Reviews, Critiques and New Technologies

Diseases of eucalypt plantations in China: challenges and opportunities

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In order to meet the needs of a rapidly growing local economy, plantations of *Eucalyptus* spp. have been extensively developed in China during the course of the past 20 years. Despite the fact that they threaten long term sustainability, very little work has been conducted on diseases and insect pests of *Eucalyptus* species in the country. In an effort to expand the base of knowledge regarding eucalypt diseases in China, surveys have been undertaken in major plantation areas, including those in Guangdong, Guangxi, and Hainan. In this review, the most important diseases of *Eucalyptus* in China, as they have emerged from surveys and other recent studies are considered. Identification of pathogens has been achieved based on morphology of the apparent causal agents and in some cases DNA sequence comparisons have been employed. The most obvious stem diseases encountered in China are bacterial wilt caused by *Ralstonia solanacearum*, stem cankers caused by *Chrysoporthe cubensis*, *Kirramyces zuluensis*, as well as species of *Botryosphaeria* and a *Ceratocystis* sp. Leaf and shoot diseases are also important and the more important pathogens include *Kirramyces destructans*, *Kirramyces epicoccoides*, *Quambalaria pitereka* as well as species of *Cylindrocladium*, *Mycosphaerella* and *Pilidiella*. This study represents the first extensive survey of eucalypt diseases in mainland China and it clearly shows that there are a great number of pathogens affecting plantations of these trees in the region. Studies have thus been initiated to further characterise the pathogens as well as to assess their relative importance. This will be followed by the development of strategies to reduce the impact of the most important diseases.

Key words: invasive species, pathogens, plantation, tree health

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Introduction

Forests and forestry are of great importance in China and until recently, have mainly been represented by native trees, growing in natural ecosystems, especially in the North-eastern and South-western parts of the country (Anonymous, 1999). The native forest ecosystem has, however, been strictly protected from logging since 2000, and this has led to the expansion of plantations of fast-growing eucalypts, including species of *Eucalyptus* and *Corymbia*. In South China Provinces such as Guangxi, Guangdong and Hainan, more than 2 million ha of these trees have been established to meet the needs of a rapidly growing pulp industry (Xie *et al*., 2006). Of these trees, over 50% represent hybrids of *Eucalyptus urophylla* with other species such as *Eucalyptus grandis*.

Pests and pathogens are rapidly emerging as one of the greatest threats to plantation forestry based on non-native species, worldwide (Wingfield, 1999, 2003; Old *et al*., 2003). Despite the importance of these trees, very limited research has been conducted on fungal diseases affecting the extensive eucalypt plantations in China. Reports have been limited to incidental studies and no systematic evaluation of *Eucalyptus* fungal diseases has been made.

The best known disease of eucalypts in China is bacterial wilt caused by *Ralstonia solanacearum*. Thus this is the only pathogen on which intensive work has been carried out

(Cao, 1982; He *et al*., 1983; Wu and Liang, 1988a, 1988b; Lin *et al*., 1996; He, 1997; Wang *et al*., 1997; Ran, 2002; Ran *et al*., 2005). The important *Eucalyptus* canker pathogen, *Chrysoporthe cubensis* is known to occur in China where it was first reported from Hong Kong in 1986 (Sharma *et al*., 1985; Hodges *et al*., 1986) and later characterised (Myburg *et al*., 2002; Gryzenhout *et al*., 2004). More recently, the stem canker pathogen *Kirramyces zuluensis* has been discovered in China (Cortinas *et al*., 2006; Andjic *et al*., 2007a) and various leaf pathogens including *Kirramyces destructans* and *Kirramyces epicoccoides* (Burgess *et al*., 2006; Andjic *et al*., 2007a, b), various new species of *Mycosphaerella* (Burgess *et al*., 2007), and *Quambalaria pitereka* (Zhou *et al*., 2007), have been found on eucalypts in plantations. Some of these are very serious pathogens in other parts of the world and there is clearly a significant need to expand the research on eucalypt health in China.

