Heartrots in Plantation Hardwoods in Indonesia and Australia

Editor: K. Barry

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Introduction

David Kaimowitz and Chris Barr*

MANY people might well wonder why anyone would devote their time and energy to holding a seminar and publishing a book about ‘heartrot’ in forest plantations. At first glance, fungal diseases in forests sounds like a rather esoteric and technical topic, of little relevance to anyone except a few academics. Indeed, even among foresters in Southeast Asia and Oceania, relatively few have given much thought to the subject or seen any real reason why they should.

Nonetheless, fungal diseases will ultimately play an important role in the future of one of Indonesia’s most important economic activities — the production of pulp and paper. As a result, the forestry community, private investors interested in pulp and paper, and national policymakers in Indonesia, all have a major stake in learning more about the issue. Root rot is a substantial problem for *Acacia mangium* plantations, causing outright tree death. This affects the marginal economics of pulp and paper production. Heartrot has been reported as a major problem in *A. mangium* in other parts of Asia, and while it may influence volume, it does not affect pulp quality for paper production at present.

However, heartrot will become important if a future solid-wood industry is considered. A report by Ken Gales in this Report outlines that there will be a future requirement for such an industry as other sources of solid-wood in Indonesia become depleted or conserved. Such an industry will rely on marginal profits just as the present pulp and paper industry does. Also, by integrating wood fibre-based products with high value veneer and sawn products, saw mill residues become a low-cost feedstock for pulp and paper production, thereby increasing the competitiveness of the entire industrial operation.

Since the late 1980s, Indonesia’s pulp and paper industries have expanded very rapidly, pushing the country into the ranks of the world’s top ten producers. Between 1988 and 2001, Indonesia’s pulp production capacity grew from 606,000 to 6.1 million tonnes per annum, while the paper industry’s processing capacity rose from 1.2 million to 8.3 million tonnes per year. Last year, pulp and paper products generated US$2.9 billion in export earnings, accounting for over half of Indonesia’s forest-related exports.

To achieve such expansion over the past decade, investors put US$12 billion into the pulp and paper industry. Much of that entailed establishing processing facilities with very large production capacities that generally have extremely high fixed costs, in several cases exceeding US$1 billion per mill. International and national banks provided most of the investment capital in the form of loans. To pay off those loans, the companies will have to operate their processing plants at almost full capacity and keep the cost of raw materials very low.

The very high growth in the pulp and paper industry has created a huge new demand for industrial roundwood. Between 1990 and 2000, the industry’s demand for roundwood grew from 4.9 to 24 million cubic metres per year. By 2010, it is currently projected to reach some 35 million cubic metres.

Until now, Indonesia’s pulp mills have relied heavily on unsustainable — and, in some cases, illegal — sources of fibre, much of which is obtained through the clear-cutting of natural forests. However, the available supply of mixed tropical hardwood near the processing facilities that can be used for producing pulp and paper is rapidly dwindling. The Indonesian Government, civil society and the international community have expressed increasing concern about the clearing of additional natural forests to make pulp and paper.

From the beginning, the pulp and paper companies have always said that, in the medium-term, the main source of raw materials for their pulp mills would come from forest plantations. To support the establishment of those plantations, the Indonesian government provided licences to develop pulp plantations on a total of 4.3 million hectares. By January 1999, private companies had planted around one million hectares of forest plantations in the areas that the government licensed to them. About 80 per cent of those plantations involved the use of

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A. mangium, which grows rapidly, provides high pulp yields and adapts well to degraded soils.

Nevertheless, despite the rapid growth in plantation area, the pulp and paper companies have continued to demand very large quantities of timber from natural forests, because the processing capacity has grown even more rapidly than the plantations. Of the 100 million cubic metres of wood estimated to have been consumed by the pulp industry during 1988–1999, only 8 per cent was harvested from plantations. That cannot continue. As it becomes more difficult and expensive to obtain raw materials from natural forests, the industry will have to supply the bulk of its raw material needs from its own plantations or from imports. Both of these options would significantly increase the operating costs of an industry that is already in financial distress.

To be economically viable in the medium to long term, Indonesia’s pulp and paper industry will almost certainly have to develop its forest plantations much more than it has in the past. To meet the companies’ expressed goals of sourcing 95 per cent of their raw material needs from tree plantations by 2009, they would have to increase the wood production of their plantations eight-fold, from four million cubic metres in 1999 to 32 million cubic metres in 2009. That will not be easy.

There are many institutional and social difficulties. In the current context of political reform, decentralisation and rising land claims by local communities, it is becoming harder and harder for the companies to find enough available land where they can plant trees or contract farmers to plant trees for them. Given their current financial difficulties, the companies will also find it hard to find the capital to invest in plantations that will take six or seven years to provide positive income flows. Intentional and accidental fires constitute another important risk.

There are also many technical issues. Few tropical countries anywhere around the world have plantation sectors as large as Indonesia is in the process of developing; and relatively few have experience with sustaining plantation yields in large areas over more than a few rotations. Much of the area where the pulp and paper companies plan new forest plantations in Sumatra is in peat swamps. This presents an additional set of technical challenges. And then there is rootrot and other fungal diseases that affect the productivity of Indonesia’s pulp plantations, but about which we still know rather little in terms of their incidence and economic impact and the long-term threat that they might pose. The establishment of a solid-wood industry in Indonesia will require similar technical research, including major diseases which affect wood quality. Making an early start on this research (in this case, heartrot) will allow information to be on hand about the extent of the problems to be expected and possible solutions.

That is what makes such compilations and the research associated with them so important. The future of a multi-billion dollar industry rests on getting the technical (as well as the economic and social) aspects right — and fungal diseases are a key part of that.

Until now, research by the pulp and paper companies and others has allowed steady increases in the productivity of the *A. mangium* plantations. The average mean annual increments have risen from around 15–20 cubic metres per hectare per year in the early 1990s to about 25–30 at present. Improved genetic material and better management practices should be able to improve those yields even more. That will depend in part though on effective research that can avoid longer-term problems such as disease, soil degradation and soil nutrient depletion.

So, whether you are a forester, an investment banker, or a government official — as long as you are concerned with present and future forestry in Indonesia or elsewhere in Southeast Asia and Oceania — this report will be of interest to you.

Plantation and Tree Improvement Trends in Indonesia

Anto Rimbawanto*

Abstract

Plantations established for industrial purposes have become important sources of wood in Indonesia. Large areas of unproductive grassland have been turned into highly productive plantations, providing the necessary raw materials for the pulp and paper industry as well as job opportunities for many local communities. Nationwide, the area planted under the HTI (hutan tanaman industri) program about one million ha, far short of the target of 2.3 million ha set in the mid-1980s. More than 600,000 ha of plantation forests of *Acacia mangium*, the dominant industrial plantation species, have been established. These plantations have the potential to produce around 90 million cubic metres of wood at a rotation length of six years. In line with the progress in plantation establishment, tree improvement measures have gained momentum. Outcomes of tree improvement programs have been put into practice and have resulted in increased plantation productivity.

MUCH HAS BEEN SAID about the state of forest resources in Indonesia, particularly in regard to the natural forests. Some comments are positive but others point out that severe degradation has occurred, both in terms of production and the potential loss of genetic resources. Reforestation and genetic conservation are two of the most effective strategies that can be adopted to prevent the forest industry from collapsing.

For more than three decades, forestry and forest-based industries have been major supporting pillars of the Indonesian economy. It has also been widely stated that utilisation of Indonesia’s natural forests has caused severe degradation of both forest productivity and species richness. Exact figures are difficult to obtain, but reports suggest that the annual loss of forest area in Indonesia is of the order of two million ha.

In the early 1980s, the government initiated a program to minimise the utilisation of natural forest by initiating plantation programs to provide wood for forest industries, known as ‘hutan tanaman industri’ or HTI, in the outer islands. The target was to convert unproductive *Imperata cylindrica* grassland and secondary scrubland into productive plantations. The program aimed to establish 2.3 million ha of plantations by the year 2000 (Ginting et al. 1996). The plan was to establish 1.5 million ha of plantation every year. In reality, some 15 years since the program started, less than one million ha have been planted.

The current plantation program has been planned to produce wood for paper and medium density fibreboard. With more than 13 pulp production plants currently in operation, Indonesian pulp production capacity is expected to reach 5.7 millions tonnes.

The plantation program has provided the momentum for tree improvement in the country. Although tree improvement initiatives in Indonesia commenced in 1920 (particularly for teak), generally the outcomes of such programs have never been put into practice. More recently, some newly introduced, fast-growing species, such as *Acacia mangium, A. auriculiformis, A. aulacocarpa, A. crassicarpa, Eucalyptus urophylla* and *E. pellita* have shown remarkable growth. Consequently, genetic improvement and research on plantation management has focused on these fast-growing species.

Today, several forest companies and research organisations, including universities, have well established tree improvement programs. The genetic materials being generated through these efforts are potentially very significant in producing high quality plantations.

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Tree Improvement Programs

Prior to 1980, a number of tree improvement initiatives, such as provenance trials of teak, and provenance and progeny tests of pine, acacia and eucalypts, had been carried out. The outcomes had never been translated into practice, however, because there was only a small planting program. This situation changed when the HTI program was introduced. Using data obtained from previous provenance and species tests, companies wanting to establish plantations looked for seeds of known origin. In the case of *A. mangium*, hundreds of kilograms of seeds of known native provenance were imported from the CSIRO Australian Tree Seed Centre.

While their planters were busy clearing land, setting up nurseries and planting seedlings, research staff were establishing tree improvement plots. Open-pollinated progeny tests and provenance resource stands were established to provide information on the genetic properties of seedlots and seeds of improved quality. Periodical measurements provided data and information on the performance of the trees.

Plantation Program

The most recently established plantations are of exotic species, mainly *Acacia* spp. and *Eucalyptus* spp. *Acacia mangium* is the principal species planted covering more than 80 per cent of the plantations. *A. mangium* is well adapted to a wide range of environments and this adaptability has made the species popular for planting on degraded lands in Indonesia and elsewhere. The recent rapid expansion in plantations of *A. mangium* is related to the decreasing supply of woods from natural forests, the opportunity to increase productivity of low potential or degraded sites, and the newer technologies which make fast-grown wood with uniform properties a valuable resource for pulp and paper and the reconstituted board industries. Other acacias being planted are *A. aulacocarpa*, *A. auriculiformis*, *A. crassicarpa*, and *A. mearnsii*.

In the past ten years, there has been a massive increase in the area planted to *A. mangium* in Indonesia for pulpwood. Conservative estimates put the figure at around 600,000 ha, with most plantations in southern Sumatra. Large resource owners of *A. mangium* include PT. Arara Abadi (Asia Pulp and Paper group supplying the pulp mill of PT. Indah Kiat) in Riau, and PT Musi Hutan Persada (logs are supplied to PT. Tanjung Enim Lestari).

A major plantation program is also taking place in Kalimantan. Recent data provided by the Regional Forestry Office of East Kalimantan (2001) shows that by 1999–2000, about 1.4 million ha of State Forest land in East Kalimantan had been allocated for plantation establishment by 32 forest companies. However, less than 500,000 ha have been planted, consisting of about 291,000 ha for pulpwood production, 77,000 ha for timber and 120,000 ha for both pulpwood and timber.

Plantation forests in East Kalimantan have been developed, mostly using fast-growing species, to supply raw material for pulp and wood panel industries, especially particleboard and medium density fibreboard (MDF). Apart from *Acacia* spp. and *Eucalyptus* spp., local species are also planted, such as *Shorea leprosula, S. johorensis, S. parvifolia, S. pauciflora, S. selanica* and *S. smithiana*.

Genetic Resources

Knowledge of the genetic origins of early introductions of *Acacia* spp. is rather patchy. Seeds were often collected from very few trees from a limited natural distribution and were distributed to a wide range of locations for planting. Information regarding genetic diversity (provenance and family) often received very little attention.

A classical example is the introduction of *A. mangium* in Sabah where seeds were collected from a few trees at Mission Beach, North Queensland and planted widely in Sabah. A similar situation developed in Indonesia during the early phase of the industrial plantation program. The practice of using good genetic materials was still very rare and almost all of the *A. mangium* plantations first established in Indonesia used seed from Subanjeriji, South Sumatra. This seed source is known to have a very narrow genetic base and suboptimal growth as it was derived from a limited number of parent trees from Northern Queensland (Jullaten, Mossman and Cassowary). Based on provenance tests conducted elsewhere, these populations are generally of inferior growth (Harwood and Williams 1992).

