Australian Government

Biosecurity Australia

Final Report

Technical Justification for Australia's Requirement for Wood Packaging Material to be Bark Free

May 2006

Cite this report as:
Biosecurity Australia (2006). Technical Justification for Australia's Requirement for Wood Packaging Material to be Bark Free. Biosecurity Australia, Canberra, Australia.

TABLE OF CONTENTS

GLOSSARY OF TERMS AND ABBREVIATIONS

ALOP	appropriate level of protection
Anamorph	the asexual form of a fungus
AQIS	Australian Quarantine and Inspection Service
Area	an officially defined country, part of a country or all or parts of several countries
Ascospore	sexual spore produced in an ascus by a fungus in the division Ascomycota
Bark	the outer protective covering of a tree formed by the cork cambium and phloem tissue. It consists of phloem tissues, which occur as living inner and dead outer zones
Bark free wood	wood from which all bark excluding the vascular cambium, ingrown bark around knots, and bark pockets between rings of annual growth has been removed
Barrier breach	where a pest or disease is detected within the national quarantine barrier, but has not spread beyond the original host shipment with which it was imported
Billet	log segment
Biosecurity Australia	a prescribed Agency within the Australian Government Department of Agriculture, Fisheries and Forestry
Break bulk cargo	general goods, commodities or wares that are customarily shipped in boxed, bagged, crated or unitized form; cargo that is not containerized
Chlamydospore	asexual, one celled fungal spore originating within an existing cell, often with a thicken cell wall, which enables the fungus to persist in a resting state over time until environmental conditions support new growth
Conidia	asexual spores of a fungus from either of the divisions Ascomycota or Basidiomycota
Consignment	a quantity of plants, plant products and/or other articles being moved from one country to another and covered, when required, by a single phytosanitary certificate (a consignment may be composed of one or more commodities or lots)
Contaminating pest	a pest that is carried by a commodity and, in the case of plants and plant products, does not feed directly on the commodity
Control (of a pest)	suppression, containment or eradication of a pest population

DAFF	Australian Government Department of Agriculture, Fisheries and Forestry
Endangered area	an area where ecological factors favour the establishment of a pest whose presence in the area will result in economically important loss
Entry (of a pest)	movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled
Establishment	the perpetuation, for the foreseeable future, of a pest within an area after entry
Green wood	freshly cut wood that is not dried or seasoned
Hardwood	wood produced by trees in the botanical division Angiospermae (now Magnoliophyta)
Heartwood	the central, woody core of a tree, no longer transporting water and dissolved minerals; usually darker and denser than the surrounding sapwood
Host range	species of plants capable, under natural conditions, of suiting a specific pest
Inspection	official visual inspection of plant, plant products or other regulated articles to determine if pests are present and/or to determine compliance with phytosanitary regulations
Interception (of a pest)	the detection of a pest during inspection or testing of an imported consignment
Introduction	entry of a pest resulting in its establishment
IPPC	International Plant Protection Convention, as deposited with FAO in Rome in 1951 and as subsequently amended
ISPM	International Standards for Phytosanitary Measures
ISPM 15	International Standards for Phytosanitary Measures Publication No. 15 *Guidelines for Regulating Wood Packaging Material in International Trade*
LCL	Less than container load
Less than container load	cargo in any quantity intended for carriage in a container
National Plant Protection Organisation	official service established by a government to discharge the functions specified by the IPPC
Official	established, authorised or performed by a National Plant Protection Organisation
Official control	the active enforcement of mandatory phytosanitary regulations and the application of mandatory phytosanitary procedures with the objective of eradication or containment of quarantine pests or for the management of regulated non-quarantine pests

Pathway	any means that allows the entry or spread of a pest
Pest	any species, strain or biotype of plant, animal, or pathogenic agent, injurious to plants or plant products
Pest categorisation	the process for determining whether a pest has or has not the characteristics of a quarantine pest or those of a regulated non-quarantine pest
Pest-free area	an area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained
Pest risk analysis	the process of evaluating biological or other scientific evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it
Pest risk assessment (for quarantine pests)	evaluation of the probability of the introduction and spread of a pest and of the associated potential economic consequences
Pest risk management (for quarantine pests)	evaluation and selection of options to reduce the risk of introduction and spread of a pest
Phytosanitary measure	any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of quarantine pests
PRA area	area in relation to which a pest risk analysis is conducted
Quarantine pest	a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled
Restricted risk	'Restricted risk' estimates are those derived when risk management measures are used
Sapwood	The comparatively new wood, comprising living cells in the growing tree, one to many rings wide, which is responsible for all water and mineral movement through the stem
Slash	branches and other woody material left on a site after logging
Softwood	wood produced by trees in the botanical division Gymnospermae (now Pinophyta) that are the predominant tree type in coniferous forests
Spread	expansion of the geographical distribution of a pest within an area
SPS Agreement	WTO Agreement on the Application of Sanitary and Phytosanitary Measures
Teleomorph	the sexual form of a fungus

Twenty one day rule .... off shore treatment of wood packaging material is accepted for containerised cargo where it has occurred within twenty one days of containerisation or shipment

Unrestricted risk .... 'Unrestricted risk' estimates are those derived in the absence of risk management measures

Wood packaging material .... wood or wood products (excluding paper products) used in supporting, protecting or carrying a commodity including dunnage

WTO .... World Trade Organization

SUMMARY

This review provides technical justification to support the continuation of Australia's longstanding requirement that wood packaging material be bark free to reduce the quarantine risk to a very low level to meet Australia's appropriate level of protection (ALOP).

The requirement for wood packaging material to be free of bark is justified because it:

- enhances the visual inspection process;
- removes the effects of bark on methyl bromide fumigation and minimises treatment failures;
- minimises the risk of entry of the quarantine pests that depend on bark for food, shelter and one or more stages of development;
- reduces the risk of infestation and re-infestation after treatment; and
- minimises the risk of introduction of soil-borne pests and contaminating arthropod pests.

The removal of bark is necessary to allow the effective monitoring of wood packaging material during quarantine inspection procedures because of the cryptic nature of many wood-inhabiting organisms.

Interception records, compiled by the Australian Quarantine and Inspection Service (AQIS) before the introduction of the International Standards for Phytosanitary Measures Publication No. 15 *Guidelines for Regulating Wood Packaging Material in International Trade* (ISPM 15), identified a large number of timber pests associated with wood packaging material, some of which are likely to be associated with bark. Recent interception data collected by AQIS has shown that timber pests continue to be detected in association with ISPM 15 compliant wood packaging material.

Consideration of the physical and chemical changes during manufacture and use suggest that wood packaging material may remain suitable for infestation by pests post ISPM 15 treatments. The presence of bark may slow drying and makes the wood packaging material more suitable for infestation by some arthropod pests. While it is recognised that ISPM 15 treatments will not kill some fungal pathogens, the presence of bark provides protected surfaces that allow the development and spread of these fungi from wood packaging material.

The review included pest risk assessments of selected pests or pest groups to assess the risks associated with the importation of wood packaging materials with bark into Australia after application of a treatment approved in ISPM 15.

The results of the individual pest risk assessments showed that three arthropod pests or groups of pests (*Callidium violaceum*, *Gnathotrichus* spp. and *Ips* spp.) and three fungi or groups of fungi (*Ophiostoma*/*Ceratocystis* spp., *Cryphonectria parasitica* and *Fusarium circinatum*) have restricted risk estimates, based on application of ISPM 15 measures, of 'Low' or 'Moderate'. The restricted risk estimates for these pests exceed Australia's appropriate level of protection (ALOP). Consequently, Australia is justified in maintaining its requirement for bark freedom, in addition to the measures in ISPM 15, to reduce the quarantine risk to a very low level to meet Australia's ALOP.

1. INTRODUCTION

The history of quarantine in relation to timber in Australia

The legislative basis of Australia's quarantine regulations is the *Quarantine Act 1908*. In 1921, human quarantine functions were allocated to the Commonwealth Government Department of Health, with plant and animal quarantine functions being transferred to the Australian Agricultural Health and Quarantine Service. The implementation of the provisions of this legislation was carried out by relevant State government agencies under agreements with the Commonwealth Government until 1986, when the Australian Quarantine and Inspection Service (AQIS) was formed.

For the 130 years before 1921, soil (as ballast), seeds, timber and potted plants were brought into Australia from around the world without precaution. Many of the introduced agricultural plant and animal pests and pathogens present in Australia gained entry during Australia's early history. However, the situation has generally been different for exotic timber and forest pests, with Australia remaining relatively pest and disease free.

Up until the 1950s, Australia's timber production was primarily based on harvesting native hardwood forests. Specialty softwood needs were met primarily through importation, mostly from North America. At that time, the exotic softwood and hardwood plantation estate and amenity plantings were small in Australia. Consequently, there were few extensive plantings of exotic host species available in which exotic timber pests could establish in Australia, even if they had managed to survive the long sea journey from Asia, Europe or North America.

From the 1950s to the 1970s, Australia relied primarily on inspection to detect pests associated with imported sawn lumber and solid wood packaging. These inspections were the responsibility of different State agencies operating under agreements with the Commonwealth Government. The quarantine risks identified for the imported timber pathways were primarily a result of frequent detections, with inspection procedures being amended in response to new detections. Historically, the focus has been on insect pests, as the rapid identification of pathogens and decay fungi has not been possible until recently.

Much of this early quarantine work was poorly reported and analysed, and responses to detections were often *ad hoc* because of limited resources, management being distributed amongst State agencies, and limited scientific expertise. Despite this, some key timber pest risk mitigation principles were identified. Amongst these principles was the removal of bark to reduce risk and improve inspection effectiveness.

With the establishment of AQIS in 1986, many of the long-standing requirements were reviewed. Where these, on the basis of the current information, were considered to be effective risk management tools, such as was the case for bark freedom for timber and solid wood packaging, they were formally incorporated into national policy documents such as the Plant Quarantine Manual 1988 (AQIS 1988).

2. WOOD PACKAGING MATERIAL

Introduction

A very large proportion of all the commodities that are traded among countries is accompanied by packing wood. Probably as much as 70 % of all cargoes transported internationally by plane, ship, rail and road are supported in transit by wooden structures. Solid wood packing material sourced from many countries associated with goods imported to Australia may range from highly processed, reconstituted or remanufactured wood through to sawn wooden slats or boards used individually or used in manufactured items such as pallets, crating, packaging blocks, cable drums, bulk heads, load boards, pallet collars and skids through to round log sections and whole round logs used to prevent movement of larger cargo items (IPPC 2002). Only a small proportion of cargo packing may be made from materials other than wood (e.g. plastic or metal). Some of the wooden packing (< 5 %) may be made of 'processed' wood (e.g. chipboard, plywood, oriented strand board, and cardboard). However, the vast majority of packing material is made of solid wood. (McNamara and Kroeker n.d.)

Reconstituted or remanufactured wood such as particle board, fibre board and plywood undergo major changes in the manufacturing process and as such are not consider relevant to the issue of bark freedom requirements for controlling the importation of invertebrate pests or fungi associated with packing materials.

Shippers may use virtually any species of woody plant, as well as bamboo and palms, in any state, from fresh-sawn to re-used, seasoned lumber. Wood from salvaged trees killed by wildfires or insect outbreaks (e.g. *Dendroctonus* outbreaks) may be used in low cost packaging. The wood used may be from non-durable species, for example, *Abies*, *Populus* and *Picea*.

The wood packaging pathway poses unusual difficulty for the characterisation of associated pest risk. Unlike wood packaging material, most commodities regulated by quarantine are identifiable by type and origin. Cargo shipments may therefore contain wood packaging material of various types and ages and from unexpected and multiple origins. (USDA 2000.)

The properties of the wood commonly used as packing material contribute to the hazard. Sawn wood packaging material is typically made from rough-sawn, low-quality wood or by-products of milling that are not acceptable as higher grade lumber. The wood may include bark or wane from the outside of the stem, insect grub holes, and fungal decay or stain. Such low-value wood is generally green. (Allen 2001b.)

The use of timber in the manufacturing of wood packaging material is very important to the timber industry. It provides a large market for the lowest quality lumber. Forty per cent of all hardwood timber manufactured in the USA goes into the manufacture of wood packaging material and a 'goodly portion' of softwood as well. (Federal Register 2004.)

Timber used in wood packaging material may be subject to some air drying before entering service as wood packaging material. It seems unlikely that fully seasoned wood would form the major portion of new wood entering the population of solid wood packing material. In contrast, the bulk of pallets in-service will probably be seasoned, as much of this material is reused. The requirement for ISPM 15 treatment will increase the value of this material and probably its lifespan.

Potential pests may already be present in or on host material at the time of harvest, or they may colonise after harvest. Many species of bark beetles and wood borers are particularly attracted to recently cut wood. In some countries of origin, wood packaging material (especially single use materials) are more likely to be constructed out of infested materials because of its general unsuitability for other uses. (USDA 2000.)

Except for direct trade in packing materials, wood packaging materials are not a commodity and are difficult to monitor during quarantine inspection procedures. Even when high-risk packing is identified in a shipment, the inspection process is complicated by limited access to visible surfaces (most surfaces are not facing the inspector, or the cargo is buried deep in a container) and the cryptic nature of many wood-inhabiting organisms (little or no sign of their presence is evident at the surface). Latent fungal infections are virtually impossible to detect through inspection of outer wood surfaces. (Allen 2001b.)

USDA (2000) reported that only 1–5 % of sawn wood packaging may be accessible for inspection at the container tailgate. Containerised cargo is usually packed tightly and often stacked to the roof (USDA 2000). Whyte (2003) reported that in New Zealand, nearly 49% of loaded containers were estimated to have wood packing material inside. Of these, 33% had unmanifested wood and of these, 9% had unmanifested wood requiring biosecurity action such as fumigation or incineration. Door inspection on the wharf was 85% effective at locating wood packaging, but only 5% effective at finding live organisms when present in containers.

Wood packaging material and Australia's requirement for bark freedom before ISPM 15

Australia and New Zealand were two of the first countries to recognise the risks associated with sawn wood packaging material (Hicks 2004). Australia's requirement that imported timber and solid wood packaging must be free of bark initially evolved in response to AQIS' operational considerations. Inspection for insect pests, an alternative to requiring time consuming and expensive treatments, required that bark had to be removed so that inspectors could ensure freedom from 'under bark' insect pests and could readily identify any fresh frass. Bark removal is also a critical component in ensuring the effectiveness of inspection for contaminating non-timber pests through removal of shelter sites and for reducing fungal risks.

The vectors of many forest fungal pathogens and wood decay fungi of quarantine concern are present in Australia; for example, *Scolytus multistriatus* the vector of *Ophiostoma novo-ulmi* (DPI 2004). Many other pathogens of forest trees can spread from infected wood and bark by aerial dispersal where fruiting bodies develop, and/or by water and soil dispersal mechanisms. Pine pitch canker (*Fusarium circinatum*), chestnut blight (*Cryphonectria parasitica*) and *Ophiostoma* and *Ceratocystis* species are ready examples (Dowding 1969, Sinclair *et al.* 1987, Phillips 2001). Insect vectors are considered in the pine pitch canker incursion plan (Gadgil *et al.* 2003).

A number of other fungal species that have an association with bark and that are of quarantine concern to Australia have been identified as a result of sampling of imported solid wood (Simpson 1999). The New Zealand import health standard for bark from all countries also lists an extensive number of fungal pathogens and decay fungi that potentially can be associated with bark on timber packaging (MAF NZ 2003). Farrell (2001) in a survey for fungi on timber imported into New Zealand reported that samples from visually compromised wood did not necessarily contain more fungi than 'clean' wood, and that the natural tendency to pick out visually compromised wood for quarantine procedures 'may be in fact negatively selecting against the wood harbouring potential disease'. For some high-risk pathogens, such as pine pitch canker, emergency response management strategies highlight that there is little chance of containment and/or eradication without widespread removal of high value plantation forests and amenity plantings (Gadgil *et al.* 2003).

Australian quarantine inspectors have reported that many of the interceptions of exotic ant species and termites have been found nesting under bark, and these may not have occurred or would have been more likely to have been detected before export, had the bark been removed. Similarly, the removal of bark before export also helps to facilitate clearance at the quarantine barrier by increasing the speed and effectiveness of inspection for those commodities that arrive as break bulk or sea cargo and in which solid wood packaging and/or dunnage has been used. (D. Walsh pers. comm.)

The Australian government has a number of strategies to address the underlying levels of non-compliance that it identifies. Where non-compliance is detected, through presence of bark, contamination and/or quarantine pests, subsequent consignments from these suppliers are targeted for additional surveillance through Customs' databases. Where bark is detected, it is removed under AQIS supervision, an appropriate treatment applied if necessary, and then consignments released. Suppliers are informed of the failure and, because AQIS is a fee for service agency, compliance costs are passed on to the importers. Hence, there is considerable commercial incentive to improve compliance.

ISPM 15

In recognition of the plant health risk associated with wood packaging material made from unprocessed raw wood, the International Plant Protection Convention (IPPC), as part of the United Nations Food and Agricultural Organisation's global program of policy and technical assistance in plant quarantine, published the International Standards for Phytosanitary Measures Publication No. 15 *Guidelines for Regulating Wood Packaging Material in International Trade* (ISPM 15) in March 2002 (See Appendix 1). This standard aims to significantly reduce the risk of unprocessed wood being a pathway for the introduction and spread of invertebrate pests through international trade.

Presently the only internationally accepted treatment options under the ISPM 15 are heat treatment or fumigation with methyl bromide. Where heat is the chosen treatment option, all wood packaging material shall be heated in accordance with a specific time-temperature schedule that achieves a minimum wood core temperature of 56°C for a minimum of 30 minutes. Where fumigation with methyl bromide is the chosen treatment option, all wood packaging material shall be fumigated in accordance with the minimum standard described in Table 2.

The above ISPM 15 approved measures aim to significantly reduce the risk posed by unprocessed raw wood with bark being used as a pathway for the introduction and spread of arthropod pests and nematodes through international trade. According to ISPM 15, where wood packaging material has been treated by one of the above approved methods, the treatment is considered to practically eliminate members of the pest groups associated with wood packaging materials listed in Table 1.

Both the USA and Canada have revised their import regulations for wood packaging material since the introduction of ISPM 15. The revised regulations are consistent with ISPM 15. The Animal and Plant Health Inspection Service (APHIS) has set standards for wood packaging material imported into the USA through the Foreign Quarantine Regulations (7 CFR 319.40 -

Importation of Wood Packaging Material, published on 16 September 2004) (APHIS 2004). Canadian Food Inspection Agency (CFIA) (CFIA 2005) published the entry requirements for wood packaging materials produced in all areas other than the continental United States. In 2004, the European Commission (EC) stipulated in the Commission's Directive 2000/29/EC that certain coniferous wood in the form of packaging materials shall be stripped of its bark (EC 2004).

The quarantine alert released by AQIS on 2 April 2004 advised that ISPM 15 approved treatments: 1) heat treatment of timber to a temperature of 56°C for 30 minutes at core temperature; or 2) methyl bromide fumigation at $48g/m^3$ for 16 hours at 21°C would be inserted into Australia's existing import requirements for wood packaging material. From 1 September 2004, AQIS has accepted sawn wood packaging material that is treated in accordance with ISPM 15 provided bark free wood is used, in addition to wood packaging material treated under existing AQIS approved treatments. ISPM 15 is not mandatory in Australia, but is an additional measure to existing import conditions for wood packaging material. The existing AQIS requirements for wood packaging material include methyl bromide fumigation at $48g/m^3$ for 24 hours and the use of bark free wood for the manufacture of wood packaging material. Thus, adoption of the ISPM 15 standard for methyl bromide fumigation has resulted in a less stringent treatment of wood packaging material imported into Australia with regard to methyl bromide treatment.

Australia is concerned that the scope of the ISPM 15 does not cover pathogens and decay fungi in general and the standard is not intended to address the issue of invertebrate infestation after treatment. There are also operational issues not covered by ISPM 15, such as difficulty in inspecting wood packaging material with bark. Also, export protocols for ISPM 15 also allow for treatment to be applied within the supply chain such as at mills, or on large dimensional timber, rather than on the final product such as a crate or pallet.

Australia's implementation of ISPM 15, the current policy framework and the operational quarantine perspective

Australia uses a risk management approach to develop quarantine policies through a clearly defined risk assessment process. Australia does not have a zero-risk policy, but manages the risk associated with imported goods in a way that facilitates trade without breaching quarantine integrity. As the operational arm of quarantine for the Australian government, AQIS manages the risks associated with imported goods within a framework called the 'continuum of quarantine' that is offshore, border and post-border quarantine. At each stage of the import process, steps can be taken to minimise the quarantine risk.

Australia has developed procedures that maximise the choices available to exporters to Australia to meet Australia's quarantine requirements. This allows exporters to Australia to adopt the option that best suits their business needs and minimise their costs. ISPM 15 conditions have been incorporated into these procedures as an additional option. However, Australia has retained its longstanding requirement that all solid wood packaging imported into Australia is free of bark, whether ISPM 15 compliant or not. This is to ensure Australia's freedom from pests, such as those listed in Table 3, by facilitating detection of treatment failures, as well as to reduce infestation by non-timber quarantine pests, pathogens and decay fungi not targeted by ISPM 15.

This measure is supported by results of a survey initiated by AQIS, based on a sampling regime for ISPM 15 solid wood packaging entering Australia, to test the validity of the concerns outlined in this paper. This sampling program ran from 01 January to 30 November 2005 where 6793 inspections of wood packaging material, displaying the ISPM15 stamp, were carried out in Sydney, Melbourne and Brisbane. During the surveillance inspections, 19522 crates, dunnage or pallets (pieces) were observed. Of the 19522 pieces, 1823 or 9.34 % were found to be non-compliant with the ISPM 15 standard and 1749 or 8.96 % exhibited something of quarantine concern. Of this 8.96 % of ISPM 15 wood packaging for which quarantine concerns were identified, 86.4 % had bark, 5.7 % had fungi and mould, and 5.9 % had evidence of live insects. On the basis of total units of wood packaging material inspected, approximately 1 in 200 units had live wood boring insects and 80 % of these insect detections were on wood packaging with bark. These figures are equivalent to Less than Container Load (LCL) survey data collected from 1997 to 1999 (Salvage 1999), except that the proportion of items with bark present has increased for ISPM 15 wood packaging material.

Previous AQIS survey data showed that out of 69,500 LCL consignments inspected, there were 3,800 interceptions (5.5%) of bark (AQIS 1999a). New Zealand conducted a survey of 2,547 LCL imported containers in 1992 and found bark in 3.7% (AQIS 1999a). In the past, AQIS has intercepted many exotic pests associated with bark on wood packaging materials (PDI 2004). Reports from other countries, including USA and Canada (USDA 2000, CFIA 2001b, Humble *et al.* 2002) also indicate that exotic bark and wood-boring beetles are often associated with bark attached to wood packaging materials, including dunnage. A Sydney port survey commissioned by AQIS identified important exotic fungal pathogens of quarantine concern associated with bark on wood products from New Zealand, Canada and USA (Simpson 1999).

Studies in progress examining infestation of wood with bark remaining after an ISPM 15 treatment are showing infestation by beetles and emergence of a subsequent generation can occur (Schröder 2005). However, examination of the data from these experimental treatments, as well as information on the biology and behaviour of a particular insect pest, needs to be done in the context of the physical and chemical nature of the wood present in solid wood packing material, and whether or not it is sapwood or heartwood.

To help address the identified risks associated with bark, ISPM 15 (IPPC 2002) allows the use of debarked logs, subject to technical justification, in the manufacture of wood packaging material. However, these processes are highly variable in their effectiveness, depending upon the age of the machinery, the type of wood being milled (thick- or smooth-barked logs), the branchiness of the logs, the individual growth characteristics of species and individual stands, as well as time of and since harvesting. Debarking may be incomplete, leaving remnants in depressions (USDA 2000).

A joint AQIS and industry visit to the USA and Canada (1999b) reported that, 'Generally, as part of the initial milling process, the debarking machines removed all the bark on the Douglas Fir, Hemlock and Western Red Cedar logs sighted, when the tapered logs were "round" along their full length. However for those logs containing old wounds, fluted or out of round surfaces, ingrown bark around knots, or bark pockets, some bark generally remained adhered to the log. This is due to the teeth of the debarking machine either skipping over or missing these areas, since the teeth were unable to make contact with the bark.' At one mill, the review team was advised that '… in summer the bark falls off, whilst in winter you have to chisel it off'.

Although the definitions used in ISPM 15 establish a tolerance for bark on bark free wood, no guidance is given in the standard as to what the operational tolerance should be or how to determine if it has been met. Consequently, proposals based upon the use of debarked logs to meet the requirement of bark freedom that may be imposed by countries that require it are likely to give rise to high levels of non-compliance.

From the 1980s, transit times for commodities have been reduced, and there has been increased use of containerisation and also the widespread use of solid wood packaging in an untreated state (Moore 2005, UN Atlas of the Oceans n.d., USDA 2003). These sectors are considered to have contributed to the introduction of Asian longhorn beetle (*Anoplophora glabripennis*), emerald ash borer (*Agrilus planipennis*) and brown spruce longhorn beetle (*Tetropium fuscum*) into North America (Keiran and Allen 2004). Similarly, the North American red turpentine beetle (*Dendroctonus valens*) is believed to have established in Chinese pine forests after gaining entry through solid wood packing and a number of other pathways (Keiran and Allen 2004, Yan *et al.* 2004).

At present under ISPM 15, there is no acceptable way to confirm that a certified treatment has been appropriately performed (Burgess 2005). The absence of bark makes it easier to detect pests that feed on seasoned wood. Additional costs imposed by ISPM 15 treatment may result in a greater reuse of packing material and an increase in the proportion of seasoned wood in the packing material population. The reuse of wood packaging allows a greater opportunity for wood to be infested after treatment, by either timber pests depending on moisture content and presence of bark or by the pests of seasoned timber. This creates issues with regard to inspection of wood packaging material.