In order to assess the occurrence of diseases of *Eucalyptus*, information was derived from the limited number of studies that have been conducted on the topic in the past. More importantly, surveys of tree diseases of *Eucalyptus* were conducted by the authors. The objectives of these surveys have been to consider the occurrence of fungal pathogens and to provide a foundation on which to build a *Eucalyptus* protection programme in order to provide long-term service to the plantation industry in China. This initiative has been launched as a collaborative venture between the University of Pretoria via the Forestry and Agricultural Biotechnology Institute (FABI) and the China Eucalypt Research Centre (CERC) and supported by various organisations including a bilateral agreement between the South African and Chinese Governments. The objectives and accomplishments of the programme known as the CERC-FABI Eucalypt Protection Programme CFEPP can be seen at the web site: http://www.fabinet.up.ac.za/cfepp/ index.

Materials and methods

Samplings

Surveys were conducted in major eucalypt plantations and a number of nurseries located in the Guangdong, Guangxi and Hainan Provinces during the period of 2006 and 2007 (Table 1). Samples showing disease symptoms from leaves, shoots and stems were collected from various eucalypt species, especially where disease problems were being encountered by foresters.

Isolation and identification

After collection, samples were kept in paper bags and transported to the laboratory for examination and identification of putative pathogens. In some cases, isolations were made from diseased tissue to generate cultures for further study. Where fruiting structures were present on diseased material, spores were carefully transferred to 2% MEA (20 g Biolab malt extract, 20 g Biolab agar, and 1000 mL deionised water) supplemented with 0.04% streptomycin (MEAS) using a fine needle under a dissection microscope. Where there were no fruiting structures present, diseased material was surface sterilized, pieces of tissue (2-4 mm long and 1-2 mm wide) were cut and placed on MEAS in Petri dishes.

For the isolation of *Mycosphaerella* spp., discs from diseased leaves were attached to the inside of the lids of the Pedri dishes with pseudotheica facing downwards towards the medium. Ascospores discharged onto the medium were examined for germination patterns using a microscope after 24 hours and single germinated ascospores were transferred to fresh 2% MEA. In order to identify *Botryosphaeria* spp., cultures were induced to sporulate by placing them on water agar supplemented with sterilised pine needles. This led to the production of pycnidia on the pine needles, from which conidia could be collected and examined using a light microscope.

Results

Leaf diseases

Leaf and shoot diseases were commonly encountered on various eucalypt species and their hybrids in China (Table 2). Some of these pathogens are well known in China, some have been recorded reasonably recently and others emerged from our surveys and are recorded here for the first time. The leaf diseases of eucalypts, most commonly encountered in

Table 1. Samplings of eucalypt diseases in China.

Date	Province	Locations	Host species (hybirds)
November-December 2006	Guangdong and Guangxi	Zhanjiang, Hepu, Shankou, Leizhou, Dongmen, and CERC nursery	U6, *Eucalyptus grandis*, *Eucalyptus pellita*, *Eucalyptus tereticornis*, *Eucalyptus urophylla* × *Eucalyptus grandis*, and *Eucalyptus urophylla* × *Eucalyptus camaldulensis*
December 2006-March, 2007	Guangdong and Guangxi	Zhanjiang, Leizhou, Shankou, and CERC nursery	U6, *Eucalyptus grandis*, W5, EC48, and JJ30
June, 2007	Hainan	Chengmai, Jianfeng Lian, and Changjiang	U6, *Eucalyptus camaldulensis*, and APP21 (*Eucalyptus urophylla* × *Eucalyptus tereticornis*)

Table 2. Eucalypt diseases encountered during the course of the study.

	Leaf diseases	Stem diseases	Nursery diseases
Causal agents	*Kirramyces destructans* *Kirramyces epicoccoides* *Mycosphaerella* sp. *Pilidiella* sp. *Quambalaria pitereka*	*Botryosphaeria* spp. *Ceratocystis* sp. *Chrysoporthe cubensis* *Kirramyces zuluensis* *Ralstonia solanacearum*	*Cylindrocladium* spp.

