# Managing Threats to the Health of Tree Plantations in Asia

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## 1. Introduction

Plantation forestry is making a significant positive contribution to the environment as well as to the livelihoods of millions of people in Asia. This chapter examines some of the major constraints facing commercial acacia and eucalypt plantations in South-east and East Asia and discusses adaptive actions in the face of climate change. Particular emphasis is placed on Vietnam and China but examples are also drawn from other parts of SE Asia where forest plantations are making a significant contribution to forest cover. The area of forest cover in Asia has declined greatly in the past 50 years due to an expanding population, and increasing demand for forest products and land for food and energy crops. For example, based on available documents, in 1943 Vietnam had 14.3 million ha of forests, with 43% forest cover; but by the year 1990 only 9.18 million ha remained, with a forest cover of 27.2%. During the period 1980 to 1990, the average forest lost was more than 100,000 ha each year. However, from 1990 to the present, the forest area has increased gradually, due to afforestation and rehabilitation of natural forest. Based on the official statement in Decision No. 1267/QD/BNN-KL-LN, dated 4 May 2009, as of 31 December 2009, the total national forest area was 13.2 million ha (forest cover of 39.1%), including 2.9 million ha of plantation forest. Recently, China too has also been able to reverse the decline in forest cover due to forest protection and afforestation. According to the 7$^{th}$ national forest resource inventory finished in 2008, there were 195.4 million ha (14.9 billion m$^3$ of standing wood volume) of forest in China, an increase of 20.5 million ha (1.1 billion m$^3$ standing wood volume) over the previous audit 5 years earlier. Of the increased forest area and volume, 3.9 million ha were from natural forests, and 8.4 million ha were from tree plantations.

In the region, logging of natural forests is proceeding at alarming rates in some countries and is tightly controlled in others. In China, the “national natural forest protection program” was started in 2000, and any logging in natural forest is illegal, as is the case in Thailand. Following that the “national reforestation program” was initiated to established tree plantations in bare land for natural protection in nort-west China and wood production in southern China. Forests are classified as ecological forests and natural forest reserves which the government will pay about 120 RMB per ha annually to the forest owners, or commercial forests for wood production. Likewise, the Government of Vietnam has given high priority to forest rehabilitation, as Program 327 and the 5 Million Hectare Rehabilitation Program (MHRP). Program 327, which lasted from 1993 until 1998, was effective in increasing afforestation and forest rehabilitation. The 5MHRP (1998 – 2010) had the objective of rehabilitating 5 million ha of forests and protecting existing forests, in order to increase forest cover to 43%. Unlike China and Thailand, Vietnam obtains more than 90% of its timber volume from natural forest.

## 2. Acacia and eucalypt plantations

There are over 4 million ha of eucalypts and nearly 2 million ha of acacias in plantations in East and SE Asia being grown predominantly for the pulp-wood market. In some areas, such as the Leizhou Peninsula of south China, plantations are in their 3rd to 5th rotation. By contrast, in parts of south-western Yunnan, central Lao PDR, north Vietnam and Kalimantan degraded lands are being converted to new hardwood plantations. Industrial scale eucalypt plantations began in Thailand in the 1970s, Lao PDR in the past 5 years and are just commencing at a small scale in Cambodia. In the Philippines, acacia and eucalypt plantations were established in the late 1980s but many on converted imperata grasslands have been unproductive. In the last 15 years, the area of acacia plantations has expanded greatly in Indonesia and non-peninsular Malaysia. Plantations are mostly monocultures but may be integrated with agriculture (Figure 1). The productivity range is broad, with the Mean Annual Increment (MAI) from less than 10 to over 45 $m^3$ $ha^{-1}$ $yr^{-1}$ for eucalypts and 20 to over 50 $m^3$ $ha^{-1}$ $yr^{-1}$ for acacias. Plantations are mostly managed for short-rotation pulp wood (Turnbull 1999). However, there is an emerging interest in sawlog production in some countries.

Eucalypt and acacia plantations in Asia are mainly planted in areas with tropical or subtropical climate. Rainfall may be distributed evenly across the year in parts of the wet tropics (Indonesia, Malaysia, eastern Mindanao) or there may be a prolonged dry season (e.g. central and north-eastern Thailand, south-western China). Temperate species of eucalypts and acacias are planted at higher altitudes where damage from low temperatures is a threat (e.g. some provinces in China, northern Lao PDR). The main eucalypt plantation belt in south China experiences a typical monsoon climate with wet season from May to October and dry season from November to April. The annual rainfall in this region is very variable, from 600 to 2500 mm annually. Vietnam is subject to the south-west monsoon from May to October and the northeast monsoon in winter. The country has two distinct climatic zones. From 16$^o$ latitude to the north, winter lasts from December to February, but without a marked dry season. From the 16$^o$ latitude southward, a marked dry season occurs from November to April. The average national rainfall is 1,300 – 3,200 mm, but some areas receive less than 500 mm (Phan Rang, Ninh Thuan province). The annual average temperature is 21$^o$C in the north and 27$^o$C in the south. Hence, subtropical/tropical species of acacias and eucalypts predominate in plantations.

There are more than 3.5 million ha of industrial hardwood plantations in south China and more than 90% are eucalypt plantations. The eucalypt plantations are mainly distributed in Guangxi (1.25 million ha), Guangdong (1.15 million ha), Yunnan (0.25 million ha), Fujian (0.25 million ha), Hainan (0.2 million ha), Sichuan (0.15 million ha), Hunan (0.1 millon ha),


Fig. 1. Three types of production systems used for eucalypts in Asia. a. Monoculture of a single clone at high density (China), b. Intercropping in the first year (the trees are suffering from Fe deficiency, Thailand), c. Wood production on rice bunds (Thailand)

Guizhou and Jiangxi provinces. Although eucalypts were first introduced to China over 100 years ago, most of those plantations were established in the past 10 years to increase industrial wood production and will soon be converted into the second rotation. Before conversion to eucalypt plantations, most of the land was covered in low-yielding pine plantations or mixed pine forests, and some degraded lands were afforested. Annual wood production is about 40-50 million $m^3$ wood for plywood, wood chips for pulp production and middle or high density fibre board, poles and firewood. The production is estimated to grow to more than 50 million $m^3$ in 2 years as more new plantations reach their first harvesting age, at 5 years of age or older. The average MAI of these plantations is about 15-20 $m^3$ $ha^{-1}$ $y^{-1}$. Usually, those plantations will be managed for coppice for the second rotation in south China. The main genetic materials used for plantations are: *E. urophylla* x *grandis, E. grandis* x *urophylla*, *E. urophylla* x *tereticornis*, *E. urophylla* x *camaldulensis*, *E. grandis*, *E. dunnii*, *E. maidenii* and *E. smithii.* Plantations of four species (*E. dunnii*, *E. maidenii*, *E. smithii* and some *E. grandis* plantations) were established with seedlings and clonal material has been used for the other genetics. In south China, most of the clonal planting stock comes from tissue culture instead of cuttings. Acacias used to be used for commercial plantations in China, for example in Hainan Dao and Guangdong provinces. Recently, they are only used for ecological forest and vegetation recovery on infertile lands due to their low productivity and poor cold tolerance in south China. The wood has been used for pulp and plywood production in the past.

There are more than 2.9 million ha of forest plantations in Vietnam, of which acacia and eucalypt plantations make up about 60%. The acacia and eucalypt plantations are mainly planted in Quang Ninh (0.1 million ha), Tuyen Quang (0.1 million ha), Yen Bai (0.1 million ha), Lang Son (0.1 million ha), Bac Giang (0.09 million ha), Phu Tho (0.1 million ha), Hoa Binh (0.09 million ha), Binh Dinh (0.07 million ha) and Thua Thien Hue (0.09 million ha). In total, about 200 provenances of 61 eucalypt species have been introduced to Vietnam for evaluation as plantation species (Nguyen Hoang Nghia, 2000). In addition to *E. urophylla*, the following species have shown potential for commercial production: *Eucalyptus camaldulensis*, *E. exserta*, *E. grandis*, *E. microcorys*, *E. pellita* and *E. tereticornis* (Nguyen Hoang Nghia, 2000). Plantations of *E. urophylla* clones U6 and PN14 are planted mostly in the northern provinces of Bac Giang, Vinh Phuc and Phu Tho. The rotation length in this part of Vietnam is about 5 to 6 years. Clone U6 is also planted in the centre of Vietnam, including Binh Dinh, Phu Yen and Quang Tri provinces. In addition, many clones of *Eucalyptus* hybrids were selected from trials for new commercial plantations from 2000 to 2010, but areas of these clones are still small due to limitations in propagation from cuttings.

Acacias were introduced to Vietnam in the 1960s and of 16 species tested, *Acacia auriculiformis* showed good growth performance and was chosen for large scale plantings in many locations, mostly in southern provinces (Turnbull et al. 1998). From 1982 to 1995, a further five *Acacia* species (96 provenances) were screened in 6 provinces at low elevation. This led to *A. mangium* and *A. auriculiformis* being selected for planting in the north-east, centre and south-east of Vietnam, and *A. crassicarpa* in coastal zones. In the following decade, 25 temperate *Acacia* species were evaluated in the highlands and *A. mearnsii* and *A. melanoxylon* are now being considered for plantations. In addition, *Acacia difficilis*, *A. torulosa* and *A. tumida* are planted on a limited scale in the dry zone in Binh Thuan province (Nguyen Hoang Nghia, 2003).

In 1991, naturally occurring acacia hybrids were first observed growing at Ba Vi research station, Hanoi city. The parents of these natural hybrids were identified to be *A. mangium* and *A. auriculiformis* (Van Bueren 2004). Trials in both north and south Vietnam have shown that selected clones outperform their parents. For example, at 45 months, the growth of *Acacia* hybrids was 60 - 100% higher than *A. mangium* and 200 - 400% higher than *A. auriculiformis* at Ba Vi (Le Dinh Kha and Ho Quang Vinh, 1988). At present, hundreds of clones of natural and artificial *Acacia* hybrids have been placed in trials in plantations. In south-east Vietnam, the best clone gave a mean annual increment of 44 $m^3$ $ha^{-1}$ $yr^{-1}$ while the worst clone gave a mean annual increment of 17.5 $m^3$/ha/yr in the trials established.