3. RISKS ASSOCIATED WITH WOOD PACKAGING MATERIAL WITH BARK ATTACHED

The properties of the wood commonly used as packaging material contribute to the hazard. Sawn wood packaging material is typically made from rough-sawn, low-quality wood or by-products of milling that are not acceptable as higher grade lumber. The wood may include a high proportion of non-durable sapwood, bark or wane from the outside of the stem, insect grub holes, and fungal decay or stain. Such low-value wood is generally not kiln dried.

Wood packaging material is difficult to monitor during quarantine inspection procedures. Even when high-risk packing is identified in a shipment, the inspection process is complicated by limited access to visible surfaces (most surfaces are not facing the inspector or the cargo is buried deep in a container) and the cryptic nature of many wood-inhabiting organisms. Latent fungal infections are virtually impossible to detect through inspection of outer wood surfaces. (Allen 2001b.)

The nutrient-rich inner bark and the cambium layer on wood packaging materials provide a food source for arthropod pests and fungi. Weed seeds, molluscs and agricultural pests may also 'hitchhike' on bark attached to wood packaging material. These factors contribute to an increased risk of spreading agricultural and wood pests.

Many species of insects attack living trees. When these trees are converted into wood packaging material, the degree of processing and treatment is often inadequate to remove or kill pests. Wood packaging therefore becomes a pathway for the introduction and spread of pests (IPPC 2002).

The nature of the quarantine risk to Australia associated with the importation of timber and solid wood packaging has changed in recent years owing to the establishment of extensive new forestry plantations, diversifying trade, increasing volumes of imports and reduced transport times. Australia has a conservative approach to managing pest risks associated with imported solid wood packaging. This is a reflection of 1) the unique native flora and fauna that has evolved in biogeographic isolation; 2) past establishment of timber pests, pathogens and decay fungi introduced only a small portion of the genetic diversity of the pest; 3) limited disease resistance in Australian exotic plantations as a consequence of use of germ plasm selected for growth and wood quality attributes in the relative absence of pests and pathogens; 4) the rising costs of pest management and their impacts on the long term economic viability of domestic plantation and timber industries; 5) escalating costs of eradication and containment programs for incursions of exotic pests; 6) the volume of wood packaging material with bark attached imported in association with a wide range of products; and 7) the high number of interception records of serious exotic timber pests on imported wood packaging material with bark.

The presence of bark in large amounts also increases the potential for transport of contaminants of quarantine concern, such as soil, as evidenced by recent United States Department of Agriculture (USDA) PRAs (Kliejunas *et al.* 2001, Tkacz *et al.* 1998, USDA 1992).

The presence of bark on wood packaging material slows the seasoning process, provides shelter for invertebrates and allows the survival of many potential pests that feed in the cambial layer under the bark, particularly bark beetles (Scolytidae) and their associated species of fungi, such as *Ophiostoma*, *Leptographium* and *Ceratocystis*, as well as mites that also spread blue stain fungi (Stone and Simpson 1991a). Wood packaging material and associated bark may not be the target of off shore phytosanitary inspection, making this pathway a high risk for the introduction of exotic arthropod pests and pathogens into Australia.

The high risk nature of bark attached to wood packaging material has been acknowledged by many countries, including USA and Canada. Between August 1995 and March 1998, 97 % of pests intercepted by APHIS inspectors at United States ports and recognised as potential threats to forest resources of the USA were associated with sawn wood packaging (USDA 2000). The USA's import requirements enacted in 1995 required solid wood packaging material to be bark free (7 CFR 319) down to and including the cambium layer. Even with this bark freedom requirement in place, inspectors found that 9 % of maritime and 4 % of air shipments containing sawn wood packaging material had bark present (USDA 2000). The lengthy list of insect pests intercepted with sawn wood packaging material at US ports of entry with origins from around the world demonstrates that environmental conditions in shipping containers and airplane cargo holds are suitable for their survival (USDA 2000).

In 1995, APHIS expanded to all source countries its import rules for unmanufactured wood articles (Federal Register 1995). The broadened rules addressed heat treatment, fumigation, irradiation and other means of pest control. Softwood logs from sources other than Canada, Mexico's US border States, Chile and New Zealand had to be debarked and heat treated (versus debarked and fumigated in the cases of Chile and New Zealand). Tropical hardwood logs had to be either debarked or fumigated. Temperate hardwoods had to be either fumigated or debarked and then heat treated. Log and lumber imports from eastern Russia (and other places north of the Tropic of Cancer and east of longitude 60ºE) had to be debarked and heat treated. (Lane 1998.)

CFIA directive D-98-08 1998 (CFIA 2005) stated among other things that 'all non-manufactured wood used as dunnage, pallets, crating or other packaging materials accompanying cargo from areas except the continental USA must be completely free of bark, visible pests and signs of living pests'.

AQIS interception records show that during the period 1975 to 2003, AQIS intercepted over 5,500 arthropod pests that are likely to be associated with wood packaging material (Table 3). AQIS' survey data also showed that 5.5 % (over 3,800 interceptions) of LCL consignments containing wood packaging material had bark attached (AQIS 1999a), despite Australia's long-standing requirement that wood packaging material be made from bark free wood (AQIS 2005). However, more recent surveys have found 7.7 % of wood had bark attached on ISPM 15 stamped wood packaging material (AQIS unpublished data). Given the early stage of ISPM 15 implementation, Biosecurity Australia has been unable to identify data that shows unequivocally that interceptions on ISPM 15 treated wood packaging are a result of 1) resistance to treatment or 2) post treatment infestation.

The organisms considered in the pest risk assessments are arthropod pests, plant pathogens and stain fungi that are associated with bark and can cause significant damage to tree resources in Australia. It is recognised that organisms that do not use wood as a host may 'hitchhike' on wood packaging material with bark attached.

Wood packaging material distributed with the commodity may be stored outside for some time. Dunnage may be distributed with the commodity if it is containerised or it may be stored for reuse. Damaged wood packaging material may be discarded at any point of the distribution chain. Disposal of the product is not controlled.

4. EFFECTIVENESS OF ISPM 15 TREATMENTS

Wood packing material may originate from anywhere in the world, so there is a large number of potential pest species possibly associated with wood before treatment. The heat treatment and fumigation tolerances of most of these pests will not be known.

The ISPM 15 treatment protocols (heat treatment or methyl bromide fumigation procedures) applied to small dimension sawn wood, and as applied to small diameter round logs are assumed to be effective in killing all invertebrates in the pest groups identified in Table 1 (with the exception noted by IPPC (2002) of some Lyctidae with heat treatment). Unless there is some non-compliance issue, such as forged documentation or inadequate or inappropriate treatment, the ISPM 15 treatments will be effective at eradicating most insect pests. However, Australia has reservations over the lack of guidelines in ISPM 15 for the application of methyl bromide treatments.

USDA has released a final environmental impact statement on the importation of solid wood packing material that supports the adoption of the IPPC (2002) standard, although the document indicates some level of concern over the effectiveness of both the methyl bromide treatment and heat treatment (e.g. USDA 2003, pages 24, 51, 60 and 61). In making comments on an earlier draft of the environmental impact statement on the importation of solid wood packing material, seven United States Government Senators (Leahy *et al.* 2002 in USDA 2003) stated 'Overall, we are concerned that the available technologies to treat wood packaging have not been shown to be effective against the full range of pests. Treating the wood with heat or chemicals will not prevent the wood packaging from being re-infested after treatment. Furthermore, it will be extremely difficult for USDA inspectors to verify that the treatments were done properly. Meanwhile, determining whether the packaging is actually pest-free will remain as difficult as it currently is.

While USDA supports the implementation of the treatments in ISPM 15, a coalition of four States has begun legal proceedings against USDA for failing to impose effective controls against pests that enter the country in solid wood packing material (Spitzer *et al.* 2005). A court order is being requested that directs USDA to examine more effective and less environmentally harmful methods of preventing insects from entering the country (Spitzer *et al.* 2005).

Table 1 Most significant pests targeted by heat treatment and methyl bromide fumigation in ISPM 15

PEST GROUP	
Insects	Anobiidae
	Bostrichidae
	Buprestidae
	Cerambycidae
	Curculionidae
	Isoptera
	Lyctidae (with some exceptions for HT)
	Oedemeridae
	Scolytidae
	Siricidae
Nematodes	*Bursaphelenchus xylophilus*

The International Plant Protection Convention expert working group responsible for developing the ISPM 15 heat treatment protocol was aware that the protocol would not adequately control fungi (Dwinell 2005a). A core temperature of 56ºC for 30 minutes will not kill all fungi (Allen 2001a, Kieran and Allen 2004). If heat treated wood is not dried, it will develop a luxuriant growth of moulds and other fungi. The survival and continued growth in the timber of fungi may make it more attractive to attack by some insects.

Fumigation with methyl bromide

A proposal has been made to increase the minimum exposure time for methyl bromide fumigation for wood packaging material from the current 16 hours to 24 hours to ensure that nematodes, such as *Bursaphelenchus xylophilus*, are killed in wood with moisture contents higher than 30 %. There remain concerns regarding the effectiveness of methyl bromide fumigation when applied to timber with a high moisture content (e.g. ability to diffuse through high density timber, conversion of methyl bromide to hydrobromic acid in the presence of water, etc.), or timber greater than 200 mm in diameter, or timber that may have a combination of these factors. Schmidt (n.d.) notes that little data is available documenting penetration of fumigants into logs (particularly with intact bark).

Table 2 Calculated theoretical dosages attained at the surface of the packing material for existing methyl bromide fumigation schedule and proposed revision to the ISPM 15 fumigation schedule

Temperature (degrees C)	Initial application rate (g/m^3)	Dosage assuming no loss (g.hr/m^3) - based on starting concentration applied over full fumigation period	Minimum dosage (g.hr/m^3) - based on interpolation of minimum concentration at fixed times of ISPM 15 schedule
Existing fumigation schedule with minimum exposure time of 16 hours			
21	48	768	293
16	56	896	347
11	64	1024	388
Proposed revised fumigation schedule with minimum exposure time of 24 hours*			
21	48	1152	699
16	56	1344	808
10	64	1536	922

***Source:** proposed amendment to Annex 1 of ISPM 15.

The proposed changes also include increases in the minimal gas concentrations after 2, 4, 12 and 24 hours. The International Forest Quarantine Research Group (IFQRG) recommended gas circulation at the beginning of the fumigation in order to achieve the increased minimum gas concentrations. IFQRG also noted that other conditions such as tarpaulin fumigation and the size of the air space could affect the treatment and should be taken into account when determining the initial concentrations of methyl bromide used. (Technical Panel on Forest Quarantine 2005.)

Cross (1991) reported that, under fumigation chamber conditions, larvae and adults of *Arhopalus tristis* and *Hylastes ater*, and worker casts of *Kalotermes brouni* were all killed with dosages of 100 mg.h/L [100 g.h/m^3], while the late egg and early larval stage of *Prionoplus reticularis* required up to 150 mg.h/L [150 g.h/m^3]. While Cross (1991) did not specify the temperature of fumigation, these lethal dosages are all well within the dosages achieved at timber surfaces under ISPM 15 (see Table 2).

A note of caution is required when comparing scientific studies dealing with fumigation with the field application of fumigants. Scientific studies typically measure the dosage (product of fumigant concentration over time) and thus obtain a relatively accurate estimation of the amount required to achieve the result attained in the study. With field application of fumigants, the starting concentration is specified but if the concentration is not monitored throughout the fumigation the actual dosage received is not known. Even under proper fumigation practices, some loses can occur from escaping gas or sorption associated with the product being fumigated. Other dosage issues may arise with poor or uneven circulation of the fumigant as well as variability in the capacity of the fumigant to penetrate into the items. When in contact with moist timber, over the exposure time a portion may hydrolyse to methanol and hydrobromic acid. Even with the assumption of monitored dosages ensuring that the minimum specified concentration is achieved at the specified times over the fumigation period, it can be seen that the actual dosage received at the surface is within a large range (Table 2).

Dwinell (2005a) notes that ISMP 15 does not address the mitigation of fungi in wood packaging material. He states that the T402 schedule of the USDA Treatment Manual is efficacious against insects and pine wood nematode, the pests that IPPC largely addressed in the Standard. He also suggests that as a 'broad spectrum fumigant' the T402 schedule may be more efficacious against fungi in general than is heat treatment (56ºC/30 min.). Dwinell does not specify to which of the schedules in T402 he is referring. The two treatments that specify plant products are T402-b-1 and T402-b-2. For T402-b-1, the temperatures that agree most closely with those in the ISPM 15 schedule have methyl bromide dose rates of 4.5 lbs/1,000ft^3 [72 g/m^3] to 9 lbs/1,000ft^3 [144 g/m^3]. For T402-b-2, the temperatures that agree most closely with those in the ISPM 15 schedule have methyl bromide dose rates of 6 lbs/1,000ft^3 [96 g/m^3] to 8 lbs/1,000ft^3 [128 g/m^3]. These doses are higher than specified in the ISPM 15 schedule.

The Australian government has also initiated the development of offshore capacity building programs with the National Plant Protection Organisations of trading partners to reduce methyl bromide treatment failures that are related to poor practices. However, Australia has serious concerns about the effectiveness of methyl bromide as a generic treatment to mitigate the risks of pathogens and decay fungi. This is particularly so for undetectable incipient decays associated with bark, as highlighted by a number of US pest risk assessments (PRAs) on the import of solid wood (Kliejunas *et al.* 2001, Tkacz *et al.* 1998, USDA 1992). These PRAs focus primarily on logs, but many of the same treatment constraints and the risk associated with bark would be expected to apply to solid wood packaging derived from them where bark is present. Export protocols for ISPM 15 also allow for treatment to be applied within the supply chain such as at mills, or on large dimensional timber, rather than on the final product such as a crate or pallet. This may influence the effectiveness of the methyl bromide treatment, owing to the moisture content and the dimension of the timber.

Insects

A study of methyl bromide fumigation penetration into *Pinus radiata* by Cross (1991) found it is not practical to achieve useful insecticidal doses beyond 100 mm in green wood using conventional tent fumigation techniques. This study (Cross 1991) is widely quoted and seems to be the basis for the justification of the requirement that wood destined for methyl bromide fumigation treatments must be <200 mm in one dimension. There does not seem to be any information that shows that green *Pinus radiata* wood is representative for methyl bromide penetration into green timber for all softwood and hardwood species. The findings of

Scheffrahn *et al.* (1992) indicate that diffusion of methyl bromide through wood is not consistent across different softwood species or across different hardwood species.

One important aspect of the Cross (1991) paper is the extent of the change in actual dosage of methyl bromide delivered as wood depth increases, when the wood is green. Thus, in green wood, to achieve 1000 mg.h/L [1000 g.h/m^3] at 60 mm depth, 2000 mg.h/L [2000 g.h/m^3] is required at the surface; at 80 mm depth, 6000 mg.h/L [6000 g.h/m^3] is required at the surface; and, at a depth of 100mm, 10 000 mg.h/L [10 000 g.h/m^3] is required at the surface (Cross 1991). The 10 000 mg.h/L [10 000 g.h/m^3] is equivalent to maintaining 417 g/m^3 at the surface for 24 hours. In contrast, in dry wood only about 1600 mg.h/L [1600 g.h/m^3] was required at the surface to achieve 1000 mg.h/L [1000 g.h/m^3] at 100 mm depth into the wood (Cross 1991). Tunnelling activity by insects may form a path from the surface for the fumigant to penetrate along but the permeability of this pathway is uncertain as in some cases it is packed tightly with frass generated by the insect, such as *Sirex* spp. (Viljoen and Banks 2002)), while other insects may maintain clean galleries.

Cross (1991) makes mention of *Coptocercus* sp. (some species native to Australia) requiring a dose of 1000 mg.h/L [1000 g.h/m^3] (temperature not specified) and email correspondence (2/6/05) between Yonglin Ren CSIRO and AQIS indicates Asian longhorn beetle kill being marginal with 950–1200 mg.h/L [1200 g.h/m^3] at 15°C. Cross (1991) quotes Harris (1963) as finding that late larval and pupal stages of *Sirex noctilio* (present in Australia) require dosages of 650 mg.h/L [650 g.h/m^3] for a reliable kill.

Based on the above there is cause for concern regarding methyl bromide fumigation under the ISPM 15 schedule if a tolerant arthropod species occurs deep in green timber.

Gastropods (molluscs)

For gastropods, a fumigation schedule for the giant African snail, *Achatina fulica*, of 128 g/m^3 for 24 hours at 12.5°C or above has been suggested in the United States, and for *Cochicella*, *Helicella* and *Monacha* spp., 128 g/m^3 for 72 hrs at 12.5°C or above is applicable (Armed Forces Pest Management Board 1990). The Australian treatment for the giant African snail is 128 g/m^3 methyl bromide for 24 hours at 21°C (AQIS ICON database, condition T9054).

The ISPM 15 methyl bromide treatment will not be effective against gastropods.

Nematodes

In a study of mortality of the nematode *Bursaphelenchus xylophilus* in red pine boards (*Pinus densiflora*) at 15°C, Soma *et al.* (2001) reported 0.01 % survival at a dosage of 1174 g.h/m^3 in wood with a 25 % moisture content, and 100 % mortality at 1188 g.h/m^3 in wood of 33 % moisture content. Dosages that will kill most of the nematodes will kill any vectors present in the wood. If the nematodes are to then infect a new host, new vectors must be introduced into the wood and these vectors and remaining nematodes must be able to survive the drying of the wood to complete a generation and move to a new host. Experimental evidence indicates a potential pathway for the spread of the nematode in infested wood chips incorporated into soil mixes that are then planted with susceptible hosts with roots damaged during transplanting (Halik and Bergdahl 1992).

There are no data for other pathogenic species of *Bursaphelenchus* (e.g. *Bursaphelenchus hunanensis*). Although the incursion of *Bursaphelenchus hunnanensis* in Melbourne, Australia has now been eradicated, we know of no records of the successful eradication of

Bursaphelenchus xylophilus. An official eradication program for *Bursaphelenchus xylophilus* was launched in Portugal in 1997 and still continues.

Fungi

Many of the pathogens and decay fungi of quarantine concern to Australia are primarily associated with bark, and can be transported with bark on solid wood (Kliejunas *et al.* 2001, Tkacz *et al.* 1998, USDA 1992). *Fusarium circinatum* and *Phytophthora ramorum* can have a direct association with bark (Cree 2002, Owen and Adams 1999), as do ophiostomatoid fungi (Hansen and Lewis 1997). Because of its very nature and where sourced from, wood packaging material with bark can be expected to contain fungal mycelia and spores. *Ophiostoma* species may survive in wood for more than a year with favourable temperature and moisture conditions, and they may even thrive under conditions that prevail during transport of wood packaging material (USDA 2000).

The treatment measures, especially methyl bromide fumigation, have not been proved effective against pathogens (Federal Register 2004). Many pathogens and decay fungi, including species of *Armillaria*, *Ceratocystis*, *Heterobasidion*, *Lachnellulla*, *Leptographium* and *Ophiostoma*, can be controlled by methyl bromide fumigation, but only where the dosage rates ensure chemical time factors that exceed 6000 mg.h/L or, for *Ceratocystis* species, methyl bromide fumigation at 240 mg·L for 3 days at 3 degrees Celsius or above (Viljoen and Banks 2002). For other representative pathogen species of quarantine concern to Australia, such as *Phytophthora ramorum*, there is little or no information on methyl bromide fumigation effectiveness (Burgess 2005).

Schedules T312-a and T312-b of the USDA Treatment Manual prescribes a methyl bromide fumigation dose of 15lbs/1,000 ft^3 [240 g/m^3] for 72 hours at 40ºC or above for oak logs, and 15lbs/1,000 ft^3 [240 g/m^3] for 48 hours at 40ºC or above for oak lumber against oak wilt caused by *Ceratocystis fagacearum*. The EU Commission Decision 93/467/EEC states that logs shall undergo fumigation with pure methyl bromide which is carried out at a minimum rate of 240 g/m^3 of total volume under cover for 72 hours and at an initial temperature of the logs of +5°C at least. The oak wilt fungus is generally confined to a zone near the wood surface, where it is more likely to come in contact with the fumigant (Morrell 1995).

A number of potential pathogens found in logs are deeper in the wood, and some fungi appear to produce survival structures that can resist methyl bromide treatment (Stasz and Martin 1988, in Morrell 1995). Removing bark, which provides a significant barrier to diffusion, might enhance fumigant movement to some extent, but this would probably not be effective in a large log (Morrell 1995). This is of significance, considering that export protocols for ISPM 15 allow for treatment to be applied within the supply chain such as at mills, or on large dimensional timber, rather than on the final product such as a crate or pallet.

Fumigation appears to be most effective against fungi within 5 cm of the wood surface. Times required for fumigation of wood can generally be predicted through determination of lethal dosages, wood moisture content and diffusion co-efficients for the species of timber being treated (Siau 1984, in Morrell 1995). Wood moisture content begins to restrict diffusion at higher values because of physical limitation on available void space for fumigant movement (Siau 1984, Smith 1968, both in Morrell 1995). With the exception of studies of methyl bromide treatment of oak and radiata pine, few data are available that show the relationship between fumigant and species of wood (Morrell 1995).

Heat treatment

Insects

Allen (2001a) cites work by Snyder (1923) indicating, that for eradication, some *Lyctus* species require treatment for 30 minutes at 82°C. More recent data for *Lyctus brunneus* (present in Australia) showed no survival when timber was heated from 24.5°C to 50°C in a time of 2.5 hours (Ertelt 1994). Becker and Loebe (1961, in Ertelt 1994) found larvae of *Lyctus brunneus* did not survive for longer than 30 minutes at 50°C. In tea chest panels containing *Xyleborus parvulus*, *Xyleborus elegans*, *Heterobostrychus aequalis* and *Minthea rugicollis*, Das and Gope (1985) reported that there was 90 % mortality when treated at 83°C for 20 minutes, up from 71 % mortality when treated for 10 minutes, while at 93°C all were dead by 10 minutes. Temperature thresholds for the European house borer (*Hylotrupes bajulus*) were also examined by Ertelt (1994), who found no survival when timber was heated from 24.5°C to 55°C in a time of 3 hours. Larvae of *Hylotrupes bajulus* tested by Becker and Loebe (1961, in Ertelt 1994, fig. 13) at 30 % relative humidity survived for as long as 300 minutes at 50°C but did not survive for longer than 50 minutes at 60°C. Dwinell (2001) reported the lethal temperature for pine wood nematode in wood chips to be 46°C. In lumber, the eggs and larvae of the vectors (*Monochamus* spp.) of the pine wilt nematode have a high mortality rate at 38°C, while pupae are slightly more tolerant, with complete mortality at 40ºC. *Monochamus* larvae in spruce, pine, and fir lumber are killed once the core wood temperature reaches 50ºC. In another study, Dwinell (2002) reported pine wood nematodes and their insect vectors were killed by temperatures of 60°C for 30 minutes.

The ISPM 15 heat treatment does not make any adjustments for humidity, which can impact on the effectiveness of the treatment. Timber that was 25 mm thick, infested by *Lyctus* and treated at 52°C core temperature required twice as long to achieve a total kill at 60 % relative humidity (4 hours) than at 80 % relative humidity (2 hours) (the original moisture content of the timber was not recorded) (Parkin 1937).

Given the large number of potential pests for which there is little information concerning temperature tolerances, it is possible that some others may exhibit similar tolerances to exposure to high temperatures. For the majority of insect species, the ISPM 15 treatment should be adequate as long as the specified temperature is achieved for the required duration (based on data in Denlinger and Yocum 1998, Strang 1992). It appears that while very high temperatures achieve quick kills, lower temperatures such as ISPM 15 treatments over a longer duration are also effective. For pests such as *Lyctus* spp. and *Hylotrupes bajulus*, the ISPM temperature and duration may be marginal for a complete kill of all life cycle stages. However, it is possible that for such borderline taxa the larger the diameter of the wood the greater the chance of a kill, because larger diameter timber will take longer to reach the core temperature and longer to cool down (Ebeling 1994). It is also reasonable to suggest that for a core temperature of 56°C for 30 minutes to be achieved in the quickest time, the surface temperature will be held well above 56°C for longer than 30 minutes (based on data in Ebeling 1994).

Fungi

Allen (2001a) stated that heat treatment of 56°C for a minimum of 30 minutes, as adopted in ISPM 15, will not eliminate 1) some stain fungi; 2) many decay fungi; or 3) most thermophilic fungi. Dwinell (2001) noted that in wood, the lethal temperature for insects is below those found for the pine wood nematode and many wood-inhabiting fungi. Dwinell (2001) also recorded that there is some indication that sapwood fungi colonizing Douglas fir (*Pseudotsuga* *menziesii*) logs are more sensitive to elevated temperature than heartwood colonizing fungi. Heating air-dried Douglas fir logs to 65.6ºC for at least 75 minutes during treatment eliminates any decay fungi in the wood. This indicates that the time-temperature schedule that achieves wood core temperature of 56°C for a minimum of 30 minutes would only arrest the development of some fungi of quarantine concern to Australia.

There is no evidence that ISPM 15 heat treatment will control, for example, species of *Ophiostoma* or *Ceratocystis*. An example of such a species is *Ceratocystis fagacearum* (oak wilt), which is found in chestnuts (*Castanea* spp.), oak (*Quercus* spp.) and *Malus* spp. (CFIA 2002). Kappenburg (1998, in Burgess 2005) reported a lethal temperature for *Ceratocystis fagacearum* of 68°C at high humidity. It is also reported that chlamydospores of *Phytophthora ramorum* when embedded in bay leaves will survive for a week with a constant temperature of 55°C; this fungal propagule is a potential means of long-distance spread of *Phytophthora ramorum*.