China are those caused by *Mycosphaerella* spp. Some of these are well known elsewhere in the world and are best known by their asexual states. The most common of these are *Kirramyces destructans* and *K. epicoccoides*. These have been recorded previously on *Eucalyptus urophylla* in China (Burgess *et al*., 2006; Andjic *et al*., 2007b) and in our surveys were found on *Eucalyptus grandis* in Shankou (Guangxi), and on hybrids of *Eucalyptus urophylla* and *Eucalyptus camaldulensis* in Dongmen (Guangxi). The former species is a serious pathogen (Burgess *et al*., 2006; Andjic *et al*., 2007b) that can cause leaf and shoot blight and where lesions are typically characterrized by having with borders that appear oily (Fig. 1-1). *Kirramyces epicoccoides* is a less serious pathogen (Knipscheer *et al*., 1990; Old *et al*., 2003), typically occurring on older or senescent leaves and where lesions are purple on the upper leaf surfaces wet dark masses of conidia emerging from stomata on the abaxial leaf surfaces (Fig. 1-2).

Symptoms of various other *Mycosphaerella* spp. are commonly seen on leaves of eucalypts in Chinese plantations. Many of these most likely represent new records for the country and probably also undescribed species. During the surveys that formed the basis of this review, an unknown *Mycosphaerella* sp. was found causing leaf diseases on *Eucalyptus* sp. in Zhanjiang (Guangdong) (Fig. 1-3). In addition, one *Pseudocercospora* sp. and three *Mycosphaerella* spp. including *Mycosphaerella yunnanensis*, *Mycosphaerella marksii*, and *Mycosphaerella crystallina* have recently been recorded from Chinese plantations (Burgess *et al*., 2007). Interestingly, surveys also led to the discovery (Zhou *et al*., 2007) of the important leaf and shoot pathogen *Quambalaria pitereka*, infecting young shoots of *Corymbia citriodora* in Leizhou (Guangdong) (Fig. 1-4). Infections of damaged *Eucalyptus* leaves, caused by a *Pilidiella* sp. (Van Niekerk *et al*., 2004), were relatively commonly encountered in the surveys.

Stem diseases

Bacterial wilt caused by *Ralstonia solanacearum* is the disease that is best known in eucalypt plantations in China. This disease is most serious in the hotter *Eucalyptus*-growing