Provenance trials established at several sites in Indonesia have revealed that the Subanjeriji seed source was outperformed by the seed source of Far North Queensland, Western Papua New Guinea and Southeast Irian Jaya. Vuokko (1996) reported that, in a South Kalimantan trial, volume growth of the Subanjeriji land race was only about one-third of the best provenances from PNG and Southeast Irian Jaya. Similarly, Hardiyanto (1997) found that the best provenances available in South Sumatra, at 26 months old, grew 160 per cent faster in stem volume than trees sourced from Subanjeriji. Therefore, considerable genetic gains can be obtained simply by planting highly productive provenances.

More companies are establishing their own improved genetic resources. At least five companies have completed first-generation selection of seedling seed orchards. Family selection of *A. mangium* from the best provenances has increased volume production up to 65 per cent compared to local land races (Kurinobu and Nirsatmanto 1996).

Clonal Propagation

Clonal propagation is generally a preferred approach in plantation programs as it can capture both the additive and non-additive genetic effects. The technology for large-scale multiplication of *A. mangium* clones by cuttings has opened the way for commercial clonal forestry. This presents opportunities to quickly capitalise on the benefits from breeding programs but brings a concomitant responsibility to address risks from potential pests and diseases. Clonal forestry using both pure species and hybrids requires back-up breeding. Cloning is appropriate if:

(1) selected high quality individuals are available;
(2) there is a sufficient number of superior clones which can be propagated to provide genetic variability in the plantations; and
(3) the program is supported by a breeding program for regular provision of more productive and disease-resistant clones.

There has been significant progress in cloning technology, both micropropagation and conventional cuttings (Banik et al. 1995; Bon and Montenuuis 1996; Bhaskar and Subash 1996), but propagation of mature individuals is still a problem. In some companies, selection of superior clones is currently in progress. It will, however, be several more years before the establishment of clonal plantations of *A. mangium* becomes common practice.

Potential Threats

The expansion of plantations in Indonesia is not without risk. Biological threats from pest and disease, environmental risks from unprecedented weather patterns and problems arising from social issues have become major risks facing many plantation projects.

Pest and diseases

There is widespread concern among forest managers and the wider community that large areas of monocultures increase the risk of catastrophic damage by pests and diseases. The rapid expansion of acacias in Indonesia has also increased concern regarding the threats posed by pests and diseases.

During 1995–1996, a series of disease surveys was undertaken in native stands, trials, and operational forestry plantations of tropical acacias in Australia, India, Indonesia, Malaysia and Thailand (Old et al. 1997). The results of the survey provide a benchmark of the current knowledge of the pathology of *A. mangium*, *A. auriculiformis*, *A. crassicarpa* and *A. aulacocarpa* in tropical areas of Southeast Asia, India and Australia. A manual of the diseases of acacia was published from this survey (Old et al. 2000).

The five most significant diseases according to the survey are rootrot (*Ganoderma* complex), stem canker (e.g. *Lasiodiplodia theobromae*, *Botryosphaeria* spp.), pink disease (*Corticum salmonicolor*), heartrot (wood decay fungi), and phyllode rust (*Atelocauda digitata*). Insect attacks have tended to be sporadic and have not caused major problems for tropical acacias to date.

Rootrot occurrence has been identified in plantations in Riau (central Sumatra). As much as 20 per cent of the trees planted have been affected (Arara Abadi 2000, pers. comm.). Symptoms of the disease are thinning of crowns, reduced size and curling of phyllode margins, and subsequent death of trees. The disease often occurs in patches with a concentric pattern of spread.

Foliar disease is becoming common in South Sumatra and several locations in Kalimantan, particularly rust fungus caused by *Atelocauda digitata*. Damage to seedlings and trees shortly after outplanting includes major distortion and hypertrophy of growing points. There appears to be considerable variation between provenances in susceptibility to disease, indicating a potential for selection for resistant genotypes (Old et al. 1997).

Social unrest

Since 1997, Indonesia has been undergoing major social changes. The enormous upsurge of populist sentiment known as *reformasi* (reform) has considerable significance for the plantation industry. One of the many impacts of these changes has been on the use of land for plantations. Local communities are seizing back traditionally-held land previously allocated as forest concessions. This is happening with no reference to the government, and the concession holders are powerless to intervene. This situation is causing uncertainty over the future of plantations, replanting of clear-cut forested lands is suspended, and plans for plantation expansion are temporarily postponed.

Nevertheless, many believe that once the euphoria generated by progress toward democracy abates, local populations will accept the reality that they need the benefits provided by plantation programs. For example, the social benefits of such plantations are clearly shown in the Pendopo area of South

Sumatra where PT Musi Hutan Persada (MHP) is operating. More than 20,000 people are directly benefiting as workers in various activities, from nursery, plantation, maintenance, research and development, harvesting, transportation, workshop and many others.

Acacia mangium

Since its first introduction in 1980 in Subanjeriji South Sumatra (Darmono and Utomo 1980), *A. mangium* growth performance has improved significantly. The land race of Subanjeriji was known to have a limited genetic base, derived from a limited number of parent trees of inferior provenance from Northern Queensland (Cairns region of Jullaten, Daintree, Mossman and Cassowary). Subsequent studies of provenance variation showed that the Subanjeriji seed source was far inferior to seed from far north Queensland (FNQ), PNG or Southeast Irian Jaya (Vuokko 1996; Hardiyanto 1997). Naturally, the use of Subanjeriji seed source in plantation establishment has shifted to PNG and FNQ.

At the present time, tree improvement R&D on *A. mangium* in Indonesia is well advanced. The first cycle of combined phenotypic and genotypic selection has been completed. Data from this study revealed that genetic improvement of the species could be significant. Expected genetic gain from family selection was 5–12 per cent for form and 5 per cent for growth (Kurinobu and Nirsatmanto 1996) compared to the local land race of Subanjeriji.

Sustainability of Acacia Plantations in Indonesia

Acacias are of considerable social and industrial importance for reforestation in Indonesia and it is expected that in the next five years the area planted will surpass one million ha. In the world market, acacia pulp is well accepted and Indonesia has become a world leader. PT. Tanjung Enim Lestari in South Sumatra is currently the biggest pulp mill in the country, using only *A. mangium* wood. PT. Tanjung Enim Lestari pulp mill is unique in that it is the first pulp mill in Indonesia’s history to start up and run, seemingly sustainably, on an *A. mangium* plantation pulpwood resource. The plantations of PT Musi Hutan Persada, which are located in the nearby area, supply the pulp-logs. The plantations, now covering a total land area of 193,500 ha, are predominantly *A. mangium* (90 per cent of the total area). Another forest plantation company actively planting *A. mangium* is PT Arara Abadi in Riau, central Sumatra, supplying raw materials for the pulp mill of PT Indah Kiat Pulp and Paper.

The devastation of tropical rain forests caused by unsustainable logging practices and illegal cutting has opened up the opportunity for plantation establishment. When the natural forests of Sumatra and Kalimantan are completely destroyed, in 2015 and 2020 respectively, as predicted by some analysts, plantation forests will be the major source of timber. Under this dire scenario, plantation programs in the form of reforestation of logged-over natural forest and unproductive grassland will be critically important.

The rehabilitation of degraded natural forest and other unproductive forest areas does not necessarily mean planting fast-growing exotic species. Indeed, the area of land that needs to be rehabilitated is already far too large and site conditions are too variable to be replanted with a handful of exotic species. Different end uses of the timber will also influence the choice of species. Therefore, the debate over the choice of indigenous species at the expense of exotic species is irrelevant. Both indigenous and exotic species will have their own roles in rehabilitating the vast, formerly forested, lands of Indonesia.

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An Understanding of Tree Defence Helps to Reduce Stem Decay in Hardwood Plantations

Karen M. Barry*,**, Malcolm F. Hall*** and
Caroline L. Mohammed*,**,***

Abstract

An overview of research completed on *Eucalyptus nitens* in Tasmania provides a background for other studies of stem decay and defence mechanisms. Eucalypts and acacias are fast-growing trees favoured for plantation throughout Australasia. *Acacia mangium* is a major plantation species in Indonesia and is known to suffer severe heartrot (central stem decay). Investigations of decay incidence and defence mechanisms can help to predict and reduce stem decay.

STEM DECAY in hardwood plantations is a major defect arising from a variety of sources. Two common sources are infected dead branches and pruned branches (Table 1). Thinning is often practised in previously logged 'regrowth' native forests, but not in 'old-growth' native forest that has never been logged.

Table 1. Sources of stem defect in native forest and plantations.

Source	Native forest	Plantations
Branch-shedding	✓	✓
Insects/animals	✓	✓
Non-biological e.g. fire	✓	✓
Pruning	✘	✓
Thinning/other operations	✓	✓

Hardwood plantations in the Australasia region mostly consist of fast-growing trees such as *Eucalyptus* and *Acacia*, grown mainly for pulp and solid-wood products. This paper provides an overview of pruning-associated decay incidence of *Eucalyptus nitens* plantations in Tasmania and an account of defence responses to decay spread. Tools used for these studies are directly applicable to the problem of heartrot in tropical *Acacia mangium* plantations.

Case Study of *Eucalyptus nitens* in Tasmania

Pruning-associated decay

Since the establishment of intensively managed eucalypt plantations in Tasmania, there have been increased concerns of the incidence of pruning-associated decay and its effect on solid-wood production (Wardlaw and Neilsen 1999). A study at five different Tasmanian sites revealed that pruning-associated decay varied among these sites one year after pruning (Figure 1). After one year, decay columns were up to 79 cm in total length, and sometimes columns from different sources would merge (Figure 2). This study confirmed that careful pruning technique is essential to reduce decay (where the branch collar was wounded, branches had a much higher probability of decay). Also, treatments such as fungicide and sealants can reduce decay compared to untreated branches (Figure 1). Treatments such as partial pruning (resulting in a branch stub) and then later completing the prune also reduced decay incidence, but is too costly for large-scale plantation management.

Variation in decay incidence between different sites (Figure 1) can generally be related to site productivity. That is, trees on the more fertile sites with high rainfall (e.g. Flowerdale, Evercreech) were more prone to decay than those growing on drier, less productive sites (e.g. Payanna). These site factors influence tree physiology (e.g. larger branches at more productive sites) as well as the decay process. Analysis of branch condition when pruned showed that at drier sites, many branches were already dead. This is probably a major factor in determining decay incidence because as the branch senesces a 'protective zone' forms in the branch base and serves to restrict decay spread (Figure 3).

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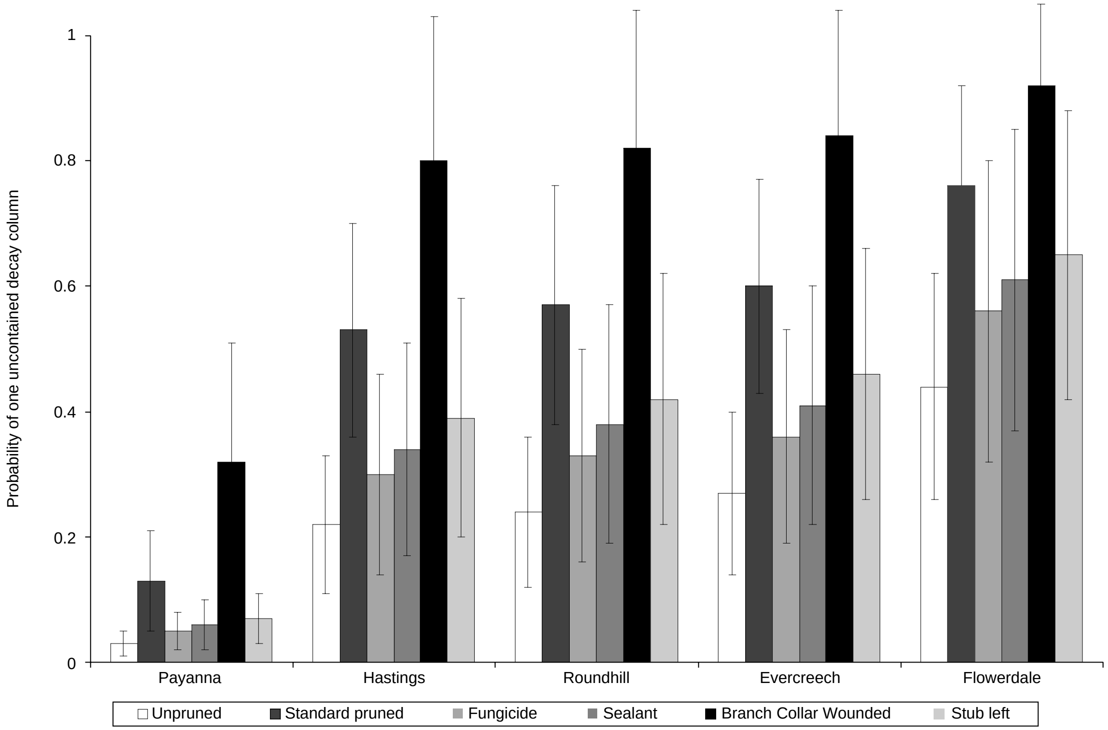

Figure 1. Probability of decay (based on observed frequency) occurring from pruning wounds at five different plantation sites in Tasmania, with various treatments (Mohammed *et al.* 2000).