The minimum moisture content widely reported as necessary for sapstain fungal growth in wood is 20 %, a value that is exceeded in green timber. If the relative humidity is 100 %, most staining fungi will stop growing at 40–50°C. At 10–20 % relative humidity, temperatures of up to 130°C are required before some species are killed. Some *Ophiostoma* species can withstand one hour at 200ºC. (Seifert 1993.)

Newbill and Morrell (1991, in Ridley and Gardner 2004) demonstrated that sapwood fungi (*Stereum sanguinolentum* and *Peniophora* sp.) and heartwood fungi (*Postia placenta* and *Antrodia carbonica*) that colonised poles of *Pseudotsuga menziesii* were killed by exposure to 65.6°C for 75 minutes. Kurpik (1976, in Ridley and Gardner 2004) found that a 150 minutes treatment was lethal at 60°C for *Coniophora cerebella* and 70°C for *Lenzites sepiaria* and that treatments worked more quickly on young mycelia in a dry atmosphere. Chidester (1937, 1939 in Morrell 1995) demonstrated that a minimum temperature of 67°C for 75 minutes was required to eliminate most wood inhabiting fungi from southern pine. Studies on fungi colonising other species have produced similar results (Miric and Willeitner 1984, Morrill and Newbill 1991, both in Morrell 1995).

Fungi capable of surviving exposure to high temperatures typically have some type of resistant survival structure, such as chlamydospores. APHIS recognised the risks associated with the lower temperature requirement and instead recommended that wood be treated to 71.1°C for 75 minutes (USDA 1995, in Morrell 1995). This treatment was not established with sawn wood packaging material in mind, but rather as a universal treatment option that would be certain to eliminate pests in all wood materials regardless of their risk level (Federal Register 2004). These universal options are relatively stringent because they must eliminate the spectrum of potential plant pests and address risks that have not been characterised (Federal Register 2004). In most cases where imported products require treatment the infesting fungi will be unknown, tentatively identified or even misidentified, and likely to be in an unknown physiological state; in such cases a broad approach to treatment is recommended (Ridley 2004).

Chlamydospore-forming root pathogens, such as *Phellinus weirii*, can survive elevated temperature exposures and become serious pests if they become established in an ecosystem where tree species have not evolved resistance to this pathogen (Morrell 1995). Species of *Phellinus* were isolated in a Sydney port survey commissioned by AQIS (Simpson 1999). ISPM 15 does not include manipulation of time-temperature relationships to minimise potential effects of heat treatment on wood properties while maximising control of colonising organisms. A major limitation to adopting such an approach is the lack of data on the time-temperature relationships for controlling many wood-inhabiting organisms (Morrell 1995).

5. COMPLIANCE ISSUES

An ISPM 15 treatment may fail or untreated wood packaging material may be marked as treated. Under such circumstances, some pests associated with the material in nature may remain after milling, assembly and transport. Dwinell (2005a) notes that 'Internationally, where the application of ISMP 15 is often self-regulated by the exporter, there may be some problems and a need for greater government oversight'.

Some forest pests attack recently felled wood and some of these will survive processing and the manufacture of solid wood packaging for shipping containers (e.g. some Scolytid, cerambycid and buprestid beetles). The presence of bark on the wood packing material provides a greater range of habitats that could support a greater number of pest species than would similar bark free wood. Other timber pests infest seasoned wood and may survive the packaging manufacturing process (e.g. termites and powderpost beetles). In all these cases, the presence of bark on the wood is likely to impede effective quarantine inspection.

In most instances, the interceptions for containerised cargo listed in Table 3 were made on solid wood packaging material that should have been subject to methyl bromide fumigation at the rate of 48 grams per cubic metre for 24 hours (with dosage compensations for temperature) within 21 days of containerisation. ISPM 15 does not prescribe a maximum time period between treatment and shipping, and re-treatment is not required in the case of solid wood packaging that is being re-used without repair. A non-compliance rate of approximately 3–6 % on wood packaging material was common because of the presence of actionable bark (Salvage 1999) but AQIS has found 7.7 % of ISPM 15 stamped wood packaging material with bark attached (AQIS unpublished data). Similar rates have been identified for New Zealand imports where bark is also subject to regulation (Glassey 1999). Actionable bark is bark that is not associated with knots and that can not be found to be free of pests on the basis of inspection.

Another example of the potential role of bark in effecting treatment efficacy is provided by a review conducted by Morrell (1995). This review suggested that the presence of bark in large amounts would impede the absorption of methyl bromide into the wood due to its relationship with moisture content. This may explain differences in effectiveness of methyl bromide fumigation on pine wood nematode highlighted by recent Korean, Chinese and Japanese research, the results of which were presented at the inaugural International Forestry Quarantine Research Group (IFQRG) meeting in February 2004 (AQSIQ and NPQS 2003, MAFF 2003) and have led to proposed changes to the methyl bromide treatment schedule discussed at IFQRG in February 2005 and proposed to the 7th meeting of the Interim Commission on Phytosanitary Measures (ICPM) in April 2005.

Joint Korean and Chinese government experimentation demonstrated that fumigation was ineffective in killing pine wood nematode at higher moisture contents of 32–40 % (in both a fumigation chamber and under tarpaulins) at a fumigation rate of 48 grams per cubic metre for 16 hours on similar density timber (AQSIQ and NPQS 2003). In all replicates, high numbers of pine wood nematodes survived. These findings are of concern given that solid wood packaging material can be made from fresh sawn timber with high moisture content.

Japanese experimental research has demonstrated that at low moisture contents and with minimal bark, methyl bromide fumigation can kill pine wood nematodes in timber of species of *Pinus* at the rate of 48 grams per cubic metre for 24 hours (MAFF 2003, Soma *et al.* 2001, Soma *et al.* 2002, Soma *et al.* 2003). In some replications at 10°C, there was some survival of pine wood nematode under a dosage of 60 grams per cubic metre for 24 hours (Soma *et al.* 2001). The experiments conducted also demonstrated differences in effectiveness between warehouse and tarpaulin fumigation. This difference in efficacy, depending on how the treatment is applied, is not recognised in ISPM 15 (MAFF 2003).

Apart from the fumigation rate, exposure times and moisture content, the only other difference between Japanese and joint Chinese and Korean government research was that the wood used by the Chinese and Korean researchers had bark on it, although the amount present was not stated (AQSIQ and NPQS 2003). Reviews by Morrell (1995) and Viljoen and Banks (2002) demonstrate that moisture content and bark on wood following harvesting are related and impact upon methyl bromide uptake. There are also considerable differences between methyl bromide fumigation penetration in hardwood and softwood timbers (Ren *et al.* 1997, in Viljoen and Banks 2002). These differences, as well as the differences in gas penetration in green and dry timber, are not addressed by ISPM 15, which treats all wood as similar and makes no allowance for operational effects.

Table 3 illustrates the nature of the risk under management and transport practices before the implementation of ISPM 15 and the taxa that could be expected to arrive associated with wood packaging material in cases of treatment failure or non-compliance. This table summarises the interceptions during port-of-entry inspections by AQIS of selected exotic pests that entered Australia with wood packaging materials. During the years 1975 to 2003, AQIS intercepted over 5,500 exotic insects, some of which are likely to be associated with bark. These selected interception records consist of 1,333 Bostrichidae (false powder-post beetles), 162 Buprestidae (metallic wood boring beetles), 1,777 Cerambycidae (longhorn beetles), 2,109 Scolytidae (bark beetles), 147 Silvanidae (flat bark beetles) and 64 Siricidae (wood wasps).

Table 3 Interception records of exotic pests associated with wood packaging material (1975–2003)

Arthropod pests	Common name	Number of interceptions
BOSTRICHIDAE		
Heterobostrychus aequalis (Waterhouse) [Coleoptera: Bostrichidae]	Kapok borer	945
Sinoxylon conigerum Gerstaecker [Coleoptera: Bostrichidae]	Conifer auger beetle	388
BUPRESTIDAE		
Buprestidae spp. [Coleoptera: Buprestidae]		161
***Melanophila* sp.** [Coleoptera: Buprestidae]	Flatheaded borer	1
CERAMBYCIDAE		
Anoplophora glabripennis Motschulsky [Coleoptera: Cerambycidae]	Asian longhorned beetle	1
***Arhopalus* sp.** [Coleoptera: Cerambycidae]		5
Arhopalus productus LeConte [Coleoptera: Cerambycidae]	New house borer	7
Arhopalus rusticus Linnaeus [Coleoptera: Cerambycidae]	Rusty longhorn beetle	8

Arthropod pests	Common name	Number of interceptions
Arhopalus tristis Fabricius [Coleoptera: Cerambycidae]		57
Asemum striatum Linnaeus [Coleoptera: Cerambycidae]	Black spruce borer	7
***Asemum* sp.** [Coleoptera: Cerambycidae]		1
Batocera lineolate Chev. [Coleoptera: Cerambycidae]	Longhorn beetle	1
***Callidium* sp.** [Coleoptera: Cerambycidae]		2
Callidium violaceum Linnaeus [Coleoptera: Cerambycidae]	Longhorn beetle	2
Callidiellum rufipenne Motschulsky [Coleoptera: Cerambycidae]	Japanese cedar longhorn beetle	11
***Celosterna* sp** [Coleoptera: Cerambycidae]	Longhorn beetle	1
***Cerambycidae* spp.** [Coleoptera: Cerambycidae]	Longhorn beetle	1600
***Cerambycinae* spp.** [Coleoptera: Cerambycidae]	Longhorn beetle	11
***Cerosterna* sp.** [Coleoptera: Cerambycidae]		2
Cordylomera spinicornis Fabricius [Coleoptera: Cerambycidae]	Longhorn beetle	1
Ergates spiculatus Lec [Coleoptera: Cerambycidae]	Ponderous borer	2
***Hylotrupes* sp.** [Coleoptera: Cerambycidae]		2
Leptura obliterata Haldeman [Coleoptera: Cerambycidae]		4
Lepturinae sp. [Coleoptera: Cerambycidae]		8
Megasemum asperum LeConte [Coleoptera: Cerambycidae]		2
Molorchus minor Linnaeus [Coleoptera: Cerambycidae]	Longhorn beetle	1
Monochamus alternatus Hope [Coleoptera: Cerambycidae]	Pine sawyer	4
Monochamus impluviatus Motschulsky [Coleoptera: Cerambycidae]	Sawyer beetle	1
Monochamus scutellatus (Say) [Coleoptera: Cerambycidae]	White spotted sawyer beetle	1
Monochamus sutor Linnaeus [Coleoptera: Cerambycidae]	Small white-marmorated longicorn	1
Neoclytus acuminatus Fabricius [Coleoptera: Cerambycidae]	Redheaded ash borer	1
***Phoracantha* sp.** [Coleoptera: Cerambycidae]	Longicorn beetle	3
Plagionotus arcuatus Linnaeus [Coleoptera: Cerambycidae]	Longihorn beetle	3
Prionoplus reticularis White [Coleoptera: Cerambycidae]		4
***Rhagium* inquisitor** Linnaeus [Coleoptera: Cerambycidae	Ribbed pine borer	1
***Rhagium* sp.** [Coleoptera: Cerambycidae]		3
Stromatium longicorne (Newman) [Coleoptera: Cerambycidae]	Tropical longicorn	3
***Stromatium* sp.** [Coleoptera: Cerambycidae]		6

Arthropod pests	Common name	Number of interceptions
Tetropium fuscum Fabricius [Coleoptera: Cerambycidae]	Brown spruce longhorn beetle	1
Xylotrechus stebbingi Gahan [Coleoptera: Cerambycidae]		2
***Xylotrechus* sp.** [Coleoptera: Cerambycidae]		6
Xystrocera festiva Thomson [Coleoptera: Cerambycidae]	Albizzia borer	1
SCOLYTIDAE		
***Scolytidae* spp.** [Coleoptera: Scolytidae]	Bark beetles, ambrosia beetle	428
Dendroctonus pseudotsugae Hopkins [Coleoptera: Scolytidae]	Douglas-fir beetle	1
***Gnathotrichus* sp.** [Coleoptera: Scolytidae]	Ambrosia beetle	634
Gnathotrichus retusus (LeConte) [Coleoptera: Scolytidae]	Western pine wood stainer	472
Gnathotrichus sulcatus (LeConte) [Coleoptera: Scolytidae]	Western hemlock wood stainer	304
***Hypothenemus* sp.** [Coleoptera: Scolytidae]		2
Hylurgus ligniperda Fabricius [Coleoptera: Scolytidae]	Bark beetle	13
Hylurgops reticulatus Wood [Coleoptera: Scolytidae]	Bark beetle	17
Hylurgus ligniperda Fabricius [Coleoptera: Scolytidae]	Bark beetle	13
***Ips* sp.** [Coleoptera: Scolytidae]	Bark beetle	8
Orthotomicus angulatus Eichhoff [Coleoptera: Scolytidae]		1
***Phloeosinus* sp.** [Coleoptera: Scolytidae]	Bark beetle	1
Pityogenes chalcographus Linnaeus [Coleoptera: Scolytidae]	Six-dentated bark beetle	1
Pseudohylesinus nebulosus LeConte [Coleoptera: Scolytidae]	Bark beetle	8
***Scolytus* sp.** [Coleoptera: Scolytidae]		3
Trypodendron lineatum (Olivier) [Coleoptera: Scolytidae]	Striped ambrosia beetle	43
***Xyleborinus* sp.** [Coleoptera: Scolytidae]	Ambrosia beetle	2
Xyleborus cordatus Eichhoff [Coleoptera: Scolytidae]	Ambrosia beetle	1
Xyleborus ferrugineus Fabricius[Coleoptera: Scolytidae]		1
Xyleborus saxesenii (Ratzeburg) [Coleoptera: Scolytidae]	Ambrosia beetle	61
Xyleborus solidus [Coleoptera: Scolytidae]		2
Xyleborus celsus [Coleoptera: Scolytidae]		2
***Xyleborus* sp.** [Coleoptera: Scolytidae]	Ambrosia beetle	91
SILVANIDAE		
Silvanus bidentatus Fabricius [Coleoptera: Silvanidae]	Flat bark beetle	147

Arthropod pests	Common name	Number of interceptions
SIRICIDAE		
Sirex cyaneus Fabricius [Hymenoptera: Siricidae]	Blue horntail	7
Sirex juvencus (Linnaeus) [Hymenoptera: Siricidae]	Horntail	23
Sirex noctilio Fabricius [Hymenoptera: Siricidae]	Sirex woodwasp	17
***Sirex* sp.** [Hymenoptera: Siricidae]	Woodwasp	6
Urocerus augur (Fabricius) [Hymenoptera: Siricidae]		1
Urocerus albicornis (Klug) [Hymenoptera: Siricidae]	White-horned horntail	1
Urocerus gigas *sens lat*. [Hymenoptera: Siricidae]	Woodwasp	7
***Urocerus* sp**. [Hymenoptera: Siricidae]		1
Xeris spectrum (Linnaeus) [Hymenoptera: Siricidae]	Horntail	1
TOTAL		**5593**

Little information is available on pathogen and decay fungi interceptions on wood products (including wood packaging materials) in Australia. AQIS had previously considered that management of insects was sufficient to prevent the entry of fungi. AQIS has now acknowledged that fungi could indeed be transported on wood products without vectors. In 1998, AQIS commissioned a study on fungi on green sawn timber imported into Australia through the port of Sydney, before the publication of ISPM 15 in 2002. The study (Simpson 1999) identified several fungi on wood products, including bark, imported into Australia. These fungi included *Botryobasidium* sp., *Chalara* anamorph of *Ceratocystis douglasii*, *Chrysonilia sitophila*, *Gonatobotryum fuscam*, *Hormonema dematioides* (teleomorph: *Sydowia polyspora*), *Lecythophora hofmannii* (synonym: *Phialophora hofmannii*), *Leptographium abietinum*, *Leptographium terebrantis*, *Leptographium* spp., *Ophiostoma europhioides*, *Ophiostoma piceaperdum*, *Ophiostoma piceae*, *Ophiostoma piliferum*, *Ophiostoma pseudotsugae*, *Ophiostoma* sp., *Penicillium* sp., *Pesotum piceae* (teleomorph: *Ophiostoma piceae*), *Pesotum* spp., *Phellinus* spp., *Postia sericeomollis*, *Rhinocladiella atrovirens*, unidentified sapstain fungi, *Schizophyllum commune*, *Spiniger meineckellum* (teleomorph: *Heterobasidion annosum*), *Sporothrix* spp., unidentified white and brown rot fungi, *Thelephora terrestris*, *Trichoderma* sp., an unidentified ascomycete and unidentified basidiomycete species.

6. THE PROPERTIES OF TIMBER IN WOOD PACKAGING MATERIAL

Across the spectrum of global trade, it is likely that the wood from many species of trees will be used in packing material and that some of this material will be unseasoned green wood or wood with minimal seasoning time. Once a living tree is felled, the wood begins to season, it starts to loose moisture and chemical changes begin to occur. In the natural environment, tree-fall events can occur on a massive scale through the action of high wind speeds. Such recently fallen timber is reported to be very attractive to a range of insects, particularly bark beetles (e.g. Aukema *et al.* 2004, Hammond *et al.* 2001). Insect attack then continues throughout the natural breakdown and decomposition process. In some instances, the recently fallen timber serves to harbour insect populations that can also attack standing living trees (Paine *et al.* 1997).

In living trees, sapwood is less susceptible to decay than heartwood, as sapwood is capable of an active response to invasion whereas heartwood is dead and has no active resistance. In dead trees, the sapwood suddenly becomes very prone to attack by decay fungi (Worrall 2005a). Packaging timber with bark may have non-durable sapwood that is very prone to decay and attack by bark beetles. However, chemicals are deposited in heartwood as it forms by dying parenchyma and this renders it more or less inhospitable to fungi (Worrall 2005a). Species vary greatly in heartwood resistance with redwood and cedars being very highly resistant, while aspen and birch have a very low resistance (Worrall 2005a). Nevertheless, every species of tree has at least a few fungi that can grow in its heartwood and cause heart rot (Worrall 2005a).

Solid wood packing material in the form of dunnage, particularly if it retains bark, may resemble recently fallen timber from an insect's perspective. Parameters such as physical shape, surface characteristics, density and chemical makeup of new dunnage material may remain similar to freshly fallen timber. In comparison, wood that has been sawn into small dimension sections and used in pallet construction presents the insects with a resource that has a poor physical resemblance to material in the natural environment. Even with bark on one surface, the remaining sawn wood surfaces present material of a different surface texture and a pathway for rapid loss of volatile chemicals and moisture, thereby making the sawn wood less attractive to insects. Wooden crates form yet another major type of solid wood packing material entering Australia. Crates fall somewhere between dunnage and pallets in the size and nature of the wood used in their manufacture. Crates holding large heavy items require large solid sections of sawn wood, particularly in their frames, and such wood may at times be little more than small round wood log sections that have been squared off to produce two flat sides, with the potential for the non-sawn sides to retain some bark. The wood taken off in the squaring process may then be further trimmed to produce the slats that make the sides of the crate and these may also have some surface bark.

There are two main oviposition strategies employed by insects infesting green wood which would also apply to newly made packaging material. Firstly, they remain on the surface and deposit eggs onto the surface, into cracks and crevices in the bark, into niches chewed in the bark, or through drills into the phloem, cambium, or sapwood. The other approach is where the insect tunnels into the host and forms simple to extensive galleries, often in the phloem or cambium, and also in sapwood in which eggs are laid. Significant changes influencing the chance and success of oviposition are likely to be associated with moisture and chemical changes associated with the wood as it seasons.

Moisture content

While the specific nature and rate of the changes occurring during the seasoning process are going to be species specific and dependent on the ambient environmental conditions the wood has been exposed to, the most obvious change over time will be to the moisture content of the wood. In a list containing 75 tree species growing in the United States, the average green heartwood wood moisture content ranged between 30 % for *Pinus elliottii* and *Pseudotsuga menziesii* to 162 % for *Populus trichocarpa* (USDA 1999). The same study reported that green sapwood moisture content ranged from 51 % for *Carya* spp. to 249 % for *Thuja plicata*. Depending on the tree species, the green wood moisture content of the sapwood and heartwood may be similar, e.g. 72 and 74 % respectively for *Betula alleghaniensis* (yellow birch), or it may be vastly different, e.g. 240 and 32 % respectively for *Thuja occidentalis* (northern white cedar) (USDA 1999). The moisture content of freshly cut timber can vary with the species and the portion of the log from which it is cut (Hutcheon and Jenkins 1967). While there will be many species that will undergo major changes in moisture content and mass while seasoning, there will be some for which such changes will be much smaller.

Softwoods and some low density hardwoods will dry more rapidly under favourable conditions than will heavier hardwoods. Generally wood of high specific gravity is slower to dry than low density woods (USDA 1999). The thickness of the timber influences drying time, with wood that is 50 mm thick requiring about three times as long to dry as wood that is 25 mm thick (USDA 1999). Wood that retains most or all of its bark also retains more moisture than sawn timber. Stone and Simpson (1987) demonstrated that moisture loss through bark was negligible when compared with loss through billet ends, in an experiment using *Pinus elliottii* billets of 70 cm length and 14–18 cm diameter. Green wood will start to loose moisture as soon as it is cut if the surrounding air is at less than 100 % relative humidity (Hutcheon and Jenkins 1967). Drying will be faster when ambient conditions comprise high temperatures and low relative humidity, as drying proceeds through evaporation from the exposed surfaces. Eventually, the point reached will be at which all the water contained in the wood is held in the fine structure of the cell walls (Hutcheon and Jenkins 1967). This condition, which is referred to as the fibre saturation point, is commonly reached at a moisture content of around 25–30 % (Hutcheon and Jenkins 1967). In drying down to this point, green wood undergoes relatively little change in physical properties save for a reduction in mass and very little if any shrinkage (Hutcheon and Jenkins 1967). When changes in moisture content beyond the fibre saturation point begin to occur, wood begins to shrink (Hutcheon and Jenkins 1967). Changes to moisture content of wood beyond the fibre saturation point will continue during the seasoning process until an equilibrium is reached with the moisture content of the surrounding environment (Cutter 1994). Hutcheon and Jenkins (1967) present a figure showing a generalised relationship for 'common woods' where, for example with a relative humidity of 50 %, the equilibrium moisture content is about 9 %. The equilibrium moisture content across 49 United States cities is reported by USDA (1999) to be as low as 4 % in Los Vegas during June to as high as 18.1 % in Juneau in September and December. Wood that is dried to below 20 % is typically not susceptible to decay or sap staining (Pastoret 1993) or to attack by bark beetles and, accordingly, would not support ongoing fungal growth that many wood and bark boring insects rely on for nutrition. Furthermore, the strength characteristics of wood may increase by 50 % or more during the process of drying to 15 % moisture content (Pastoret 1993).

In the data presented by USDA (1999), the time taken for sawn timber to dry to a particular moisture content varies as a function of species, location and time of year. For example, 25 mm *Pinus ponderosa* timber in Flagstaff, Arizona dries to 15 % moisture content in seven days when stacked in June and 94 days when stacked in October, while in Everett, Washington, 25 mm *Pseudotsuga menziesii* dries to 20 % moisture content in 18 days when stacked in August and 206 days when stacked in September (USDA 1999).

There is also some evidence for differences in the moisture content of bark (phloem) tissue between summer and winter months. The moisture content of *Pinus resinosa* phloem was recorded to be 10.2 % in July, around 8 % from August to November and 6.8 % by January (Redmer *et al*. 2001). On 16 cm diameter *Pinus resinosa* logs, the moisture content of phloem was reduced by 20 % after storage for 37–97 days; by 27 % after storage for 127 days, by 37 % after storage for 157 days, and by 50 % after storage for 183 days (Redmer *et al*. 2001).

Changes in moisture content and the capacity of wood with bark remaining to attract insects and enable a new generation to be produced

Based on the factors that influence moisture content described above, the differences that cut green wood presents as a food and habitat resource for insects may be very minor (for intact log sections covered in bark from trees that naturally have low moisture content wood) to substantial (for lengths of small dimension wood without bark from trees that naturally have high moisture content wood). Whether this material can be used by insects that typically attack standing or fallen timber in nature will in part depend on the factors that control insect choice in oviposition and, for some, gallery excavation, and in part will also depend on whether wood that is drying will retain enough moisture to support larval growth through to maturity. Moisture content is a limiting factor in the growth of the ambrosia fungi, which in turn influences the survival of the beetles feeding on the fungus. Once moisture content falls to <40 %, sawn timber ceases to be attractive to ambrosia beetles (Rudinsky 1962). Novák (1960, in Rudinsky 1962) showed that larval development of the ambrosia beetle *Trypodendron lineatum* was not adversely affected between moisture contents of 63–144 %. However, once moisture content was <53 %, the adult beetles that maintain the galleries left.

It seems possible that for many insects with long larval periods, enhanced moisture loss rates for sawn wood will severely reduce or eliminate chances of successful breeding. *Prionoplus reticularis* White, for example, will lay eggs under loose bark, in exit holes of insects between boards, and beneath the fillet line in sawn timber (Hosking 1978). However, establishment of newly hatched larvae depends on moist conditions. The larval period extends over at least two to three years and later larval stages can only continue development in seasoned timber where the moisture content remains above the fibre saturation point of 25 % (Hosking 1978). Moisture contents below 25 % eventually result in larval mortality (Morgan 1961). Thus, while *Prionoplus reticularis* may attack wood subsequent to an ISPM 15 treatment being applied, the infestation is unlikely to proceed through to production of new adults, because only some of the larger pieces of dunnage could perhaps retain enough moisture.

