by the fungus *Puccinia psidii*. This pathogen is native on Myrtaceae in South and Central America and it became established on *Eucalyptus* when they were established as non-natives in that part of the world (Coutinho *et al*., 1998). The pathogen has begun to move to new areas in recent years and it is amongst the most feared threats to eucalypts in plantations and in natural forests (Glen *et al*., 2007).

A more recent example of a pathogen that has undergone a host shift to infect *Eucalyptus* is the canker-causing fungus *Chrysoporthe austroafricana*. This fungus, now known to be restricted to southern Africa and thought to be native to the region, was previously believed to be the well-known canker pathogen *Cryphonectria cubensis* (Gryzenhout *et al*., 2004). Recent research has shown that the fungus occurs as a native on native Myrtaceae in southern Africa (Heath *et al*., 2006; Nakabonge *et al*., 2006) and it appears to have undergone a host shift to infect *Eucalyptus*. Various other species of *Chrysoporthe,* including *C. cubensis*, have been shown to occur as natives on native Melastomataceae in South America and South-east Asia (Hodges *et al*., 1986; Rodas *et al*., 2005) and also to have undergone host shifts to infect *Eucalyptus* species in these regions. These fungi now pose a significant threat to *Eucalyptus* species and probably other Myrtaceae and Melastomataceae in areas where these trees and shrubs are native.

An intriguing example of an insect pest that has apparently undergone a host shift to infest *Eucalyptus* is that of the cossid moth, *Coryphodema tristis*. This insect is thought to be native to South Africa where it has been known as a pest of many woody plants, including fruit trees such as quince and vines (Petty, 1917; Gebeyehu *et al*., 2005). Recently, *C. tristis* became established on *Eucalyptus nitens* in a relatively confined part of the *Eucalyptus*-growing region of South Africa. In this situation, the insect has caused severe damage but, interestingly, it has not moved to any other *Eucalyptus* species. It has also not been found on native woody plants in the area.

Host shifts from native woody plants to eucalypts appear to be increasing in number. The biological processes defining these events are poorly understood. This clearly limits our ability to deal with them. These ‘new’ eucalypt pests and pathogens have caused severe losses to plantations of these trees in the areas in which they have emerged. It is, however, of greater concern that they now have the ability to be moved accidentally to areas where the new host trees are native and might not have resistance to them. This would be similar to situations such as chestnut blight caused by *Cryphonectria parasitica*, which is native and minimally damaging on *Castanea* (chestnut) trees in South-east Asia, but is a devastating pathogen of European and North American chestnuts (Anagnostakis, 1987).

Predicting likely risks

It is generally difficult to predict which pests and pathogens are most likely to be introduced into new environments. While one might predict that fungi with powdery spores or small rather than large insects might be most easily moved, examples show few clear patterns. When one considers some of the pests and pathogens that have appeared for the first time in a country, other than the one in which they are native, these often seem to be the most unexpected candidates.

Clearly, understanding pathways of movement (Wingfield *et al*., 2000; Haack, 2006) provides one mechanism by which risks can be managed. Such pathway analyses also provide the basis for quarantine systems aimed at reducing the occurrences of new pest or pathogen introductions. As mentioned earlier, pests and particularly pathogens of eucalypts appear to have moved very actively into new environments with germplasm such as seed. While one would wish that this were not true, rooted *Eucalyptus* plants have clearly moved between countries and this path of introduction must be considered particularly threatening. Wood-boring insects such as species of *Phoracantha* have moved from Australia to most countries where eucalypts are grown, and have most likely been transported in wood products or wood packaging material. It is also likely that soil or soil-bearing products have been moved between countries and this would have provided for the movement of various serious soil-borne pathogens. The introduction of *Armillaria* species (Coetzee *et al*., 2003) and *Phytophthora* species (Zentmyer, 1988) into new environments represent this pathway of introduction.

The past history of movement of a plantation pest or pathogen appears to provide a strong signal as to the future movement of that organism. Thus, once a pest or pathogen has become established in plantations of a country where it was previously not present, the likelihood is it will move to additional countries or even regions. This can easily be seen in the pace of global movement of many eucalypt pests such as *Gonipterus scutellatus*, *Phoracantha semipunctata*, *Leptocybe invasa*, *Ctenarytaina eucalypti* and, most recently, *Thaumastocoris peregrinus* (Tooke, 1928, 1955; Hodkinson, 1999; Lanfranco and Dungey, 2001; Mendel *et al*., 2004; Jacobs and Nesser, 2005). Little is known regarding this pattern of spread and such movement might be explained in various ways. Some of these factors include the following:

- a pest or pathogen that has the capacity to move to a new environment would presumably move again, relatively easily;
- once a pest or pathogen has become established in a new plantation environment, its population density would be very significantly increased above that typical of a native organism. The increased numbers of individuals of the pest or pathogen must logically increase the likelihood of further movement.

Many forestry companies have close working relationships, leading to trade or exchange of forest products and equipment. Pests and pathogens, particularly those with dense populations, would easily come into contact with products that might be moved. Furthermore, there is an active exchange of staff members between forestry companies around the world and this movement of people enhances opportunities for the movement of pests and pathogens.

Various tools can be used to predict whether a particular pest or pathogen might pose serious problems if it were to be introduced into a new environment. These prediction models typically rely on climate data and they consider whether the environment is likely to be conducive to the organism in question. Clearly, these predictions must consider the likely susceptibility of the target trees and it is in this situation that over- or underestimations tend to occur. This is particularly because most organisations planting eucalypts have developed unique planting stock such as that based on hybrids, the susceptibility of which is difficult to predict.