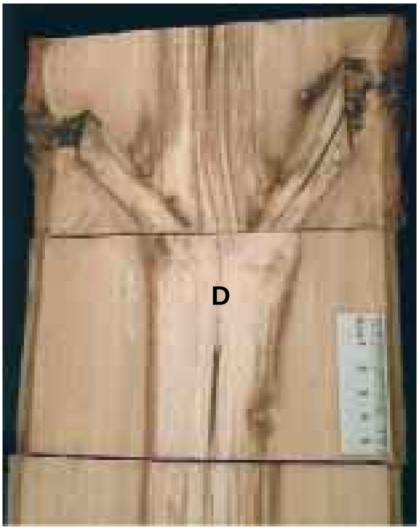

Figure 2. Billets of an *E. nitens* tree from Evercreech after pruning, in which both branches are a source of decay (D).

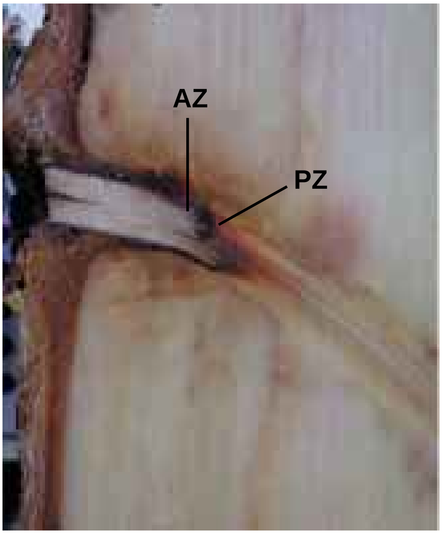

Figure 3. Dead branch of *E. nitens* with a protective zone (PZ) — one year after pruning. The branch is in the process of abscission (abscission zone, AZ).

While less decay results from pruning dead branches, these are associated with two major defects. Firstly, loose-knots will result and, secondly, dead branches can break internally and result in a 'kino-plug' defect throughout the clearwood (Wardlaw and Neilsen 1999). Therefore, to avoid these problems, pruning of living branches is the practice currently adopted by industry.

The incidence of decay associated with living branches is affected by branch size and also varies in some trees with the season of pruning (Gadgil and Bawden 1981). In *E. nitens*, pruning of large (> 2 cm diameter) living branches resulted in a greatly increased level of decay (Figure 4). The effect of season was not significant, and therefore pruning can theoretically be completed at any time of year.

Antimicrobial defence

The formation of a protective zone in dying branches and the inherently hostile nature of wood for fungal growth are both passive antimicrobial defences. Active defences which are induced by wounding and infection can determine the extent of decay spread.

Decay that extends internally from the living branches spreads mostly in an axial direction. At the earlier ages of pruning (3–4 years for first-lift pruning), this wood will be sapwood. Sapwood present at the time of wounding or pruning can respond to infection by the formation of a 'reaction zone' (Pearce 1996). Another ubiquitous response to wounding is the 'barrier zone' which develops in the wood formed after wounding. Barrier zones are particularly effective in stopping decay from spreading out of the knotty core, but may become ineffective after about 14 years (White and Kile 1994). In other eucalypt species such as *E. globulus*, kino veins often form as macroscopic barrier zones (Eyles and Mohammed, in press).

In *E. nitens*, the reaction zone typically consists of two visually distinct zones (Figure 5). The basis for the terminology of these two zones has been described (Barry et al. in press). Closest to the decay is a narrow brown polyphenolic barrier from which decay fungi can be isolated, which has been termed the interface reaction zone (IRZ). A diffuse zone (often purple in colour) enriched with monomeric hydrolyzable tannins surrounds this and decay-fungi are rarely isolated from this zone (Barry 2001; Barry et al. 2000). This has been termed the reaction zone as it has antifungal properties, but it is reminiscent of transition zones (Shain 1979; Yamada 1992; Pearce 1996).

The diffuse purple reaction zone of *E. nitens* contains greatly increased levels of a range of hydrolysable tannins in comparison with 'healthy' sapwood (Barry et al. 2001a). These compounds are listed in Table 2. Ellagitannins (e.g. pedunculagin) may be effective in defence due to fungistatic properties. For example tannins may specifically bind to fungal enzymes (Field and Lettinga 1992) or act as antioxidants (Hagerman et al. 1998) that quench the free radical breakdown of lignin (Pearce et al. 1997). Pedunculagin does not appear to be directly

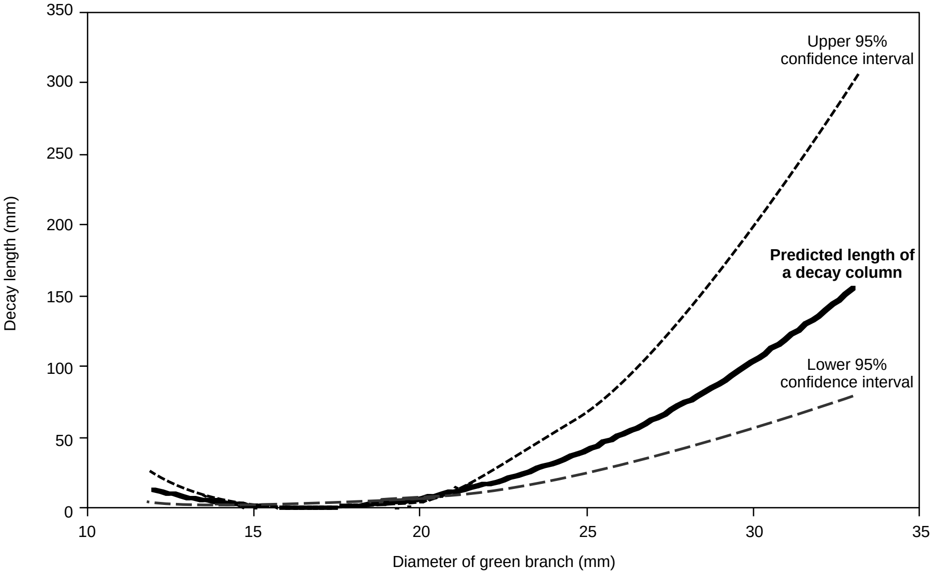

Figure 4. Model of relationship between the diameter of a green branch and the length of resulting decay columns (Mohammed et al. 2000).

Figure 5. Transverse section of an *E. nitens* decay column (D), showing the purple reaction zone (pRZ) and brown interface of decay (IRZ). A white zone is also occasionally present (W).

fungitoxic in *in vitro* bioassays, although some unresolved compounds in the crude reaction zone extract are fungitoxic (Barry 2001).

The induction of phenolic compounds (such as the tannins in Table 2) appears to be important early in the defence process, with evidence of three-fold increases in tetragalloylglucose within 24 hours after wounding and fungal inoculation (Figure 6). Other early responses include complete tylose formation in vessels by three days (Barry et al. 2001b).

Fundamental knowledge regarding defence reactions may help to explain why trees are more or less susceptible to decay and may provide useful applications to forestry in the future. For example, different genetic material (provenances, families, clones) could be screened for phenol accumulation in

Table 2. Molecular weight ($[M\text{-}H]^-$), retention time (RT) and relative abundance of various phenol compounds in *E. nitens* healthy sapwood (HS) and reaction zone (RZ). From Barry et al. 2001a.

$[M\text{-}H]^-$	RT (minutes)	Compound	Relative Abundance[a]	
			HS[b]	RZ[b]
169	2.79	Gallic acid[c]	tr	+
289	10.03	Catechin[c]	+	tr
301	28.93	Ellagic acid[c]	+	++
481	1.55	HHDP-glucose	tr	+++
483	8.83	Di-GG[v]	tr	tr
	10.67	Di-GG[w]	tr	tr
	12.00	Di-GG[x]	tr	tr
	13.59	Di-GG[y]	tr	tr
	14.49	Di-GG[z]	tr	tr
633	9.61	HHDP-GG	tr	++
635	12.46	Tr-GG[wc]	+	+
	14.75	Tr-GG[xc]	++	++
	16.23	Tr-GG[yc]	++	++
	16.39	1,2,6-Tr-GG[c]	tr	tr
	16.79	Tr-GG[zc]	+	+
649	27.82	Me-(Tr-GG)	++	+++
783	2.40	di-HHDP-glucose	tr	++
	3.16/5.00	Pedunculagin[c]	+	++++
785	7.27/12.19	Tellimagrandin I[c]	++	+++
	13.52	HHDP-di-GG[x]	tr	++
	14.19	HHDP-di-GG[y]	+	++
	16.85	HHDP-di-GG[z]	+	++
787	16.29	Te-GG[wc]	+	+
	21.08	Te-GG[xc] + 1,2,3,6-Te-GG	++	+++
	22.86	Te-GG[yc]	tr	tr
	24.04	Te-GG[zc]	tr	tr
935	9.32	Casuarinin*	0	+
	15.02	Casuarictin*	0	+
	23.10	di-HHDP-GG	tr	+
937	16.91	HHDP-tri-GG[x]	tr	+
	18.02	Tellimagrandin II[c]	tr	+
	19.24	HHDP-tri-GG[y]	tr	+
	32.95	HHDP-tri-GG[z]	+	0
939	25.42	Pe-GG[c]	tr	+
951	5.64/10.84	(Trisgalloyl)-HHDP-glucose[y]	tr	+++
	6.88	(Trisgalloyl)-HHDP-glucose[z]	0	+++

[a] Relative Scale; 0 = none detected, tr = 0–1 (trace amount); + = 1–10; ++ = 10–50; +++ = 50–100; ++++ = 100$^+$.
[b] HS = healthy sapwood; RZ = reaction zone.
[c] = unequivocal identification. [v,w,x,y,z] are to discriminate putative individual isomers.

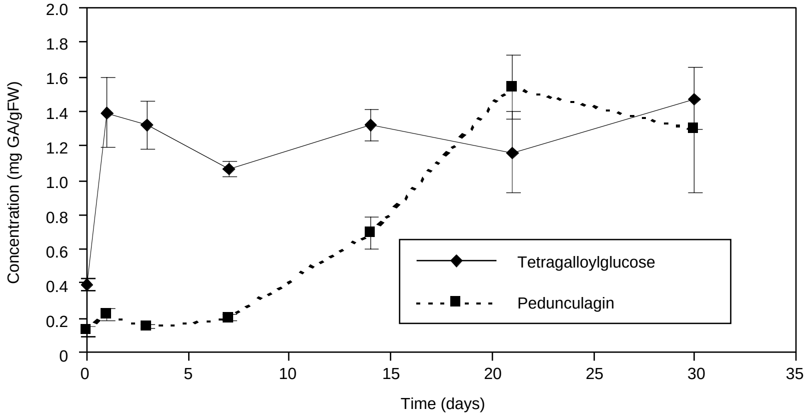

Figure 6. Concentration (mg gallic acid/gFW) of two major hydrolyzable tannins in pot-grown *E. nitens*, following wounding and fungal inoculation with *Ganoderma adspersum*.

controlled conditions at early stages of wounding and infection. If this can be related to decay resistance or susceptibility in longer-term field studies, it may become a tool for early selection of decay resistant genotypes. Studies of decay spread in different provenances and families of *E. nitens* have not as yet established genetic differences at this level (White et al. 1999). Genetic differences in decay containment exist in some tree species at least at the clonal level (Smith and Shortle 1993).