In a laboratory experiment with 0.5 m long sections of 20 year old *Picea abies* logs approximately 100–120 mm in diameter, Schröder (2005) investigated the colonisation of the logs by the bark beetle *Pityogenes chalcographus* after treatment with heat according to ISPM 15. There were 10 replications of each treatment. The log sections were either debarked, left with two opposing sides retaining bark, or remained fully covered with bark, with moisture content for each log type falling by 16, 15 and 12 % respectively after heat treatment. One week later the moisture content had fallen a further 8 – 16 %, with the debarked wood now at 39 % and the other logs at approximately 52 % moisture content. At this time, the wood was exposed to the beetles. All logs were colonised but no insects emerged from the debarked logs. The beetles did not go on to produce a new generation in four of the logs that had half of the bark removed and an average 19 beetles emerged per log from the remaining six logs, with all emergence ceasing within 2.5 months. Only one log that retained all bark failed to produce any beetles, and the remaining logs averaged 340 emergences, which ceased to occur after 5.5 months (Schröder 2005). Six months after cutting, the moisture content for all logs was between 11 and 13 % (Schröder 2005). While caution is required when extrapolating beyond single species (plant and beetle) experiments such as described above, it seems likely that the lower retained moisture content by the debarked wood contributed to the breeding failure in this substratum, and may have also contributed to the timing of the cessation of emergence from the half barked logs. Importantly, Schröder's (2005) work demonstrates the importance of bark retention to beetle breeding success following an ISPM 15 treatment.

Shrinkage effects and potential attractiveness of wood with bark remaining to insect infestation

As a consequence of drying beyond the fibre saturation point during in-service seasoning, different rates of shrinkage may apply to the bark layers as may apply to the sapwood. If so, then several scenarios may occur. If the bark shrinks more than the wood, then the bark may form an even tighter clasping seal around the wood or may shrink so much as to develop splits and crevices in which contaminating pests (hitchhikers) may hide. If the wood shrinks more than the bark, then a space between the surfaces of the bark and wood will form and provide places for contaminating pests to hide. Any crevices in the bark or gaps between the bark and wood may provide semi-stable micro-environments. Under any humid conditions of storage or transport, surface growing fungal colonies may develop and attract fungus feeding invertebrates such as the flat bark beetle *Silvanus bidentatus*, which is often intercepted on wood imported into Australia. The fungal feeders present a concern in that firstly, they may act as vectors of fungi either by spores adhering to the exoskeleton or passing intact through the gut, and secondly, since these may be generalist fungal feeders there is a possibility they may replace some native species occupying the same functional feeding group.

Chemical signature of timber/wood and insect attraction

Some insects locate their host plant by a random search process with indiscriminate landing occurring on both host and non-host (Wood 1982a), while others are initially attracted to chemicals released from the host. For some, this is then followed by a testing of the wood to determine its suitability as a host. Those first insects to arrive may then release pheromones to attract further insects (Haack and Slansky 1987). Insects that find host material via a random search approach are not likely to be influenced by seasoning of the wood or by a previous ISPM 15 certified treatment, although simply locating host material does not imply that the host is suitable for colonisation. Raffa and Berryman (1980, in Haack and Slansky 1987) reported that *Scolytus ventralis* individuals colonise about 4 % of the trees they attack, and *Dendroctonus ponderosae* individuals colonise about 66 %.

Some insects have been reported to be attracted to cut logs almost immediately on felling, with this response thought to arise because of the insects' attraction to volatile chemicals emitted by the fresh cut wood (Wood 1982a). Fresh cut hickory, oak and pine logs that retained bark and were subjected to an ISPM 15 heat treatment within two weeks of being cut were found to be more attractive to ambrosia beetles and bark beetles than untreated logs (Haack *et al.* n.d.). Freshly cut wood, while not found in nature, probably most closely resembles trees or tree tops blown down in storms, and damage to the trees leads to wounds that can produce an oleoresin that releases volatile monoterpenes attractive to some bark beetles (Byers 1989). Other insects, such as sapwood feeders and secondary bark beetles that infest trees in more advanced stages of decay (Byers 1989), appear attracted to volatile compounds released from the host as it deteriorates owing to a mixture of factors including other insects, pathogens and/or physical factors (Wood 1982a). If wood that has been treated under ISPM 15 conditions is stored near untreated wood, then any ISPM 15 treated material that is still attractive to and capable of supporting an infestation of insects may be readily colonised from the material waiting to be treated.

Timber selected for use in wood packing material is likely to be of variable quality, with dunnage often made from low quality wood that presents the greatest pest risk (Federal Register 2004). Dunnage may 'include whole logs' (USDA 2000). Thus the initial chemical signatures of wood selected for use in packing material may resemble freshly felled or wind-thrown timber and encompass timber without pests and pathogens to timber that is already well colonised by pests and pathogens. For insects that are attracted to the volatiles released solely from the wood tissues, it seems likely that the smaller the dimensions of the packing material, the shorter the duration of its potential attractiveness to these insects as it dries out. This possibility is supported by the work of Dwinell (2005b), who reported fresh cut slabs, cants and boards of *Pinus taeda* retaining some bark were largely not attractive to species of *Monochamus* compared with small log sections retaining bark. Dwinell (2005b) suggested the observed differences in colonisation by the beetles of green logs and cut timber was because cell mortality, host odours and moisture content were different for logs and sawn timber.

There have been numerous studies in the northern hemisphere that indicated that trees felled in autumn are more attractive to scolytid beetles than trees felled shortly before the beetles' flight period (e.g. references cited in Lindelöw *et al.* 1992). However, as Lindelöw *et al.* (1992) noted, the early work examining the influence of cutting date and beetle attack did not distinguish between beetles being attracted to volatiles emitted from the wood or aggregation pheromones produced by beetles already present in the wood. Lindelöw *et al.* (1992) examined the attraction of ten species of beetles to fresh wood and to wood cut six months earlier then stored in the field in plastic bags. By using unbarked spruce wood protected with mesh, Lindelöw *et al.* (1992) were able to conclude that volatiles emitted from the stored wood were more attractive or equally attractive to all ten species of beetle. Chemical analyses showed that the volatile constituents of some of the stored material had higher concentrations of ethanol and acetaldehyde. Ethanol produced by microbial activities is a common attractant for secondary insect species (Byers 1989). It may be assumed that an ISPM 15 certified treatment will be effective at killing insects in the wood and would disrupt, alter or eliminate any aggregation pheromones that might have been produced by insects residing in the wood before treatment. However, it is unlikely that the ISPM 15 treatment will eliminate all microbial activity, so some limited production of microbial-produced insect attractants such as ethanol may continue.

7. INSECT COLONISATION OF TIMBER AND THE IMPLICATIONS FOR INFESTATION FOLLOWING ISPM 15 TREATMENT

In a review of the nutritional ecology of the principal families of wood feeding insects in the orders Coleoptera, Hymenoptera and Lepidoptera, Haack and Slansky (1987) considered three condition types of woody material inhabited by insects. Live material was defined as living and healthy, weakened, or dying trees; dead material was defined as recently killed or felled trees to well-decayed logs; and lumber was defined as partially or fully seasoned timber in any stage of processing. In addition, Haack and Slansky (1987) considered three principal tissues used by these insects to be the inner bark, sapwood and heartwood. Most wood-feeding insects feed in the subcortical tissues and sapwood, with fewer species feeding within the heartwood (Savely 1939, in Hanks 1999).

Insects in the order Lepidoptera are primarily considered to inhabit live material (Haack and Slansky 1987) and are therefore not expected to infest wood previously treated under ISPM 15 certified conditions in any significant way. However, any Lepidoptera that naturally lay eggs on bark, such as *Lymantria dispar*, may still lay eggs on a bark surfaces present on ISPM 15 treated materials. Some of these species disperse at the first instar stage, with newly hatched larvae producing gossamer threads and subsequently drifting off in the wind to a new host plant. Such species would remain a threat after an ISPM 15 treatment without removal of bark.

Termites are another group of well known insects that attack wood, from the heartwood of living trees to seasoned wood in buildings. While some termites are capable of consuming bark in mulches (Duryea *et al.* 1999), there seems to be no evidence that the presence of bark is likely to attract termites to a particular piece of wood. Under some conditions of packing material storage and use, termites would be expected to infest wood previously treated under ISPM 15 certified conditions.

Colonies of ants in the genus *Camponotus* (carpenter ants) inhabit heartwood of living trees, trunks of standing dead trees, stumps, fallen logs and wooden structures (Hansen and Akre 1985). In addition to damaging timber and structural wood, carpenter ants can significantly damage utility poles, shade trees and lawns (Cannon 1998). Treatment under ISPM 15 conditions is unlikely to prevent subsequent infestation by these timber pests but bark is unlikely to be a factor influencing infestation.

A group of wood boring insects highly significant to Australia’s plantation pine forest resources are the Siricidae, with one species *Sirex noctilio*, already introduced to and established in Australia. In Europe, most siricids only attack damaged or dying trees but they may also deposit into newly felled logs (Viitasaari and Heliövaara 2004). In Australia, *Sirex noctilio* attacks live, healthy trees. The indigenous woodwasps of North America attack trees weakened or dying from fire, disease or other injury (Middlekauf 1960). *Sirex areolatus* has been reported as ovipositing in cured redwood in lumber yards (Essig 1926, in Middlekauf 1960) and may also deposit eggs in bark (Essig 1958, in Morgan 1968). In North America, the larvae have four or five instars and may take from two to five years to complete development (Mussen 2000). In Europe, reports exist for adults emerging from timber in buildings several years after construction (Escherich 1942, in Viitasaari and Heliövaara 2004). This indicates that siricid larval development is to some extent tolerant of host timber that is drying out. The effect of the timber drying out is to lengthen the development time. *Sirex juvencus*, *Sirex noctilio* and *Sirex cyaneus* have been frequently intercepted on wood packaging materials entering Australia. There are also some interception records for *Urocerus albicornis*, *Urocerus gigas*, *Urocerus augur* and *Xeris spectrum* on this material. The capacity for some of the Siricidae to attack fallen trees and curing cut timber and to survive in seasoning timber indicates some species may be capable of infesting timber subsequent to an ISPM 15 treatment.

The most commonly intercepted insect group associated with wood packaging materials in the United States is bark beetles (family Scolytidae). They account for more interceptions than all other insect groups combined (Haack 2003). Many bark beetles have short generation times, down to as little as one to two months (Haack and Cavey 1997) and if any of these species were to infest wood treated under ISPM 15 certified conditions, they may successfully conclude a generation before the wood dried out and inhibited larval growth and pupation. Phloem tissues have a higher proportion of protein than xylem tissues and in general bark beetles that feed in phloem tissue have a shorter developmental cycle than beetles living in sapwood (Rudinsky 1962). Of the 50 exotic scolytid species known to be established in the United States, approximately three quarters of them are inbreeding species, where brother-sister mating occurs before emergence from the host and lone females can create new populations where suitable hosts are present (Haack 2003).

In an experimental study, the pine engraver (Scolytidae: *Ips pini* — absent from Australia) was introduced to 0.3 m sections of *Pinus resinosa* logs (15.8–16.7 cm diameter) that had their ends sealed with wax to reduce moisture loss (Redmer *et al.* 2001). One set of beetles was introduced within 72 hours, another set after 30–45 days and on other occasions another set up to 175–190 days. All introductions lead to the production of a new generation, although with later introductions the number of offspring was lower. The reduction in offspring from later introductions coincided with a reduction in phloem moisture content, which was up to 50 % at 183 days (Redmer *et al.* 2001). *Ips pini* attacks living trees, wind-thrown material, freshly cut logs and slash over 50 mm diameter of many species of pine (Furniss and Carolin 1980). It is possible that *Ips pini* and other species with similar life histories may be capable of infesting wood packing material with extensive bark covering such as dunnage or crate components after an ISPM 15 treatment. *Ips pini* is a known vector for several species of *Ophiostoma* fungi (Kooper *et al.* 2004), some of which are of quarantine concern to Australia. Beetles in the family Scolytidae, including *Ips* spp., have been intercepted entering Australia in association with wood packaging material.

With ambrosia beetles such as those in the genus *Gnathotrichus*, male beetles select dying standing trees or recently cut or fallen logs (Wood 1982b). Once boring commences in a host, the beetle produces an aggregation pheromone and more beetles are drawn to the host, mating takes place on the surface near the hole and both adults work to extend and maintain the gallery. Attack densities of over 2500 holes per m^2 of log surface have been reported (Shore 2000). They may also continue to infest the same log or tree for more than one year, and may colonise logs felled 2–3 years previously. They have been known to attack debarked logs (Daterman and Overhulser 2002). Stumps are also susceptible to attack (Liu and McLean 1993). Beetles will attack trees felled as recently as two weeks before their flight (Shore 2000). *Gnathotrichus sulcatus* has also been reported as attacking freshly sawn hemlock lumber at a mill in British Columbia (McLean and Borden 1975). For *Gnathotrichus retusus*, development from eggs to adult took a minimum of 40 days in Douglas-fir logs in British Columbia (Liu and McLean 1993). Interceptions associated with wood packaging material entering Australia are occasionally made for both *Gnathotrichus sulcatus* and *Gnathotrichus retusus*. With such a relatively quick generation time, it seems possible that some of the larger pieces of ISPM 15 treated wood may remain suitable host material for these beetles while the wood is moist enough to support growth of the ambrosia fungi.

Among other beetles intercepted in wood packaging materials entering Australia, a significant number are in the families Anobiidae, Bostrichidae and Cerambycidae. In many cases, interceptions are of larvae and identification is usually not taken beyond family level. Some Buprestidae have also been intercepted, but none has been identified. The beetles in these families include many species that attack live trees, or recently felled or wind blown trees. Hanks (1999) noted that cerambycids attacking woody plants that are severely stressed may show a preference for oviposition in freshly felled trees and cut logs, and that these species are able to rapidly locate and use suitable host material. Such species may be more likely to infest treated wood where large amounts of bark are retained. These cerambycids feed almost exclusively within the subcortical zone and may only move into the sapwood once the cambium has been consumed or the bark becomes thin (Hanks 1999). Removal of bark would deprive such beetles of egg laying opportunities and degrade the value of the wood as a food resource. In contrast, cerambycids that attack healthy hosts or plants whose defences are compromised often feed only briefly under bark and spend most of their larval stage in sapwood or heartwood (Hanks 1999). While the bark may provide oviposition sites for such species attacking living hosts, they are less likely to successfully infest treated wood.

Cerambycidae usually deposit eggs under bark or in cracks in the wood but others gnaw excavations in the wood and deposit a single egg in each hollow (Evans *et al.* 2004). *Monochamus scutellatus* (Say) chews eggs slits or niches in the bark of hosts (Rose 1957). Dwinell (2005b) has shown that *Monochamus* spp. (pine sawyers) were able to infest heat treated *Pinus taeda* logs (380 mm long and 180 mm diameter) and also transmit *Bursaphelenchus xylophilus* (pine wood nematode) to the logs. However, boards and cants retaining edge bark were not attacked by pine sawyers, while only a very small portion of slabs retaining surface bark were attacked and these rapidly dried to below the fibre saturation point (Dwinell 2005b). The conclusion that can be reached from Dwinell's (2005b) study is that sawn timber retaining edge bark after an ISPM 15 treatment does not present a pest risk for *Monochamus* spp. The use of intact log lengths as dunnage may still present some risk if the wood retains enough moisture to allow larval development through to the adult stage. *Monochamus* spp. in the United States are reported to have a one to two year lifecycle (Wilson 1962). *Tetropium fuscium* (intercepted in wood packaging entering Australia from Italy on 26 March 2001), originally from Europe, has been introduced to Nova Scotia, Canada and is also in Japan. *Tetropium fuscium* lays 1–10 eggs in the bark of standing or recently felled trees (spruce, firs, pines and larches). The larvae feed in the phloem and a generation is completed within three months (Plant Health Survey Unit 2005). Recently cut trap logs have been found to be attractive to egg laying females and the beetles have also responded to traps baited with host volatiles (Canadian Forestry Centre 2005). This indicates that for ISPM 15 treated, bark-covered, green timber, such as larger dunnage items, there may be some chance of post treatment infestation.

Of the small number of the intercepted Anobiidae identified to species level, all have become established in Australia. Nevertheless, some of the Anobiidae not present in Australia, such as the New Zealand *Leanobium flavomaculatum* Español, present potential risks for structural building timbers. Eggs of *Leanobium flavomaculatum* are laid in crevices in wood or bark, or on the rough sawn ends of billets. Larvae feed under the surface of bark when the host is first infested but have also been found in the heartwood (Milligan 1979). The presence of bark could make such pests more difficult to detect. The capacity of such pests to use bark to lay eggs in and then feed under indicates that ISPM 15 treated wood with bark on remains liable to post treatment infestation. This species is a common house borer in older houses in New Zealand. While the lifecycle is not well known, in one case adults emerged 4 years after the eggs were laid in red beech billets (Milligan 1979), an indication the beetle is able to survive in seasoned timber.

Bark freedom would be expected to influence the risk associated with post treatment infestation by both timber and non-timber arthropod pests. Many timber insect pests are attracted to the volatiles released from sawn wood over many months following harvesting. Methyl bromide fumigation of fresh green timber will kill any remaining living cells (Stone and Simpson 1991a), otherwise some cells may remain viable for up to two months (Feist *et al.* 1971, in Stone and Simpson 1991a). Billets of freshly felled *Pinus elliottii* treated with methyl bromide before exposure to the bark beetle *Ips grandicollis* were reported to have a strong fermenting odour compared with unfumigated billets (Stone and Simpson 1991a), with the odour noticeable within a week (J.Simpson pers. com.). In wood where the cells are already dead, methyl bromide fumigation may impact on the volatiles attributable to microbial decay if the dosage is high enough but it is unclear if there would be any direct effect on volatiles arising from chemical changes in the wood arising from cell death. The heat treatment detailed in ISPM 15 also has not been assessed in terms of reducing the release of volatiles, and recent research within Europe and the USA indicates that bark, whether heat-treated or not, is still susceptible to infestation by bark beetles post-treatment (Haack *et al.* n.d., Schröder 2005). Many insects lay eggs into bark crevices, with the larvae developing and feeding under bark in the cambium (Morrell 1995). Removal of bark would reduce these infestation risks following treatment, as well as address the risks associated with non-timber pests using bark for shelter.

Solid wood packing material with bark comprises four sites that may harbour invertebrate pests. These are in the wood under the bark, at the interface between the wood and bark surfaces, deep in the bark, and on bark surfaces including crevices and fissures. The treatment of such material under ISPM 15 should kill the insect pests and the pine wilt nematode targeted by ISPM 15 treatments (see Table 1) in any of these four sites if the treatment has been correctly applied. However, even with treatment, invertebrate pests are continuing to be intercepted in association with solid wood packaging material (Table 3). While the nature of the data collected at this stage precludes firm conclusions concerning the pathway by which pests continue to be associated with solid wood packaging material, three potential sources of infestation are discussed below.

One potential source of infestation will be a treatment failure or the non-application of a treatment, even though the material has been stamped as treated. This is dealt with under compliance issues in Section 5.

The second potential source is infestation of the wood packaging material after an effective approved ISPM 15 treatment. Although information has been poorly recorded historically, Australia has recently recorded separate barrier breaches of Cerambycidae larvae and emerging *Sinoxylon conigerum* associated with bark on fumigated solid wood packaging. There was no other evidence of fumigation failure. In addition, some experimental work is underway. Laboratory work has commenced, using the bark beetle *Pityogenes chacographus* (e.g. Schroder unpublished), and Haack *et al.* (n.d.) have demonstrated that some bark beetles will attack heat treated 1 metre log sections with bark intact, placed along a forest edge.

While it is well known that a number of important timber pests oviposit in the bark, with the larvae then continuing to feed in the bark or moving into the wood to feed, it remains uncertain how attractive the solid wood packing material with bark would be to such pests. It is possible that the processes in converting the wood into packing material and then treating it under ISPM 15 will alter some of the physical and chemical cues that attract some, albeit not necessarily all, insects to such material.

In addition, given the likely preference of many such insects for woodland or forest locations and the likely places one would find treated solid wood packaging material, the chance for infestation of wood packaging would be lower than wood left remaining in a natural forest situation. Nevertheless, if the material is capable of being infested, as seems possible given recent and on-going experimental work, then the presence of bark in large amounts is likely to impede effective quarantine inspection, and eggs recently laid in bark crevices particularly those small, cryptic and laid singly, would be unlikely to be detected during inspection.

Type of wood packaging material subject to the application of an ISPM 15 treatment and the opportunity for post treatment invertebrate infestation — an examination of scenarios

The following assessment is based on the assumption that which ever ISPM 15 certified treatment is applied, it will be effective in killing all nematode and insect pests associated with the wood before treatment, as the wood is of a dimension where even deep wood pests can be killed. Pests that attack seasoned wood are more likely to enter the pathway after the ISPM 15 treatment and may continue to do so during the service life of the product. The presence of bark is not regarded as a significant contributing factor in attack by and survival of most invertebrate pests of seasoned wood, except in circumstances where the bark may offer additional protection for any life stages of these pests. The assessment also notes that there is no direction provided under ISPM 15 concerning storage and use of treated material. Such instructions are likely to vary from country to country and to be implemented to varying degrees depending on the treatment provider. Lumber used in the first four scenarios is likely to be all or mostly sapwood. It may have both stain fungi and incipient decays. Lumber used in scenarios 5 and 6 may have heartwood, depending on the species of tree used, and may have a carry over of fungi in branch stubs, bark, etc. that were in the live tree.

1. *Fresh cut green timber, sawn to size, air dried at least to fibre saturation point, one side covered with bark, ISPM 15 treated and assembled into pallets.* Based on the consideration of physical changes occurring in small size sawn timber owing to seasoning, and the biology of invertebrates that preferentially or only attack wood when there is a surface covered with bark, it seems most unlikely that ISPM 15 treated wood material of pallet size dimensions will attract and produce a succeeding generation of insects that seek out and feed on wood or phloem material because it has some bark remaining.

2. *Fresh cut green timber sawn to size, no drying, one side covered with bark, ISPM 15 treated and assembled into pallets.* If such wood packing material was made at a time of year and at a location when natural air drying would be slow, and this coincided with the flight season of insects that have short generation times and are attracted to green fresh cut wood with bark, then under such a set of circumstances, infestation and a subsequent next generation of insects being successfully raised to maturity in the packing material may be possible. However, such a simultaneous combination of these critical factors, while unlikely, is possible.

3. *Fresh cut green timber, sawn to size, air dried at least to fibre saturation point, one side covered with bark, ISPM 15 treated and assembled into crates or used as wood packaging material of larger than pallet size dimensions.* Such material will continue to dry through the seasoning process until an equilibrium is reached with the moisture content of the surrounding environment. It is unlikely that ISPM 15 treated wood material of crate size dimensions with such low moisture content will attract and produce a succeeding generation of insects that seek out and feed on wood or phloem material because it has some bark remaining.

4. *Fresh cut green timber sawn to size, not dried before treatment, one side covered with bark, ISPM 15 treated and assembled into crates or used as wood packaging material of larger than pallet size dimensions.* Once cut, wood begins to dry and the larger the dimensions the longer it takes to dry. The longer the moisture content remains above the fibre saturation point, the greater the chance that the wood may attract and support an insect infestation that initially arrives owing to the presence of bark.

5. *Fresh cut green timber with wood sawn to 200 mm in one cross-sectional dimension (claimed maximum size for effective methyl bromide penetration), one side covered with bark, ISPM 15 treated and set aside for later use either for dunnage purposes or to be later sawn to pallet or crate size dimensions.* The use of such wood for pallets is perhaps less likely, as in most cases it will be faster and cheaper to treat when sawn to smaller dimensions as there would also be less wastage of treated material. However, ISPM 15 certification does not rule out such a scenario. In fact, it would allow a treated log with bark on to be stored before being sawn up into pallet/crate/dunnage material. It seems that under a limited range of conditions, infestation by invertebrates owing to the presence of bark, which then go on to successfully produce a new generation, is a possibility, particularly if the wood is in a situation where drying is slow and the time for a pest to complete a generation is short.

6. *Fresh cut green timber used in dunnage either as intact log sections or trimmed to have less than half the bark removed being no more than 200 mm in one cross-sectional dimension, ISPM 15 treated and used shortly thereafter or set aside for later use.* Under such circumstances the greater the amount of bark remaining, the greater the amount of natural moisture retained in the wood and the more attractive the dunnage would be to insect infestation. Potentially, species that are attracted to freshly fallen or cut lumber, particularly small dimensional material such as slash, could find such material attractive if it was in a position to gain access to it. Of these species, those that can complete a generation in the shortest time are likely to be most successful. Pests with larval stages of extended durations of perhaps a year or more are less likely to thrive.

8. POST TREATMENT INFESTATION BY CONTAMINATING ARTHROPOD PESTS

The third potential source of infestation is by contaminating arthropod pests (hitchhikers). Some of these, such as the Cucujidae (flat bark beetles), may be specifically attracted to the habitat provided by the presence of bark on the wood and the food sources that would normally be present. Other species that are not specifically timber pests or otherwise associated with timber may be attracted to the greater variety of surfaces and places of concealment provided by wood with bark and its associated fissures and cracks, than wood without bark. The interface between the wood and bark will also provide a further place to hide that is not present on wood alone. With a greater range of concealment places, the chances of inspection detecting the presence of such pests will be reduced.

ISPM 15 has no measure within it specific to the risks of post treatment infestation of solid wood packaging material by non-timber arthropod pests. Australia has historically relied on the use of the twenty one day rule (see Glossary) and bark freedom to address this risk. Despite these measures, interceptions still occur.

In all the cases above, the greater the amount of bark present on wood packaging material, the more intensive and time consuming quarantine inspections will need to be to ensure freedom from pests. This is likely to lead to significantly higher costs and delays to industry. Alternatively, not increasing inspection intensity would be likely to lead to arthropods of quarantine concern being introduced to Australia in wood packaging material with bark.