The supply of raw material for the wood pulp and paper industry is a key defining factor in forest plantation planning. In China it is expected that more than 70% of the wood harvested and 85% of the wood used for the wood industry will be from tree plantations. Annually, about 12 million $m^3$ eucalypt wood is used for pulp production and about 30 million $m^3$ wood is used for plywood and fibre board manufacture. In Vietnam, the wood for this industry currently comes from both natural forests and plantations, but increasingly is shifting to plantations. In 2000, 1.6 million $m^3$ of plantation wood went for industrial production. The national paper and pulp industries required about 300,000 $m^3$/year. Timber from plantations is also used for manufacturing particle boards and MDF. Vietnam's national demand for saw logs was about 2.2 million $m^3$ in 2003. In 2000, some 390,000 $m^3$ of saw logs came from plantations, including 190,000 $m^3$ of rubber wood. Plantations mainly provide supplies of small timber.

In central Vietnam, eucalypt wood is mainly processed into chips for export whereas in the north of the country, eucalypt wood is used for pulp, chip and housing construction. In Vietnam, *Acacia* wood is used for various purposes, depending on species and age. At the age of between 6 and 8, almost all kinds of *Acacia* wood are used for pulp, chip, finger join boards and MDF boards. Only a few trees with large diameter are being processed for sawn timber and construction materials. The rotation age for sawlogs is about 15 years. *Acacia mangium* wood is use mainly as raw materials for chip board, pulp and artificial board. *A. auriculiformis* wood is popular at present for the production of woodwork such as slat shaped products, finger join board, and engraved wood products because of its high physical properties (equivalent to those of *Tectona grandis*). The *Acacia* hybrids are being grown primarily for the production of pulp.

Like all tree plantations, acacia and eucalypt plantations are vulnerable to pests and diseases. Over time, disease and pest problems have tended to increase in plantations (Wingfield 1999) and this has been particularly evident in eucalypt plantations in Asia (Dell et al. 2008). Recently, Wingfield et al. (2011) have concluded that plantations of Australian acacias are increasingly threatened by pests and pathogens. In addition, soil infertility when poorly managed can greatly limit productivity and predispose trees to some biotic agents. Major threats to acacia and eucalypt plantations in Asia will now be introduced followed by consideration of their management under climate change.

## 3. Causes of stress and tree decline

### 3.1 Abiotic factors

Site condition and climate are key drivers of tree health and productivity. Soil fertility constraints for plantation productivity and their management are provided (Table 1). In general, as fertilization has become more routine in plantations, macronutrient deficiencies are becoming less common. Of particular importance are micronutrient deficiencies because they remain problematic, symptoms are common, and are not well managed (Xu and Dell 2002, Dell et al. 2003, Dell et al. 2008). Some fertilizer practices exclude micronutrients even where symptoms are observable in the field (Dell et al. 2001). Furthermore, micronutrient disorders can be induced by fertilization with macronutrients which promote initial rapid tree growth that exceeds the supply characteristics of the plantation soil. This has been observed by us for B and Zn in acacias and B, Cu and Zn in eucalypts. In other situations, soil properties may restrict access by roots to micronutrients or limit their utilization (e.g. Cu and B in peaty soils in Indonesia, Fe in calcareous soils in Thailand and China), or soils may be so deficient in micronutrients that tree growth is severely impaired from an early age [e.g. Fe deficiency in *Acacia mangium* on acidic sands in Sumatra (Dell 1997), B deficiency in *Eucalyptus* in Yunnan (Dell & Malajczuk 1994)], or heavy metals in soils may result in Fe deficiency in *A. mangium* (Dell 1997).

| Factor | Occurrence | Impact | Management |
|---|---|---|---|
| Nitrogen deficiency | Soils low in organic matter content mostly in degraded lands, also sandy soils such as coastal sands, riverine deposits, volcanic deposits | Chlorosis of older leaves, loss of basal foliage, reduction in canopy size, reduced growth | Apply fertilizer, use legumes as intercrop species for eucalypts, ensure *Acacia* is nodulated with effective strains of *Bradyrhizobium*, retain harvest residue onsite |
| Phosphorus deficiency | Highly weathered soils of coarse texture and high P-fixing soils such as ferrosols, laterites, red and yellow earths | Leaf reddening and sometimes necrosis, loss of basal foliage, reduction in canopy size, reduced growth | Apply fertilizer, add effective mycorrhizal fungi to nursery containers if abundance and diversity are low in plantation soils, retain harvest residue onsite |
| Potassium deficiency | Soils of low cation-exchange capacity, sandy soils | Leaf chlorosis and necrosis, loss of basal foliage, reduction in canopy size, reduced growth | Apply fertilizer, retain harvest residue onsite |
| Boron deficiency | Sandy soils derived from sandstones and granite, quaternary deposits, peaty soils, some serpentine soils | Shoot dieback, especially in the dry season, brittle and deformed leaves, multiple stems, twisted stems, altered fibre size in eucalypts, increased insect and fungal attack | Include B (0.5-1.5 kg/ha) in the fertilizer blend at planting and reapply if foliar levels decline markedly |
| Iron deficiency | Calcareous and alkaline soils, occasionally on acid sands and serpentine soils | Severe leaf chlorosis | It is not economic to apply Fe fertilizer to soils of high pH due to the large amounts that are needed and their poor utilization. Application of organic matter can be beneficial. Select species and genotypes that are adapted to these soil conditions |
| Copper deficiency | Peaty soils such as in lowland swamps and some upland rainforests | Impaired growth at the shoot tip, malformed leaves and sometimes stem bleeding and poorly lignified wood | Include Cu (1-4 kg/ha) in the fertilizer blend at planting and spot apply to increase availability |
| Zinc deficiency | Lateritic and sandy soils, black earths, some volcanic soils | Small leaves, dwarf trees | Include Zn (0.5-2 kg/ha) in the fertilizer blend at planting |
| Metal toxicity | Soils derived from serpentine and other ultramafic rocks | Leaf chlorosis, necrosis and tip dieback from toxic levels of Ni and other heavy metals | Avoid planting sensitive species |

Table 1. Major soil fertility constraints for sustainable wood yield in acacia and eucalypt plantations in SE Asia and their management options.

Eucalypts and acacias are sensitive to B deficiency resulting in loss of crown vigour, shoot death, poor stem form and bunchy canopies. Boron deficiency is a major constraint to the productivity of plantations in many parts of Asia, especially in new plantations in China, Indonesia, Lao PDR, Philippines, Thailand and Vietnam (Figure 2). Symptoms of deficiency are more severe during the dry season and mildly affected trees may partially recover during the following wet season (Dell et al. 2008). Sites with sandy soils derived from granite and sandstones are especially vulnerable when there is a long dry season.

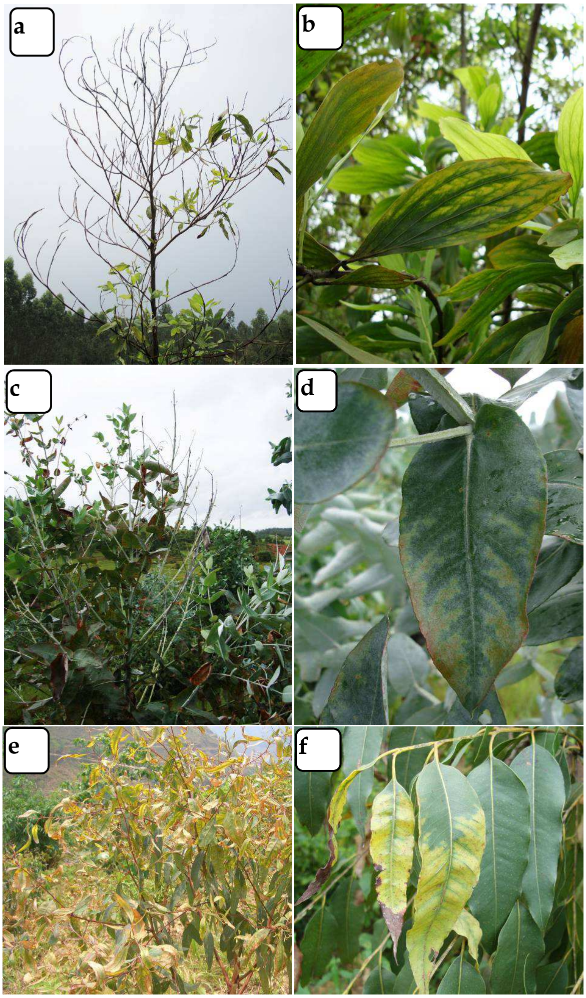


Fig. 2. Boron deficiency is a serious nutrient disorder in acacia (a, b) and eucalypt (c-f) plantations in Asia. Symptoms include shoot dieback (a, c), yellowing between the veins (b, d) or from the leaf tip (f), and malformed leaves (e). (a, b Vietnam; c, d, f Lao PDR; e China)

There are three aspects of climate that impair tree growth in the region. Firstly, seasonal drought is typical in areas with a monsoonal climate, and drought may extend from several months to over six months a year. If the soil is not deep enough to conserve water for transpiration in the dry season, trees stop growing and shed leaves. In China, a severe drought from October 2008 to June 2009 in Yunnan and Guizhou provinces caused symptoms of water deficit in eucalypts but most trees survived. However, tree death has been observed in central Thailand on shallow soils in a drought period (Figure 3a). Secondly, cold damage has killed or caused top dieback of trees at higher elevations. At first, eucalypt plantations were established in tropical and southern subtropical areas of south China. As available land become less and less, new eucalypt plantations expanded into areas with a subtropical climate where the minimum temperature is less than 0°C. In the beginning of 2008, eucalypt plantations were seriously damaged by cold ice-rain (Figure 3b). From December 2010 to January 2011, *E. dunnii* was seriously damaged by cold weather in Fujian province. From the temperature data in the field, young *E. dunnii* do not tolerate -5°C. The reason is partly due to the temperature decreasing from 13°C to -5°C in 24 hours on December 23, 2010 and trees were not prepared. Furthermore, clones of *E. grandis* planted in Yongan were not able to tolerate -3°C. This is of concern as some climate models forecast the possibility for further extreme cold events in the future. Lastly, eucalypt and acacia plantations in China, Vietnam and the Philippines are exposed to typhoons. Strong winds can defoliate trees (Figure 3c), snap stems or completely destroy plantations. Usually, clones from *E. urophylla* x *grandis* and *E. grandis* x *urophylla* are poorer in terms of typhoon tolerance and better in terms of tree growth than clones from *E. urophylla* x *tereticornis* and *E. urophylla* x *camaldulensis*. In sites where typhoons are frequent, foresters should pay more attention to selecting clones that have some resilience to typhoons rather than focusing only on tree growth.