There appear to be some general traits of defence processes in fast-grown evergreen plantation trees which vary from the slower-grown deciduous trees such as oaks and maples (Pearce 1996; Schwarze et al. 2000; Barry et al. 2001b). Studies of a number of fast-grown hardwoods therefore provide an interesting comparison to the many slower-grown European species that have been studied.

Heartrot in *Acacia mangium* Plantations in Southeast Asia

Background and future approaches

A number of studies in Malaysian plantations (see paper by Lee in this report) have revealed that *Acacia mangium* is particularly susceptible to heartrot.

Decay in *A. mangium* is usually associated with dead branches and dead branch stubs. This is in contrast to the pruned plantations of *E. nitens* in Tasmania, where dead branches form a protective zone. It is speculated that *A. mangium* may not form effective protection zones due to early heartwood formation in the branch as only living tissue can form protective zones during branch senescence. Heartwood would appear to be low in natural resistance, and also sapwood wound responses appear to be poor in *A. mangium* (Schmitt et al. 1995)

Surveys in Malaysia have shown that hybrids of *A. mangium* × *A. auriculiformis* have less heartrot than *A. mangium*. Clarifying this and elucidating the basis in terms of defence would be paramount for selective breeding. A variety of factors including branch physiology and induced defence may explain this trend. For example, in *A. auriculiformis* heartwood may not form in the branch and a complete protective zone may develop, thereby preventing decay spread into the branch and then heartwood.

Methods and tools to study decay and defence responses

Surveys and field studies are essential to gauge the incidence of heartrot in a tree species. These have not as yet been completed for *A. mangium* in Indonesia. To test and understand genetic differences between species, hybrids, provenances, families or clones, controlled *in vivo* experiments are required. This would involve well-replicated and controlled wounding experiments (preferably at similar sites) using the same challenge fungus to test both sapwood and heartwood resistance. *In vitro* methods include fungal bioassays with heartwood samples from different provenances, hybrids or species.

General tools for defence response studies include microscopy of wood sections, examination of wood extracts for phenolics (qualitative and quantitative) using a variety of chromatographic techniques and mass spectrometry facilities.

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Shared Tree Species — Shared Tree Pathogens

Ken Old[*]

Abstract

Hardwood plantations in Indonesia mostly consist of trees native to Australia, Papua New Guinea and eastern parts of the Indonesian archipeligo. Large scale industrial plantation establishment of acacias and eucalypts has been most extensive in Sumatra and Kalimantan where they can be regarded as exotic introductions. *Acacia mangium* plantations have, so far, been relatively free from disease and insect outbreaks, although some problems have emerged, notably heartrot, root and butt rot and phyllode rust. Eucalypts commonly suffer from leaf and shoot blights in the humid tropics and have been less widely planted in Sumatra and Kalimantan. This paper briefly summarises some of the research carried out by CSIRO and collaborating institutions in Southeast Asia on our shared trees and shared pathogens. Also indicated are the potential dangers from pathogens that are either already in our region or extending their geographical range, and from *Puccinia psidii*, a rust of Myrtaceae currently restricted to South America which attacks eucalypts and other species indigenous to Australia and Indonesia.

‘SHARED TREE SPECIES’ means ‘shared tree pathogens’ is a thread that has continued through a series of collaborative research projects during the past eight years. These projects have been carried out by CSIRO pathologists and tree improvement specialists, with ACIAR and CIFOR support, in collaboration with their counterparts from government research agencies and universities, in Indonesia and five other countries of Southeast Asia. One of the most successful of these projects was the survey of diseases of tropical acacias carried out during 1995–96, the main outputs of which were a report of the proceedings of a workshop held in Subanjeriji, South Sumatra, (Old et al. 1996) and a manual of diseases of tropical acacias (Old et al. 2000). The manual was published by CIFOR and has been widely distributed. The new project, led by the University of Tasmania with inputs by CSIRO Forestry and Forest Products scientists, is addressing one of the problems highlighted in the above publications, namely decay of stems in acacia plantations.

This paper summarises some outputs of projects previously carried out by our research teams in Southeast Asia, especially as they apply to Indonesian forestry. A current collaborative project being carried out in Brazil with ACIAR support and its implications for exotic threats to Indonesian plantations and native vegetation is also described.

Diseases of Tropical Acacias

During discussions between myself, Dr Lee Su See, Professor Hadi and Dr J.K. Sharma at a IUFRO meeting in Kerala India in 1993, we recognised that despite the huge investment and rapid expansion of plantations of acacias in Southeast Asia, there was no comprehensive collection of information regarding the main pathogens and the threats they represent to growth and product quality. During 1995, surveys were carried out in Australia, Indonesia, Malaysia, Thailand and southern India and a workshop was sponsored by Musi Hutan Persada at Subanjeriji in 1996. Representatives from several major Indonesian pulp and paper companies who attended the workshop requested that the findings of the surveys should be published in a well-illustrated manual suitable for field and laboratory use. This was completed, again with ACIAR and CIFOR help, in 2000 (Old et al. 2000). Three of the major acacia diseases identified during the surveys were heartrot, rootrot and phyllode rust. The first two diseases will receive attention as part of this project and will not be discussed further in this paper. Since 1996, research has been carried out on phyllode rust in northern Queensland and the results have significant implications for plantations in Indonesia.

Phyllode rust caused by *Atelocauda digitata*, recently renamed *Racospermyces digitatus* (Walker 2001) has been recognised for many years in native

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stands in northern Australia and in plantations in Java and other regions of Indonesia. The potential of this disease to damage plantations has, however, not been fully appreciated, due probably to an adequate degree of genetic variation in rust resistance within the provenances being grown on a wide scale. Also, it seems likely that the rust is increasing its geographical range within Southeast Asia and many plantations in the region have not, so far, been exposed to the pathogen.

Infections in nurseries and of juvenile trees after out-planting can cause shoot and stem distortion and even death of young seedlings (Figures 1 and 2). Older trees can suffer significant defoliation with the risk of reductions in growth rates. There appears to be very little data available on the impacts of this disease in plantations in Indonesia, other than anecdotal information. Trends in tree improvement, notably selection of hybrids with subsequent vegetative propagation and the increasing use of cuttings or tissue-cultured, clonal plantations may provide conditions favouring major outbreaks of this disease. It is advisable therefore that, in future, clonal plantations consist of rust-resistant trees.

Differences in resistance and susceptibility have been identified at the species, provenance and family levels (Old et al. 1999) and rust resistance has been selected as a trait for marker-aided selection in a joint project between CSIRO and the University of Jogyjakarta. Variation has also been identified in the rust and there is a strong indication that the new taxon *R. digitatus* is probably a complex of several acacia rusts (Walker 2001). Selection for resistance, therefore, to one rust population may not confer protection against other populations.

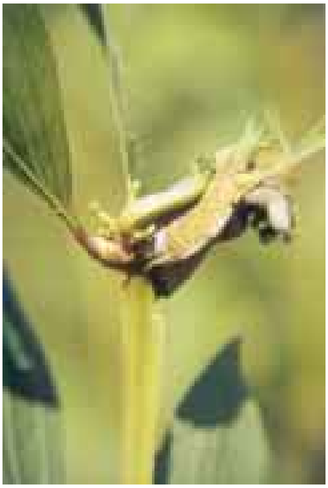

Figure 1. Terminal shoot of *Acacia mangium*.

Figure 2. Rust-affected seedling infected by *Atelocauda racospermyces*.

Diseases of Eucalyptus

The CSIRO Forest Health Team has worked closely with the Forest Sciences Institute of Vietnam, and the Royal Forestry Department Thailand, with ACIAR support, on a major leaf blight problem of eucalypts grown in the humid tropics of Southeast Asia. At least three leaf and shoot pathogens were associated with defoliation, namely, *Cylindrocladium quinqueseptatum*, *Cryptosporiopsis eucalypti* and *Pseudocercospora eucalyptorum*. Clones of *E. camaldulensis*, and *E. brassiana* with a high level of resistance to these pathogens, have been identified in trials in south-east Vietnam and Thailand by the project scientists (Old et al. 2001).

Surveys of disease were carried out in all provinces of Vietnam where eucalypts are grown on a significant scale and a bioclimatic modelling approach was used to predict those areas at risk from regular and serious epidemics of *Cylindrocladium* leaf blight (CqLB) (Booth et al. 2000). A good fit was found between predictions and disease outbreaks, not only for Vietnam but also for Thailand and Laos.

The area planted to eucalypts in Indonesia is quite limited compared to acacia plantations. This may be a reflection of high impacts of leaf and shoot pathogens on eucalypts in the humid environments commonly present in regions where plantations have been established. During 1996–97, limited surveys of eucalypts in species trials were carried out with Indonesian colleagues in Subanjeriji and Perawang, Sumatra and Palaut Luat and Riam Kiwa, Kalimantan. Leaf pathogens recorded include *Phaeophleospora epicoccoides* and *Coniella fragariae* although the level of defoliation of *E. urophylla* seen at Perawang and at Subanjeriji (Figure 3) suggests that more serious leaf pathogens are present. Stem cankers included *Cryphonectria gyrosa* on *E. citriodora* at Perawang and *C. cubensis* on a *E. grandis* × *urophylla* hybrid at Palaut Luat.

Figure 3. Eucalyptus species/provenance trial Subanjeriji, Sumatra. Large differences in susceptibility to leaf blight are present.

A very damaging pathogen, *Phaeophleospora destructans*, was reported from northern Sumatra on *E. grandis* (Wingfield et al. 1996). This pathogen has recently invaded clonal plantations of *E. camaldulensis* in eastern Thailand (Figure 4). It is not clear how serious this incursion will be, or whether it will spread to Vietnam and Laos.

Eucalyptus rust caused by *Puccinia psidii* is regarded by forest pathologists and conservationists in Australia as a major exotic threat. Present only in South and Central America, this rust has a very wide host range within Myrtaceae. It is very damaging to young eucalypts (Figure 5) and affects many plantation species, e.g. *Melaleuca* (tea tree), *Syzygium* (cloves) and *Pimenta* (allspice). The consequences of incursion by this pathogen into Indonesia or Australia could be very serious. The CSIRO Forest Health Team has commenced a project in Brazil with Professor Alfenas of the University of Vicosa to screen a wide range of eucalyptus species and a representative sample of genera and species across the Myrtaceae. Similar methods as those used to map high hazard areas for CqLB will again be employed to predict which eucalypt plantation areas and native forests in South Africa, Australia and Southeast Asia could be at risk from eucalyptus rust.

Figure 4. *Eucalyptus camaldulensis* clone in Thailand infected by *Phaeophleospora destructans*.

Figure 5. *E. grandis* × *urophylla* hybrid in Brazil, infected with rust.

Conclusion

Given the geographical proximity of Australia and Indonesia, common forest plantation species and native vegetation components, it is essential that collaborative initiatives such as the heartrot project are given high priority. The network of pathologists, entomologists and tree improvement researchers in the Australia-Southeast Asia region that we all have striven to develop over the past decade has now been joined by the University of Tasmania, the main managing agency for this project, with overall direction to be undertaken by Dr. Mohammed. We look forward a successful and productive project and will continue to seek further opportunities for collaboration in this region.

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Heartrot in Forest Plantations — Significance to the Wood Processing Industry

Kenneth Gales*

Abstract

The Indonesian wood processing industry will become increasingly dependent on wood from forest plantations. So there is a need to improve the quantity, quality, and value of the wood produced from plantations. This includes learning how to minimise the effects of heartrots and rootrots on forest productivity and on wood quality. The threat of fungal disease in living trees (decay of wood and disease of roots) is probably the most serious threat to the forest plantations — greater than the threat of fire. So far, attacks have not been serious, but we must develop strategies now to avoid attacks, control them when they occur, and recover from them.

UNTIL TWENTY YEARS AGO, logs were exported from Indonesia. In 1985, an export ban was put into place to encourage the establishment of a domestic wood processing industry. The export ban was removed in 1992, but was replaced by an export tariff that was so high that it was effectively a ban.