9. INFESTATION OF SEASONED TIMBER BY TIMBER PESTS POST ISPM 15 TREATMENT

Timber pests found in dry seasoned packing timber are likely to fall into two broad categories. The first category are those that infest timber before the fibre saturation point is reached and then continue to complete their lifecycle in the wood as it dries to the equilibrium moisture point. These species typically do not reinfest the same timber, although they may take many years before the adults emerge from the wood. *Buprestus aurelenta* may infest recently dead or dying trees, unseasoned logs and unseasoned lumber with attached bark, but when the infested wood is used in structures and subject to seasoning and low humidity, 60 years may pass before the adults emerge, whereas in the forest the larval stage may last two to four years (Duncan 1991). Timber packing with attached bark could be attacked by *Buprestus aurelenta* or other insects with similar life histories after ISPM 15 treatment until the timber seasons. *Hylotrupes bajulus* (old house borer) lays its eggs in cracks and crevices of bark on logs and stored wood (Jacobs 2003). This species is unusual as it is also capable of infesting seasoned timber and may reinfest the timber from which the adults have emerged (Ebeling 1975). While this species only appears to attack softwoods, any suitable timber that retains bark may be capable of being infested subsequent to an ISPM 15 treatment. *Hylotrupes bajulus* has been introduced into Western Australia and is presently under official control.

The second category of seasoned wood pests are those that are capable of infesting timber that has dried beyond the fibre saturation point and will typically continue to infest or reinfest timber until the food supply is exhausted. These include insects in the following groups: Isoptera (termites); Formacidae (the carpenter ants); and beetles in the Bostrichidae, Lyctidae and Anobiidae (Ebeling 1975). There seems to be little if any indication that bark plays any direct role in the infestation of timber by these pests. The beetles in the Lyctidae and Anobiidae typically lay their eggs directly into cracks or crevices of the wood or oviposit directly into the pores or vessels, while the Bostrichidae adults bore into the wood producing egg tunnels (Ebeling 1975). *Xylobiops basilare*, the only species of Bostrichidae that has larvae known to damage seasoned timber, bores through bark into the sapwood to deposit eggs (Chamberlin 1953). *Xylobiops basilare* has a wide host range mostly among the hardwoods, including *Eucalyptus*, as well as some conifers and vines. It occurs naturally in North America (Solomon 1995). Many of the seasoned wood pests present serious quarantine concerns for Australia. The ISPM 15 treatments will not reduce the chance of post treatment infestation, but the presence of bark is likely to make inspections for these pests more difficult and may provide additional places for emergent adults to hide. The bostrichid beetles *Heterobostrychus aequalis* and *Sinoxylon conigerum* are frequently intercepted in association with wooden packing material entering Australia.

10. PEST RISK ASSESSMENTS FOR SELECTED QUARANTINE PESTS

SCOPE

ISPM 15 allows countries, subject to technical justification, to require that imported wood packaging material be subjected to additional measures (IPPC 2002). Consistent with this requirement of ISPM 15, this document provides technical justification for Australia's long-standing requirement that wood packaging material be made from bark free wood.

This section provides individual pest risk assessments for selected quarantine pests or groups of quarantine pests that could enter Australia through the importation of wood packaging materials with bark that are stamped with the ISPM 15 mark, are absent from Australia, could establish or spread in Australia and have the potential for economic consequences in Australia. These pest risk assessments for selected quarantine pests are based on restricted or mitigated risk estimates following the application of the 'risk management' treatments in ISPM 15.

This pest risk analysis (PRA) does not consider the full range of quarantine pests likely to be associated with the importation into Australia of wood packaging materials stamped with the ISPM 15 mark and with bark attached. Rather, this assessment focuses on selected pests to provide an indication of the kinds of economically important quarantine arthropod pests and fungi that may gain entry into Australia on wood packaging materials with attached bark.

Because of similarities in pest biology, and consequent similarities between the risk assessments for some of the pests, the risk assessments below are based on groupings of similar pests where appropriate.

The following pest taxa have been selected for individual pest risk assessment:

1) *Callidiellum rufipenne* (Japanese cedar longhorn beetle);

2) *Callidium violaceum* (violet tanbark beetle);

3) *Gnathotrichus* spp. (ambrosia beetles);

4) *Ips* spp. (engraver beetles);

5) *Ceratocystis/Ophiostoma* spp. (stains and wilts);

6) *Cryphonectria parasitica* (chestnut blight); and

7) *Fusarium circinatum* (pine pitch canker).

METHOD FOR PEST RISK ASSESSMENTS

The pest risk assessments in this PRA were conducted in accordance with the *Guidelines for Import Risk Analysis*, draft September 2001, published by Agriculture, Fisheries and Forestry – Australia (AFFA 2001). The methods used for the detailed risk assessments conducted on the quarantine pests are given below.

Assessment of the probability of entry, establishment or spread

Details of assessing the 'probability of entry', 'probability of establishment' and 'probability of spread' of a pest are given in ISPM 11.

Assessing the probability of entry requires an analysis of each of the pathways with which a pest may be associated, from its origin to distribution in the PRA area. The probability of entry may be divided for assessment purposes into the following components:

- *The probability of importation*: the probability that a pest will arrive in Australia when a given commodity is imported; and
- *The probability of distribution*: the probability that the pest will be distributed (as a result of the processing, sale or disposal of the commodity) to the endangered area, and subsequently be transferred to a suitable site on a susceptible host.

In breaking down the probability of entry into these two components, Biosecurity Australia has not altered the original meaning. The two components have been identified and separated to enable onshore and offshore pathways to be described individually.

The probability of establishment is estimated on the basis of availability, quantity and distribution of hosts in the PRA area; environmental suitability in the PRA area; potential for adaptation of the pest; reproductive strategy of the pest; method of pest survival; and cultural practices and control measures. Similarly, the probability of spread is estimated on the basis of suitability of the natural and/or managed environment for natural spread of the pest; presence of natural barriers; the potential for movement with commodities or conveyances; intended use of the commodity; potential vectors of the pest in the PRA area; and potential natural enemies of the pest in the PRA area.

Qualitative likelihoods are assigned to the probability of entry (comprising an importation step and a distribution step), the probability of establishment and the probability of spread. Likelihoods are categorised according to a descriptive scale from 'high' to 'negligible' as shown in Table 4.

Table 4 Nomenclature for qualitative likelihoods

Likelihood	Descriptive definition	Probability (P)
High	The event would be very likely to occur	Range = 0.7 → 1
Moderate	The event would occur with an even probability	Range = 0.3 → 0.7
Low	The event would be unlikely to occur	Range = 0.05 → 0.3
Very low	The event would be very unlikely to occur	Range = 0.001 → 0.05
Extremely low	The event would be extremely unlikely to occur	Range = 10^{-6} → 0.001
Negligible	The event would almost certainly not occur	Range = 0 → 10^{-6}

The likelihoods of entry, of establishment and of spread are combined using the tabular matrix shown in Table 5.

Table 5 Matrix of rules for combining descriptive likelihoods

	High	Moderate	Low	V. Low	E. Low	Negligible
High	High	Moderate	Low	V. Low	E. Low	Negligible
Moderate		Low	Low	V. Low	E. Low	Negligible
Low			V. Low	V. Low	E. Low	Negligible
Very low				E. Low	E. Low	Negligible
E. low					Negligible	Negligible
Negligible						Negligible

Assessment of consequences

The basic requirements for the assessment of consequences are described in the SPS Agreement, in particular Article 5.3 and Annex A. Further detail on assessing consequences is given in the 'potential economic consequences' section of ISPM 11. This ISPM separates the consequences into 'direct' and 'indirect' and provides examples of factors to consider within each. In this PRA, the term 'consequence' is used to reflect the 'relevant economic factors' / 'associated potential biological and economic consequences' and 'potential economic consequences' terms as used in the SPS Agreement and ISPM 11, respectively.

The direct and indirect consequences were estimated based on four geographic levels. The terms 'local', 'district', 'regional' and 'national' are defined as:

Local: an aggregate of households or enterprises — e.g. a rural community, a town or a local government area;

District: a geographically or geopolitically associated collection of aggregates — generally a recognised section of a state, such as the 'North West Slopes and Plains' or 'Far North Queensland';

Region: a geographically or geopolitically associated collection of districts — generally a state, although there may be exceptions with larger states such as Western Australia; and

National: Australia-wide.

The consequence was described as:

- '*unlikely to be discernible*' is not usually distinguishable from normal day-to-day variation in the criterion;
- '*minor significance*' is not expected to threaten economic viability, but would lead to a minor increase in mortality/morbidity or a minor decrease in production. For non-commercial factors, the consequence is not expected to threaten the intrinsic 'value' of the criterion — though the value of the criterion would be considered as 'disturbed'. Effects would generally be reversible;
- '*significant'* consequence would threaten economic viability through a moderate increase in mortality/morbidity, or a moderate decrease in production. For non-commercial factors, the intrinsic 'value' of the criterion would be considered as significantly diminished or threatened. Effects may not be reversible; and

- '*highly significant*' would threaten economic viability through a large increase in mortality/morbidity, or a large decrease in production. For non-commercial factors, the intrinsic 'value' of the criterion would be considered as severely or irreversibly damaged.

The values are translated into a qualitative score (A–F) using the schema outlined in Table 6.

Table 6 The assessment of local, district, regional and national consequences

Impact score	Local	District	Regional	National
F	-	-	-	Highly significant
E	-	-	Highly significant	Significant
D	-	Highly significant	Significant	Minor
C	Highly significant	Significant	Minor	Unlikely to be discernible
B	Significant	Minor	Unlikely to be discernible	Unlikely to be discernible
A	Minor	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible

Level

The overall consequence for each pest was achieved by combining the qualitative scores (A–F) for each direct and indirect consequence using a series of decision rules. These rules are mutually exclusive, and are addressed in the order that they appear in the list — for example, if the first rule does not apply, the second rule is considered. If the second rule does not apply, the third rule is considered and so on until one of the rules applies.

- Where the impact score of a pest with respect to any direct or indirect criterion is 'F', the overall consequences are considered to be 'extreme'.
- Where the impact scores of a pest with respect to more than one criterion are 'E', the overall consequences are considered to be 'extreme'.
- Where the impact score of a pest with respect to a single criterion is 'E' and the impact scores of a pest with respect to each remaining criterion is 'D', the overall consequences are considered to be 'extreme'.
- Where the impact score of a pest with respect to a single criterion is 'E' and the impact scores of a pest with respect to remaining criteria are not unanimously 'D', the overall consequences are considered to be 'high'.
- Where the impact scores of a pest with respect to all criteria are 'D', the overall consequences are considered to be 'high'.
- Where the impact score of a pest with respect to one or more criteria is 'D', the overall consequences are considered to be 'moderate'.
- Where the impact scores of a pest with respect to all criteria are 'C', the overall consequences are considered to be 'moderate'.
- Where the impact score of a pest with respect to one or more criteria is considered 'C', the overall consequences are considered to be 'low'.
- Where the impact scores of a pest with respect to all criteria are 'B', the overall consequences are considered to be 'low'.
- Where the impact score of a pest with respect to one or more criteria is considered 'B', the overall consequences are considered to be 'very low'.
- Where the impact scores of a pest with respect to all criteria are 'A', the overall consequences are considered to be 'negligible'.

Method for determining the restricted risk estimate

The restricted risk estimate for each pest is determined by combining the likelihood estimates of entry, of establishment and of spread with the overall potential consequences. This is done using the risk estimation matrix shown in Table 7. The cells of this matrix describe the product of likelihood of entry, establishment or spread and consequences of entry, establishment or spread.

Table 7 Risk estimation matrix.

Likelihood of entry, establishment or spread	Negligible impact	Very low	Low	Moderate	High	Extreme impact
High likelihood	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Moderate	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Low	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk	High risk
Very low	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk
Extremely low	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk
Negligible likelihood	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk

Consequences of entry, establishment or spread

Australia's appropriate level of protection (ALOP)

The SPS Agreement defines the concept of an 'appropriate level of sanitary or phytosanitary protection (ALOP)' as the level of protection deemed appropriate by the WTO Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory.

Like many other countries, Australia expresses its ALOP in qualitative terms. Australia's ALOP, which reflects community expectations through government policy, is currently expressed as providing a high level of sanitary or phytosanitary protection aimed at reducing risk to a very low level, but not to zero. The band of cells in Table 7 marked 'very low risk' represents Australia's ALOP.

PEST RISK ASSESSMENTS

Callidiellum rufipenne (Japanese cedar longhorn beetle)

- *Callidiellum rufipenne* (Motschulsky)

Probability of importation

The likelihood that *Callidiellum rufipenne* will arrive in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on): **Low**.

This beetle is native to East Asia (China, Korea, Sakhalin, Japan, and the Ryukyu Islands (Oshima, Okinawa) (Hoebeke 1999). It is also present in Taiwan, where it is believed to have been introduced. It has also been introduced into Italy, Spain (Hoebeke 1999), Argentina (Di-Iorio 2004) and the United States (Connecticut, New Jersey, North Carolina) (CFIA 2001a). The pest readily infests wood used in solid wood packaging material and has been intercepted in Australia (PDI 2004) and in New Zealand, Europe and Canada (CFIA 1998, Maier and Lemmon 2000). It has also been intercepted hundreds of times at USA ports in at least 21 States (Maier and Lemmon 2000).

Host range

In Asia, *Callidiellum rufipenne* attacks stressed and freshly cut conifers, where hosts include *Chamaecyparis obtusa* (Hinoki cypress), *Chamaecyparis pisifera* (Sawara cypress), *Cryptomeria japonica* (Japanese cedar), *Thujopsis dolabrata* (false arborvitae) *Abies* spp. (fir) and *Pinus* spp. (pine) (Hoebeke 1999).

In the United States and Europe, hosts include *Cupressus macrocarpa* (Monterey cypress), *Juniperus communis* (juniper) *Juniperus virginiana* (eastern redcedar) and *Thuja occidentalis* (American arborvitae) (Hoebeke 1999). In Connecticut, this beetle has been observed in healthy American arborvitae plants (Maier and Lemmon 2000). In Canada, stands of *Thuja plicata* (western red cedar) and *Chamaecyparis nootkatensis* (yellow cedar) are considered at risk (Humphreys and Allen 2000).

Survival of ISPM 15 treatment

All stages of the beetle are likely to be killed by an ISPM 15 compliant treatment.

However, post ISPM 15 treatment infestation could occur.

On the pathway

Wood packing materials can be made of both coniferous and non-coniferous raw wood. Based on the existing interception records, some of the host species of *Callidiellum rufipenne* are used in the manufacture of wood packaging material. The infestation of living nursery stock in the United States indicates that small dimensional material is suitable for hosting this species, and CABI (2005a) notes that this species does not select host material on the basis of size, with damage known to occur on branches and trunks larger than 25 mm in diameter (CABI 2005a). The eggs are laid singly or in small groups in the crevices of the bark on dead or dying trees (CABI 2005a) and hatch within two weeks (Humphreys and Allen 2000), so removal of bark will likely prevent infestation. Newly hatched larvae feed on the phloem and cambium tissue, and when mature, they enter the xylem to pupate (Hoebeke 1999). This occurs in late summer or autumn (CABI 2005a). One year is required to complete the lifecycle in Connecticut and in southern Japan, and two years may be required in northern Japan (Maier and Lemmon 2000).

Emergence occurs in spring, but may continue into summer and the beetle overwinters as an adult (CABI 2005a).

Based on the above, it is possible that freshly cut green timber treated to be ISPM 15 compliant may still be attractive to the beetles. The extent of attraction may be minimal to non-existent for small dimensional pallet material retaining bark on one edge. Larger sized crate and dunnage wood that retains significant amounts of bark may still remain attractive for the beetles if the wood is fresh. Any logs used as dunnage that retain bark are likely to be capable of supporting beetle attacks while sufficient moisture is retained. While the beetle is known to attack dead timber, Biosecurity Australia has been unable to find any information concerning survival and growth to maturity of the larvae in relation to wood drying out through the seasoning process. Since the larval period appears to last for at least four to five months, if not longer, the capacity of the larvae to survive in seasoning wood will be important in determining if live beetles enter Australia and reach maturity after a post treatment infestation of ISPM 15 treated wood.

Compliance issues

Larvae of *Callidiellum rufipenne* form galleries under the bark, and damage may not be apparent on the host material until the adult emerges. The adult beetles vary between 6–13 mm long and produce 4 × 2 mm oval exit holes (Hoebeke 1999). Given the moderate size of the beetles, treatment failures or other compliance issues with wood packaging material containing these species would be easily detectable in the absence of bark. Infestations that have not reached the adult stage and that originally occurred in living tissue, where the larval gallery has calloused over, could be difficult to detect with bark remaining on the wood in the event of a treatment failure.

Probability of distribution

The likelihood that *Callidiellum rufipenne* will be distributed in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on) and transferred to a suitable site on a susceptible host: **Moderate**.

All the life stages of the pest can be transported in solid wood packaging material, including dunnage. For larger crate sized material, the infested packaging material may be distributed throughout Australia to wholesale distribution centres. Items such as cable drums/spools may finish up in any part of the country. Such material may be reused or it may be discarded. Infested dunnage material, if not reused, is likely to remain at the primary cargo handling and distribution centres until disposed of.

Only those stages that survive to emerge as adults would have the capacity to fly to new host plants. The distance that *Callidiellum rufipenne* can fly is unknown. However, beetles in the family cerambycidae are usually strong fliers (Humphreys and Allen 2000) therefore an adult beetle emerging from imported wood packing material would be expected to be capably of flying to any nearby hosts. In its native range, the beetle attacks stressed and freshly cut conifers (Hoebeke 1999). In North America, where it has been introduced, it has expanded its host range (Humphreys and Allen 2000) and also attacks living hosts (Maier and Lemmon 2000). Based on this behaviour, it is unclear if the beetle is attracted to specific host chemicals or relies on a random search process to find suitable hosts. In Japan, adult males were reported on average to live for 18 days and females for 16.6 days (Shibata 1994). Thus the beetles would have around two weeks to locate a suitable host, find a mate and lay eggs.

Callidiellum rufipenne has a wide host range as listed above. Included among the known hosts are ornamental trees planted in parts of southern Australia. The genus *Pinus* is listed as a host in Asia (Hoebeke 1999), although the species grown in softwood plantings in Australia's national forest estate are not recorded as hosts. However, this may be because those pine species have not yet been exposed to *Callidiellum rufipenne*. *Callidiellum rufipenne* appears to be able to increase its range of coniferous host species when it establishes in regions outside its native range. The mechanism *Callidiellum rufipenne* uses to find suitable host material does not appear to be documented, but an attraction to stressed or freshly cut host material may indicate it is attracted to host volatiles.

Callidiellum rufipenne is naturally distributed where suitable hosts are found across the cool to warm temperate areas of East Asia and has been introduced into Italy, Spain and North America (Hoebeke 1999). Hence outside the tropics, the climate around Australia's sea ports and internal transport routes would not reduce survival chances for the beetles within the packaging material.

Probability of entry (importation x distribution)

The likelihood that *Callidiellum rufipenne* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on) and be distributed in a viable state to a susceptible host: **Low**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Probability of establishment

The likelihood that *Callidiellum rufipenne* will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **Moderate.**

In its natural and extended range, *Callidiellum rufipenne* is found in regions with cool to warm temperate climatic conditions. However, based on experimental evidence adult emergence and ovarian development is influenced by the apparent requirement for a chilling period (Matsuura and Fujita 1997). Accordingly, the beetle could be expected to be capable of establishing in Australia where suitable host plants are available within areas where winter temperatures remain low for a month or more.

Of the natural hosts listed by Hoebeke (1999), all are listed as being suitable and available for planting as garden and park trees in Australia (Conifer Gardens Nursery 2006). With these hosts, the adult is reported to attack plants that are either stressed or freshly cut, suggesting that with its native hosts it either does not attack or cannot complete development in healthy trees. For much of Australia there are frequent periods of drought. In areas where ornamental and amenity plantings are made, the trees often survive under marginal conditions for extensive periods of time with obvious drought stress, as evidenced by the common occurrence of dead limbs and branches. Of more concern is a report that *Callidiellum rufipenne* has been able to attack one to two meter high healthy nursery plants of *Thuja occidentalis* in the United States (Maier and Lemmon 2000). The capacity of *Callidiellum rufipenne* to attack healthy plants would increase the likelihood of its establishment.

Probability of spread

The likelihood that *Callidiellum rufipenne* will spread based on a comparative assessment of those factors in the area of origin and in Australia considered pertinent to the expansion of the geographical distribution of the pest: **Moderate**.

Australia has a wide climate range and many areas are suitable for the establishment and spread of *Callidiellum rufipenne*. Regions of Australia where suitable coniferous hosts are grown would be suitable for the spread of these beetles because these species are recorded from similar environments within their native range. Long distance spread may largely depend on the transportation of infested materials. Given the known host range, this is most likely to involve movement of nursery stock, especially if the *Pinus* species grown in Australia for forestry purposes are not suitable hosts. The remaining host species are not grown for timber in Australia. The distance that *Callidiellum rufipenne* can fly is unknown but beetles in the family cerambycidae are usually strong fliers (Humphreys and Allen 2000). Therefore, *Callidiellum rufipenne* could be expected to be a strong flier and readily move between nearby hosts. The distribution of hosts is likely to be associated with population centres, meaning that spread of the insect would be more likely along the coastal areas north and south of Sydney than, for example, it would be outside the Adelaide region.

In addition to the list of hosts for *Callidiellum rufipenne* where it occurs naturally, Hoebeke (1999) also provides a further three different host genera that the beetle attacks where it has been introduced in the United States and Europe. Based on this, it is likely that the range of suitable host species is not yet circumscribed and is likely to expand as the beetle is introduced to new areas. Australia has over 35 species of native conifers and more than 600 different exotic conifers (species or cultivars) are available in Australian nurseries. If it were to enter Australia, *Callidiellum rufipenne* is likely to have many suitable hosts to assist its spread.

Probability of entry, establishment and spread

The overall likelihood that *Callidiellum rufipenne* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on), be distributed in a viable state to susceptible hosts, establish in that area and subsequently spread within Australia: **Low**.

The probability of entry, establishment or spread is determined by combining the probabilities of entry, establishment and spread using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Consequences

Consequences (direct and indirect) of *Callidiellum rufipenne*: **Very low**.

Criterion	Estimate
Direct consequences	
Plant life or health	**B** — While only considered to attack dead and dying plants in its natural range, *Callidiellum rufipenne* is known to attack healthy host plants in the United States and may cause loss of high value ornamental and amenity plantings. While the genus *Pinus* is listed as a host in Asia (Hoebeke 1999), there is no evidence that the plantation species grown in Australia will be attacked. Pines are not recorded as hosts in the United States. It is estimated that *Callidiellum rufipenne* would have consequences that are likely to be significant at the local level and minor at the district level, based on its effect on amenity and ornamental species.

Criterion	Estimate
Any other aspects of the environment	**A** — The introduction of *Callidiellum rufipenne* into areas where native conifers grow would not be anticipated to have any consequences for healthy plants and the ecosystems they are part of, but it is unknown if unhealthy plants would be attractive to the beetles. *Callidiellum rufipenne* is estimated to have consequences that are unlikely to be discernible at the local level.
Indirect consequences	
Eradication, control, etc.	**B** — This pest's ability to infest nursery stock and mature trees and shrubs of host plants (Maier and Lemmon 2000) presents some cause for concern. The establishment of populations established in ornamental plantings could lead to frequent spraying programs during the adults' flight season to achieve some control. Should they become established, *Callidiellum rufipenne* is estimated to have potentially significant consequences at a local level.
Domestic trade	**B** — The presence of these pests in commercial production areas is estimated to have significant consequences at the local level owing to any resulting trade restrictions on movement of potentially infested nursery stock, which may result in loss of markets.
International trade	**B** — The presence of *Callidiellum rufipenne* is estimated to have potentially significant consequences at the local level owing to any limitations to access to overseas markets where these pests are absent and there is trade in nursery stock.
Environment	**B** — Pesticides are likely to be used to attempt control of *Callidiellum rufipenne* in ornamental plantings; otherwise plants may have to be removed. This is estimated to have consequences that are unlikely to be discernible at the district level and potentially significant at the local level.

Note: Refer to Table 6 (The assessment of local, district, regional and national consequences) and text under the 'Method for assessing consequences' section for details on the approach taken to consequence assessment.

Restricted risk estimate

The restricted risk estimate for *Callidiellum rufipenne*, determined by combining the overall 'probability of entry, of establishment, and of spread' with the 'consequences' using the risk estimation matrix (Table 7): **Negligible**.

Callidium violaceum (violet tanbark beetle)

- *Callidium violaceum* (Linnaeus)

Probability of importation

The likelihood that *Callidium violaceum* will arrive in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on): **High.**

This beetle is native to northern, central and south-eastern Europe, reaching to northern Mongolia, Korea and Japan (Kolk and Starzyk 1996a). Also reported from England (Whitehead 1988), eastern North America, and introduced into Uruguay (Monné and Hovore 2002). The pest has been intercepted in Australia infesting solid wood packaging material (PDI 2004).

Host range

Callidium violaceum mainly attacks various conifers and rarely attacks deciduous trees (oak, beech and alder) (Kolk and Starzyk 1996a). Conifers attacked include *Picea* spp. (spruce), *Pinus* spp. (pine), *Abies* spp. (fir) (Karasev 1974) and *Larix* spp. (larch) (Munro 1928). Weakened, dying and dead trees are attacked, as is wood and wooden materials where bark remains (Kolk and Starzyk 1996a). Damage has been reported to timber in timber yards (Karasev 1974) and to unbarked roof timbers (Nuorteva and Nuorteva 1955). In Sweden, infestation of building timbers was reported in buildings up to 70 years old, as long as some bark remained on the wood (Tragardh 1947).

Survival of ISPM 15 treatment

All stages of the beetle are likely to be killed by an ISPM 15 compliant treatment.

However, post ISPM 15 treatment infestation could occur.