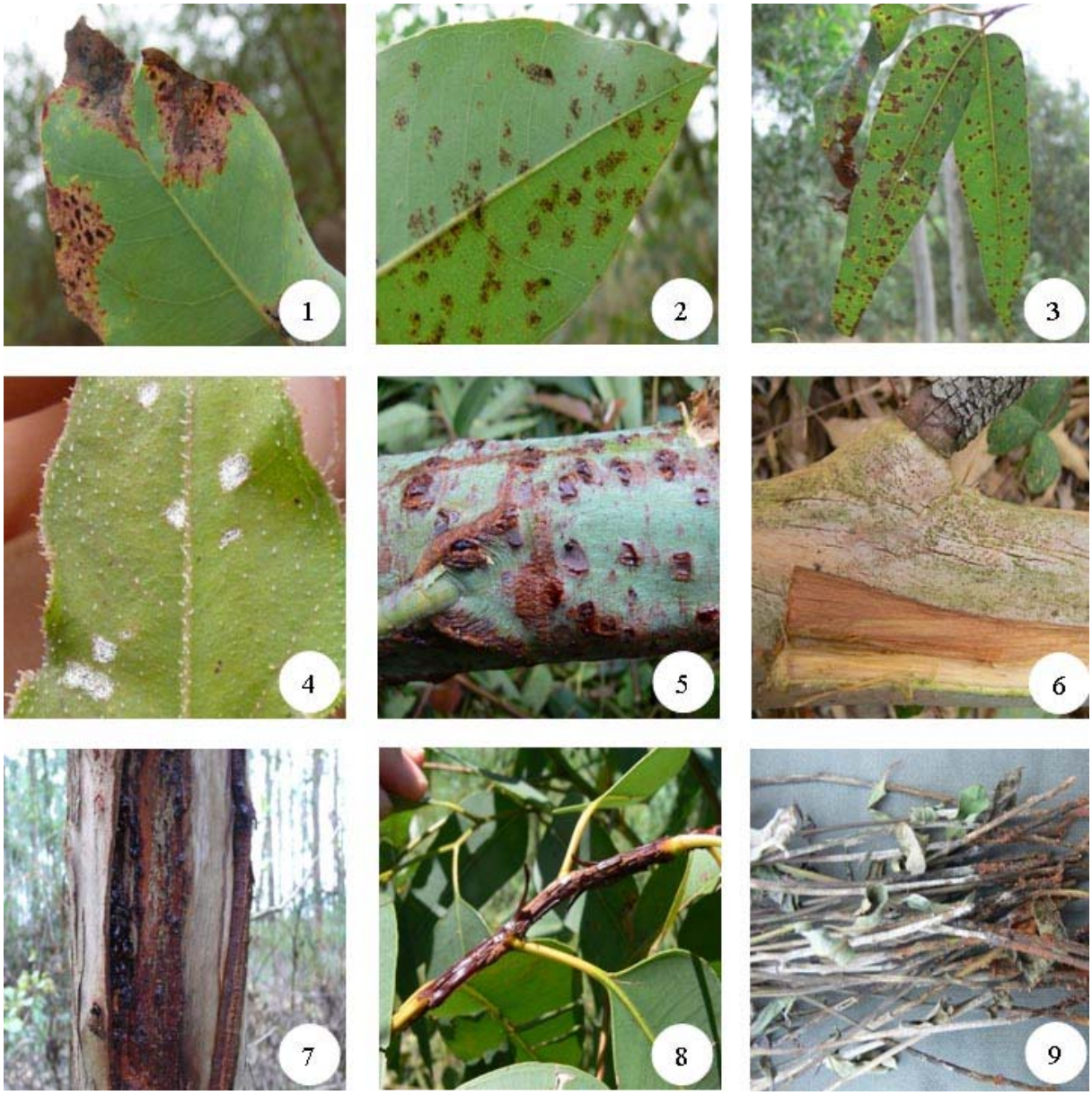

Fig. 1. Fungal disease symptoms on eucalypt trees in China. *Kirramyces destructans* **(1-1)** and *Kirramyces epicoccoides* **(1-2)** causing severe leaf blight; a *Mycosphaerella* sp.**(1-3)** causing leaf spot disease; *Quambalaria pitereka* **(1-4)** causing leaf blight present with white powder mildew; *Kirramyces zuluensis* **(1-5)** canker with typical symptoms of measle-like necrotic spots; *Chrysoporthe* canker **(1-6)** caused by *Chrysoporthe cubensis*; *Botryosphaerella* spp. causing severe cankers on stems with copious exudation of kino **(1-7)** and on shoots **(1-8)**; *Cylindrocladium* spp. **(1-9)** causing mass death of cuttings in the nursery.

areas, where it is also commonly associated with damage to trees caused by typhoons. The disease has been recorded from various *Eucalyptus* spp. and their hybrids in China (Cao, 1982; Wu and Liang, 1988b; He, 1997), and it was encountered in various plantations visited during the surveys on which this overview is based.

Stem canker diseases are common on eucalypts in China (Table 2) but they have been very poorly studied. One of the more serious pathogens to be encountered in the surveys and which has also recently been recorded in the country (Cortinas *et al*., 2006) is *Kirramyces zuluensis*. This disease is characterised by necrotic lesions that develop on the green, vigorously growing parts of the stems of trees. These lesions have a measle-like appearance on the stems and they commonly exude kino (Fig. 1-5). Other commonly

encountered pathogen causing stem cankers are *Chrysoporthe cubensis* (Fig. 1-6) and species of *Botryosphaeria* (Fig. 1-7, 8). The former fungus is a serious pathogen that can cause girdling cankers and death of trees and it is easily recognised by the long-necked pycnidia and perithecia that form on the surface of cankers. *Botryosphaeria* spp. were commonly encountered associated with cankers and these have yet to be assessed for the role that that they might contribute to disease.