Indonesia now has a wood processing industry that exports high quality products to most parts of the world. Various products are manufactured, and each is made from timbers that have specific mechanical properties, chemical properties, and appearance (Table 1).

The Natural Forest as a Source of Logs

During the past 20 years, the industry has had an abundant supply of logs from the natural forests. The forests have provided high quality raw material for all three categories of product listed in Table 1. The Indonesian forests are usually described as ‘the Dipterocarp forests’, although there are many commercial species that are not dipterocarps. Most of the species are very suitable for the products mentioned above, because they have favorable mechanical properties, chemical properties, and appearance. As an example, the dipterocarps have been much used for plywood, because the logs are large diameter, cylindrical, long, and easy to peel. The logs have gradual taper, and are free of knots because the trees are self-pruning when they are young. The veneers are of uniform colour and texture, because the trees have no seasonal rings.

Some of the species that are too hard for peeling to make plywood (more than about 900 kg/m^3 density) are suitable for heavy duty and outdoor applications such as decking and flooring. Some species, both medium density and high density, have excellent working properties and appearance, which makes them suitable for furniture parts, mouldings, and fittings in houses and public buildings.

The Diminishing Supply of Logs

The availability of logs from the natural forest is now diminishing. The logs are becoming progressively smaller in diameter, and the most desirable species are becoming difficult to find. For example, ramin is now on the CITES list and only ramin from plantations may be exported.

The decrease in the availability of logs is the result of over-cutting by some forest concession holders, illegal logging by organised groups, and land clearing for agriculture by poor rural people. If the illegal logging and over-cutting continue, the long-term negative consequences will be far worse than the short-term positive consequences (Table 2). From the point of view of the wood processing industry, negative consequences 10 to 13 (Table 2) are the most important.

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Table 1. Various products made with wood from the natural forest.

Product	Examples of wood types that are used, from the natural forest	
	Dipterocarps	Non-dipterocarps
Engineered timber		
Plywood	Kapur (plywood core)	Bintangor (plywood face)
Blockboard	Keruing (plywood core)	Binuang
Particle board	Meranti, dark red	Duabanga
LVL	Meranti, light red	Jabon
MDF	Meranti, red	Jelutong
	Meranti, white	Matoa
	Meranti, yellow	Pulai (plywood core)
	Merawan	Sengon (blockboard core)
	Mersawa	Yemane
Solid timber		
Surfaced sawn timber	Balau	Gia
Mouldings	Bangkirai	Kempas
Furniture	Giam	Merbau
Flooring	—	Ramin
Decking	—	Sonokembang
		Sungkai
Chemically processed timber		
Pulp	Mixed tropical hardwoods	Mixed tropical hardwoods
Viscose rayon	Mixed tropical hardwoods	Mixed tropical hardwoods

Table 2. The likely consequences of continued illegal logging and over-cutting of forests.

The positive consequences	
1	A few people get rich quickly (the illegal ‘timber barons’).
2	Many people get a subsistence level wage, working for the illegal timber barons.
	Log prices come down in the short term, because the market is flooded.
3	Land is cleared for subsistence level farming.
The negative consequences	
1	The forest is disappearing.
2	Biodiversity is being lost.
3	Genetic diversity within species is decreasing.
4	Some species may become extinct.
5	There will be increased soil erosion, probably severe and irreversible, on hilly land.
6	There will be increased silting of rivers.
7	There will be flooding in low-lying towns such as Banjarmasin, in the rainy season.
8	There will be drought in the upland and lowland areas in the dry season.
9	There will be no cash income for rural people from log sales.
10	The price of logs will eventually increase to levels that are non-competitive.
11	There will be a shortage of wood for the wood processing industries.
12	Indonesia will probably become a log importer.
13	There will be a shortage of wood for local needs such as house-building and boat-building.

The Importance of Plantations

The most effective action that the forestry industry can take is to intensify its plantation activities. Plantations will supply wood for the industries, help to protect some of the previously deforested land against erosion, and will provide employment for local people. Trees grown in plantations will provide wood that is suitable for many, though not all, of the end uses for which natural forest species were used in the past.

Forest plantations have existed in Indonesia for more than 100 years. They are mostly teak and pine plantations, with a rotation length of more than 30 years, and sengon plantations with a rotation length of 8 to 15 years. There are also some small plantations of other species including sungkai, and ramin. There are large plantations of rubber, which were established originally for latex production, but are now recognised as a valuable source of rubberwood when they are no longer useful as a source of latex.

In the past 15 years, there has been an increase in the area of short rotation species, to provide logs for pulping and to make medium density fibreboard (MDF). There are now several hundred thousand hectares of such plantations, mostly in Sumatra and Kalimantan, and some in Java. The most widely planted species is *Acacia mangium*, but there are also smaller areas of other *Acacia* species, some *Eucalyptus*, and *Gmelina*.

Most of the *A. mangium* plantations have been established as a source of pulpwood and chipwood. In the future, *A. mangium* and other fast-growing species from plantations will probably be used for other, higher-value products. Various wood products, including sawn timber and plywood, that formerly were made using timber from the natural forest, will be made from plantation-grown timber.

Pulpwood is a low-value wood product. It has a 2001 price of approximately US$24 per cubic metre at the mill gate. Other kinds of wood that are harvested at larger diameters, and used as saw-logs or peeler logs are priced at US$50 to US$200 per cubic metre. If *A. mangium* and other short-rotation species can be grown to a larger diameter and produce good quality timber, then they also can be used as saw logs and peeler logs.

Acacia mangium is sometimes spoken of as being unsuitable for peeling. One reason for this is that the logs often split soon after felling, which makes them unsuitable because the veneers do not come off as continuous sheets. There are also problems caused by the presence of knots, decay, and stains. This should not deter us from persisting in trying to develop *A. mangium* as a peeler species. Tests have shown that logs that do not split can be peeled successfully and the veneers made into good plywood. Research on silviculture, tree breeding, harvesting, and peeling methods must be done, to find out what methods of management and processing are needed so that *A. mangium* logs can be used to make plywood. Even the well-known *Pinus radiata* (Monterey pine), planted widely in Australasia and Chile, needed a lot of research to find out how to make plywood veneer from it.

The pulp industry itself will benefit if logs from the *A. mangium* stands can be used for higher-value end uses. Pulp mills all over the world compete with one another on the basis of the cost of their raw material. The cost of building and running a pulp mill is almost the same anywhere in the world. It is capital intensive, and almost all of the expensive equipment comes from just a few countries: Scandinavia, Germany, USA, Canada, and Japan. The cost of management and labour is small compared to the capital cost, and is also not very different from one place to another.

In many mills, some of the raw material (pulp logs) is a by-product of another forest industry. Where a stand of trees is grown as a source of lumber or veneer, the small diameter logs (thinnings, and tops of stems at final harvest) are sent to the pulp mill. This kind of raw material is cheaper than logs from stands that are managed specifically as a source of pulp logs. Even though the investment in the plantation is less than 10 per cent of that in the pulp mill, the efficiency with which the plantation is managed is important in determining the competitiveness of the pulp mill. The best combination is to have plantations that are associated with an integrated wood processing industry. The most valuable logs are used for the highest value products, while the least valuable logs are made into pulp.

The Risks of Plantations

So far, the *Acacia mangium* plantations have enjoyed robust health. There have been occasional occurrences of insect damage and fungal attack. The occurrences have not been serious or widespread, but they are increasing. The fact that the *A. mangium* plantations have been free, so far, from significant attack by pests and diseases might have caused companies to become complacent. An attack of insects or disease could come at any time. There are some plantations of a single species that are larger than 100,000 ha and consist of several areas where there are contiguous stands of more than 20,000 ha. In these conditions, diseases can spread quickly.

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It has often been said that the greatest threat to the *A. mangium* plantations in Indonesia is fire. This might not be true. We know how fires start, and spread. We know how to minimise the risk of fires starting, how to slow down their spread, and how to extinguish them. For example, *A. mangium* trees do not burn easily. Even dry *A. mangium* leaf litter is difficult to ignite. When a fire spreads through a stand of *A. mangium* the fuel is the weeds. The heat from burning weeds kills the trees. The key to minimising fire damage is weed control. This does not mean that fire prevention and control are easy, and that fires should not occur. Fires are a serious problem, and difficult to prevent and control.

Prevention and control of fungal attack are more difficult than prevention and control of fires. Our understanding and preparedness are lower. If the trees in a plantation are infected by heartrot, not only might the yield of merchantable wood be decreased, but also the value of the wood might be diminished. The presence of heartrot will make the wood unsuitable for some end uses.

It is well known that *A. mangium* is susceptible to heartrot. It is believed that the fungi that cause heartrot enter the tree through wounds in the stem and branches. Careless pruning or singling may cause many of these wounds. The fungi may enter also through roots that have been damaged mechanically or have been infected by root-rotting fungi. For pulpwood plantations, heartrot is not yet a significant problem, because pulp logs are harvested at six to nine years of age. At the time of harvest, the rot does not affect a large part of the log volume, and the presence of stains in the wood, although undesirable, is not a serious problem for the pulping process.

If *A. mangium* trees are allowed to grow to about 10 to 15 years old, so that the logs are big enough to be used as saw logs or peeler logs, then the heartrot may affect a larger part of the log volume. Also, the wood may be so badly stained that it cannot be used for sawn timber or veneer.

A. mangium wood, when free from defects, looks similar to teak: golden brown, but without seasonal growth rings. It is suitable for furniture and sliced veneer. But the presence of dark stains, which may result from fungal decay, turn valuable furniture wood into cheap pulp wood.

Conclusion

From the point of view of the industry, it is important to develop strategies for avoiding fungal disease in plantations, and controlling such diseases if they occur. Now is the time to take pre-emptive action against all biological threats, especially fungal diseases. The key questions are as follows:

- What diseases are present, even at a low level of occurrence?
- What diseases may not yet be present, but are likely to occur at some time in the future?
- Under what conditions do diseases attack the trees?
- How does the intensity or frequency of attack change from year to year?
- How do silvicultural practices affect the occurrence of diseases?
- What actions can be taken to avoid the occurrence of disease?
- What actions can be taken to minimise the effects of disease, and its spread, after it has been detected?
- Can diseases be avoided by selection of the right provenances, or by tree breeding?
- How do we recognise diseases at an early stage in their development?
- Can we predict the occurrence of disease by observing weather patterns, and tracking the occurrence of disease on a regional scale?
- How will diseases affect the quality of the wood and its value?
- How will diseases affect the growth rate and survival of the trees?

If these questions can be answered for diseases of *Acacia mangium*, and maybe some other species, then general principles and strategies can be established.

Identification and Diagnostic Technology Development for Characterising and Detecting Heartrot Disease Fungi in *Acacia mangium*

Neale L. Bougher and Inez C. Tommerup*

Abstract

Detection and identification of the causal fungi of heartrot disease is fundamental to effective disease management strategies for heartrot pathogens in tree plantations. Issues include diagnosis of specific fungi at early stages of disease in outwardly healthy trees and symptomless wood, and recognition of previously unknown heartrot fungi in *Acacia mangium.* This paper explores the need for detection, characterisation and identification of heartrot fungi as a basis for disease management. An approach is advocated which centres on integrating molecular methods with traditional taxonomical methods to develop a reference database of attributes for identified heartrot fungi. This will create a capacity to match and identify specific unknown fungi from diseased wood in *Acacia mangium* plantations and enhance disease assessment and management.

PLANTATIONS of *Acacia mangium* are extensive throughout many parts of Southeast Asia and are an increasing proportion of Indonesia's HTI — Hutan Tanaman Industri (industrial timber or pulp plantations). Many fungal diseases occur in these plantations, including foliar diseases, stem cankers, heartrot and root rot (Nair and Sumardi 2000; Old et al. 2000). *A. mangium* is highly susceptible to heartrot, but the incidence of heartrot disease in Southeast Asian plantations is variable in relation to factors such as geographic location, site conditions, tree genotype, and tree age (e.g. Ito and Nanis 1994; and see article by S.S. Lee in this report). Heartrot fungi are capable of accessing heartwood via wounds and causing decay within the interior of living trees. Invasion by heartrot fungi in living trees instigates a series of defence responses by the tree, and degrades commercially significant structural, chemical, and visual qualities of the wood (e.g. with *Acacia* — Lee et al. 1988; *Eucalyptus* — Barry et al. 2001). In Australia, more than 70 per cent of the fungal species associated with heartrot of eucalypts are those causing white rot (Kile and Johnson 2000). The type of rot most commonly found in *A. mangium* heartwood is a white fibrous rot; but the colour and texture of the rotted wood depends on the fungus involved (Lee and Noraini Sikin 1999). However, some brown rot fungi have been reported to be associated with heartwood decay in *A. mangium* (see below).