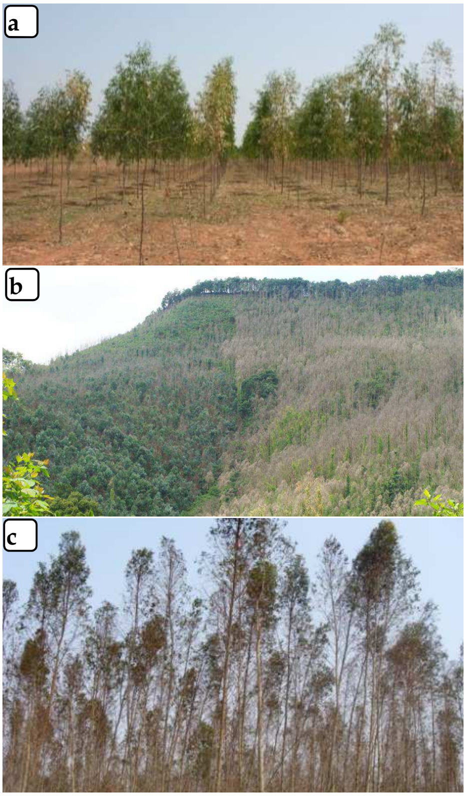


Fig. 3. Damage to eucalypt plantations caused by drought (a, Thailand), low temperature (b, China) and typhoon (c, China)

### 3.2 Biotic factors

As the eucalypt and acacia plantation estate has expanded in Asia over the past two decades, significant new pests and diseases have emerged to reduce their productivity. A large number of insect pests have been recorded feeding on these hosts but only a small number of species have caused significant damage so far (Tables 2 and 3). Nearly all the insect pests are resident in the areas where plantations have been established or have moved within the region. In general they are able to complete their life cycle on other host species and some are pests of horticultural and other crops in the region. Several have become quarantine listed in other regions of the world. As plantations are planted in new geographical locations it is likely that additional pests will emerge. It is difficult to predict what insects will become problematic in the future and climate change makes this more challenging as the detailed biology of many species is unknown. The biggest threat to plantation health comes from the incidence and severity of plant pathogens (Tables 4 and 5), mostly fungi. Unlike for the insect pests, about half of these fungi are not native to the region and incursions from other parts of the world, including Australia, is likely to persist for some time. The potential to cause damage has forced the plantation sector to consider screening and breeding for resistance to some key pathogens in the last decade, but much

| Name | Country | Impact |
|---|---|---|
| *Coptotermes formosanus* | Vietnam | Termite causing local damage to *A.mangium* and acacia hybrids |
| **Ericeia* spp. (Fig. 4a-c) | China, Vietnam | Leaf eating caterpillars causing damage to *A. mearnsii* in Fujian Province and *A. mangium* in Vietnam |
| *Gryllotalpa africana* | Vietnam | Cricket causing minor damage to *A. auriculiformis, A. mangium* and acacia hybrids |
| **Helopeltis* spp. (Fig. 4g, h) | Lao PDR, Indonesia, Philippines, Vietnam | Mosquito bugs causing local severe damage to shoot tips |
| *Holotrichia trichophora* | Vietnam | Root eating beetle causing minor damage to *A. mangium* and acacia hybrids |
| *Hypomeces squamosus* | Thailand, Vietnam | Leaf eating beetle causing minor damage to *A. auriculiformis, A. mangium* and acacia hybrids |
| *Macrotermes* spp. | Indonesia, Lao PDR, Thailand, Vietnam | Termites causing local damage to *A. auriculiformis, A. mangium* and acacia hybrids |
| *Microtermes pakistanicus* | Vietnam | Termite causing local damage to *A. auriculiformis, A. mangium* and acacia hybrids |
| **Phalera grotei* | Indonesia, Vietnam | Leaf eating caterpillar, sometimes causing severe damage to *A. auriculiformis* in Vietnam |
| **Pteroma plagiophleps* | Indonesia, Malaysia, Philippines, Thailand, Vietnam | Bag worm causing local damage to *A. auriculiformis, A. mangium* and acacia hybrids |
| *Speiredonia retorta* (Fig. 4d, e) | Vietnam | Leaf eating carterpillar causing local damage to *A. auriculiformis, A. mangium* and acacia hybrids |
| *Sinoxylon anale* | Vietnam | Bark beetle causing minor damage to *A. auriculiformis* |
| **Xylosandrus crassiusculus* (Fig. 4i, j) | Vietnam | Ambrosia beetle causing damage and blue stain fungi disease in *A. mangium* |
| *Xylotrupes gideon* (Fig. 4f) | Lao PDR | Beetle causing local damage to *A. mangium* |

Table 2. Pests threatening productivity of acacia plantations in Asia. Those marked with an asterisk are major threats.

more needs to be done. Zhou and Wingfield (2011), for example, point out the particular challenge for China where there is an acute lack of forest pathologists in that region.

| **Name** | **Country** | **Impact** |
|---|---|---|
| *Agrilus* spp. | Indonesia, Philippines | Buprestid borers causing local damage |
| *Anoplophora chinensis* | China | Citrus longhorned borer causing mild impact in Guangdong, Guangxi and Jiangxi |
| *A. glabripennis* | China | Asian longhorned borer causing mild impact in Guangdong, Guangxi and Yunnan |
| **Aristobia testudo* | Vietnam | Longhorned beetle causing severe damage to young *E. camaldulensis* |
| **A. approximator* (Fig. 5c) | Lao PDR, Thailand, Vietnam | Longhorned beetle causing mild damage to young plantations |
| *Batocera horsfieldi* | China | Stem borer causing mild impact in *E. citriodora* and *E. exserta* in Guangdong, Guangxi and Jiangxi |
| **Buzura suppressaria* (Fig. 6c, d) | China, Indonesia, Vietnam | Leaf eating caterpillar causing severe damage in susceptible clones |
| *Chalcophora japonica* | China | Stem borer causing mild impact in Guangxi |
| *Coptotermes formosanus* | Vietnam | Termite causing local severe damage to young *E. urophylla* clones PN2 and U6 |
| *Endoclita hosei* | Malaysia | Stem borer causing local damage |
| *Gryllotalpa africana* | Vietnam | Cricket causing mild damage to *E. urophylla* clones PN2 and U6 |
| *Holotrichia trichophora* | Vietnam | Root eating beetle causing minor damage to *E. pellita* and *E. urophylla* clone U6 |
| *Helopeltis* sp. | Indonesia | Mosquito bug causing damage to shoot tips in young stands |
| *Heterobostrychus aequalis* | China | Stem borer causing mild impact in Yunnan and Guangxi |
| **Leptocybe invasa* (Fig. 6b) | China, Laos PDR, Thailand, Vietnam | Gall wasp causing severe impact in susceptible clones, especially of *E. camaldulensis* |
| *Macrotermes* spp. (Fig. 5a, b) | Lao PDR, Vietnam | A number of termite species (mainly *M. annadalei, M. gilvus* and *M. malaccensis*) causing local damage to young *E. urophylla* |
| *Microtermes pakistanicus* | Vietnam | Termite causing local damage to young *E. urophylla* |
| *Phassus* sp. | China | Stem borer causing mild impact in Guangdong, Guangxi and Guizhou |
| **Sarothrocera lowi* (Fig. 6e, f) | Vietnam | Stem borer causing severe damage to *E. urophylla*, clone U6 |

| Name | Country | Impact |
|---|---|---|
| *Strepsicrates rothia* | China, Vietnam | Leaf roller causing moderate damage in north Vietnam, Guangdong, Guangxi and Fujian |
| **Trabala vishnou* | China, Vietnam | Leaf eating caterpillar causing severe local impact in many places in Vietnam and in Guangdong and Guangxi |
| *Xyleborus mutilatus* | China | Stem borer causing mild impact in Guangdong, Guangxi, Hunan, Jiangxi and Yunnan |
| *Xylosandrus crassiusculus* | Vietnam | Ambrosia beetle causing local damage |
| *Xylotrupes gideon* (Fig. 5d, 6a) | Lao PDR | Beetle causing stem damage |
| *Zeuzera* spp. | China, Indonesia, Thailand, Vietnam | Stem borers causing mild impact in *E. saligna* in Guangdong and Guangxi, and *E. urophylla* in Indonesia and Vietnam |

Table 3. Pests threatening productivity of eucalypt plantations in Asia. Those marked with an asterisk are major threats.