Management options

There is little question that plantations of non-native eucalypts will be increasingly challenged by damage due to pests and diseases. As has been discussed earlier in this paper, these will come from new accidental introductions, but also from pests and pathogens that have evolved locally. Although every attempt must be made to avoid accidental introductions of new pests and pathogens, there are limitations to how effective such quarantine will ever be. Certainly, the appearance of new pests and diseases of eucalypts, even in countries with relatively rigorous quarantine procedures, presents a worrying view of the future. The challenge for forestry companies relying on eucalypts must, therefore, be to manage forestry operations to reduce losses.

The aim of this paper is not to consider options for management and control of pests and diseases affecting eucalypts in plantations. This topic has been covered relatively well in a suite of other publications (Wingfield *et al*., 1995; Keane *et al*., 2000; Old *et al*., 2003), although a general review of the topic is overdue. What is important is to recognise that there are many outstanding opportunities to reduce the impact of pests and diseases affecting eucalypt plantation forestry. Simply, selection of species that are not susceptible to infestation or infection is an approach that has been applied virtually since the start of eucalypt plantation forestry. In this case, one might interpret the management option as avoidance of planting species in environments where they are considered off-site. While this may be true in some cases, it is an oversimplification of fact, because pests and pathogens often behave very differently in different situations, e.g. when the host is in its native environment, compared to when it is grown as a non-native in intensively managed and genetically uniform plantations. Furthermore, where trees are exposed to pests and pathogens that they never encounter in their native habitats, their responses to these encounters are often unusual and unique.

One of the most exciting technological developments relating to eucalypt plantation development has been the introduction of vegetative propagation of desirable eucalypt clones. This has made it possible to select planting stock resistant to the ravages of pests and diseases and especially to introduce hybrids of species that offer excellent opportunities to avoid pest and disease problems. Indeed, the wide-scale advent of vegetative propagation in Brazil is believed to have emerged through a need to multiply natural hybrids of *E. grandis* × *E. urophylla*, in order to avoid damage due to *Cryphonectria* canker (Wingfield, 2003). While hybridisation and cloning is very well established in most areas where eucalypts are grown as non-natives in plantations, there will certainly be many advances in this field in the future and unique hybrids will undoubtedly continue to represent one of the most important strategies for disease avoidance. The advance of recombinant DNA techniques to rapidly identify resistant planting stock is also certain to contribute significantly in the future. The recently approved project to sequence the entire *Eucalyptus* genome (DOE Joint Genome Institute, 2008) will provide a major impetus in this direction.

Avoidance of disease and pest problems through the deployment of resistant or tolerant planting stock represents a major tool to avoid losses. However, this approach is much more relevant to diseases than it is to most insect pests. This is mainly because most eucalypt insect pests have relatively wide host ranges. Chemical control has and will continue to be used to reduce the impact of insect pests, but the nature of forestry is such that this approach must be followed with great caution. Certainly the most important tool to manage insect pests lies in biological control via the introduction of natural enemies. There have been outstanding examples of biological control of eucalypt pests in the past (Tooke, 1955; Hanks *et al*., 1996; Hodkinson, 1999) and this will continue to be true in the future.

Genetic modification of plants to avoid the impact of pests and pathogens is a growing field that has already been extensively applied in agriculture. In *Eucalyptus* plantation forestry, this technology is currently hardly mentioned because of environmental concerns and due to restrictions applied by, for example, the Forestry Stewardship Council (http://www.fsc.org). While we do not wish to promote the view that deployment of genetically modified (GM) eucalypts should occur without appropriate research and knowledge, our view is that GM eucalypts will emerge as a *tour de force* in future plantation forestry. As pest and disease problems increase in number and in impact, the need for new tools such as genetic modification will undoubtedly increase. The present concerns will be addressed, probably relatively soon, and those organisations that have invested in this field will then have a major advantage over others.

Future prospects

When eucalypts have been planted in areas where these trees or their close relatives are native, the impact of pests and pathogens emerged as a limiting factor very rapidly. Planting eucalypts as non-natives has provided outstanding opportunities to capitalise on the absence of pests and pathogens. This is a situation that is clearly changing and the costs relating to pest and pathogen management will certainly increase. It is likely that profits will coincidentally also drop and competition to produce fibre profitably will emerge as a driving force in plantation forestry.

All available evidence suggests that *Eucalyptus* plantation forestry based on non-native species is likely to be increasingly threatened by pest and disease problems. New introductions are occurring increasingly more frequently and there is no reason to believe that this trend is likely to change. While we would not wish to be negative, our view is that successful forestry companies will be those that clearly recognise the reality of the situation and that plan accordingly.

Resolution of pest and disease problems in *Eucalyptus* forestry already lies firmly in the implementation of modern technologies. As new problems emerge, new technologies will also follow. These should make it possible to deal with even the most complex pest and disease problems. However, the driving issue here is whether companies will have the vision to invest in these technological opportunities sufficiently rapidly to avoid levels of damage beyond the so-called 'point of no return'. Our belief is that companies failing to invest vigorously in disease and pest avoidance strategies, and to do so early, will be doomed to failure. This might appear as a strongly pessimistic view but there are sufficient examples of failure in forestry and agriculture due to pests and pathogens that the future appears relatively clear.

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