Detection and identification of heartrot fungi is fundamental to effective disease management strategies for heartrot pathogens in tree plantations. Identification of the pathogens causing disease (and using their correct name) is a fundamental research tool enabling accurate communication of the pathological and ecological attributes of each fungus. Additionally, knowledge of fungal species aggressiveness is a prerequisite to decay risk prediction in relation to site characteristics, and can aid prediction of consequences of heartrot for wood product quality. This paper explores the need to detect, characterise and identify heartrot fungi from fruit bodies and, in their absence, from mycelium in diseased wood. Having the capacity to detect specific fungi in wood would enable their diagnosis at early stages of disease in outwardly healthy trees and symptomless wood. This capacity would presumably also lead to the recognition of previously unknown heartrot fungi in *A. mangium.*

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Causal Fungi of Heartrot

Heartrots are mainly caused by basidiomycete fungi. About 80 per cent of the fungi causing eucalypt stem and butt rot belong to the Aphyllophorales, and 20 per cent in the Agaricales (Simpson 1996; Kile and Johnson 2000). For example, the most often reported genera causing eucalypt stem and butt rot in Australia are *Phellinus* and *Inonotus*, and the species with the widest reported host range are *Piptoporus portentosus* and *Piptoporus australiensis*. The Aphyllophorales — more loosely referred to as ‘polypores’, includes fungi with poroid, corticioid, and hydnoid fruit body forms. They are extremely diverse in Australasia (Cunningham 1965; Buchanan 2001; Suhirman and Núñez 1998), and are undoubtedly the dominant causal organisms of heartrot in the region. Many polypore fungi are known to be associated with heartrot of acacias, including *A. mangium*. *Phellinus pachyphloeus* and *Trametes palustris* are known from India (Mehrotra et al. 1996), while *Phellinus noxius, Tinctoporellus epimiltinus, Oxyporus* cf. *latemarginatus,* and *Rigidoporus hypobrunneus* have been found associated with heartrot of *A. mangium* in Peninsular Malaysia and/or East Kalimantan (Lee and Noraini Sikin 1999). Some of these fungi may also cause root and butt rot diseases (Kile and Johnson 2000). Other fungi are likely to be involved in heartrot of *A. mangium*, as few studies have been undertaken. In Southeast Asia, polypore fungi may be: well known and widely dispersed; more restricted; or possibly undiscovered species (Núñez and Stokland 2000). Heartrot fungal species, new to science, have been discovered in association with other *Acacia* species relatively recently (e.g. Larsen et al. 1985).

The taxonomy of the Aphyllophorales has been largely structured on classical phenotypic attributes such as macro- and micro-morphology of fruit bodies. Many of the fungi have had a long history of nomenclatural confusion and instability, but current revisions incorporating molecular data are clarifying the relationships of many groups. A wealth of classical taxonomic literature is available about specific groups of Aphyllophorales fungi (e.g. Corner 1987). However, most of the published literature is highly technical and diagnostic keys rely on phenotypes which require considerable taxonomic experience for interpretation of character states. Currently, there is little information available enabling identification of Aphyllophorales fungi in Southeast Asia using field-based or easily observed characters (Pegler 1997).

Identification of Heartrot Fungi

Classical protocols for identifying wood decay fungi are based on characteristics of their fruit bodies and cultures, and to a lesser extent the type of associated wood rot (Buchanan 1989; Simpson 1996). Macromorphological attributes of fruit bodies often need to be determined in the field as some diagnostically important characters such as colours and moisture can rapidly change after collection. Micromorphological attributes of fruit bodies such as hyphal types, spores, and cystidia can be examined in either fresh or preserved specimens. Morphological attributes may enable identification to various taxonomic levels, depending on the rigour of examination, and usually can provide an indication of the family or genus of the specimen.

Identification based on fruit bodies of heartrot fungi has limitations. Fruit bodies are produced unpredictably, and the presence of fruit bodies may only be indicative of an advanced stage of heartrot. Also, heartrot in any individual tree may be caused by several fungi, none or only some of which may be fruiting at any particular time. Trees with heartrot can often appear healthy with no visible symptoms of fungal presence, especially in earlier stages of attack. For disease assessment and management, diagnostic tools are needed to detect the presence of heartrot fungi in symptomless wood and in the absence of fruit bodies.

Pure cultures isolated from rotted wood, fruit body tissue or spores often grow vigorously on artifical media and can be characterised in numerous ways to help identify heartrot fungi. Standardised morphological and physiological coding systems have been developed enabling comparison of unknown cultures with coded known fungi (Nobles 1965; Stalpers 1978). However, this approach is limited by the relatively few fungi which have been assigned codes. For some heartrot fungi, it is possible to encourage cultures to produce fruit bodies to confirm Koch’s postulate and to aid identification. For example, Lee and Noraini Sikin (1999) produced fruit bodies on rubber (*Hevea brasiliensis*) wood blocks of several species from mycelium isolated from rotted *A. mangium* wood. Mating and vegetative compatibility tests between unknown and identified isolates of fungi can lead to identification of some fungi (Buchanan 1989).

Protein and DNA techniques can provide alternative or complementary tools for detecting and identifying wood decay fungi (Palfreyman 1998). Isozymes can distinguish some wood decay fungi. For example, Smith and Sivasithamparam (2000) found, using cellulose acetate gel electrophoresis, that a single isozyme (glucose-6-phosphate dehydrogenase) distinguished five Australian species of *Ganoderma*. Unique molecular markers are now widely adopted for detecting and characterising many fungi; based on extraction, amplification, digestion, and/or sequencing of DNA from various stages of fungal lifecycles such as fruit bodies, mycelium, and spores. These techniques have many desirable features in that they:

- can be applied to plantation wood samples or isolated pathogens
- avoid the need for interpretation of fruit body phenotypes requiring a high degree of taxonomic experience
- allow direct comparisons of data sets which are unlikely to be variable in relation to environmental conditions
- can contribute expanded data sets additional to the often limited number and type of character attributes used in classical taxonomy
- can be used to infer evolutionary relationships between fungal taxa.

Identification/diagnostic Technology for Heartrot Fungi

For basidiomycetes, molecular characters are being applied to determine phylogeny (Hibbett and Thorn 2001), and to build up sequence databases of specific biotrophic groups such as ectomycorrhizal fungi (e.g. Bruns et al. 1998). Molecular techniques are increasingly being applied to detect and identify basidiomycete biotrophs in the absence of fruit bodies, for example on roots (Glen et al. 2001a,b), and rots in wood (Demetriou et al. 2000). Many of these applications integrate classical and molecular technologies to enable molecular profiles from unknown fungal fruit bodies, mycelium, and isolated cultures to be cross-matched against a reference database of identified fungi. For example, CSIRO and Murdoch University have developed highly sensitive techniques to identify 150 forest fungi in 1–3 mm long fine rootlets of trees recovered from forest soils. The techniques involve comparison of data from rootlets with a database of molecular patterns of fungi which were identified by the morphological and molecular attributes of their fruit bodies (Glen et al. 2001a,b). Such methods are gaining wide acceptance as existing and potential tools for practical and rapid diagnosis of pathogens, in diseased or asymptomatic tissue (Demetriou et al. 2000).

Molecular techniques are directly applicable to the development of a diagnostic tool kit for identification and detection of heartrot fungi in the absence of fruiting bodies and other symptoms of decay. Such a kit would incorporate DNA markers and classical attributes to enable molecular profiles from unknown fungal fruit bodies, mycelium in wood, and cultures isolated from diseased trees in *A. mangium* plantations to be cross-matched against a reference database of identified fungi. The approach involves exploiting genetic variation (DNA polymorphisms) which characterise specific fungi to produce informative DNA markers, and building a molecular database of known fungi identified as fruit bodies. More specifically, the conserved nature of the internally transcribed spacer (ITS) ribosomal region of the nuclear genome is likely to be informative for molecular diagnostic methods to identify heartrot fungi of *A. mangium* in the presence of other organisms. ITS of nuclear rDNA has been used to distinguish many taxa of Aphyllophorales, such as *Ganoderma* (Moncalvo 2000) and various other genera (e.g. Moreth and Schmidt 2000). Unknown fungi present as fruit bodies or mycelium in, or isolated as cultures from, diseased wood can be compared and matched with the reference database to determine their identity.

Bioinformatics, in particular the quality of the reference database of identified fungi, is a key concern likely to determine the potential for wide adoption and application of identification/diagnostic technology for heartrot pathogens. Bioinformatics includes the physical resource of preserved fungal specimens, and associated database enabling searching for and matching filtered data. To build a high quality permanent fungal resource, rigorous protocols are needed to capture and database appropriate classical and molecular attribute data about the fungi. Building and maintaining this resource incorporates a diverse range of key activities such as field sampling protocols to capture, maximise and standardise descriptive and ecological data about specific fungi, data quality assurance, curation of preserved specimens, herbarium-based identification of fruit bodies by comparative micromorphology, reference resource of historical and current taxonomic literature (such as genera monographs and keys), culture collection management, molecular protocols, and development of a database.

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Overview of the Heartrot Problem in *Acacia* — Gap Analysis and Research Opportunities

Lee Su See*

Abstract

Heartrot in *Acacia mangium* was first reported from Sabah, Malaysia in 1981 and it has since been found in most countries where plantations of the species have been established, such as Papua New Guinea, India, Indonesia, Thailand and Vietnam. Apart from Malaysia, there are no reports of surveys for the incidence of heartrot in *A. mangium* having been conducted elsewhere. The incidence and severity of *A. mangium* heartrot increased with age of trees but the volume affected was generally small (0.03–18 per cent of wood volume) in trees 2–9 years old. Heartrot in *A. mangium* is a typical white rot where the wood is bleached a pale yellowish-white colour and becomes fibrous and stringy. Recovery of sawn timber from *A. mangium* affected by heartrot varied from 39.1 to 45.6 per cent, depending on how thoroughly defects could be removed during sawing. The most important infection courts for heartrot fungi in *A. mangium* are dead branch stubs, dead or broken branches and stem cankers/unhealed wounds. A number of fungi known to cause wood discoloration and wood decay have been identified from *A. mangium,* and it is anticipated that molecular techniques and DNA sequencing may enable the identification of many more fungi associated with heartrot. Very few studies have been conducted on the effect of pruning and wound response on heartrot development and incidence.

ALTHOUGH THERE IS now a considerable body of information on heartrot of *A. mangium*, there are still many knowledge gaps and opportunities for research. An assessment of the susceptibility of different *A. mangium* provenances, *Acacia* hybrids and other *Acacia* species to heartrot and species-site matching studies would permit the selection of more resistant and better adapted species for plantation establishment. The effects of prescribed silvicultural practices, wound responses, and progress of infection by different wood decay fungi in causing heartrot need to be investigated. In addition, the establishment of a database for heartrot and wood inhabiting fungi would not only be of great importance in decay risk prediction and the formulation of disease control and management strategies, but also be of great service to researchers in the region and to mycology in general.

Heartrot is generally a defect of old trees where the heartwood progressively decays. However, the term heartrot has been widely used to refer to the rot found in the core wood of stems and branches in *Acacia mangium* trees as young as two years old where it is unlikely that any heartwood has yet formed. It is the latter usage of the term that is referred to throughout this paper.

Heartrot was first reported in *A. mangium* from Sabah, Malaysia in 1981 where the heartwood of 12 per cent of 44-month-old thinnings from a plantation were found to be affected by a white fibrous decay surrounded by a dark stain (Gibson 1981). In a sawn timber recovery study of *A. mangium* in Sabah, Chan (1984) found that about 16 per cent of logs were affected by heartrot. The defect was subsequently observed in trees sampled from four-, five- and six-year-old plantations in Pahang, Peninsular Malaysia (Lee et al. 1988). Studies conducted both in Peninsular Malaysia and Sabah in the 1990s established the high incidence of heartrot in *A. mangium* trees of various ages with the defect being present in trees as young as two years old (Table 1). Since then, heartrot of *A. mangium* has been found in most countries where plantations of the species have been established, such as Bangladesh, Papua New Guinea, India, Indonesia, Thailand and Vietnam. However,

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Table 1. Results of heartrot surveys in Malaysia.