| Type | Name | Status | Impact |
|---|---|---|---|
| Leaf disease | *Atelocauda digitata* (Fig. 8e) | Indonesia, Malaysia | Phyllode rust damages foliage in nurseries and young plantations |
| | *Cephaleuros virescens* | Widespread | Present in dense canopies of *A. mangium* in Vietnam. Low impact |
| | *Colletotrichum gloeosporioides* | Widespread | Anthracnose leaf spot pathogen associated with stressed trees ; when severe can lead to stem cankers in *A. mangium* and acacia hybrid plantations in Vietnam. Low impact |
| | *Oidium* spp. | Widespread | Sometimes problematic in nurseries in Vietnam and Thailand; also in one year old plantations in Vietnam |
| | *Meliola* sp. | Widespread | Black mildew of low impact |
| | *Pestalotiopsis neglecta* | Widespread | Leaf spot pathogen associated with stressed trees in Vietnam. Low impact |
| | *Phomopsis* sp. | Vietnam | Low impact |
| Wilt | **Ceratocystis* spp. (Fig. 8a-c) | Becoming more widespread in Indonesia, Lao PDR, Malaysia and Vietnam | Beginning to cause severe damage in many locations leading to tree dieback and death |
| Stem canker | *Botryosphaeria* and related genera | Widespread | Stem and branch cankers associated with stressed *A. mangium* and *A. auriculiformis*. Low impact |
| | **Corticium salmonicolor* (Fig. 8d) | Widespread | Pink disease has high impact in some clones of *A. mangium* and acacia hybrids in Vietnam in many locations |

| Type | Name | Status | Impact |
|---|---|---|---|
| | *Lasiodiplodia theobromae* | Widespread | Stem canker of low impact |
| | *Macrovalsaria megalospora* | Vietnam | Stem canker of low impact |
| | *Nattrassia mangiferae* | Vietnam | Stem canker of low impact |
| Heart rot | *Various Hymenomycetes (e.g. species of *Phellinus*, *Tinctoporellus*, *Rigidoporus*) (Fig. 7b) | Widespread in wet tropics | *A. mangium* and *A. auriculiformis* are susceptible; in Indonesia and Malaysia infection ranges from <5 to >40%; problematic for saw-log production but death of young stands can occur; entry via wounds. Low impact in Vietnam |
| Root rot | **Amauroderma* and *Ganoderma* spp. (red rot) (Fig. 7a, c, d), *Phellinus noxius* (brown rot), *Rigidoporus lignosus* (white rot), *Tinctoporellus epimiltinus* (brown rot) | Widespread in wet tropics | Level of impact varies with site and may exceed 30% depending on infection levels in previous forest or plantations in Malaysia and Indonesia |
| | **Phytophthora cinnamomi* | Vietnam | Patch death of *A. mangium* and acacia hybrids |
| | **Pythium vexans* | Vietnam | Patch death of *A. mangium* and acacia hybrids |

Table 4. Pathogens threatening productivity of acacia plantations in Asia. Those marked with an asterisk are major threats.

| Type | Name | Status | Impact |
|---|---|---|---|
| Leaf diseases | *Pilidiella* spp. | Widely distributed | Low impact, associated with herbivore damage |
| | **Cylindrocladium* (*Calonectria*) spp. (Fig. 9d) | Well-established in SE Asia | Severe in Thailand and Vietnam; moderate in China. The most damaging species are *C. reteaudii* and *C. quinqueseptatum* |
| | **Cryptosporiopsis eucalypti* | Well-established in SE Asia | Severe in Thailand and Vietnam, minor damage to *E. globulus* in Yunnan |
| | *Pestalotiopsis neglecta* | Widely distributed | Low impact leaf spotting |
| | *Pseudocercospora eucalyptorum* | Widely distributed | Low impact leaf spotting |
| | *Teratosphaeria epicoccoides* | Now widespread in SE and E Asia | Moderate damage in many countries |
| | **T. destructans* (Fig. 9a-c) | Now widespread in SE and E Asia | Severe in Sumatra, Thailand, Vietnam and Lao PDR; moderate in China |
| | *Quambalaria pitereka* | Present in S China | Mild |
| | *Q. eucalypti* | Present in China, Lao PDR and North Vietnam | Potential to cause damage as the pathogen spreads to susceptible species and clones |
| | *Xanthomonas* sp. (Fig. 10d, e) | Lao PDR | Potential to cause local damage |
| | **Puccinia psidii* | Not present in the region | Unknown but potentially severe leaf pathogen |

| Type | Name | Status | Impact |
|---|---|---|---|
| Wilt | **Ralstonia solanacearum* (Fig. 10a-c) | Some biovars of bacterial wilt are widespread | Moderate in Vietnam and China; *E. urophylla* clone PN2 very susceptible |
| Canker diseases | *Botryosphaeria* and related genera | Widespread in SE Asia | Minor damage often to stressed trees |
| | *Corticium salmonicolor* | Widespread in Asia | Pink disease of low impact |
| | *Chrysoporthe cubensis* | Widespread in SE Asia | Minor impact in Vietnam and Thailand |
| | *Ch. gyrosa* | Vietnam | Low impact |
| | **Teratosphaeria zuluensis* (Fig. 9e-g) | Widespread in SE and E Asia | Minor impact in Thailand, Vietnam and China |
| Root rot | *Ganoderma lucidum* | Widespread in SE Asia | Very minor impact in Guangdong and Guangxi in China |
| | *Phytophthora* sp. | Vietnam | Local low impact on *Eucalyptus* hybrid |

Table 5. Pathogens threatening productivity of eucalypt plantations in Asia. Those marked with an asterisk are major threats.

### 3.3 Major pests of acacia

*Ericeia* sp.: In Fujian province (China), *E. fraterna* damages *A. mearnsii*. There are 4 generations per year and larval development takes 27-42 days. In Vietnam, a related species is causing defoliation of acacias in north Vietnam (Figure 4a). There, early instar larvae make small holes in soft, immature foliage, predominantly in the upper crown, the fourth and fifth instar larvae eat entire phyllodes. Larvae damage 2-10 year old *A. mangium* plantations, with most severe damage to 4-10 year old plantations. There are 5-6 generations each year, larvae are present all year round, with the largest populations from September to December.

*Helopeltis* spp. (Mosquito bugs): These sap-sucking hemipterans damage young phyllodes and shoot tips (Figure 4g, h). Successive attacks by nymphs and adults can stunt the growth of nursery stock and clonal hedges in particular. Damage appear initially as a lesion or area of necrosis around the feeding site and progresses to wilt and shoot death. There are many generations each year. The main species damaging acacias are *H. fasciaticollis* and *H. theivora.* They are polyphagous feeding on a broad range of hosts.

*Phalera grotei*: The first instar larvae chew the upper and lower surfaces of young phyllodes, sometimes making holes. Second and third instar larvae chew the edges of young and mature phyllodes. Fourth and fifth instar larvae feed on entire phyllodes. Outbreaks can cause complete defoliation. There are 3 generations each year.

*Pteroma plagiophleps* (Bag worm): This pest is widely distributed in SE Asia, attacking acacia and some other woody legumes causing severe defoliation.

*Xylosandrus crassiusculus* (Granulate ambrosia beetle): This small ambrosia beetle (Figure 4j) is widely distributed in tropical and subtropical Asia. Females bore into the stems of trees where they excavate a system of tunnels. The larvae feed on symbiotic ambrosial fungi. Heavy infestation together with the development of wood invading fungi (Figure 4i) can result in tree decline and death. Many trees appear to be stressed prior to beetle attack. The species is highly polyphagous.

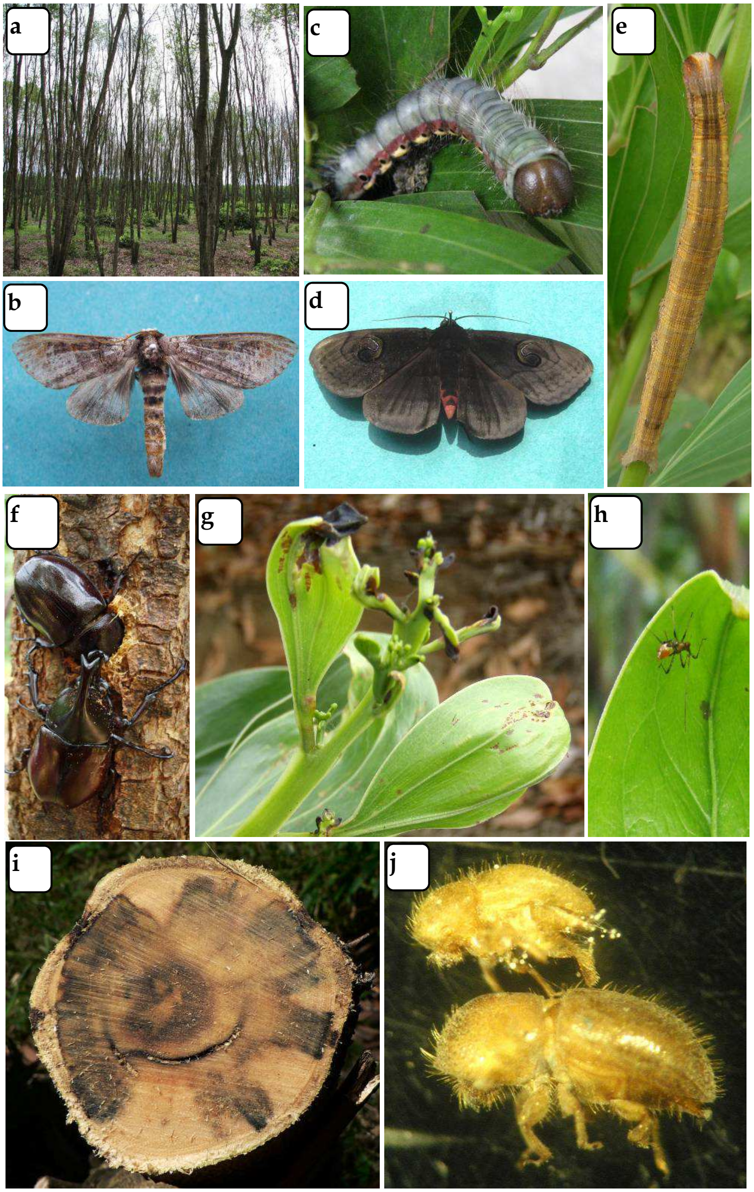


Fig. 4. Pests causing severe damage to acacia plantations in Asia. a-c. *Ericeia* sp. (Vietnam); d,e. *Speiredonia retorta* (Vietnam); f. *Xylotrupes gideon* (Lao PDR); g,h. mosquito bug *Helopeltis* sp. (Sabah, photos David Boden); i. blue-stained wood from fungi associated with *Xylosandrus crassiusculus* (j) (Vietnam)

### 3.4 Major pests of eucalypts

*Aristobia approximator* (Aristobia longhorned beetle): This pest is widely distributed in SE Asia and locally the adults (Figure 5c) cause damage to young eucalypt plantations (Figure 5c). The species is polyphagous, known to damage other plantation crops such as *Pterocarpus* and *Casuarina*. If the pest can use plantation eucalypts for their life cycle, this will threaten some plantations in the region. There is one generation per year. Adults emerge from June to August.