On the pathway

Wood packing materials can be made of both coniferous and non-coniferous raw wood. Based on the existing interception records, some of the host species of *Callidium violaceum* are used in the manufacture of wood packaging material. The eggs are laid in bark crevices and the larvae feed under the bark, making galleries up to 15 mm wide. Mature larvae may widen the galleries to 20–30 mm, before boring 10 cm into the wood to pupate (Kolk and Starzyk 1996a). A generation may take one or two years to complete, depending on climatic conditions (Kolk and Starzyk 1996a). Adults are active over late spring to mid-summer (Kolk and Starzyk 1996a). While no information is available on the minimum size of host material, Kolk and Starzyk (1996a) give a size range for adults of 8 to 18 mm long and for the larvae up to 26 mm long.

Based on the above, it is possible that small pieces of wood retaining thin strips of bark and recently colonised by *Callidium violaceum* after an ISPM 15 compliant treatment may not be suitable for the development of adult beetles. However, as the adult beetle appears to be capable of colonising recently dead to well seasoned wood as long as some bark is present, it seems likely that crate sized timbers and dunnage could remain viable substrates for as long as they retain bark.

Compliance issues

Larvae of *Callidium violaceum* form galleries under the bark, and damage may not be apparent on the host material until the adult emerges. Given the moderate size of the beetles, treatment failures or other compliance issues with wood packaging material containing these species would be easily detectable in the absence of bark.

Probability of distribution

The likelihood that *Callidium violaceum* will be distributed in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on) and transferred to a suitable site on a susceptible host: **High**.

All the life stages of the pest can be transported in solid wood packaging material, including dunnage. For larger crate sized material, the infested packaging material may be distributed throughout Australia to wholesale distribution centres. Items such as cable drums/spools may finish up in any part of the country. Such material may be reused or it may be discarded. Infested dunnage material, if not reused, is likely to remain at the primary cargo handling and distribution centres until disposed of.

Only those stages that survive to emerge as adults would have the capacity to fly to new host plants. The distance that *Callidium violaceum* can fly is unknown but beetles in the family cerambycidae are usually strong fliers (Humphreys and Allen 2000). Therefore an adult beetle emerging from imported wood packing material would be expected to be capably of flying to any nearby hosts.

The range of host genera indicates this beetle is likely to have low host specificity. Included among these hosts is the genus *Pinus*. It is likely that some of the conifers found in Australia's national forest estate and those used as ornamental or amenity plantings may be suitable hosts. The indication from Kolk and Starzyk (1996a) that some deciduous genera may also serves as hosts would widen the range of ornamental or amenity plantings that may provide suitable host material.

Callidium violaceum is naturally distributed where suitable hosts are found across the cold to cool temperate areas of Europe and into East Asia (Kolk and Starzyk 1996a), and it has been introduced into Uruguay (Monné and Hovore 2002). Hence, outside the tropics and warmer areas, the climate around Australia's southerly sea ports and internal transport routes would not reduce survival chances for the beetle within the packaging material.

The mechanism *Callidium violaceum* uses to find suitable host material does not seem to be documented. Its attack of weakened or dying trees (Kolk and Starzyk 1996a) might suggest it is attracted to emissions of volatile compounds from the host, but its capacity to also attack old wood where bark remains (Tragardh 1947) seems to suggest that finding suitable host material may be more of a random approach.

Probability of entry (importation x distribution)

The likelihood that *Callidium violaceum* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on) and be distributed in a viable state to a susceptible host: **High**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Probability of establishment

The likelihood that *Callidium violaceum* will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High.**

In its natural range, *Callidium violaceum* is found in regions with cold to cool temperate climatic conditions. Accordingly, the beetle could be expected to be capable of establishing in Australia where suitable host plants or dead wood with bark remaining are available.

For much of Australia there are frequent periods of drought. In areas where ornamental and amenity plantings are made, the trees often survive under marginal conditions for extensive periods of time with obvious drought stress, as evidenced by the common occurrence of dead limbs and branches. The adult of *Callidium violaceum* attacks weakened, dying and dead trees, as well as wood and wooden materials where bark remains (Kolk and Starzyk 1996a). It seems likely that many exotic coniferous garden and amenity plantings could be subject to attack, as well as some of the commercial forest plantation species.

Probability of spread

The likelihood that *Callidium violaceum* will spread based on a comparative assessment of those factors in the area of origin and in Australia considered pertinent to the expansion of the geographical distribution of the pest: **Moderate**.

Callidium violaceum mainly attacks various conifers but it is also capable of attacking deciduous trees (oak, beech and alder) (Kolk and Starzyk 1996a). Suitable hosts include weakened, dying and dead trees, as well as wood and wooden materials where bark remains (Kolk and Starzyk 1996a). It has been reported to attack timber in timber yards (Karasev 1974) and unbarked roof timbers (Nuorteva and Nuorteva 1955). In Sweden, infestation of building timbers was reported in buildings up to 70 years old, as long as some bark remained on the wood (Tragardh 1947).

Australia has a wide climate range and some southern upland and coastal areas of eastern Australia are likely to be suitable for the spread of *Callidium violaceum*. Moderate-sized cerambycid beetles, such as *Callidium violaceum*, are likely to be capable of flying several kilometres and readily move between nearby hosts. Long distance spread may largely depend on the transportation of infested materials and, if plantation species are infested, this could be an important means for spreading the beetle.

Of the conifer genera listed as being attacked, *Picea*, *Pinus*, *Abies* (Karasev 1974) and *Larix* (Munro 1928), one Australian conifer nursery (Conifer Gardens Nursery 2006) lists 67 species and many cultivars among these genera as being suitable and available for planting as garden and park trees in Australia. The adult of *Callidium violaceum* is also recorded as attacking *Pinus* species in timber yards (Karasev 1974). While *Pinus radiata* is the most widespread in commercial plantings, five other species are also grown in commercial quantities (*Pinus caribaea, Pinus pinaster, Pinus elliotti, Pinus ponderosa* and *Pinus taeda*) (Wood *et al* 2001). If *Callidium violaceum* is also to able attack these plantation species, the potential for spread would be greater.

Probability of entry, establishment and spread

The overall likelihood that *Callidium violaceum* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on), be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Moderate**.

The probability of entry, establishment or spread is determined by combining the probabilities of entry, establishment and spread using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Consequences

Consequences (direct and indirect) of *Callidium violaceum*: **Low**.

Criterion	Estimate
Direct consequences	
Plant life or health	**B** — *Callidium violaceum* attacks weakened, dead and dying plants and may thus have significant consequences at the local level where suitable host trees are under some stress. *Callidium violaceum* may also hasten the death of any plants in poor condition.
Any other aspects of the environment	**A** — The introduction of *Callidium violaceum* into areas where native conifers grow would not be anticipated to have any consequences for healthy plants and the ecosystems of which they are part, but it is unknown if unhealthy plants would be attractive to the beetle. *Callidium violaceum* is estimated to have consequences that are unlikely to be discernible at the local level.
Indirect consequences	
Eradication, control, etc.	**B** — Coniferous timber retaining bark is not an important building timber in Australia and thus the beetle would not be a pest of buildings in Australia. Some changes to forest practices may be required if the beetle infests any of the commonly grown plantation species. Spraying is not likely to be used to control the pest. If *Callidium violaceum* attacks plantation pine species, it would be estimated to have minor consequences at the district level.
Domestic trade	**C** — The presence of these pests in commercial production areas is estimated to have potentially significant consequences at the district level owing to any resulting trade restrictions on movement of infested wood and downgrading of timber owing to feeding by the larvae.
International trade	**B** — The presence of *Callidium violaceum* is estimated to have potentially minor consequences at the district level owing to any limitations to access to overseas markets where these pests are absent.
Environment	**A** — Pesticides are unlikely to be used to attempt control of *Callidium violaceum*. This is estimated to have consequences that are unlikely to be discernible at the district level and minor at the local level.

Note: Refer to Table 6 (The assessment of local, district, regional and national consequences) and text under the 'Method for assessing consequences' section for details on the approach taken to consequence assessment.

Restricted risk estimate

The restricted risk estimate for *Callidium violaceum*, determined by combining the overall 'probability of entry, of establishment, and of spread' with the 'consequences' using the risk estimation matrix (Table 7): **Low**.

Gnathotrichus species (ambrosia beetles)

- *Gnathotrichus retusus* (LeConte)
- *Gnathotrichus sulcatus* (LeConte)

In this PRA, these two species of *Gnathotrichus* are considered to be similar enough in their biology to treated together rather than as individual species. They also have overlapping distributions and host ranges.

Probability of importation

The likelihood that either *Gnathotrichus retusus* or *Gnathotrichus sulcatus* will arrive in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on): **Moderate**.

High levels of infestations of these ambrosia beetles are found in North America in coastal forests from southern Alaska through to British Columbia to California (Daterman and Overhulser 2002). The distribution of *Gnathotrichus retusus* is reported as British Columbia, Oregon (CABI 2003a), the Pacific coast and northern Rocky Mountains (Furniss and Carolin 1980), and probably into Mexico (Liu and McLean 1993). The distribution of *Gnathotrichus sulcatus* is reported as British Columbia to Mexico, Guatemala and Honduras (CABI 2003b) and the western United States (Furniss and Carolin 1980).

Host range

The hosts of *Gnathotrichus retusus* are *Pseudotsuga menziesii* (Douglas-fir) and *Tsuga heterophylla* (western hemlock) (CABI 2003a). In addition, Furniss and Carolin (1980) list *Tsuga*, *Pinus* and rarely *Abies* and *Picea* as hosts. In addition to *Pseudotsuga menziesii*, Wood (1982b) lists: *Alnus* sp.; *Picea englemanii* (Englemann spruce); *Pinus contorta* (lodgepole pine); *Pinus flexilis* (limber pine); *Pinus jeffreyi* (Jeffrey pine); *Pinus radiata* (Monterey pine); *Pinus ponderosa* (ponderosa pine); and *Populus trichocarpa* (black cottonwood). *Alnus rubra* (red alder) is reported by Kuhnholz *et al.* (2000). The hosts of *Gnathotrichus sulcatus* are *Pseudotsuga menziesii* (Douglas-fir), *Thuja plicata* (western red cedar) and *Tsuga heterophylla* (western hemlock) (CABI 2003b). Furniss and Carolin (1980) list *Picea*, *Tsuga*, *Abies* and sometimes *Pinus*, *Sequoia*, *Thuja* and other conifers as hosts. In addition, Wood (1982b) lists: *Abies concolor* (white fir); *Abies magnifica* (California red fir); *Abies religiosa* (sacred fir); *Pinus leiophylla* (Chihuahua pine); *Pinus ponderosa* (ponderosa pine); and *Pinus pseudo-strobus* (white bark pine).

Survival of ISPM 15 treatment

All stages of the beetle are likely to be killed by an ISPM 15 compliant treatment.

However, post ISPM 15 treatment infestation could occur.

On the pathway

Wood packing materials can be made of coniferous and/or non-coniferous wood. Some of the host species of *Gnathotrichus* spp. are likely to be used in the manufacture of wood packaging material. Male beetles select dying standing trees or recently cut timber or fallen logs and begin to construct a tunnel into the wood and inoculate the tunnel wall with fungal spores (Wood 1982b). Once boring commences in a host, the beetle produces an aggregation pheromone and more beetles are attracted to the host. Mating takes place on the surface near the entrance hole and both adults work to extend and maintain the gallery. Attack densities of over 2500 holes per m^2 of log surface have been reported (Shore 2000). The beetles may continue to infest the same log or tree for more than one year, may colonise logs felled 2–3 years previously, and they have been known to attack debarked logs (Daterman and Overhulser 2002). *Gnathotrichus sulcatus* has been reported as attacking freshly sawn hemlock lumber in British Columbia (McLean and Borden 1975). Based on the above, it is possible that freshly cut green timber treated to ISPM 15 specifications may still be attractive to the beetles. The extent of attraction may be minimal to non-existent for small dimensional pallet material retaining bark on one edge, while larger sized crate and dunnage wood that retains a significant amount of bark may still remain attractive to beetles.

The larvae feed on the fungus growing in the tunnels. In British Columbia, Liu and McLean (1993) reported that for *Gnathotrichus retusus* development from eggs to adult took a minimum of 40 days in Douglas-fir logs. Survival of the brood is likely to be dependent on the adults maintaining the galleries and the continued growth of the fungus. Survival of the fungus will depend on the wood retaining adequate moisture levels, with the greater the thickness of the wood and the more bark present the longer moisture levels supporting fungal growth will be maintained.

Compliance issues

Both species of *Gnathotrichus* form galleries in the sapwood (Daterman and Overhulser 2002). Holes produced in the timber by the beetles are relatively small at about 1.3 mm in diameter (Shore 2000). Treatment failures of wood packaging material containing these species could be difficult to detect with bark remaining on the wood, particularly if the attack is of low intensity.

Probability of distribution

The likelihood that either *Gnathotrichus retusus* or *Gnathotrichus sulcatus* will be distributed in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on) and transferred to a suitable site on a susceptible host: **High**.

All the life stages of the pest could be transported in solid wood packaging material including dunnage. For larger crate sized material, the infested packaging material may be distributed throughout Australia to wholesale distribution centres. This material may be reused or it may be discarded. Infested dunnage material, if not reused, is likely to remain at the primary cargo handling and distribution centres until disposed of.

Only those stages that survive to emerge as adults would have the capacity to fly to new host plants. While there does not appear to be any data on the flight range of *Gnathotrichus* species, some data is available for another ambrosia beetle of similar small size and habits, *Trypodendron lineatum.* Salom and McLean (1989) reported that *Trypodendron lineatum* flew at least 100 m to pheromone baited traps, while traps at 500 m only collected beetles that had flown downwind. For *Gnathotrichus* species, flight takes place when daytime temperatures exceed 15°C to 18°C (Daterman and Overhulser 2002), temperatures that occur throughout most of Australia. Beetles in the genus *Gnathotrichus* appear to be initially attracted to volatiles emitted from the host (Cade *et al.* 1970, McLean and Borden 1977). Once boring commences in a host, the beetle produces an aggregation pheromone and then more beetles come to the host (Shore 2000).

These ambrosia beetles have a wide host range, and it is likely that many softwood plantings in Australia's national forest estate would contain suitable hosts, including the extensive *Pinus radiata* plantations. Suitable hosts for ambrosia beetles would also be found among ornamental and amenity plantings in much of southern coastal and upland Australia.

The ambrosia beetles have a widespread distribution along the Pacific coast in Canada and the United States (Furniss and Carolin 1980, Wood 1982b). The climate around Australia's sea ports and internal transport routes would not reduce survival chances for the beetles. All stages of *Gnathotrichus* overwinter in the log (Daterman and Overhulser 2002) and larvae of all species are within the sapwood and may develop into adult beetles either in transit or at the final destination.

Probability of entry (importation x distribution)

The likelihood that either *Gnathotrichus retusus* or *Gnathotrichus sulcatus* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on) and be distributed in a viable state to a susceptible host: **Moderate**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Probability of establishment

The likelihood that either *Gnathotrichus retusus* or *Gnathotrichus sulcatus* will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High**.

In their natural range, ambrosia beetles are found over a wide range of climatic conditions, and they would be expected to be capable of establishing in Australia where suitable host plants are available.

Male beetles select dying standing trees or recently cut timber or fallen logs (Wood 1982b) and appear to be initially attracted to volatiles emitted from the host (Cade *et al.* 1970, McLean and Borden 1977). Once boring commences in a host, the beetle produces an aggregation pheromone and then more beetles come to the host (Shore 2000). For much of Australia there are frequent periods of drought. In areas where ornamental and amenity plantings are made, the trees often survive under marginal conditions for extensive periods of time with obvious drought stress, as evidenced by the common occurrence of dead limbs and branches. In addition, *Gnathotrichus* would find suitable host material among the slash and discarded logs from several plantation forestry species grown in Australia. Hence, in many parts of Australia, the presence of suitable unthrifty host material as well as recently cut timber would favour the establishment of species of *Gnathotrichus.*

Probability of spread

The likelihood that either *Gnathotrichus retusus* or *Gnathotrichus sulcatus* will spread based on a comparative assessment of those factors in the area of origin and in Australia considered pertinent to the expansion of the geographical distribution of the pest: **High**.

Australia has a wide climate range, and many areas are suitable for the spread of ambrosia beetles. Regions of Australia where suitable coniferous hosts are grown would be suitable for the spread of these beetles because these species are recorded from similar environments within their native range. In British Columbia, Liu and McLean (1993) reported that development of individuals of *Gnathotrichus retusus* from eggs to adult took a minimum of 40 days in Douglas-fir logs. Such a fast generation time would enhance the opportunity for spread. The widespread plantings of suitable hosts and an adult stage capable of flight provides the opportunity for spread beyond an initial establishment. With the harvesting and transport of infested logs from plantations, there is likely to be movement of all stages of the beetles beyond the immediate forest locality.

The widespread plantings of suitable hosts both as amenity or ornamental trees and as a forestry species (*Pinus radiata*) and an adult stage capable of flight of probably at least 100 m (and possibly >500m downwind) provides the opportunity for spread beyond an initial establishment without the movement of infested host material. A capacity to spread would be enhanced by the beetles' attraction to volatiles emitted by the host as well as to aggregation pheromones produced by beetles that have found a host.

Among the suitable host species occurring in Australia, *Thuja plicata* is sold as a specimen tree for parks and large gardens or for windbreaks. Some cultivars are sold as a screen or trimmed hedge plant. *Tsuga heterophylla* is sold as a specimen tree for gardens. *Pseudotsuga menziesii* is sold as a specimen tree for gardens and cultivars are sold for use in rockeries. It is also promoted as a farm forestry tree for upper elevations in southern Australia. The major coniferous forestry species planted in Australia is *Pinus radiata*. Some of the other *Pinus* species are also used in commercial forestry as well as being available as specimen plants for parks and gardens. Other potential host species in the genera *Abies*, *Alnus*, *Picea* and *Sequoia* are used as specimen plantings in parks and gardens. The widespread distribution of these hosts would favour the spread of these pests.

Probability of entry, establishment or spread

The overall likelihood that either *Gnathotrichus retusus* or *Gnathotrichus sulcatus* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on), be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Moderate**.

The probability of entry, establishment or spread is determined by combining the probabilities of entry, establishment and spread using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Consequences

Consequences (direct and indirect) of ambrosia beetles: **Low**.

Criterion	Estimate
Direct consequences	
Plant life or health	**A** — Ambrosia beetles do not attack healthy host plants. They are more likely to attack standing dead or unthrifty plants already undergoing decline. It is estimated that ambrosia beetles have consequences that are unlikely to be discernible at the district level and a minor effect at the local level.
Any other aspects of the environment	**A** — The introduction of ambrosia beetles into areas where native conifers grow would not be anticipated to have any consequences for healthy plants and the ecosystems of which they are part, but it is unknown if unhealthy plants would be attractive to the beetles. Ambrosia beetles are estimated to have consequences that are unlikely to be discernible at the district level.
Indirect consequences	
Eradication, control, etc.	**C** — While fresh cut timber is not likely to be attacked, *Gnathotrichus* may attack logs felled more than two weeks previously (Shore 2000), making logs stockpiled in the forest or in lumber yards susceptible to infestation. Debarked logs are not attacked (Daterman and Overhulser

Criterion	Estimate
	2002), but stumps and low quality logs left remaining in the forest will be. When logs infested with ambrosia beetles are processed into timber, beetle damage is evident by the presence of small holes surrounded by dark stains that are caused by the fungus the beetle brings to the log. Such defects degrade the value of the timber (Daterman and Overhulser 2002). Some changes to harvesting and processing procedures would be needed, but the application of pesticides is unlikely to be practical. Pheromone traps and trap logs could be used to reduce beetle populations. Should they become established, ambrosia beetles are estimated to have significant consequences at a district level.
Domestic trade	**C** — The presence of these pests in commercial production areas is estimated to have significant consequences at the district level owing to any resulting trade restrictions on the movement of logs, and downgrading of timber may result in the loss of markets.
International trade	**C** — The presence of ambrosia beetles in commercial plantation areas is estimated to have significant consequences at the district level owing to any limitations to access to overseas markets where these pests are absent.
Environment	**A** — Pesticides are unlikely to be used to control ambrosia beetles, but pheromone traps, if used, may prove attractive to some native insects. It is estimated that ambrosia beetles would have consequences that are unlikely to be discernible at the district level and of minor significance at the local level.

Note: Refer to Table 6 (The assessment of local, district, regional and national consequences) and text under the 'Method for assessing consequences' section for details on the approach taken to consequence assessment.

Restricted risk estimate

The restricted risk estimate for the ambrosia beetles, determined by combining the overall 'probability of entry, of establishment, and of spread' with the 'consequences' using the risk estimation matrix (Table 7): **Low**.

Ips species (engraver beetles)

- *Ips calligraphus* (Germar)
- *Ips confusus* (LeConte)
- *Ips lecontei* Swaine
- *Ips paraconfusus* Lanier
- *Ips pini* (Say)
- *Ips plastographus* (LeConte)
- *Ips sexdentatus* (Börner)

In this PRA, these seven species of *Ips* are considered to be similar enough in their biology to treated together rather than as individual species. They have been selected for inclusion in this PRA because they all have the genus *Pinus* in their host range, including one or more of the species that are planted in Australian commercial forests.

Probability of importation

The likelihood that *Ips* beetles will arrive in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on): **Moderate.**

Beetles in the genus *Ips* are distributed across the coniferous forests of Europe, Asia, India, North Africa, and North and South America (Wood 1982b). One species, *Ips grandicollis*, has been introduced to Australia and has established on at least two occasions. The genus contains approximately 60 species, 25 of which occur in North America (Wood 1982b).

The seven species considered in this pest risk assessment are a non-exhaustive list of those known to attack the species of *Pinus* grown commercially in plantations in Australia. It is also likely many more species of *Ips* beetles would be capable of attacking the wide range of amenity plantings of conifers in Australia or may adapt to the commercially grown species of pine.

Host range

The genus *Ips* has a wide host range in the Family Pinaceae. For the seven species of *Ips* considered here, the list of hosts is given below.

The hosts of *Ips calligraphus* are *Pinus attenuata* (knobcone pine), *Pinus banksiana* (jack pine), *Pinus clausa* (sand pine), *Pinus echinata* (shortleaf pine), *Pinus elliottii* (slash pine), *Pinus flexilis* (limber pine), *Pinus kesiya* (khasya pine), *Pinus montezumae* (montezuma pine), *Pinus occidentalis* (Haitian pine), *Pinus oocarpa* (ocote pine), *Pinus ponderosa* (ponderosa pine), *Pinus pseudostrobus* (Mexican white pine), *Pinus pungens* (Table Mountain pine), *Pinus resinosa* (red pine), *Pinus rigida* (pitch pine), *Pinus strobus* (eastern white pine), *Pinus taeda* (loblolly pine), *Pinus tropicalis* (tropical pine), *Pinus virginiana* (scrub pine) (CABI 2005b). Also on *Pinus glabra* (spruce pine), *Pinus palustris* (longleaf pine), *Pinus sabiniana* (digger pine) and *Pinus serotina* (pond pine) (Connor and Wilkinson 1983).

The hosts of *Ips confusus* are *Picea engelmannii* (Engelmann spruce), *Picea pungens* (blue spruce), *Pinus aristata* (Rocky Mountain bristlecone pine), *Pinus edulis* (pinyon pine), *Pinus flexilis* (limber pine), *Pinus monophylla* (singleleaf piñon pine), *Pinus ponderosa* (ponderosa pine), *Pinus quadrifolia* (Four-needle or Parry pinyon pine) and *Pinus radiata* (Monterey pine) (CABI 2005b).

The hosts of *Ips lecontei* are *Pinus leiophylla* (smooth-leaved pine), *Pinus oocarpa* (ocote pine), *Pinus ponderosa* (ponderosa pine) and *Pinus pseudostrobus* (Mexican white pine) (CABI 2005b).

The hosts of *Ips paraconfusus* are *Pinus attenuata* (knobcone pine), *Pinus balfouriana* (foxtail pine), *Pinus contorta* (lodgepole pine), *Pinus coulteri* (big-cone pine), *Pinus jeffreyi* (Jeffrey pine), *Pinus lambertiana* (big pine), *Pinus monticola* (western white pine), *Pinus muricata* (bishop pine), *Pinus ponderosa* (ponderosa pine), *Pinus radiata* (Monterey pine), *Pinus sabiniana* (digger pine) and *Pinus torreyana* (Torrey pine) (CABI 2005b).

The hosts of *Ips pini* are *Larix laricina* (eastern larch), *Picea engelmannii* (Engelmann spruce), *Picea glauca* (white spruce), *Picea rubens* (red spruce), *Pinus banksiana* (jack pine), *Pinus contorta* (lodgepole pine), *Pinus coulteri* (big-cone pine), *Pinus durangensis* (Durango pine), *Pinus flexilis* (limber pine), *Pinus jeffreyi* (Jeffrey pine), *Pinus ponderosa* (ponderosa pine), *Pinus resinosa* (red pine), *Pinus strobus* (eastern white pine) and *Pinus sylvestris* (Scots pine) (CABI 2005b).

The hosts of *Ips plastographus* are *Picea sitchensis* (Sitka spruce), *Pinus contorta* (lodgepole pine), *Pinus muricata* (bishop pine), *Pinus ponderosa* (ponderosa pine) and *Pinus radiata* (Monterey pine) (CABI 2005b).

The hosts of *Ips sexdentatus* are *Abies nordmanniana* (Nordmann fir), *Picea asperata* (dragon spruce), *Picea orientalis* (oriental spruce), *Pinus armandii* (Chinese White Pine), *Pinus kesiya* (khasya pine), *Pinus koraiensis* (fruit pine), *Pinus leucodermis* (palebark Heldreich pine), *Pinus nigra* (black pine), *Pinus pinaster* (maritime pine), *Pinus pinea* (stone pine), *Pinus radiata* (radiata pine), *Pinus sibirica* (Siberian stone pine), *Pinus sylvestris* (Scots pine), *Pinus tabuliformis* (Chinese pine), *Pinus taiwanensis* (Taiwan pine) and *Pinus yunnanensis* (Yunnan pine) (CABI 2005b).