Age of tree	Location	Incidence	Length of bole	Volume discoloration	Volume heartrot	Total vol. loss	Invasion point	Remarks	Reference
44 months, thinnings	Sabah	12%		–	–	–	Not noted		Gibson 1981
4 years	Kemasul, P. M’sia	–	50–100%	18–48%	3–8%	26–54%	Branch stub, basal pruning wound		Lee et al. 1988
5 years	Kemasul, P. M’sia	–	74–100%	46–35%	7–18%	42–64%	Branch stub, basal pruning wound, broken branch		Lee et al. 1988
6 years	Kemasul, P. M’sia	–	50–100%	34–47%	4%	38–51%	Branch stub, basal pruning wound		Lee et al. 1988
5 years, thinnings	Rantau Panjang, Selangor	21%	–	–	–	–	–	Only stem base observed	Hashim et al. 1991
5 years, thinnings	Ulu Sedili, Johor	29%	–	–	–	–	–	Only stem base observed	Hashim et al. 1991
6 years, thinnings	Ulu Sedili, Johor	14%	–	–	–	–	–	Only stem base observed	Hashim et al. 1991
6 years, thinnings	Ulu Sedili, Johor	12%	–	–	–	–	–	Only stem base observed	Hashim et al. 1991
3 years, thinnings	Bengkoka, Sabah	4%	–	–	–	–	Mainly pruning wounds	–	
6 years	Kolapis, Sabah	28%	–	`	0.03–3.21%	0.04–5.8%	Dead branch stubs, knots, stem cankers, unhealed pruning wounds	–	Mahmud et al. 1993
6 years	Telupid, Sabah	37%	–	–	0.07–6.19%	0.76–23.9%	Dead branch stubs, knots, dead branches, stem cankers, butt and root	–	Mahmud et al. 1993
8 years	Gum–Gum, Sabah	30%	–	–	0.02–2.78%	0.32–2.8%	Dead branch stubs, knots, dead branches, stem cankers	–	Mahmud et al. 1993
8 years	Keningau, Sabah	49%	–	–	0.05–18.1%	0.30–18.1%	Dead branch stubs, knots, dead branches, stem cankers, forking injury	–	Mahmud et al. 1993

Table 1. Results of heartrot surveys in Malaysia (continued).

Age of tree	Location	Incidence	Length of bole	Volume discoloration	Volume heartrot	Total vol. loss	Invasion point	Remarks	Reference
8 years	Kudat, Sabah	10%	–	–	0.03–10.82%	0.3–12.6%	Dead branch stubs, knots	–	Mahmud et al. 1993
8 years	Ulu Kukut, Sabah	10%	–	–	0.03%	0.29%	Stem cankers	–	Mahmud et al. 1993
9 years	Ulu Kukut, Sabah	60%	–	–	0.36–1.71%	0.04–5.8%	Stem cankers	–	Mahmud et al. 1993
2 years	Sabah	0%	–	–	–	–	–	–	Ito 1991, Ito & Nanis 1997.
3 years	Bongkol, Sabah	0%	–	–	–	–	–	–	
4 years	Bongkol & Lumat, Sabah	10–40%	–	–	–	–	Mainly dead branches, some wounds	Also mentions dead branch stubs, dead branches, forking injuries, unhealed wounds and unknown causes in another paper from the same study.	
5 years	Ulu Kukut, Sabah	20–40%	–	–	–	–	Wounds, squirrel damage		
6 years	Ulu Kukut, Sabah	40%	–	–	–	–	Dead branches, some wounds and squirrel damage		
7 years	Bongkol, Sabah	40–50%	–	–	–	–	Dead branches, wounds, cankers	–	
9 years	Kinarut & Bongkol, Sabah	50%	–	–	–	–	Dead branches, some wounds and squirrel damage	–	
5 years	Sabah	50%	–	–	–	–	–		
5 years*		0%	–	–	–	–	–	*A. auriculiformis*	
5 years	Sabah	0%	–	–	–	–	–	*Acacia* hybrid	
2 years	Data pooled from plantations in various states of Peninsula Malaysia	57%	–	–	–	1.20%	–	–	Zakaria Ibrahim et al. 1994
3 years		49%	–	–	–	0.70%	–	–	
4 years		72%	–	–	–	2.20%	–	–	
5 years		74%	–	–	–	3%	–	–	
6 years		82%	–	–	–	1.50%	–	–	
7 years		94%	–	–	–	2%	–	–	
8 years		98%	–	–	–	2.80%	–	–	

apart from Malaysia, there are no reports of systematic surveys of heartrot having been conducted elsewhere.

In a study conducted in Sabah, Malaysia, heartrot was reported to be present in five-year-old plantations of *A. mangium* but absent in similarly aged plantations of *A. auriculiformis* and an *A. mangium* × *A. auriculiformis* hybrid (Ito and Nanis 1994, 1997). The defect has, however, been reported to be present in *A. auriculiformis* in India (Browne 1968). Other species of acacias reportedly infected by heartrot are shown in Table 2 extracted from Lee (1993) but it is not known whether heartrot is present in the other tropical plantation acacias grown in Southeast Asia, such as *A. aulacocarpa* and *A. crassicarpa*, as no data are available.

From an extensive survey carried out in Peninsular Malaysia, Zakaria et al. (1994) reported that the number of *A. mangium* trees with heartrot was positively correlated with increase in age of trees but not to plantation site, seed source or pruning treatment. They did not detect any correlation between volume of wood affected by heartrot and age and noted that the actual volume loss due to heartrot was less than ten per cent. Earlier studies by Lee et al. (1988) and Mahmud et al. (1993) also reported small losses in wood volume: 3–17 and 0.03–18 per cent respectively. Studies conducted in Sabah by Ito and Nanis (1997) reported that the incidence of heartrot and disease severity (the progression of discoloration and decay in the heartwood) increased with age of trees, but no figures for the volume of wood affected were given.

So far, only two studies have been carried out on the recovery of sawn timber from *A. mangium*. In Sabah, Chan (1984) obtained a recovery rate of 40.4 per cent for sawn timber of various grades. In Peninsular Malaysia, Ho and Sim (1994) obtained a comparable recovery rate of between 39.1 and 45.6 per cent, depending on how thoroughly the defects due to heartrot and wane could be removed during sawing. They found that almost all the 11-year-old logs sampled contained heartrot around the pith. In terms of volume of heartrot expressed as percentage of log volume, 53 per cent of the logs had about 1 per cent heartrot, another 18 per cent had about 3 per cent heartrot with the remainder having 5–27 per cent heartrot. The quality of sawn boards was impaired by the presence of unsound knots; 63 per cent of the boards had two or more knots over a length of 2 m and 35 per cent of knots were spaced at distances equal to or less than 30 cm. Ho and Sim (1994) concluded that the use of *A. mangium* for reconstituted panel products would eliminate the problem of defects such as the presence of unsound

Table 2. The occurrence of heartrot and associated fungi in some of the more widely planted acacias in East Asia and the Pacific region.

Tree species	Associated fungus	Country	Reference
A. auriculiformis	*Ganoderma applanatum*	India	Browne (1968)
A. catechu	*Fomes badius*	India	Bakshi (1957)
	Fomes fastuosus, F. senex, Ganoderma applanatum	India	Browne (1968)
	Pseudophaeolus baudonii	Thailand	Kamnerdratana et al. (1987)
A. dealbata	*Ganoderma australe*	Australia	Browne (1968)
A. mearnsii	*Stereum ostrea, Ganoderma applanatum*	Tanzania, Australia, Sri Lanka	Browne (1968)
A. melanoxylon	*Stereum sanguinolentum, Ganoderma applanatum*	Australia	Browne (1968)
A. modesta	*Ganoderma applanatum, Fomes fastuosus*	Pakistan Widespread	Browne (1968)
	Phellinus badius, G. applanatum, Ravenelia taslimii	Pakistan	Quraishi & Ahmad (1973)
A. nilotica	*Ganoderma applanatum*	India	Browne (1968)
	Fomes badius, F. fastuosus, F. rimosus	India	Dargan (1990)
A. pycnantha	*Ganoderma applanatum*	Australia	Browne (1968)

Source: Lee (1993)

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knots, wane and warping that could occur on sawn timber. A seminar on the *Potential of Acacia and Other Plantation Species* held in Malaysia at the end of 1993 (Anon. 1995) came to the conclusion that the major defect affecting the use of acacia for solid wood end uses was knots rather than heartrot.

Characteristics of Heartrot in *A. mangium*

Young *A. mangium* trees may not have true heartwood, defined as non-functional tracheary elements often blocked by tyloses and infiltrated with organic compounds, but usually have an inner darker coloured heartwood-like core surrounded by a paler outer sapwood-like layer. These distinctively coloured layers have often been referred to as sapwood and heartwood in discussions of *A. mangium* wood and that convention is used here. In *A. mangium* trees, sound sapwood is pale yellow to straw in colour while sound heartwood is pale olive brown to grey brown. In contrast, discoloured sapwood is light to dark greenish yellow while discoloured heartwood is purple-black in colour. Incipient decay is difficult to detect but the wood colour is intermediate between that of sound and decayed wood, and usually darker than normal heartwood. When affected by heartrot, the wood becomes a light yellow to bleached straw colour in advanced stages it is bleached almost white, becoming fibrous and stringy to corky in texture and easily removed with a penknife. The rot is often confined to small pockets in the central core; but in trees where the central core has completely rotted away, a hollow core is formed.

Acacia, like most fast-growing trees, possess a high proportion of juvenile wood which has sometimes been mistaken for heartrot. In acacia the juvenile wood is pale coloured wood of low density located in the centre of the log, and it is often soft and easily marked with a fingernail. As heartrot is often located within the juvenile core, this can often be confusing to the inexperienced eye. Juvenile wood usually forms in the stem of the live crown and has been known to constitute up to ten per cent by volume of the wood in eight- to nine-year-old trees (Ivory 1993).

Lee and Maziah (1993) described seven types of rot from *A. mangium* based on differences in colour, texture and general appearance of the rotted heartwood. These differences were probably due to the different stages of decay as well as characteristics of the individual fungi involved. Overall, the rot can be considered typical of white rot caused by hymenomycetes which attack both cellulose and lignin, leaving behind a yellowish-white, spongy or stringy mass. White rot is the most common type of rot found in tropical hardwood timbers.

Infection Courts

Although it is generally known that heartrot fungi are wound parasites that enter trees through injuries and branch stubs, few of the studies on *A. mangium* heartrot have actually assessed and determined the importance of the various infection courts for development of the disease. To date data is only available from three studies, one conducted in Peninsular Malaysia (Lee et al. 1988, 1996) and two in Sabah (Mahmud et al. 1993; Ito and Nanis 1994, 1997). A summary of the data from these studies is presented in Table 3.

Table 3. Types of infection courts on *A. mangium* trees with heartrot and proportion of trees with the various types of infection courts.

Types of Infection Courts	Peninsula Malaysia (Lee et al. 1988)	Peninsula Malaysia (Lee et al. 1996)	Sabah (Mahmud et al. 1993)	Sabah (Ito and Nanis 1994)	Sabah (Ito and Nanis 1997)
Dead branch stubs and knots	62.5%	38.4%	41.5%	45.5%	38.2%
Dead/broken branches	1.25%	–	28.7%	27.3%	20.6%
Stem cankers	–	–	23.6%	–	–
Butt and root rot	–	–	0.03%	–	–
Unhealed pruning* wounds	62.5%	38.6%	0.02%	31.8%	19.1%
Forking injury	–	–	0.01%	–	7.4%
Animal damage (including termites)	–	20.3%	–	–	5.9%
Wind damage	–	2.3%	–	–	–
Unknown/lightning	–	0.3%	–	–	8.8%
Age range of trees	1–8 years	2–8 years	6–9 years	1–9 years	2–9 years
No. of trees sampled	8	1097	195	22	140

*Ito and Nanis (1994, 1997) did not make any distinction between wounds caused by pruning or other factors.