*Aristobia testudo* (Litchi longhorned beetle): This pest is widely distributed in south and SE Asia. Damage to eucalypt plantations has occurred in south Vietnam. Females girdle branches by chewing off 10 mm strips of bark prior to laying eggs. There is one generation per year. Adults emerge from June to August. Larvae hatch from late August and live under the bark until January when they bore into the wood and create tunnels up to 60 cm long. Adult beetles chew bark for food.

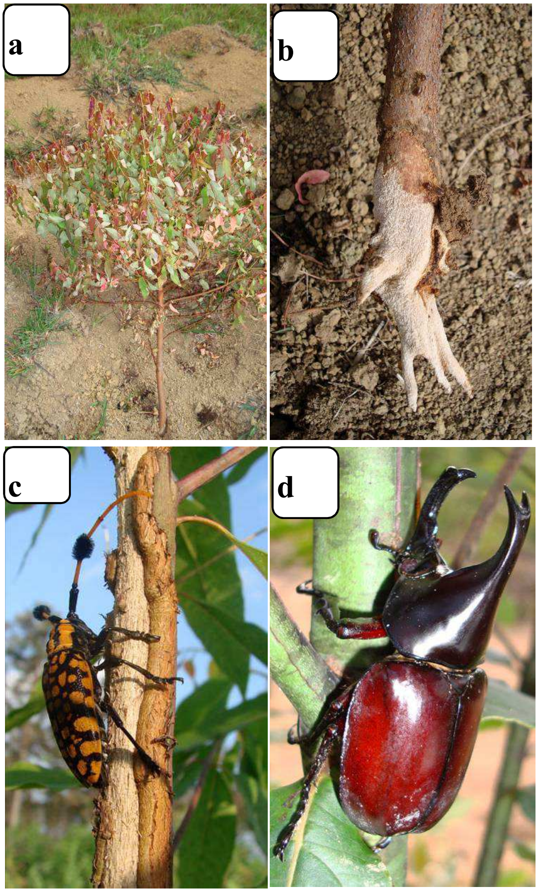


Fig. 5. Pests causing damage to eucalypt plantations in Asia. a, b. *Macrotermes* sp. destroying tree roots (Lao PDR); c. *Aristobia approximator* (Lao PDR); d. *Xylotrupes gideon* (Lao PDR)

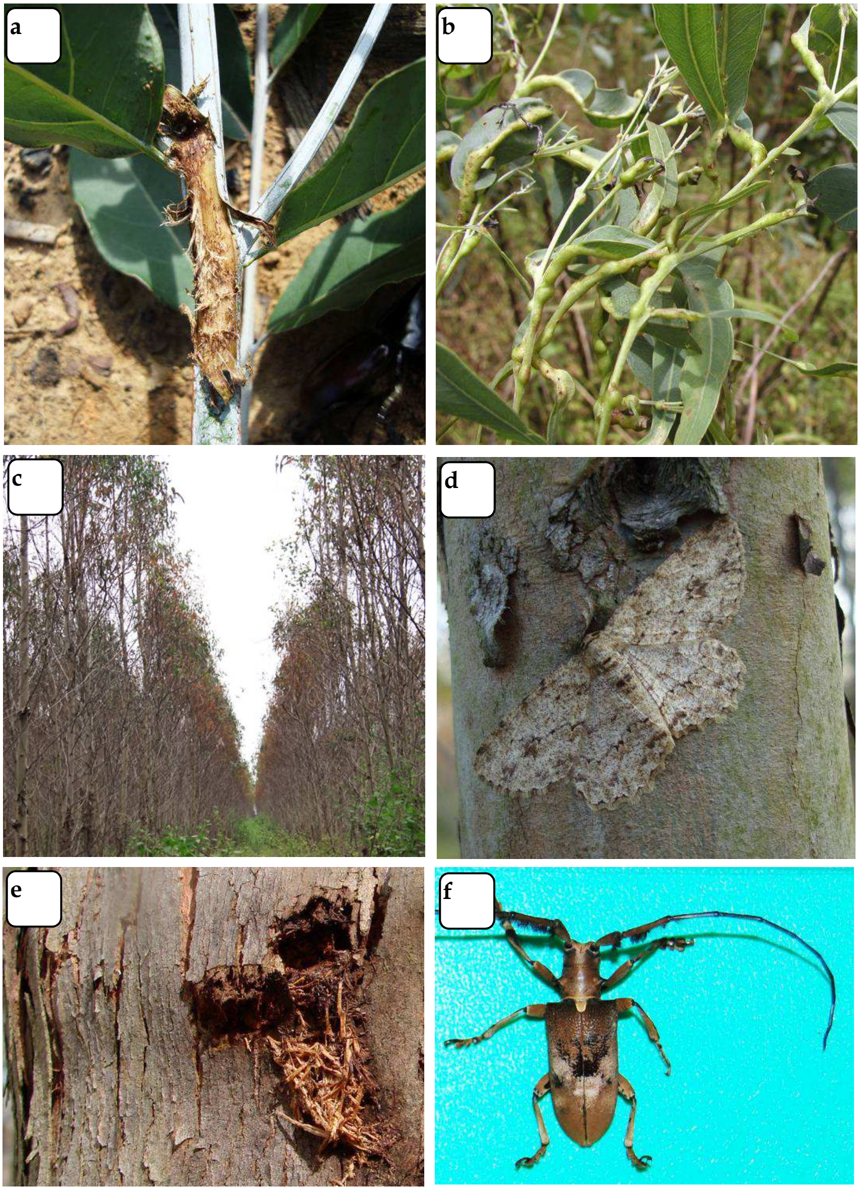


Fig. 6. Pests causing damage to eucalypt plantations in Asia. a. Damage from *Xylotrupes gideon* (Lao PDR; b. *Leptocybe invasa* galls (Vietnam); c, d. *Buzura suppressaria* (China); e, f. *Sarothrocera lowi* (Vietnam)

*Buzura suppressaria* (Tea looper): Geometrid moths have become serious pests in eucalypt planatations in recent years, reducing growth due to larvae feeding on young leaves and shoots. Of the more than 6 types of geometrid moths that feed on eucalypts in SE Asia, the most damaging so far is *B. suppressaria* (Figure 6d). In south China there can be 3-4 generations a year causing defoliation of eucalypts mainly in summer and autumn. The insect is polyphagous and is a pest of tea, citrus and other crops in the region. Biological control agents are available including products containing mycoparasites.

*Leptocybe invasa* (Gall wasp, blue gum chalcid): In the past decade this pest has spread rapidly through SE Asia affecting nursery stock, clonal hedges and plantations including young coppice especially in China, Thailand and Vietnam. Susceptible hosts include *E. camaldulensis*, *E. dunnii, E. globulus, E. grandis, E. grandis* x *camaldulensis*, *E. tereticornis* and *E. urophylla*. Female *L. invasa* insert their eggs in the epidermis. Larvae feed within plant tissues causing distinct swellings (Figure 6b) on the petioles, leaf midribs and stems on new foliage of both young and mature trees. Galling causes the leaves to curl and may stunt growth and weaken the tree; thus, *L. invasa* can cause substantial damage or death to young trees. In an outbreak situation, wasp pressure is intensive and all new growth may be damaged. The impact of the wasp on the development of an adult tree is not yet clear, although galls can be found on most leaves if the wasp occurs in large numbers. The industry is moving quickly to identify resistant clones. Meanwhile, braconid wasp parasitoids have been moving naturally in the region and are having some effect as biological control agents.

*Sarothrocera lowi*: This long horned beetle (Figure 6f) is thought to have spread to Vietnam from the wet tropics. Females deposit eggs singly into slots made in the bark. Larvae emerge and initially feed just under the bark, later boring into the stem. Pupation occurs towards the end of April and adults emerge from the end of May to early June.

*Trabala vishnou* (Lappet moth): Larvae are leaf feeders. Larvae prefer soft, immature foliage and most damage occurs in the upper crown. There are four or more generations per year. The insect is polyphagous and is a pest of many trees in south and SE Asia.

### 3.5 Major pathogens of acacia

*Ceratocystis* spp.: Three new species of *Ceratocystis* have recently been described associated with a serious disease of young *A. mangium* trees, which developed after pruning in the Riau area, Sumatra (Tarigan et al. 2011). In a recent survey, *C. acaciivora* (Figure 8a) was found on dying *A. mangium* in the absence of pruning wounds. For disease management, the impact of pruning will require careful consideration and the role of wood boring insects as vectors of this pathogen will need to be understood. Ceratocystis damage has been observed in Sabah (Figure 8b) and Lao PDR.

*Corticium salmonicolor* (Pink disease): Pink disease causes serious damage in Vietnam and the wet tropics, including Indonesia. At first, white mycelium extends over the surface of the bark. Later, a pink crust is produced on the affected area and cankers (Figure 8d) may develop. Infected branches wilt and die, followed by crown dieback. Disease resistant clones have been identified and their employment may reduce the impact of the disease in plantations. The pathogen has a wide host range including eucalypts, mango and citrus.

Heart rot: Wood-rotting basidiomycete fungi attack living trees as well as dead wood. They are particularly problematic in the wet tropics causing considerable loss in plantations in Indonesia and Malaysia. Heart rot in *A. mangium* results from fungal decay of heartwood (Figure 7b) which reduces wood quality but the tree is not killed. Heart-rot fungi generally enter trees through injuries and branch stubs and do not preferentially attack living tissue.

Root rot: Disease results from basidiomycete pathogens attacking living root tissue (Figure 7c, d) leading to crown decline and patch death (Figure 7a). The disease is spread by the contact of a diseased root or infested woody debris with a healthy root. Root rot is problematic where trees are established in previously infested areas as the fungi can survive on roots and other woody debris left after harvest.

*Phytophthora cinnamomi*: This tropical water mold has been widely dispersed around the world causing diseases in native forests, horticultural crops and city gardens. This pathogen has recently been associated with loss of *A. mangium* stands in north Vietnam.

*Pythium vexans*: This pathogen has recently been identified as the cause of decline in plantations and clonal hedges of *A. mangium* in north Vietnam.