Survival of ISPM 15 treatment

All stages of the beetle are likely to be killed by an ISPM 15 compliant treatment.

However, post ISPM 15 treatment infestation could occur.

On the pathway

Wood packing materials can be made of both coniferous and non-coniferous raw wood. Some of the host species of *Ips* spp. are likely to be used in the manufacture of wood packaging material. *Ips* beetles feed in the inner bark of the host species, where the bark is thin. The surface of the sapwood may also be engraved (Furniss and Carolin 1980). Removal of bark will prevent infestation and will either eliminate or reveal any beetles present. Wood with bark remaining presents a potential opportunity for colonisation of fresh green wood after an ISPM 15 treatment. Species of *Ips* have been intercepted in association with wood packaging material entering Australia (PDI database).

The males of most species attack slash, broken and felled trees, dying trees and, under some circumstances, some species will also attack healthy trees (Wood 1982b). *Ips calligraphus* commonly occurs on the trunks of large trees and rarely infests material less than 100 mm in diameter (Foltz 2001). It also attacks dying or fallen trees, preferring thicker portions of the bark (Furniss and Carolin 1980). *Ips confusus* attacks injured and stressed trees and slash (Hagle *et al.* 2003), and also uprooted trees (Furniss and Carolin 1980). *Ips lecontei* is reported to be attracted to fresh cut pine and pine lumber. Disposal of slash over 76 mm is needed to prevent outbreaks where it can attack sapling and pole sized trees (Furniss and Carolin 1980).

Ips paraconfusus is capable of breeding in fresh slash and recently fallen trees and can also attack saplings, pole sized trees and tree tops (Furniss and Carolin 1980). *Ips pini* breeds in windthrown trees, fresh cut logs, slash <50 mm diameter and in the tops and limbs of dead trees and can also attack healthy trees (Furniss and Carolin 1980). *Ips plastographus* attacks the upper side of fallen trees or cut logs (Wood 1982b). *Ips sexdentatus* breeds in fresh logs or in weakened or dying trees (CABI and EPPO 1997. It sometimes attacks weakened standing or fallen, wind broken trees and timber with thick bark, being active in timber yards where logs with bark are available (Kolk and Starzyk 1996b). This species can attack healthy or slightly weakened trees (Kolk and Starzyk 1996b).

In field conditions, species of *Ips* in the United States generally have two to five generations in a year and emergence of new adults typically occurs 1.5–2 months after initial attack (Furniss and Carolin 1980). Under laboratory conditions, at a constant 27ºC, *Ips sexdentatus* can complete brood development from the start of gallery construction to emergence of new adults in 2–3 weeks (CABI and EPPO 1997). *Ips calligraphus* is reported to have 1–12 generations in a year and development time can range from 3–20 weeks (references cited in CABI 2005b).

Based on the above, it is possible that freshly cut green timber treated to be ISPM 15 compliant may still be attractive to the beetles. The extent of attraction may be minimal to non-existent for small dimensional pallet material retaining bark on one edge. Larger sized crate and dunnage wood that retains a significant amount of bark may still remain attractive to the beetles if it has not dried out too much. Any logs used as dunnage that retain bark are likely to be capable of supporting beetle attack and infestation while sufficient moisture is retained and as such would favour the importation of these beetles to Australia.

Compliance issues

All species of *Ips* form galleries in or under the bark. Adult beetles in the United States are 2–7 mm long and approximately 1–2.5 mm wide (Wood 1982b). The largest species is *Ips sexdentatus*, 7–8 mm long (CABI and EPPO 1997). Given the small size of the beetles, treatment failures or other compliance issues with wood packaging material containing these species could be difficult to detect with bark remaining on the wood, particularly if the attack is of low intensity. The beetles would be removed or exposed with the removal of the bark.

Probability of distribution

The likelihood that *Ips* beetles will be distributed in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on) and transferred to a suitable site on a susceptible host: **High**.

All the life stages of the pest could be transported in solid wood packaging material, including dunnage. For larger crate sized material, the infested packaging material may be distributed throughout Australia to wholesale distribution centres. This material may be reused or it may be discarded. Infested dunnage material, if not reused, is likely to remain at the primary cargo handling and distribution centres until disposed of.

Only those stages that survive to emerge as adults would have the capacity to fly to new host plants. There seems limited data on flight distances for the species of *Ips* considered here. *Ips sexdentatus* adults were captured (in pheromone-baited traps) at up to 4 km distance from release point, with most dispersal occurring on the first day (Jactel 1991). In flight mill testing of *Ips sexdentatus,* Jactel and Gaillard (1991 cited in Byers 2000) found that 50 % of beetles would be able to fly more than 20 km based on 50 interrupted flights amounting to 2.5 hours of flight. For another species *Ips typographus* (not dealt with in this PRA), the furthest any flew during a fresh outbreak in a Danish forest was 650 m, although the majority flew less than 500 m (Wichmann and Ravn 2001). Based on flight mill testing, Byers (2000) suggested *Ips typographus* would be capable of flying 45.6 km unaided by wind.

Since the beetles will attack slash, broken and felled trees as well as dying trees (Wood 1982b), there is likely to be limited host resistance to attack. Male *Ips* beetles either respond to host volatiles or finding a suitable host is a random process (Byers 2004). Once they find a host, they release an aggregation pheromone when they feed on the phloem of the host tree (Ivarsson *et al.* 1998) thereby attracting more beetles.

The *Ips* beetles have a wide host range and it is likely that many softwood plantings in the Australian national forest estate would be suitable hosts for some *Ips* species, including the extensive *Pinus radiata* plantations. Suitable hosts for the beetles would also be found among ornamental and amenity plantings in much of southern coastal and upland Australia.

Beetles in the genus *Ips* are distributed across the coniferous forests of Europe, Asia, India, North Africa, North and South America (Wood 1982b). Hence the climate around Australia's sea ports and internal transport routes would not reduce survival chances for the beetles. Larvae and eggs of all species are found within the inner bark (Furniss and Carolin 1980) and may develop into adult beetles either in transit or at the final destination.

Probability of entry (importation x distribution)

The likelihood that *Ips* beetles will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on) and be distributed in a viable state to a susceptible host: **Moderate**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Probability of establishment

The likelihood that *Ips* beetles will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High**.

In their natural range, *Ips* beetles are found over a wide range of climatic conditions and they would be expected to be capable of establishing in Australia where suitable hosts are available. Hosts are widely planted in Australia, both as amenity or ornamental trees and as forestry species such as *Pinus radiata*. One species, *Ips grandicollis*, has been introduced to Australia and on two occasions it has successfully established.

Adult *Ips* beetles will attack slash, broken and felled trees, and dying trees and under some circumstances living trees (Wood 1982b). Once they find a host, they release an aggregation pheromone when they feed on the phloem of the host tree (Ivarsson *et al.* 1998), thereby attracting more beetles. For much of Australia there are frequent periods of drought. In areas where ornamental and amenity plantings are made, the trees often survive under marginal conditions for extensive periods of time, with obvious drought stress as evidenced by the common occurrence of dead limbs and branches. In addition, all of the *Ips* species listed above would find suitable host material among the slash and discarded logs from several plantation forestry species grown in Australia. Hence, in many parts of Australia, the presence of suitable unthrifty host material as well as recently cut timber would favour the establishment of species of *Ips* beetles.

Probability of spread

The likelihood that *Ips* beetles will spread based on a comparative assessment of those factors in the area of origin and Australia considered pertinent to the expansion of the geographical distribution of the pest: **High**.

Australia has a wide climate range and many areas are suitable for the establishment and spread of *Ips* beetles. Regions of Australia where suitable coniferous hosts are grown would be suitable for the spread of these beetles because these species are recorded from similar environments within their native range. The warm mild climate across much of Australia where suitable hosts grow would promote faster generation times and, for much of the year, many *Ips* species may go through a generation within a month. Such a fast generation time would enhance the opportunity for spread.

Long distance spread depends on the transportation of infested materials (CABI and EPPO 1997). With the harvesting and transport of infested logs from plantations, there is likely to be movement of all stages of the beetles beyond the immediate forest locality. Experimental evidence from laboratory studies (Jactel and Gaillard 1991, in CABI and EPPO 1997) indicated 10 % of *Ips sexdentatus* would have been capable of flying >45 km and 50 % >20 km. Some individuals of *Ips sexdentatus* and *Ips typographus* are capable of flying up to four to six hours, although only a quarter were able to fly for more than an hour (Forsse and Solbreck 1985, Jactel 1993, both in Sauvard 2004) on more than one occasion across several days (Forsse 1989, in Sauvard 2004). The adult beetles would seem readily capable of flying to nearby host trees.

Included among the suitable host species occurring in Australia are several that are grown in commercial plantation forestry. While *Pinus radiata* is the most widespread of the plantation species, other commercially planted hosts include *Pinus elliotti, Pinus ponderosa* and *Pinus taeda* (Wood *et al.* 2001). Other potential host species in the genera *Abies, Picea* and *Pinus* are used as specimen plantings in parks and gardens. The widespread distribution of these host species would favour the spread of these beetles.

Probability of entry, establishment and spread

The overall likelihood that *Ips* beetles will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on), be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Moderate**.

The probability of entry, establishment or spread is determined by combining the probabilities of entry, establishment and spread using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Consequences

Consequences (direct and indirect) of *Ips* beetles: **Low**.

Criterion	Estimate
Direct consequences	
Plant life or health	**C** — *Ips* beetles will attack healthy host plants and may cause loss of high value forest areas and ornamental and amenity plantings. They also attack standing dead or unthrifty plants already undergoing decline. They are also a vector for ophiostomatoid (stain) fungi. It is estimated

Criterion	Estimate
	that *Ips* beetles will have consequences that are significant at the district level and highly significant at the local level.
Any other aspects of the environment	**A** — The introduction of *Ips* beetles into areas where native conifers grow would not be anticipated to have any consequences for healthy plants and the ecosystems of which they are part, but it is unknown if unhealthy plants would be attractive to the beetles. *Ips* beetles are estimated to have consequences that are unlikely to be discernible at the district level.
Indirect consequences	
Eradication, control, etc.	**C** — Logs from infested areas would require debarking before being transported from the area. Logs retaining bark and stockpiled in the forest or in lumber yards will be susceptible to attack. The capacity for some species to breed and build up populations in slash, fallen trees and limbs may require changes to some forestry practices. Some changes to harvesting and processing procedures would be needed, but the application of pesticides is unlikely to be practical. Should they become established, *Ips* beetles are estimated to have significant consequences at a district level.
Domestic trade	**C** — The presence of these pests in commercial production areas is estimated to have significant consequences at the district level owing to any resulting trade restrictions on movement of logs, and downgrade of timber may result in loss of markets.
International trade	**C** — The presence of *Ips* beetles in commercial plantation areas is estimated to have significant consequences at the district level owing to any limitations to access to overseas markets where these pests are absent.
Environment	**A** — Pesticides are unlikely to be used to control *Ips*. It is estimated to have consequences that are unlikely to be discernible at the district level and of minor significance at the local level.

Note: Refer to Table 6 (The assessment of local, district, regional and national consequences) and text under the 'Method for assessing consequences' section for details on the approach taken to consequence assessment.

Restricted risk estimate

The restricted risk estimate for the *Ips* beetles, determined by combining the overall 'probability of entry, of establishment, and of spread' with the 'consequences' using the risk estimation matrix (Table 7): **Low**.

Ophiostoma and *Ceratocystis* species (stains and wilts)

- *Ceratocystis angusticollis* E.F. Wright & H.D. Griffin
- *Ceratocystis coerulescens* (Münch) B.K. Bakshi
  Anamorph: *Chalara ungeri* Saccardo
- *Ceratocystis coronata* Olchowecki & J. Reid [should be a species of *Ophiostoma*, Seifert *et al.* (1993b)].
- *Ceratocystis douglasii* (R.W. Davidson) M.J. Wingfield & T.C. Harrington
- *Ceratocystis fagacearum* (Bretz) J. Hunt
  Synonym: Endoconidiophora fagacearum Bretz (EPPO n.d. c)
  Anamorph: *Thielaviopsis quercina* (B.W. Henry) A.E. Paulin (Index Fungorum 2005)
- *Ceratocystis laricicola* Redfern & Minter
  Anamorph: *Chalara* sp.
- *Ceratocystis minor* (Hedgcock) J. Hunt
  Anamorph: *Hyalorhinocladiella* sp.
- *Ceratocystis montia* (Rumbold) J. Hunt
- *Ceratocystis pluriannulata* (Hedgcock) C. Moreau
- *Ophiostoma europhioides* (E.F. Wright & Cain) H. Solheim
  Anamorph: *Leptographium* sp.
- *Ophiostoma nigrocarpum* (R.W. Davidson) de Hoog
  Anamorph: *Sporothrix* sp.
- *Ophiostoma novo-ulmi* Brasier
  Anamorphs: *Graphium* sp. and *Sporothrix* sp.
- *Ophiostoma piceaperdum* (Rumbold) Arx
  Anamorph: *Leptographium* sp.
- *Ophiostoma polonicum* Siemaszko
- *Ophiostoma pseudotsugae* (Rumbold) Arx
- *Ophiostoma ulmi* (Buisman) Nannfeldt
  Anamorph: *Sporothrix* sp., *Pesotum ulmi* (M.B. Schwarz) J.L. Crane & Schoknecht

These pests constitute a very large group of saprophytic and pathogenic fungi. Anamorphs associated with species of *Ophiostoma* include species of *Sporothrix*, *Leptographium*, *Hyalorhinocladiella*, *Pesotum*, *Graphium*, *Acremonium* and probably others (de Hoog 1993, Nag Raj and Kendrick 1993, Seifert and Okada 1993, Wingfield 1993). Anamorphs associated with species of *Ceratocystis* are mainly species of *Chalara* (Nag Raj and Kendrick 1993). In contrast to species of *Ophiostoma*, most of which are saprophytes or weakly pathogenic, all of the described species in the genus *Ceratocystis* are virulent plant pathogens (Kile 1993).

The ophiostomatoid fungi are adapted to insect dispersal (Wingfield *et al.* 1993). Species from both genera cause sapstain, sometimes called bluestain (Seifert 1993).

Probability of importation

The likelihood that stain and wilt fungi will arrive in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on): **High**.

Species of *Ophiostoma* and *Ceratocystis* are numerous and widespread worldwide. For example, *Ceratocystis fagacearum*, the oak wilt fungus, is found in many States of the USA and is found in a number of countries in Europe. (CABI 2004.)

Species of *Ophiostoma* (*Ophiostoma europhioides*, *Ophiostoma piceaperdum*, *Ophiostoma piceae*, *Ophiostoma piliferum*, *Ophiostoma pseudotsugae* and an unidentified species of *Ophiostoma*, as well as unidentified species of *Leptographium* (most are anamorphs of *Ophiostoma*), were isolated in a 12-month survey of green sawn timber imported into Australia (Simpson 1999).

Fungi in these genera may survive the treatments approved under ISPM 15. However, the presence of bark may facilitate survival by impeding the penetration of methyl bromide. It may also prolong the seasoning process, as well as provide a suitable microclimate for fungal spores to germinate and infest ISPM 15-treated timber.

Host range

Species *of Ophiostoma* and *Ceratocystis* have a wide host range, with many being recorded on species used in wood packaging material. Many of these hosts are widely distributed.

Ceratocystis

Ceratocystis angusticollis: *Pseudotsuga* (Farr *et al.* 1989).

Ceratocystis coerulescens: *Pinus*, *Pseudotsuga*, *Liquidamber*, *Liriodendron*, *Magnolia*, *Picea*, *Quercus* (Farr *et al.* 1989); sugar maple (Wingfield *et al.* 1993); and *Picea* and *Pinus* (Harrington and Wingfield 1998).

Ceratocystis coronata: *Pinus* species and possibly *Eucalyptus* species (Hutchison and Reid 1988).

Ceratocystis douglasii: *Pseudotsuga menziesii* (Harrington and Wingfield 1998).

Ceratocystis fagacearum: Red Oak (Wingfield *et al.* 1993); all species of oak, although species in the red oak group are more seriously affected, *Malus* spp., American and European *Castanea*, *Castanopsis*, *Lithoscarpus* and Chinese *Castanea* (CFIA 2002).

Ceratocystis fimbriata: *Acacia*, *Eucalyptus*, *Fagus*, *Ficus*, *Hevea*, *Larix*, *Malus*, *Populus*, etc. (CABI Crop Protection Compendium 2004); and *Platanus*, *Prunus*, *Ipomea batatas* (sweet potato), *Coffea* spp., *Theobroma cacoa* (cocoa), *Mangifera indica* (mango), *Gmelina arborea*, *Citrus* spp., *Dioscorea esculenta* and *Colocasia esculenta* (taro) (USDA 2000).

Ceratocystis laricicola: larch (Wingfield *et al.* 1993).

Ceratocystis moniliformis: angiosperms (Seifert 1993).

Ceratocystis pluriannulata: *Pinus* species, possibly *Eucalyptus* species (Hutchison and Reid 1988); and this species has been isolated from *Pinus radiata* logs (Thwaites *et al.* n.d.).

Ceratocystis minor [as *Ophiostoma minus*]: conifer lumber, including *Pseudotsuga*, *Pinus*, *Thuja* and *Tsuga* (Farr *et al.* 1989).

Ceratocystis montia [as *Ophiostoma montia*]: pines (Wingfield *et al.* 1993).

Ceratocystis fagacearum: occurs on North American oaks (EPPO n.d. c); plantation-grown Chinese chestnuts can also be naturally infected by the oak wilt fungus; and over 35 native

USA and exotic oaks are susceptible, as well as American and European chestnuts, species of chinkapin, tanoak, and several varieties of apple (Rexrode and Brown 1983).

Ophiostoma

Ophiostoma piceaperdum: *Pseudotsuga*, and has also been recorded on a range of conifers including *Pinus*, *Thuja* and *Tsuga* (Farr *et al.* 1989); and *Pinus banksiana* (jack pine), *Pinus nigra* (black pine or Austrian pine), *Pinus ponderosa* (ponderosa pine), *Pinus resinosa* (red pine), *Pinus strobus* (eastern white pine), *Pinus sylvestris* (Scots pine) (CABI 2003c).

Ophiostoma nigrocarpum: conifers including *Pinus*, *Pseudotsuga*, *Thuja* and *Tsuga* (Farr *et al.* 1989).

Ophiostoma polonica: spruce (Wingfield *et al.* 1993).

Ophiostoma pseudotsugae: has been isolated from imported timber of *Pseudotsuga menziesii* (Simpson 1999).

Ophiostoma ulmi/*novo-ulmi*: elms (Wingfield *et al.* 1993).

Survival of ISPM 15 treatment

Survival of heat treatment

Many stain and wilt fungi may survive the ISPM 15-approved heat treatment as discussed below, but the presence of bark may prolong the seasoning process and also provide a suitable microclimate for fungal spores to germinate and infest ISPM 15-treated timber.

The time-temperature schedule that achieves wood core temperature of 56°C for a minimum of 30 minutes would only arrest the development of some fungi of quarantine concern to Australia. The heat treatment process 'actually increases the risk of "bluestain"' (Covey, email 16/11/05). Most ophiostomatoid fungi will be killed at temperatures of 40–50ºC when the relative humidity is 100% (Seifert 1993). At 20–25% relative humidity, temperatures of up to 130ºC are required before some species are killed (Zimmermann and Butin 1973, in Seifert 1993). Seehan (1965, in Allen 2001a) showed that fungal growth of some species of ophiostomatoid fungi was inhibited when treated for 60 minutes at 150–170ºC. Seehan (1965, in Seifert 1993) showed that some *Ophiostoma* species were able to withstand one hour at 200ºC. Jones (1973, in Allen 2001a) demonstrated that *Ceratocystis fagacearum*, the oak wilt fungus, was killed when logs were treated for six hours at >54ºC. Kappenburg (1998, in Allen 2001a) reported a lethal temperature for *Ceratocystis fagacearum* of 68ºC at high humidity. Dwinell (2001) reported that *Ceratocystis fagacearum* can be killed in *Quercus* logs by heating the logs in hot air at 43ºC for 48 hours or 54ºC for 54 hours.

The heat process at 56°C is effective at killing insects and nematode but is too low to kill many fungi, and some may even be stimulated by the period of moderately high temperature. Standard kiln schedules developed by the UK Forest Products Research Laboratory (now BRE) for fungal sterilisation are around 70°C, whilst those for insects are 52°C to 60°C. The heat treatment is of far too short a duration to have a measurable drying effect on wood in the kiln and indeed was never intended to do so. Whilst the insects and nematodes are killed, the moulds and stains can grow rapidly under warm conditions. The warm up and cool down of closely piled wood packaging material being treated at a core temperature of 56°C for 30 minutes may extend over many hours or even days. Mild weather considerably lengthens the cooling down period so undried wood with the presence of ample moisture, usually well above the 20% decay threshold, creates ideal conditions for bluestain to grow rapidly. There are many variables that determine whether the heat process is followed by enhanced fungal growth or not, including timber species, time of year, moisture content, storage area and degree of ventilation in and between timber stacks. Even kiln dried timber subsequently going through heat treatment cannot be regarded as being permanently immune from stain. Unless kept under cover, rain will soak into closely piled timber and spores carried on the wind will wash between timber boards with rain. Close piling will ensure that some enclosed surface moisture remains high even during a rain-free period and the staining process at favourable temperatures could start within a week. (Harvey 2005.) The presence of bark could provide a suitable microclimate for the spores of these fungi to germinate and infect the timber.

Bluestain may also be exacerbated by poor kiln schedules. Although a pack of timber may have fully met ISPM 15 requirements, the final cooling/ventilation may be at fault. For example, a UK kiln manufacturing company found that if a batch of timber or pallets is placed in a kiln and the temperature is increased over several hours to achieve the required core temperature, a great deal of moisture is evaporated from the timber and relative humidity of 80% at 70°C is typical. If the kiln is then allowed to cool down before unloading, the relative humidity can exceed 100% and the timber will be soaked with the condensated water leaving the surface very wet and warm, making it susceptible to bluestain. (Harvey 2005.)

Survival of methyl bromide treatment

The ability of methyl bromide to penetrate into wood has limited its efficacy, although removal of bark facilitates the penetration of the fumigant into wood (Ricard *et al.* 1968, in USDA 1991). The presence of bark may also be of concern if larger sized timber is treated before being sawn into boards. After treatment, bark would also impede drying of the timber, keeping it greener for longer and making the treated timber more prone to infestation by fungi.

Substantially higher treatment levels of fumigants are required for fungal kill or stain prevention than are used for insect control (Schmidt n.d.). If wood packaging material is dry penetration of methyl bromide is relatively unimpeded, but green material requires high treatment c : t products (Cross 1991).

Methyl bromide fumigation at the rate of 48 g/m^3 for 16 hours may not be effective against fungi (Burgess 2005). Schedule T312 of the USDA Treatment Manual prescribes methyl bromide fumigation dose rates of 15 lbs/1,000ft^3 at 40ºF [240 g/m^3 for 72 hours at 4.4°C] for the treatment of oak logs and 15 lbs/1,000ft^3 at 40ºF [240 g/m^3 for 48 hours at 4.4°C] for the treatment of oak lumber against oak wilt disease caused by *Ceratocystis fagacearum* (APHIS Treatment Manual, Chapter 5 2004). The above specification has been used by the EU for the import of oak logs with bark, under Commission Decision 93/467/EEC (Burgess 2005). To deal with the demonstrated failure of methyl bromide fumigation of timber with a high moisture content to kill pine wood nematode, a modification of ISPM 15 methyl bromide treatment schedule was proposed at ICPM, session 7, Rome, 4–8 April 2005. This increases the treatment time to 24 hours to facilitate penetration of the gas and ensure that adequate concentrations of the fumigant are maintained during the treatment (see Table 2).

Viljoen and Banks (2002) reported that *Ceratocystis* can be controlled by methyl bromide fumigation, but only where the dose rates ensure chemical time factors that exceed 6000 mg·h·L, or methyl bromide fumigation at 240 mg/L for 3 days at 3°C or above.

Fumigation will also not prevent future infestation of sapwood by saprophytic fungi. If the moisture content of the fumigated wood is above fibre saturation point, the sapwood is susceptible to colonisation by sapstain fungi and moulds (e.g. Zygomycetes, *Penicillium*, *Trichoderma, Gliocladium* and *Aspergillus*) (Dwinell 2001) and so may attract fungus feeding insects and mites. These may assist the distribution of ophiostomatoid fungi (USDA 2000).

On the pathway

Wood packing materials can be made of both coniferous and non-coniferous green wood. Many host species are used in the manufacture of wood packaging material. For example, oak is commonly used in the construction of wood packaging material in Canada. (CFIA 2002.)

Wood packaging material is usually inferior quality timber and, as such, is likely to suffer from various imperfections such as growth abnormalities, physical damage, presence of bark, and (most importantly from the forest health point of view) wood pests and diseases (McNamara and Kroeker n.d.).

Sapstain generally occurs during seasoning or transportation of green lumber before the wood is dried and is enhanced at relative humidities above 90 %. The minimum moisture percentage widely reported as necessary for fungal growth in wood is 20 %, a value that is usually exceeded in green timber. The optimum water content for maximum stain development is 60–80 %. When the moisture content is lowered beyond a critical threshold, sapstain is not a problem unless the wood is rewetted. (Seifert 1993.)