Surveys of eucalypt stems led to the discovery of a *Ceratocystis* sp. associated with freshly cut stems, and possibly associated with failure of coppice growth. Various *Ceratocystis* spp. belonging to the *Ceratocystis fimbriata* sensu lato species complex are serious pathogens of *Eucalyptus* spp. and the fungus in China is thus being identified and evaluated for its relative importance.

Nursery diseases

Very little research has been carried out on nursery diseases on eucalypts in China. In the survey that formed the basis of this overview, powdery mildew was found killing plants of a *Eucalyptus urophylla* × *Eucalyptus grandis* clone in the nursery of China Eucalypt Research Centre (CREC) (Fig. 1-9). A number of *Cylindrocladium* spp. (Table 2) were also found in nurseries and these are currently being identified and evaluated for their importance.

Discussion

Relative to the rest of the world, *Eucalyptus* plantation forestry in China is in its early stage of development. However, growth is occurring extremely rapidly and China is likely to be amongst the largest producers of *Eucalyptus* fibre in the world. One of the greatest threats to this resource will be found in pests and diseases. This overview has illustrated how, contemporary surveys have led to the discovery of some of the world's most important eucalypt pathogens in China. Others are likely to appear in time, and every effort should be made to slow their arrival.

Some of the pathogens causing diseases that have been found on eucalypts in China are likely to be native to the region. For example, *Chrysoporthe cubensis* causing stem cankers is most probably a native pathogen. This view is based on the fact that the fungus occurs in two very distinct phylogenetic lineages, one of which is distinct for countries of South East Asia (Myburg *et al*., 2002; Gryzenhout *et al*., 2006a). Indeed, an isolate of the fungus from China has previously been shown to reside in the Asian clade of the fungus (Myburg *et al*., 2002). It seems probable that this pathogen has originated from native *Melastomataceae* in South East Asia, in a manner similar to that proposed for South America (Gryzenhout *et al*., 2006b). Other pathogens occurring on eucalypts in China and that are probably native would include species of *Cylindrocladium* and some species of *Botryosphaeria*.

A relatively large number of the eucalypt diseases noted in this overview are caused by pathogens that have probably been introduced into China. These diseases most likely include leaf and shoot blight caused by *Kirramyces destructans*, stem canker caused by *Kirramyces zuluensis* and leaf and shoot blight caused by *Quambalaria pitereka*. All three of these pathogens have caused very serious damage to eucalypts grown in plantations elsewhere in the world (Cortinas *et al*., 2006; De Beer *et al*., 2006; Andjic *et al*., 2007b; Zhou *et al*., 2007) and they are likely to be very important in China in the future.

The importance of eucalypt pathogens in China plantations is not directly related to whether they are native or whether they have been introduced into the country. Both categories of pathogens have equal capacity to cause serious disease. However, it is likely that introduced pathogens will have a more limited genetic base than those that are native. This may in turn impact on the long term durability of resistance in planting stock that has been selected for resistance to a particular pathogen.

It is unfortunate that a relatively large number of serious pathogens have appeared in Chinese eucalypt plantations so early in the establishment of plantations. These pathogens have most likely been introduced into China through the movement of pathogen contaminated seed or other planting stock. The speed at which plantations are being developed in the country will provide substantial temptation to introduce large quantities of seed or even rooted plants into China. Yet this approach is

beset with risks and any introductions should be made with extreme care. While there will clearly be short-term gains in terms of growth opportunities, the long term costs due to disease and pest control could easily outweigh these.

While this overview has shown clearly that a relatively large number of diseases threaten eucalypt forestry in China, this should not be seen as the authors being negative about the future of eucalypt forestry in China. Many opportunities exist to avoid the ravages of eucalypt disease. Breeding and the selection of disease-tolerant species and hybrids has already been shown to be highly effective (Old *et al*., 2003; Van Heerden *et al*., 2005). This and the application of other associated technologies are likely to also be a key approach to dealing with disease problems in China in the future. However, the implication is also that Chinese forestry companies will invest strongly in the scientific resources that will be needed to contend with disease problems that will represent a continuous challenge.

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