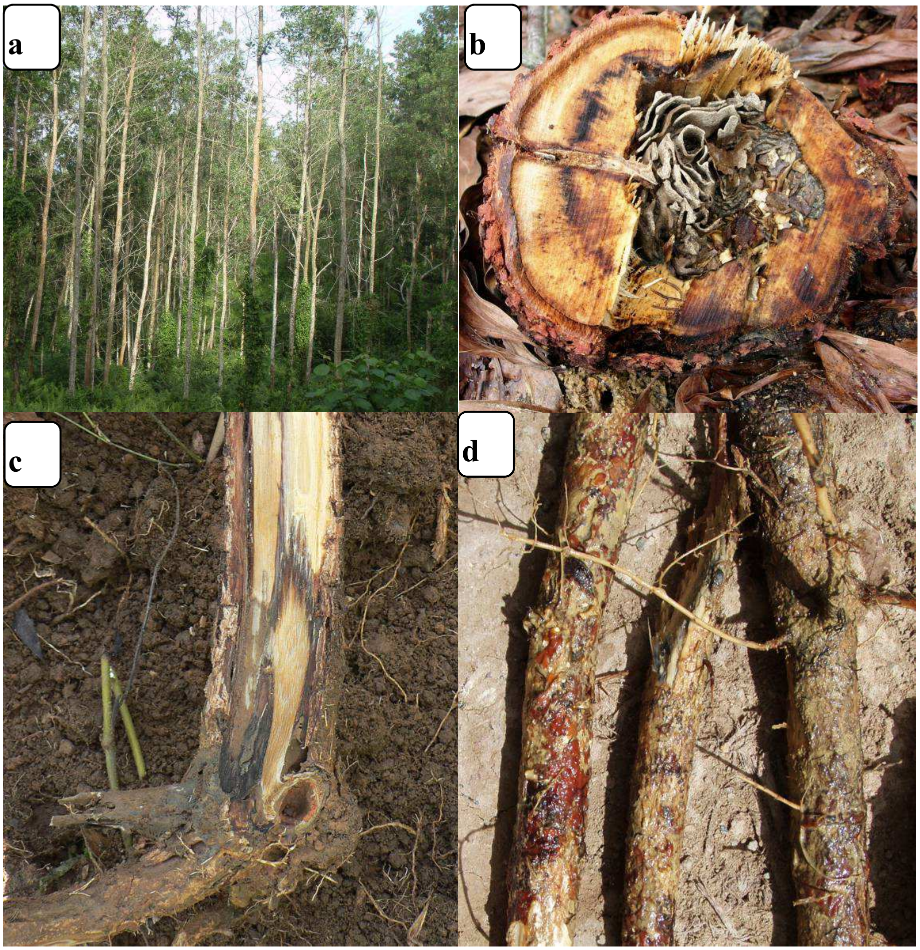


Fig. 7. Heart and root rots in acacia in Asia. a. patch decline in Sabah (Photo David Boden); b. heart rot and termite damage (Sarawak, photo Lee Su See); c. root rot in young tree (Lao PDR); d. red rot on roots (Sabah, photo David Boden)

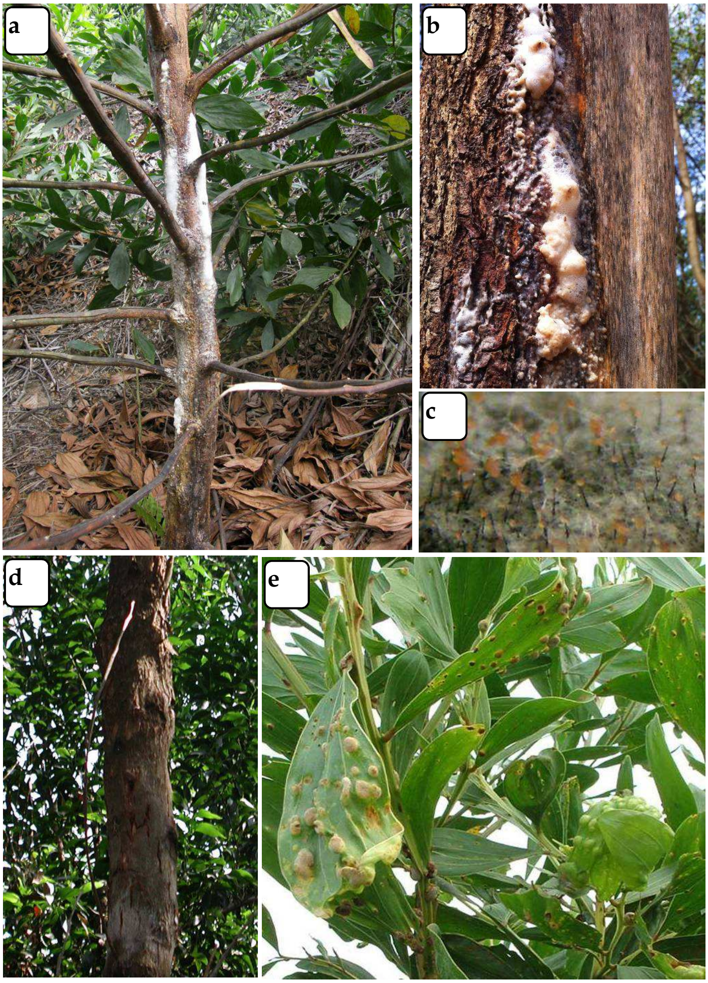


Fig. 8. Stem and leaf diseases in acacia in Asia. a. Stem infected by *Ceratocystis acaciivora* (Indonesia, photo Marthin Tarigan); b. Stem infected with *Ceratocystis* after elephant damage (Sabah, photo David Boden); c. *Ceratocystis* sporulating (Vietnam); d. *Corticium salmonicolor* canker (Vietnam); e. *Atelocauda digitata* phyllode rust (Malaysia, photo Lee Su See)

### 3.6 Major pathogens of eucalypts

*Cylindrocladium* spp. (Teleomorph = *Calonectria*): The initial symptoms of these blights are greyish, water soaked spots on young leaves. These spots then coalesce developing into extensive necrotic areas. Under conditions of high humidity and frequent rainfall, necrotic lesions cover the entire area of the leaf. Fungal mycelia and fruiting bodies cover and kill young shoot tips, resulting in leaf and shoot blight symptoms. Damage is severe in the wet season (Figure 9d). New species of *Calonectria* have recently been described for eucalypts in China (Chen et al. 2011).

*Cryptosporiopsis eucalypti*: This blight infects leaves and stems. Leaf spots are discrete but irregularly shaped and often dark chocolate-brown in colour. On mature leaves extensive areas of reddish-brown tissue burst through the leaf, producing a very rough surface. Infected shoot tips become distorted, drop their leaves and die. The tree may produce epicormic shoots forming double leaders. These may also become reinfected the following season. The crown assumes a flattened appearance.

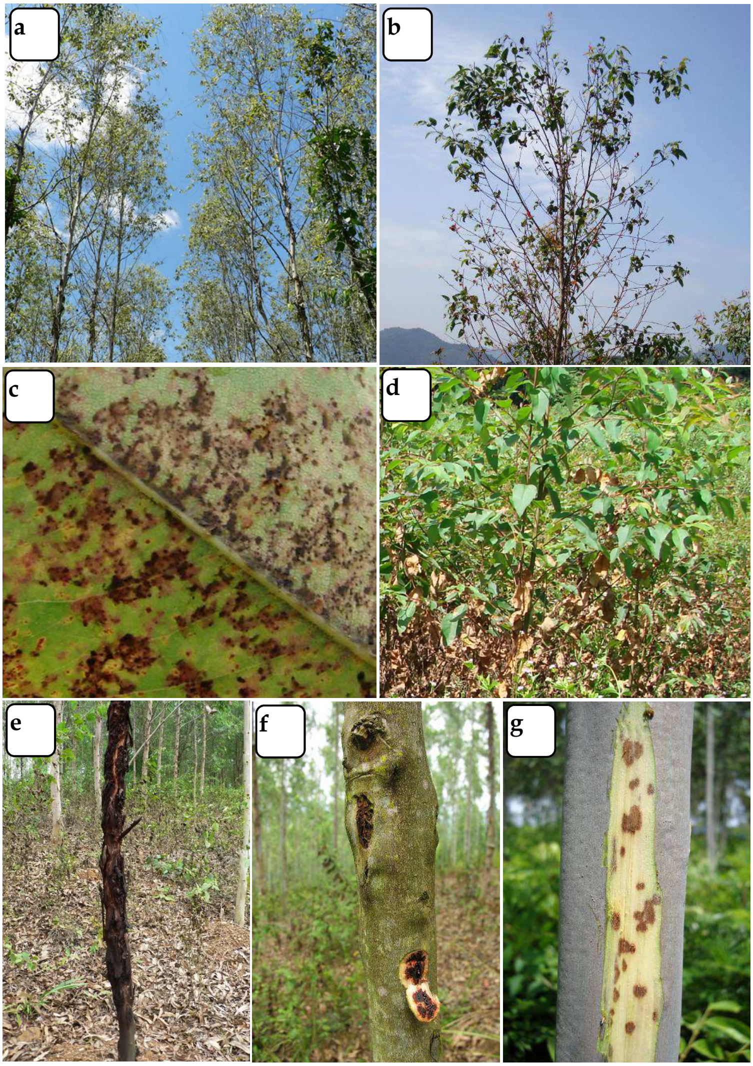


Fig. 9. Leaf and stem diseases in eucalypts in Asia. a-c *Teratosphaeria destructans*, loss of canopy (a. Lao PDR, b. Vietnam), leaf symptoms (c. Vietnam); d. Necrosis of lower foliage in the wet season from *Calonectria* (*Cylindrocladium*) spp. (Vietnam); e-g. stem cankering from *Teratosphaeria zuluensis* (e, f. Vietnam, g. Lao PDR)

*Puccinia psidii* (Guava rust): This rust fungus is a major quarantine concern (Coutinho et al. 1998) for Asia. In Brazil, the fungus attacks susceptible species of eucalypts, guava and some other genera in the Myrtaceae. This disease can cause deformation of leaves, heavy defoliation of branches, dieback, stunted growth and even death. Recently, a closely related taxon in the guava rust (*Uredo rangelii* or Myrtle rust) complex has entered Australia (Carnegie et al. 2010) and is likely to spread into SE Asia.