It is clear that the most important infection courts for heartrot fungi in *A. mangium* are dead branch stubs, dead or broken branches, and stem cankers/ unhealed wounds. From the available data it is difficult to determine whether the 'unhealed wounds' were due to pruning activities or other factors. Discoloration and decay also develop in callused-over stubs due to the breakdown of compartmentalization by reactivated microorganisms resident in the wood. These stubs are often not associated with external indicators or symptoms and, if so, can only be seen when the bolts of wood are split.

It is also clear that the sample size and age of trees sampled would have an effect on the data obtained. Pruning wounds would be easily detectable in young trees 1–3 years old, but more difficult to determine in older trees. It is also important to take note of site factors, silvicultural treatments carried out, and occurrence of strong winds and fires at the chosen study site as these factors have been found to have an effect on the occurrence of infection courts (Mahmud et al. 1993).

Fungi Associated with Heartrot in *A. mangium*

A zone of discoloration usually surrounds the heartrot in *A. mangium*. Fungi isolated from this discoloured wood generally consist of moulds and pioneer wound-invading fungi such as *Aspergillus* spp., *Ceratocystis fimbriata*, *Chalara* spp., *Fusarium* spp., *Macrophoma* spp., *Paecilomyces* spp., *Penicillium* spp., *Pestalotia* spp., *Phialophora* spp., *Rhinocladiella* spp., and *Trichoderma* spp. (Lee 1986; Lee *et al.* 1988; Hashim *et al.* 1991; Ito and Nanis 1997).

The fungi actually associated with/causing heartrot in *A. mangium* are difficult to detect in the absence of basidiomata. Previously, studies had relied on cultural, morphological and physiological characteristics of the mycelia and comparison with the species codes developed by Nobles (1948, 1965) and Stalpers (1979). Using such techniques Lee and Maziah (1993) identified *Phellinus noxius* as one of the fungi associated with heartrot of seven- and eight-year-old *A. mangium* trees in Peninsular Malaysia. They could not, however, positively identify additional isolates because these often had features or a combination of features not found in the species codes used. Moreover, the codes cover only a limited range of fungi, mainly of temperate species. Using cultural characteristics, Mehrotra et al. (1996) identified *Phellinus pachyphloeus* and *Trametes palustris* from heartrot of 7–10-year-old *A. mangium* trees in West Bengal, India. More recently, Lee and Noraini Sikin (1999) managed to identify four fungi (*Rigidoporus hypobrunneus*, *Phellinus noxius*, *Tinctoporellus epimiltinus* and *Oxyporus* cf. *latemarginatus*) isolated from heartrot of *A. mangium* from Peninsular Malaysia and East Kalimantan using a simple technique for the production of basidiomata. However, this method is time-consuming, not always successful, and still dependent on identification based on published keys in the literature. Other fungi that have been reported to be associated with heartrot in other species of acacias are shown in Table 2.

It is envisaged that with the use of molecular techniques and DNA sequencing, much better progress can be made in the recognition and identification of the heartrot fungi.

Pruning and Wound Response

In an attempt to determine the effect of pruning on heartrot incidence, Ito and Nanis (1994) pruned two-year-old *A. mangium* trees in a plantation in Sabah and treated the pruning scars with paint or a fungicide (Topzin®). One year later they found that wounds treated with Topzin® had the best recovery rate with over 60 per cent of the pruned branches completely healed, compared with 50 per cent in the untreated wounds and in wounds treated with paint. Ito and Nanis (1994) also found that the percentage of discoloured and decayed knots was very high in unpruned trees which had many dead branches. They suggested that first pruning be carried out on one-year-old trees when the branches are still of small diameter and living.

In Peninsular Malaysia, Zakaria et al. (1994) found no difference in heartrot incidence between pruned and unpruned trees. It should be noted that in this study it was not stated at what age the trees had been pruned. Although the trees should generally be pruned at about one year, very often the treatment is delayed until the trees are over two-years-old, by which time heartrot would have already developed via naturally occurring dead branches and branch stubs.

In a study on eight-year-old *A. mangium* trees in Peninsular Malaysia, artificially induced wounds were monitored over a period of four weeks (Schmitt et al. 1995). Electron microscopy revealed that wounding induced the secretion of substances from the parenchyma cells into vessels and fibres but this did not lead to complete blockage of the cells, thus affording poor protection. Although parenchyma cells around the wound also became suberised as additional protection, fungal hyphae could still rapidly invade the wound-affected xylem with corresponding degradation. Schmitt and his co-workers concluded that the efficiency of the wound response in *A. mangium* was low compared with reactions of European hardwoods. No other reports on the wounding response in *A. mangium* appear to be available.

Gap Analysis and Research Opportunities

Heartrot is a disease/defect that normally goes undetected in general disease surveys as there are usually no outwardly visible indications or symptoms. In many countries where acacias, in particular *A. mangium,* are planted, systematic surveys for the incidence and impact of heartrot would be important and informative both for the determination of wood yield and quality.

Although there is now a considerable body of data and information on heartrot in *A. mangium*, there are still many gaps and research opportunities that need to be addressed. These are discussed below.

Heartrot in different provenances of *A. mangium* and species-site matching studies

Differing results have been reported with respect to the incidence of heartrot in different provenances of *A. mangium*. From a five-year-old provenance trial in Sabah, Ito and Nanis (1994) reported that heartrot incidence and disease severity were higher in the two provenances from Papua New Guinea compared to provenances from Australia and Sabah, with lowest disease severity in the latter. They suggested that tree form and branch size could have an effect on development of heartrot. In contrast, Zakaria et al. (1994) did not detect any differences in heartrot incidence in 2–8-year-old trees established from seeds obtained from different sources.

Studies carried out in Peninsular Malaysia have shown no relationship between heartrot incidence and site (Zakaria et al. 1994). In Sabah, on the other hand, the incidence of heartrot was found to be significantly lower at Kudat (10%) than at Keningau (49%) (Mahmud et al. 1993). This difference was attributed to factors such as better soil drainage at Kudat, and to the impact of the 1987 fire at Keningau which caused scarring of trees (Mahmud et al. 1993).

In its natural habitat in north-east Australia, the eastern islands of the Indonesian archipelago and Western Province of Papua New Guinea, *A. mangium* occurs in a range of vegetation types, including swamp grassland, grassland, savanna, dry evergreen forest and woodlands (Skelton 1987). It is associated chiefly with rain forest-savanna boundaries, which are regularly affected by dry-season fire, and disturbed sites on well-drained acid soils of low fertility (Pinyopusarerk et al. 1990).

In Malaysia and many parts of Southeast Asia, *A. mangium* has been planted in areas of high annual rainfall (up to 4500 mm) with no distinct rainfall seasonality. Yet it originates in areas with strong rainfall seasonality with average rainfall being less than 100 mm per month for up to five months each year. Lee and Arentz (1997) have suggested that the absence of a dry season in Peninsular Malaysia leads to poorer branch shedding and consequently greater potential for heartrot fungi to enter the stem through large diameter stubs when the lower branches eventually die. The humid environment in Peninsular Malaysia is also conducive to fungal infection. However, the above hypothesis still needs to be proven.

There is, therefore, a need for species/provenance-site matching studies to establish the heartrot susceptibility of the same set of *A. mangium* provenances established at a range of different sites with different soils and climates, including sites with year-round humid climates. Trials of a wide range of provenances could be set up at different locations in Indonesia and Australia for monitoring of long-term interactions between provenances and environment on decay development.

Clones obtained from a range of provenances selected for a wide range of genotypes could also be planted at several locations with contrasting climatic and edaphic environments. This would provide very good information on site versus genotype interactions, thus enabling the selection of genotype(s) best suited to particular site conditions.

Heartrot in *Acacia* hybrids and other popular *Acacia* species

Natural hybrids of *A. mangium* and *A. auriculiformis* are gaining popularity as potential plantation species because many hybrids have fine branching and a tendency for strong apical dominance which will eventually develop into a single-stemmed tree with good length of clear bole (Pinyopusarerk 1990). The wood density of some hybrids is intermediate between the two pure species and paper pulp productivity, breaking strength, folding endurance and brightness of the paper produced can be superior to those of the parents (Yamada et al. 1992; Kha 2000).

There is only one report of a survey for heartrot in an acacia hybrid where a limited survey of ten trees of each species was carried out in five-year-old plantations of *A. auriculiformis*, *A. mangium* and an inter-specific hybrid in Sabah (Ito and Nanis 1997). The study found that five of the ten *A. mangium* trees had heartrot, while both *A. auriculiformis* and the hybrid did not. A more extensive survey of such hybrids should be conducted to assess their relative resistance to heartrot. Such surveys should also be extended to some of the other tropical acacia species, such as *A. crassicarpa* and *A. aulacocarpa*, which have been established in plantations but for which data on heartrot susceptibility is lacking.

Heartrot in natural stands and natural regeneration

An assessment of the occurrence and incidence of heartrot should be conducted in naturally occurring stands and natural regeneration of *A. mangium* both in Australia and Indonesia. Tree density is normally much higher in young naturally occurring stands while naturally regenerated trees do not seem to have the multiple branching at the tree base, and branches appear to be finer. Ito and Nanis (1994), however, found that heartrot incidence and severity were highest in *A. mangium* trees planted at 1.0 × 1.0 m spacing, compared to trees planted at 2.1 × 2.1 m and 4.2 × 4.2 m spacing. They attributed this to the trees having many more dead branches and wounds, probably caused by frequent branch/tree contact and movement. Due to lack of experience with planting density, it is not possible to make any conclusion about the relationship between tree density, tree form, branching habit and branch size, self-pruning ability, and heartrot incidence in naturally occurring stands of *A. mangium*.

Relationship between silvicultural activities and heartrot incidence

Dead branches and branch stubs have been clearly established as the main points of entry for the heartrot fungi in *A. mangium*. Proper pruning techniques carried out with the right tools at the right time have been repeatedly emphasised as being very important in the prevention of heartrot development in trees grown for timber. Some forest plantation managers also advocate the application of wound paint/dressings as a routine practice after pruning, despite the lack of data on their effectiveness in *A. mangium*.

Long-term studies should be set up to monitor and assess the relationship between prescribed silvicultural operations, such as proper pruning and chemical treatments, on callus formation, wound healing and subsequent heartrot. In addition, the establishment of properly designed spacing and thinning trials using reasonably genetically uniform trees would be able to provide information on the relationship between tree density, tree form, branching habit and branch size, self-pruning ability, and heartrot incidence.

Wound response and progress of heartrot in *A. mangium*

Studies on wound responses should be carried out on young trees aged between one and two years as this is the age when singling and pruning are usually carried out. Similar studies should also be carried out on branches of various diameters. This is to verify or confirm the low efficiency of the wound response in *A. mangium* that had previously only been studied in eight-year-old trees (Schmitt et al. 1995). Variation of wound responses with seasonality (dry versus wet seasons) should also be tested.

Studies could also be carried out on the progress and rate of infection by different heartrot fungi in the stem to determine how the host reacts to the infection. Assessment of the efficiency of host defence mechanisms in combating the dominant heartrot fungi would allow for selection of more resistant host species.

Database of heartrot/wood decay fungi

There are many opportunities for research on the taxonomy of tropical fungi, be they wood decay fungi or otherwise, as many tropical fungi have yet to be discovered and/or described. One of the main problems with identification of the heartrot fungi has been the lack of information and references on tropical wood decay fungi generally. The establishment of a database for wood decay fungi including information on their pathogenicity, would be a useful service not only for researchers in the project and the region but also for mycology in general. Some quarters may view studies in fungal taxonomy to be mainly academic; however, decay risk prediction and disease control and management strategies are based on such knowledge.

Collection and identification of wood-inhabiting fungi from the vicinity of the study sites should be carried out so that these fungi may be compared with those isolated from the heartrot samples. This is in view of the high diversity of fungi isolated from *A. mangium* heartrot and the frequent occurrence of a range of many wood-inhabiting fungi on material such as woody debris and dead branches in *A. mangium* plantations (Lee and Maziah 1993). If indeed the wood-inhabiting fungi prove to be the inoculum sources for the heartrot fungi, then removal of woody debris may be one management consideration for reduction of the disease inoculum potential.

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