*Ralstonia solanacearum*: Bacterial wilt typically affects young trees growing on ex-agricultural sites in hot wet areas (Figure 10a). It is characterised by the sudden wilting and death of a branch or the entire crown, associated with streaking in the stem (Figure 10b). Wilting of plants may begin within months of planting, particularly in areas where daytime temperatures regularly exceed $30^0$C. Xylem vessels become filled with bacterial slime which ooze out when a freshly cut stem is inserted for a few minutes into water (Figure 10b). Attempts to produce resistant clones has so far proved to be unsuccessful.

*Teratosphaeria destructans* (Synonyms *Kirramyces destructans, Phaeophleospora destructans*): The fungus causes a severe blight of shoots and leaves, producing light brown leaf spots, which are irregular to rounded, with indistinct borders. Masses of spores ooze onto the surface of leaves, often giving them a sooty appearance (Figure 9c). This pathogen can cause extensive blights (Figure 9a, b), distortion of young leaves and premature leaf abscission as a result of necrosis of the leaf and petiole. It was first described from Sumatra (Wingfield et al. 1996) and has spread rapidly into eucalypt plantations across Asia (Burgess et al. 2006).

*Teratosphaeria zuluensis* (Synonyms *Colletogleopsis zuluense*, *Coniothyrium zuluensis*): Initial infection of *T. zuluensis* results in small, circular necrotic lesions on the green stem tissue in the upper part of trees (Figure 9g). These lesions expand, becoming elliptical, and the dead bark covering them typically cracks giving a cat eye appearance (Figure 9f). Lesions coalesce to form large cankers (Figure 9e) that girdle the stems, giving rise to epicormic shoots. The canker was first described in South Africa and later was reported in Thailand, China (Cortinas et al. 2006) and Vietnam.

## 4. Managing abiotic and biotic threats

In the past, the high cost of inorganic fertilizers has prevented the application of optimum levels of macronutrients for tree growth in many areas, but this has largely been overcome in recent years. For example, in south China fertilizers are applied up to three times in a rotation (about 1 tonne of N, P and K compound fertilizers per hectare). However, micronutrient deficiencies are an ongoing problem on many new sites being afforested for the first time. The small amounts of micronutrients that are needed to correct or prevent the onset of deficiencies, typically a few kg per hectare, should not constrain their wider use where correct diagnosis of nutrient constraints are available (Bell & Dell 2008). Foliar analysis has proven to be an effective tool in the diagnosis and prevention of micronutrient disorders and standards are available for some plantation species (Dell et al. 2001). However, this approach is not widely adopted in the region and many foresters rely on the expression of symptoms before making silvicultural decisions. It is important to realise that substantial loss of wood volume can occur before symptoms of nutrient disorders become obvious.

In China, more and more eucalypt plantations are being established in the upper Yangtse and Pearl river catchments, and some of the locations have an annual rainfall less than 1200 mm. Locally there is concern that the expansion of eucalypt plantations may reduce water production in the small catchments and the function of ecological services from the catchments. So far, there is no long term catchment water production study in these regions. Furthermore, recent climate change patterns for these high land regions show a reducing rainfall. Another concern is whether nutrient runoff from heavy fertilization of eucalypt trees will degrade water quality in the rivers and reservoirs. Long term monitoring is necessary to allay these fears.

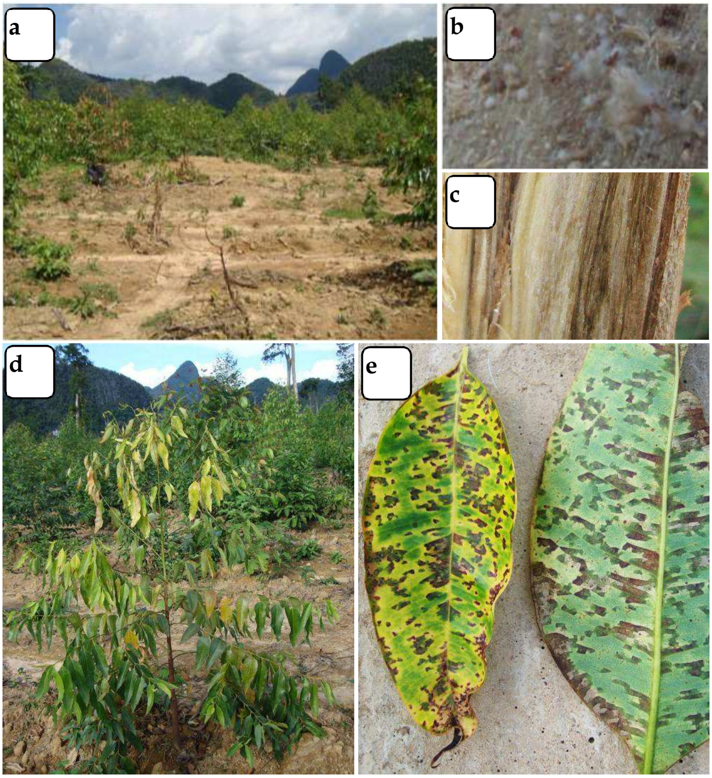


Fig. 10. Bacterial diseases in eucalypts in Asia. a-c. *Ralstonia solanacearum* (a. dead trees, b. bacteria oozing from cut stem, c. streaking in wood, Lao PDR); d, e. *Xanthomonas* sp. (Lao PDR)

Widespread planting of eucalypts and acacias in Asia has been associated with the appearance of significant foliar and stem diseases and, to a lesser extent, damage from insects. Across the whole region, the most damaging eucalypt pathogens are those that cause leaf and shoot blights. By contrast, in acacias, the pathogens differ markedly between the wet tropics and drier sub-tropics even for the same host species. In Vietnam, stem canker, crown wilt and root rot diseases cause the most damage whereas heart rot fungi have been of the greatest concern in Indonesia. In both geographical areas, the fungi are favoured by warm, humid climates, and have the potential to greatly reduce the growth, yield and product quality of plantations. Experience in Vietnam from the period 1998-2010 has shown that, provided reliable diagnoses are made of the pathogens present in replicated clonal trials and well-designed provenance and progeny trials, resistance to these pathogens can be readily identified at the individual tree or clone, family, provenance and species levels. Resistant selections can then be propagated as clonal plantations or established as clonal seed orchards to provide seed for planting in disease-prone environments. About 60 ha trials of clones of *E. camaldulensis*, *E. brassiana*, *A. mangium*, *A. auriculiformis* and acacia hybrid (*A. mangium* x *A. auriculiformis*) have been established in many high risk disease locations of Vietnam from 1998 to 2010. Disease scoring and growth measurement of every tree in the trials were conducted on an annual basis. Clones showing good growth performance and no disease symptoms were selected for large scale plantings. There are now 22 clones of *E. brassiana*, *E. camaldulensis*, *A. auriculiformis*, *A. mangium* and acacia hybrid recognized in Vietnam with characteristics of fast growth and disease resistance. Examples of three clones follow:

*Eucalyptus brassiana* Clone SM7: fast growing on low hills in soils of low fertility; mean annual increment (MAI) of 36.6 $m^3$ $ha^{-1}$ $yr^{-1}$ in Dong Nai; resistant to leaf blight disease caused by *Cylindrocladium reteaudii* (*C. quinqueseptatum*), leaf spot diseases caused by *Cryptosporiopsis eucalypti* and *Teratosphaeria destructans*.

*Acacia mangium* Clone M5: good form (one main stem, small branches, high bole height); fast growing on low hills, on ferralic soils of low fertility; MAI of 36.2 $m^3$ $ha^{-1}$ $yr^{-1}$ in Dong Nai; resistant to pink disease caused by *Corticium salmonicolor,* crown wilt caused by *Ceratocystis* sp., root rot caused by *Phytophthora cinnamomi.*

Acacia hybrid Clone AH7: superior stem form; fast growing on flat sites which have a thin soil surface and low fertility as well as on old alluvial soil; MAI of 24.4 to 34.9 $m^3$ $ha^{-1}$ $year^{-1}$; strong resistance to pink disease caused by *Corticium salmonicolor,* crown wilt caused by *Ceratocystis* sp., and root rot caused by *Phytophthora cinnamomi.*

The approach adopted above for developing fast growing trees with disease resistance has also been undertaken in other countries in the region with varying levels of success. Increasingly, more and more of this research is being undertaken by the private sector, especially in Indonesia, Thailand and China. The severity of leaf and shoot blights on eucalypts in Thailand forced the plantation industry to rapidly introduce new clones into production. Clone Banks established in the early 1990s were used to detect lines differing in susceptibility to *Cryptosporiopsis eucalypti* shortly after the pathogen was first detected in Thailand (Pongpanich 1997). A few years later, various eucalypt clones, including hybrids, were being screened for their level of resistance to the damaging pathogen, *Teratosphaeria destructans*, that had invaded from Sumatra. One of these clones is now prominent in plantations that were later established in Lao PDR. These examples illustrate the importance of having large replicated clonal trials and well-designed provenance and progeny trials that can be used to screen for resistance to current and future pathogens.

Far less progress has been made in responding to the threats of insect pests in the region. In only a few countries is there any systematic attempt to monitor the scale and type of insect outbreaks and damage to plantations. There is a shortage of trained forest entomologists. The lack of information results in pests not being sufficiently considered in plantation management. Selecting for insect resistance in plantation trees is difficult (Henry 2011) and little progress has been made with either eucalypts or acacias in this regard. A notable exception is shown in Figure 11. The potential for pest outbreaks to cause damage is high where the genetic diversity of plantations is low, such as in south China. In a discussion as to whether tree-improvement programs can keep pace with climate change, Yanchuk and Allard (2009) conclude that there needs to be better alignment of forest genetics and forest health research programs in order to help mitigate the projected negative impacts of climate change on forest productivity and health. The Research Institute of Tropical Forestry, Chinese Academy of Forestry is leading a research group to create new hybrids of *E. urophylla* x *grandis*, *E. urophylla* x *tereticornis* and *E. urophylla* x *camaldulensis* for the selection of clones with a higher nutrient and water use efficiency and insect and disease resistance. This group is also producing new hybrids of *E. grandis* x *dunnii* and *E. urophylla* x *dunnii* for the selection of clones with improved cold resistance and rooting ability. In Thailand, progress is being made with the selection of eucalypt clones more resistant to the damaging blue gum chalcid.

Fig. 11. Genetics trial in Binh Phuoc province, Vietnam established to screen for resistance to *Leptocybe invasa*

## 5. Responding to climate change

There is undisputable evidence that the world's climate is changing due to global warming. The reader is referred to the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC) for discussion on climate trends and projected climate change. Over the past decades extreme climate events and climate anomalies have been reported in SE Asia (Cruz et al. 2007), including floods and droughts. The vulnerability of plantations to biotic and abiotic stressors is likely to be exacerbated in the future by climate change. All the climate change scenarios generated from the various models predict a warming trend in Asia but there is high uncertainty in projected rainfall amount and distribution for the region. Extreme weather events associated with El Niño have increased in frequency. There has, for example, been an increase in tropical cyclones originating in the Pacific and impacting on China, Philippines, Vietnam and Cambodia (Cruz et al. 2007). Whilst precipitation may increase in the tropics, the frequency and intensity of drought periods may also increase in parts of China, Indonesia, Lao PDR, Thailand and Vietnam during or following ENSO events. ENSO is the primary driver of precipitation fluctuations for SE Asia (Malhi and Wright 2004). Climate change is likely to affect tree physiology and increase the spread and impact of pests and diseases in the region.

In may be surprising to learn that climate change may also increase the frequency of special low temperature periods in sub-tropical China and Vietnam in winter. Already cold damage to eucalypt plantations is occurring in the region. Furthermore, global warming will increase the frequency of typhoons leading to prolonged periods of high temperature and humidity which are favourable for foliar diseases. In most countries in E and SE Asia, floods are common in the typhoon or monsoon seasons. These will impact on plantations on floodplains, such as along the Mekong. For the most part, acacia and eucalypt plantations are not planted on alluvial plains as these soils are prized for food production. Changes in rainfall patterns are likely to be complex and season and region specific. For example, in Vietnam monthly rainfall is decreasing in July and August and increasing in September, October and November (MoNRE 2003). Overall, total rainfall is likely to increase (Hoang and Tran 2006) but, because it will be more concentrated in the wet season, an exacerbation of drought problems is expected in the dry season (Johnston et al. 2009). In parts of south-west China, in the central highlands and the south central coast region of Vietnam, and in central and north-eastern Thailand, droughts are likely to increase under current climate change scenarios. Drought-induced tree deaths are now evident in a small number of young eucalypt plantations growing on shallow and sandy-textured soils. By contrast, plantations in tropical areas such as Sumatra, Sabah, Kalimantan and eastern Mindanao are less impacted by changes in temperature and rainfall.

To ensure the sustainable production of plantation wood into the future, existing and future abiotic and biotic threats need to be managed under a prolonged period of climate change. A dual focus on research/development, discussed earlier, and adaptive silviculture are necessary. An assessment of vulnerabilities due to climate change can be included when formulating operation schedules. For example, an increase in intensity of precipitation could result in increased soil erosion on slopes or in leaching of nutrients such as B. Intercropping with agricultural species in the first year of establishment can reduce erosion if minimum tillage practices are adopted. Application of less soluble forms of B, to those soils where B is limiting production, would reduce leaching loss. Consideration should also be given to the extra nutrient demands that will be placed on fragile soils due to enhanced sequestration of carbon under higher atmospheric $CO_2$ levels resulting in more biomass and nutrients being harvested. Retention of harvest residue and bark on site will minimize nutrient rundown over time.

In areas with a prolonged and intensive dry season, water deficit can be more important in limiting productivity than soil infertility. Future actions for consideration include:

- Improving site selection using knowledge of regoliths, hydrology and tree water use at the stand level,
- Reducing the density of tree planting at a catchment level so that the water balance is not unduly impacted by tree water use,
- Changing the species to one more suited to the climate and site type, and
- In the longer term, breeding and deploying water use-efficient genotypes,

Abiotic and biotic factors should not be considered in isolation as they often interact in their impact on plantation health. These interactions are likely to become even more important with climate change (Moore and Allard 2008). Deficiencies of micronutrients such as Cu, B and Mn have implications for tree defence against some fungal pathogens (Dell et al. 2008). For example, attack by ambrosia beetles and incidence of *Botryosphaeria* and other cankers are more prevalent in B-stressed *A. mangium* than in trees of balanced nutrition. *Botryosphaeria* damage was high in drought-stressed stands of *A. mangium* in west Thailand (Pongpanich 1997). Dell and Xu (2006) observed a connection between weather (incidence of typhoons, reduced rainfall) and soil B availability on damage from *Ralstonia* wilt in eucalyptus plantations in China. A link between rainfall and the incidence of heartrot in acacia was suggested by Lee and Arentz (1997).

It is now clear that climate change is having a severe impact on the health of many of the world's forests (Ayres and Lombardero 2000) including plantations. Worldwide, tree mortality due to increasing drought and heat (Allen et al. 2010), diseases (Sturrock et al. 2011), pests (Kausrud et al. 2011) and other stresses is increasing. Climate change will affect the pathogen/pest, the host and the interaction between them. The projected damage from pests will arise as pests encounter more suitable climatic conditions for their establishment and biology, and by host tree species becoming more susceptible to pests due to climate induced stress such as drought (FAO 2010). Likewise for pathogens, climate change will facilitate expansion in the range of some virulent species. In addition, increased globalization of trade is likely to accelerate the spread of pests and pathogens in the future. Incursions of fungal pathogens such as *Teratosphaeria destructans* and pests such as *Leptocybe invasa* in Asia demonstrate how the health of plantations can quickly be impacted over just a few years.

However, it is difficult to project the vulnerability of plantations to pests and pathogens in a changing climate (possible scenarios are given in Table 6). This is because the biology of most pest and pathogen species of interest is poorly known. What is clear is that biological invasions will continue and plantations will increasingly be exposed to new threats. Wingfield et al. (2011) point out that Australian acacias are increasingly threatened by pests and pathogens when planted outside Australia. For the most part, the sensitivity of eucalypts and acacias to increased temperatures is unknown. Furthermore, plantations are likely to be exposed to new threats from the introduction of exotic pests and pathogens as well as from organisms already present but at low population levels in native forests. Once the organisms are well understood, their geographical range and activity can be simulated (Volney and Fleming 2000, Bale et al. 2002, Desprez-Loustau et al. 2007, La Porta et al. 2008). However, this is an ongoing task that requires considerable investment in research, particularly in the region being discussed in this chapter. In the meantime, it is prudent to undertake actions in advance of this knowledge, including the following:

- Monitor plantation health and condition on a regular basis in order to detect change,
- Undertake surveillance of diseases and pests of concern,
- Identify new pests and diseases accurately and early,
- Reduce spread of pests and pathogens through improvement in quarantine,
- Undertake comprehensive risk analysis, including simulation modeling and climate mapping, to identify high-risk species and areas,
- Increase the diversity of clones, and where desirable – species, in plantations, and
- Breed for resistance to pests and pathogens of greatest impact, that are present in the region or have the potential to persist if introduced.

Booth et al. (2000) identified preliminary areas in SE Asia that are vulnerable to *Cylindrocladium quinqueseptatum* leaf blight using a simple model based on long-term mean climatic information. They concluded that climate change should increase the disease hazard in parts of Vietnam, Lao PDR and Thailand. Similar mapping can be undertaken for the hosts (Booth et al. 1999).

| Climate parameter | Impact of pathogens and pests |
|---|---|
| Increased temperature | Unknown (lack of information on temperature responses of pathogens, pests and hosts) |
| Increased incidence of cold weather events | Increased risk of damage from stem borers and canker fungi |
| Increased frequency of severe weather events | Increased risk of pest and pathogen spread from typhoons in China, Philippines, Cambodia and Vietnam |
| | Increased damage from leaf pathogens due to prolonged periods of high temperature and high humidity |
| | Increased risk of root damage from strong winds creating entry ports for *Ralstonia* and other soil-borne pathogens |
| Increased length of the wet season | Increased damage from leaf pathogens |
| Increased incidence and severity of drought | Increased damage from stem cankers and possibly from borer insects (more sites with water deficit in the dry season) |

Table 6. Likely impacts of climate change on health of *Acacia* and *Eucalyptus* plantations in Asia.

## 6. Concluding remarks

The health of acacia and eucalypt plantations is dynamic, changing in place and time and likely to become more challenging to manage if their vulnerabilities to biotic and abiotic factors are exacerbated by climate change. Indeed, the impact of climate change on plantation function and tree physiology is poorly understood. In spite of considerable recent taxonomic effort, not all the potential threatening species have been described. Even the biology of some of the most damaging biota is incomplete. Clearly, considerable more research and development is needed to underpin adaptive actions by plantation managers in the future. The steep increase in the number of eucalypt pathogens that have appeared in the Asian region over the past decade is of great concern as very little new tree genetics has been introduced into the field with any resistance to these pathogens in Asia. Furthermore, as clonal forestry continues with a low number of clones, the risk of damage in the future remains high. Given the proximity of Australasia to plantations in SE Asia, it is inevitable that further incursions of damaging pathogens will occur. The most likely candidate fungus is Myrtle rust.

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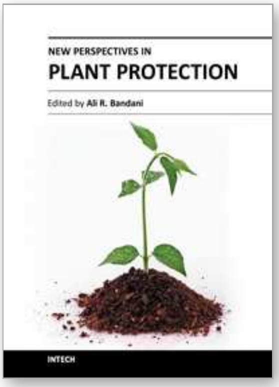


**New Perspectives in Plant Protection**

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Crop losses by pests (insects, diseases and weeds) are as old as plant themselves but as agriculture are intensified and cropping patterns including the cultivation of high yielding varieties and hybrids are changing over time the impact of the pests becoming increasingly important. Approximately less than 1000 insect species (roughly 600-800 species), 1500 -2000 plant species, numerous fungal, bacterial and nematode species as well as viruses are considered serious pests in agriculture. If these pests were not properly controlled, crop yields and their quality would drop, considerably. In addition production costs as well as food and fiber prices are increased. The current book is going to put Plant Protection approaches in perspective.