Until newly felled trees lose their natural moisture, certain species, including pines and spruces, are particularly susceptible to bluestain, which is caused by a combination of moisture, moderate to warm temperatures and restricted air movement. This particularly arises just after felling and sawmilling when wood is at high moisture content and usually closely piled, excluding ventilating airflow. These fungi, the spores of which drift into timber stacks on the wind, are active at any stage after sawmilling where timber has a moisture content greater than 20%, which in practical terms means almost all wood used by pallet and casemakers. Closely piled, tight-banded, outdoor stacks, which are normal in sawmills or pallet timber storage yards, will provide the ideal conditions to cause bluestain in wood that is neither dried nor chemically protected. The susceptibility to staining varies with timber species: pine sapwood, for example, stains more readily than that of Douglas fir, spruce or hemlock. Staining can not only affect the surface but can also penetrate throughout the sapwood showing up as staining on end grain. Occasionally, in certain species, the stain also invades the heartwood. However, the problem can also occur with air or kiln dried wood left outside unprotected from rain. Sawn wood, even though it is at 20% moisture content or below through air or kiln drying, may only be safely closely piled for storage as boards or assembled pallets if total protection from rain is provided. (Harvey 2005.)

Timber which under ISPM 15 has been heat treated (HT) to 56°C for 30 minutes, but not kiln dried and then stored ready for use, can be badly affected by bluestain. The effect of heat treatment without kiln drying can lead to a very rapid discolouration of the timber. Pallet manufacturers, who purchase heat treated timber for export, have used the timber for non-heat treated jobs, just to move stock before it became so black that it would have been totally unacceptable. (Harvey 2005.)

Species of *Ophiostoma* (*Ophiostoma europhioides*, *Ophiostoma piceaperdum*, *Ophiostoma piceae*, *Ophiostoma piliferum*, *Ophiostoma pseudotsugae* and an unidentified species of *Ophiostoma*), as well as unidentified species of *Leptographium* (most are anamorphs of *Ophiostoma*), were isolated in a 12-month survey of green sawn timber imported into Australia (Simpson 1999).

In a diseased red oak, spores of *Ceratocystis fagacearum*, move passively within the transpiration stream and this usually results in the fungus being transported to all parts of the tree (EPPO n.d. c). Antagonistic fungi hasten the degeneration of the sporulating mat, and the pathogen usually disappears from the above-ground parts of a dead tree within a year of wilting (CFIA 2002, EPPO n.d. c). Survival in the root system may be more prolonged, especially if the roots are grafted to those of neighbouring trees (EPPO n.d. c). In a diseased white oak, distribution of the fungus in xylem of the current annual ring is much more restricted than in red oaks (EPPO n.d. c). Thus, oak wood carrying sporulating mats of the fungus is the main practical pathway that has been envisaged for international spread (EPPO n.d. c). If the wood carries bark, oak bark beetles are more likely to be present and provide an immediate pathway for transmission (EPPO n.d. c). Searles (2005) recognised that ISPM 15 was not written to control oak wilt. Removal of bark would mitigate the risk of bark beetles being present.

Many of the more pathogenic species of *Ceratocystis* are not very long lived in low temperature storage in pure culture or on the cut surfaces of overwintered logs. This characteristic suggests that these fungi will not survive for extended periods on dry, cut timber or other wood products. *Ceratocystis fimbriata* has been reported to survive for at least five years in large pieces of wood of *Platanus acerifolia* buried in soil. (USDA 2000.)

Most of the fungi in the genus *Ophiostoma* will survive in wood for more than a year with favourable temperature and moisture regimes, and they may even thrive under conditions that prevail during transport of wood packaging material (USDA 2000).

Dowding (1970, 1973), in field studies on small billets (30–40 cm long × 10–15 cm diameter) of *Pinus sylvestris* (Scots pine), found that much of *Ophiostoma piceae*, *Ophiostoma piliferum*, *Ophiostoma minus* and *Ceratocystis coerulescens* infection occurred on logs without insecticide treatment that had been wounded in such a way as to create sapwood wounds that were protected by residual flaps of bark. Dowding (1970) found that *Ceratocystis* species are restricted to the colonisation of protected wood surfaces not readily accessible to airborne spores, for example, cracks between bark and wood at the ends of logs, under flaps of bark, on debarked areas under logs or on the wood surfaces of bark beetle galleries. Dowding (1970) argued that the most likely means of transmission was casual arthropod transfer where the sticky spores were introduced to protected situations on the log, although water splash might be locally important. Dowding (1970) found that colonisation of protected blazes by basidiomycetes, *Trichoderma* species, and *Ceratocystis* species increased with length of time, as these areas retained their moisture content for longer. If logs had been stored for longer periods, cracking in the xylem, and between the inner bark and xylem at the ends of logs, would have created an additional port of entry for *Ceratocystis* species in particular, as the surfaces are protected from desiccation and light.

Dowding (1970) found that many internal colonies of *Ceratocystis* fungi never appeared on the end surface of the log, especially if external conditions caused drying of the log. These colonies usually originated in close association with beetle attack. They also arose from infections between the bark and the wood in older logs where the fungus had been able to grow and establish itself before growing back into the end. Removal of bark would mitigate the risk of these fungi by removing protected surfaces where spores germinate.

Wood that has been seasoned will be subject to colonisation by stain-producing fungi, moulds, and wood decay fungi. However, the fungi colonising rewetted wood may not be the same as those that inhabited the wood before drying (Dwinell 2001).

Probability of distribution

The likelihood that stain and wilt fungi will be distributed in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on) and transferred to a suitable site on a susceptible host: **High**.

Fungi within wood packaging material with bark would remain viable during distribution of commodities with wood packaging material via the wholesale or retail trade. Wood packaging material with bark can be expected to contain fungal mycelia and spores. Fungi in the genus *Ophiostoma* may survive in wood for more than a year with favourable temperature and moisture regimes, and they may even thrive under conditions that prevail during transport of wood packaging material (USDA 2000).

Some species can survive up to 10 years in wood stored at 30–40 % relative humidity (Seifert 1993). Some of the important sapstaining species of *Ophiostoma*; for example, *Ophiostoma piceae* and *Ophiostoma piliferum*, can be isolated readily from wood for up to 18 months after felling (Käärik 1968, in Seifert 1993). Presence of bark may assist survival of these fungi by retaining moisture in the timber.

Species of *Ophiostoma* (*Ophiostoma europhioides*, *Ophiostoma piceaperdum*, *Ophiostoma piceae*, *Ophiostoma piliferum*, *Ophiostoma pseudotsugae* and an unidentified species of *Ophiostoma*), as well as unidentified species of *Leptographium* (most are anamorphs of *Ophiostoma*), were isolated in a 12-month survey of green sawn timber imported into Australia (Simpson 1999).

Complete debarking of logs is widely practised to control beetle attacks and has been observed to apparently control airborne bluestain infections as well (Björkman 1946, 1958 a, b, in Dowding 1969). Bark is often removed or torn by transport operations and also separates from wood at the ends of logs stored for several months. These sites are to some extent protected from desiccation and form a frequent point of entry for bluestain infections (Dowding 1969).

The presence of bark on wood packaging material may allow the formation of fruiting structures and would make inspection for fungal activity more difficult. It is highly likely that the fungus would sporulate on the surface of infected wood under favourable environmental conditions. For example, a species of *Ceratocystis* has been observed fruiting on dunnage in Chile (USDA 2000).

Under conditions of transport, substantial inoculum in the form of conidiospores or ascospores can be expected to the present upon arrival at ports of entry (USDA 2000). The likelihood of these organisms coming into contact with suitable hosts may be high given the presence of appropriate vectors near the ports of entry or cargo destinations (USDA 2000).

Fruiting structures develop at the bark-wood interface (Hansen and Lewis 1997). *Ceratocystis fimbriata* produces asexual (form genus *Chalara*) and sexual fruiting bodies on the surface of cankers and also on the cut surfaces of infected wood, for example, on the cut ends of logs or sawn timber. Both types of fruiting structures produce sticky spores that are easily passively acquired and transported by a wide variety of insects (Hinds 1972). Contaminated insects may then be attracted to fresh wounds through which infection occurs (USDA 2000). Local spore dispersal may be accomplished by splashing water (USDA 2000).

Probability of entry (importation x distribution)

The likelihood that stain and wilt fungi will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on) and be distributed in a viable state to a susceptible host: **High**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Probability of establishment

The likelihood that stain and wilt fungi will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High**.

Blue stain fungi typically invade a host along medullary rays giving cross sections of logs a triangular or wedge-shaped section; for example, *Ceratocystis fimbriata* var. *platani*, which is capable of killing a healthy tree in a few months, develops from a single infection point, such as spores entering a small wound, and spreads through the tree by mycelial growth in the medullary rays and by mycelial growth and spore transport in the vessels (Gibbs 1993).

Research by Lindgren (1942, in Gibbs 1993) on penetration of *Ophiostoma piliferum* through blocks of fresh *Pinus echinata* sapwood showed that longitudinal growth of the fungus in the sapwood was 4.5 mm a day at 25 to 28°C. Rates of radial and tangential colonisation were appreciably slower, at 1 and 0.5 mm a day respectively. This may reflect the greater physical barriers to growth in these directions, but it may also reflect the fact that fungi often grow more rapidly in nutrient-poor than in nutrient-rich environments (Gibbs 1993). Liese and Schmid (1961, in Gibbs 1993), found that both *Ophiostoma piliferum* and *Ophiostoma piceae* colonised tracheids, rays and resin canals in naturally blue-stained wood of pine and spruce, and blocks of fresh pine wood. Progress of the fungi from tracheid to tracheid was through bordered pits or through direct penetration of the wall.

An example of the close relationship between ophiostomatoid fungi and insects can be seen with the pathogens that cause Dutch elm disease. Climatic conditions in the breeding galleries of the bark beetles are important for the growth of *O. novo-ulmi* inside the bark and its subsequent sporulation. Under optimum growth temperatures (22°C for *O. novo-ulmi* and 28°C for *O. ulmi*) (Braiser 1981), *Ophiostoma* sporulates inside the bark in the breeding galleries of its bark beetle vectors (*Scolytus* and *Hylurgopinus*) (CABI 2004). Microclimatic conditions are best for the fungus in relatively thick parts of the bark, where the moisture content is highest and relatively constant. The young beetle is often surrounded in its pupal chamber by synnemata of the fungus and has ample opportunity to catch a high number of spores (Webber 1990). *Scolytus scolytus*, the most effective vector, may carry up to 350,000 spores (Webber 1990), and about 1,000 spores are generally required for effective infection by *O. novo-ulmi* on an intermediate susceptible host such as *Ulmus procera* (Webber 2000). The fungus is inoculated into the phloem and xylem of a susceptible host by the beetle during its maturation feeding phase. After establishment of infection, the fungus spreads through the xylem and causes a vascular wilt.

Probability of spread

The likelihood that stain and wilt fungi will spread based on a comparative assessment of those factors in the area of origin and Australia considered pertinent to the expansion of the geographical distribution of the pest: **High**.

One of the distinctive features of most species of the genus *Ophiostoma* is their close association with bark beetles (Wingfield *et al.* 1993). Some of the species have a highly evolved relationship with their bark beetle vectors as specific mycangial fungi (Six and Paine 1997). On the other hand, with few exceptions, species of *Ceratocystis* do not have bark beetle associations but are rather associated with species of nitidulids (Nitidulidae), mites and other insects that are attracted by the strongly aromatic or fruit-like odours produced by these species (Malloch and Blackwell 1993), meaning that the spread potential of these fungi can be considered high (USDA 2000). A large majority of the more than 120 plus described species of ophiostomatoid fungi have intimate associations with arthropods, especially bark beetles (Scolytidae) (i.e. *Ophiostoma*) and nitidulids (Nitidulidae) (i.e. *Ceratocystis*) (Harrington 1993, Mallock and Blackwell 1993, Wingfield *et al.* 1997). Vectors of *Ceratocystis* species can be a diverse collection of fungal feeders that are attracted to the fruity odour of the mycelium (Harrington and Wingfield 1998). These unspecialised insect associates may serve to carry conidia to other mycelial mats for spermatization of protothecia or may disperse ascospores to fresh plant wounds or bare wood (Harrington and Wingfield 1998).

The importance of the microfauna factor (mites) in dissemination of bluestain fungi was first suggested by Dowding (1970), and emphasized again by Powell *et al.* (1995, in Uzunović *et al.* 1999). The work of Uzunović *et al.* (1999) also emphasized the role of microfauna and other insects in transmission of stain to log stacks in the absence of bark beetle vectors. Verrall (1941, in Dowding 1969) trapped various insects including flies and beetles and found many to be carrying the spores of blue stain fungi.

One of the main vectors of *Ophiostoma ulmi* and *Ophiostoma novo-ulmi*, *Scolytus multistriatus*, is well-established in Australia and has the potential to spread *Ophiostoma* spp. should an introduction occur. Potential native and exotic bark beetles, such as *Ips* spp., may also be efficient at spreading these fungi through contact with infected hosts. The bark beetle breeds in the inner bark of elm stems and movement of infested elm wood, including wood packaging material with bark attached, may spread the beetle and spores of the fungi to endangered areas. The close association of *Ophiostoma ulmi* and *Ophiostoma novo-ulmi* with bark beetles has made their spread over large areas and their integration into a fully functioning host-vector-pathogen system possible (CABI 2004). Certainly, the highest risk for spread of the fungi comes from the bark, as it harbours the vectors of the fungi. In addition to dispersal by vectors, *Ophiostoma ulmi* and *Ophiostoma novo-ulmi* are known to spread to new hosts via root grafts that frequently occur between neighbouring trees (CABI 2004).

The beetle *Hylastes ater* has been suggested as the mechanism by which a number of species of sapstain fungi were introduced to New Zealand (Wingfield & Gibbs 1991, in Thwaites *et al.* 2005). This beetle is widespread in Australia (APDD 2005). Reay *et al.* (2002, in Thwaites *et al.* 2005) described the significant relationship between sub-lethal attack of seedlings by the introduced bark beetle *Hylastes ater* and the subsequent invasion by many sapstain fungi in New Zealand. *Ophiostoma querci*, *Ophiostoma piceae*, *Leptographium procerum*, *Leptographium truncatum*, *Ophiostoma huntii*, and *Ophiostoma galeiforme* were isolated from living *Pinus radiata* seedlings damaged by *Hylastes ater* (Reay *et al.* 2002, in Thwaites *et al.* 2005). In this study, only one species, *Ophiostoma ips*, was isolated from *Hylastes ater* beetles. In a subsequent study, Reay *et al.* (2005) isolated *Ophiostoma galeiforme*, *Ophiostoma huntii*, *Ophiostoma floccosum*, *Ophiostoma setosum*, *Leptographium procerum* and *Leptographium truncatum* from *Pinus radiata* stumps, living seedlings damaged by *Hylastes ater*, and also from *Hylastes ater* beetles. *Ophiostoma querci* was isolated from stumps and beetles and *Ophiostoma stenoceras* was isolated from damaged seedlings. *Hylastes ater* was confirmed as a vector of many *Ophiostoma* species to *Pinus radiata* seedlings in laboratory experiments (Reay *et al.* 2005).

Some species of *Ophiostoma* have already established in Australia, such as *Ophiostoma huntii*, *Ophiostoma ips*, *Ophiostoma minus*, *Ophiostoma piceae* and *Ophiostoma piliferum* (Simpson ms), as well as *Ophiostoma quercus* (de Beer *et al.* 2003).

In addition to the association between fungi and beetles, ophiostomatoid fungi are dispersed by other means. Dowding (1969) found that species of *Ophiostoma* and *Ceratocystis* or their anamorphs released large numbers of conidia in misty air and, even in still air, these propagules were splash-dispersed up to four metres from a petri dish. The propagules dispersed were primarily conidia, while the ascospores generally remained in intact masses. Dowding (1969) found that ascospores were dispersed in a relatively insoluble viscous matrix. Conidia showed no change in germination rate over eight hours on heavily overcast days, but lost viability within eight hours in direct sunlight. Within and between piles of wood packaging material, water splash and run-off could spread spores from exposed fruiting mycelium, and if conditions remained moist and the spores were deposited in suitable areas for colonisation, new infections could easily be produced (Dowding 1969).

The conidia and ascospores of *Ceratocystis fagacearum*, the oak wilt fungus, are reported as long-lived, especially at low humidities and at low temperatures (Jewell 1953, Merek and Fergus 1954, both in Dowding 1969). *Ceratocystis fagacearum* can spread by root grafts that allow fungal hyphae to grow between diseased and healthy oaks (EPPO n.d. c).

Probability of entry, establishment and spread

The overall likelihood that stain and wilt fungi will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on), be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **High**.

The probability of entry, establishment or spread is determined by combining the probabilities of entry, establishment and spread using the matrix of ‘rules’ for combining descriptive likelihoods (Table 5).

Consequences

Consequences (direct and indirect) of the stain and wilt fungi: **Moderate.**

The relationship between sapstaining ophiostomatoid fungi and their hosts is varied. In some cases there is virtually no pathogenic activity; in other cases some blue stain fungi cause serious diseases in which the fungus is capable of overwhelming the resistance mechanisms of a healthy tree. (Gibbs 1993.)

The discoloration of timber by staining fungi is a severe problem resulting in significant economical losses (BioMat Net 2005). It affects domestic and export earnings for the forest industries (Thwaites *et al.* 2005). Blue stain does not damage the structural integrity of the wood, but most mills still deduct for the discoloration (Society of American Foresters 2005). Bluestain fungi lower the market value of wood, possibly causing major financial losses (Natural Resources Canada 2005). An example of this problem is the losses caused after the recent hurricanes in Florida, USA. Forest managers were advised that damaged trees that could be sold for veneer and sawn timber products should be harvested first as, after 4–6 weeks, a blue stain fungus will degrade the quality of these high-valued trees and they will have to be sold for pulpwood (Florida Department of Agriculture & Consumer Services 2004–2005). Timber with bluestain fungi loses value and eventually becomes worthless (USAToday 2005).

The fast growth and subsequent high proportion of sapwood of *Pinus radiata* imparts greater susceptibility to detrimental fungi, including sapstain fungi (Thwaites *et al.* 2005).

The potential impact that pathogenic ophiostomatoid fungi could have in Australia is demonstrated by the devastation of the American elm (*Ulmus americana* L.) in North America in two pandemics caused successively by *Ophiostoma ulmi* (introduced from Europe in elm logs) and *Ophiostoma novo-ulmi* (Mireku and Simpson 2002). The introduction of *Ophiostoma novo-ulmi* to North America, Europe and parts of Asia in a catastrophic pandemic caused the death of most mature elms. In some parts of Europe, 60–70% of elm trees were killed (Tainter and Baker 1996), and by the 1990s probably well over 25 million elms out of an estimated population of 30 million were killed in the United Kingdom (Brasier 1996). Losses caused by the two Dutch elm disease pandemics have been estimated to be over hundreds of millions of elms (Brasier 2001). The extreme virulence of the ophiostomatoid fungi indicates that economic damage would be high in the event of their introduction into Australia. The introduction of *Ophiostoma ulmi* or *Ophiostoma novo-ulmi* into Australia would have a significant impact on Australian urban landscapes, particularly in Victoria, South Australia, New South Wales, Tasmania and the Australian Capital Territory, owing to the loss of amenity trees. Such an introduction into the urban environment in Australia would have serious aesthetic and social loss at regional and local levels.

Exotic elm trees have been widely planted in temperate Australia since European settlement as amenity trees. Most plantings occur in Victoria, Tasmania, South Australia, New South Wales and the Australian Capital Territory (DPI 2004). Following the death of millions of elms in the northern hemisphere last century due to pests and disease, Australia is now regarded as having the finest collection of mature European elms in the world (DPI 2004). The exotic smaller European elm bark beetle, *Scolytus multistriatus*, one of the vectors of *O ulmi* and *O. novo-ulmi*, is well established in Victoria (DPI 2004). It is considered a minor pest in the absence of *Ophiostoma* spp. However, its potential to assist in the establishment of *O ulmi* and *O. novo-ulmi* in Australia is of concern should an introduction occur.

Some of these ophiostomatoid fungi occur on species of *Eucalyptus* (e.g. *Ceratocystis coronata* and *Ceratocystis pluriannulata*).

Covey (Email 16 November 2005) notes that in pallets used in the food and beverage sector '"Bluestain" is unsightly and many customers are concerned that it will lead to mould, and this is generally unacceptable in the food and beverage sector'.

Criterion	**Estimate**
Direct consequences	
Plant life or health	**D**— Stain and wilt fungi are capable of causing direct harm to a wide range of hosts (CABI 2003c, CABI 2004, Farr *et al.* 1989, Harrington and Wingfield 1998, Hutchison and Reid 1988, Seifert 1993, Thwaites *et al.* n.d., Rexrode and Brown 1983, Wingfield *et al.* 1993). These include important forestry species and native species. In spite of observations concerning the occasional poor survival of many species of *Ceratocystis* outside their natural host-parasite existence, the extreme virulence and pandemic producing potential of this group of fungi indicates that economic damage can be high in the event of an introduction (USDA 2000).

Criterion	Estimate
Any other aspects of the environment	**C** — Damage to amenity trees could cause significant alteration to the urban landscape. Introduction of a pathogen with tree-killing abilities into the urban tree environment would have major social impacts (USDA 2000).
Indirect consequences	
Eradication, control, etc.	**C** — Programs to minimise the impact of stain and wilt fungi are likely to be costly.
Domestic trade	**C** — The presence of these fungi in plantations or in nursery stock (e.g. *Ceratocystis fimbriata* causing cankers on fruit trees or on *Citrus* species (recorded on *Prunus domestica* but not *Prunus amygdalus* or Citrus species in Australia, APPD 2005)) may result in interstate trade restrictions. These restrictions may lead to a loss of markets.
International trade	**C** — The presence of these fungi in plantations or in nursery stock may have a significant effect at the district level owing to any limitations to access to overseas markets where these fungi are absent.
Environment	**B** — Pesticides required to control these fungi are estimated to have consequences that are unlikely to be discernible at the regional level and significant at the local level owing to the cost of treating individual trees.

Note: Refer to Table 6 (The assessment of local, district, regional and national consequences) and text under the 'Method for assessing consequences' section for details on the approach taken to consequence assessment).

Restricted risk estimate

The restricted risk estimate for stain and wilt fungi, determined by combining the overall 'probability of entry, of establishment and of spread' with the 'consequences' using the risk estimation matrix (Table 7): **Moderate**.

Cryphonectria parasitica (chestnut blight)

- *Cryphonectria parasitica* (Murrill) M.E. Barr
  Anamorph: *Endothiella parasitica* Roane

Probability of importation

The likelihood that *Cryphonectria parasitica* will arrive in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on): **Moderate**.

Cryphonectria parasitica is widespread in Asia (China, India, Japan, North Korea, South Korea, Turkey), Europe (Austria, Belgium, Bosnia and Herzegovina, Croatia, France, Germany, Greece, Hungary, Italy, Macedonia, Netherlands, Poland, Portugal, Romania, Russian Federation, Serbia and Montenegro, Slovakia, Slovenia, Spain, Switzerland, Ukraine), Africa (Tunisia) and North America (Canada, USA) (CABI 2004).

Cryphonectria parasitica, the chestnut blight fungus, has caused extensive mortality of American chestnut (*Castanea dentata*) in the eastern United States, but is not known as a major damaging agent in its Asian homeland (Kliejunas *et al.* 2001). Chestnut species in Asia are: *Castanea mollissima*; *Castanea seguinii*; *Castanea henryi* (China); and *Castanea crenata* (Japan and South Korea) (Flora of China n.d.).

European chestnut, *Castanea sativa*, currently occupies more than 1,700,000 ha in southern Europe (López and Alía 2005). It covers important areas in France, Italy, Spain, Portugal, Turkey, the United Kingdom and Greece (López and Alía 2005). It is found mainly as cultivated varieties in grafted orchards to produce nuts, and in coppices to produce small pieces of wood (López and Alía 2005). France and Italy are the most important producers of chestnut timber (COST, Multidisciplinary Chestnut Research n.d.). High forest, to produce high-quality timber, is very scarce but the area is increasing (López and Alía 2005). European chestnut (*Castanea sativa*) is used in wood packaging material (Defense Supply Center Columbus n.d., European Commission 2001).

Host range

Cryphonectria parasitica has a wide host range that covers utility plants, plantation trees and native species including *Eucalyptus*. Exotic host trees have been widely planted in temperate Australia since European settlement as amenity trees.

Cryphonectria parasitica affects leaves, stem and the whole plant. It is most important as a pathogen of *Castanea* and *Quercus* species although it may be found as a saprophyte or a weak pathogen on other species. The most important susceptible species are *Castanea dentata* (American chestnut) and *Castanea sativa* (European chestnut), although the latter is considered less susceptible than American chestnut. The important Asian species, *Castanea mollissima* (Chinese chestnut) and *Castanea crenata* (Japanese chestnut) are blight resistant but can develop severe disease. *Castanea seguinii* and *Castanea henryi* from China are hosts. *Castanea pumila*, from eastern USA, and other chinquapins are susceptible. Oaks such as *Quercus virginiana* (live oak) and *Quercus stellata* (post oak) are the only oaks in North American to be seriously affected by *Cryphonectria parasitica* and some trees may be killed. *Quercus coccinea* (scarlet oak) is commonly infected by *Cryphonectria parasitica* (Roane *et al.* 1986, Nash and Stambaugh 1989, Torsello *et al.* 1994, all in CABI 2004). *Cryphonectria parasitica* has been reported from *Quercus* in Slovakia (Juhasova 1991, in CABI 2004), on *Quercus petraea* (durmast oak) in Switzerland (Bissegger and Heiniger 1991, in CABI 2004), and on a range of trees in Italy, including *Alnus cordata* (Italian alder), *Ostrya carpinifolia*, *Quercus ilex* (evergreen oak) and *Quercus pubescens* (downy oak) (Turchetti *et al.* 1991, in CABI 2004), although the symptoms were mild. *Eucalyptus* is a host, as are *Castanopsis chrysophylla*, *Quercus rubra*, *Malus*, *Acer*, *Fagus*, *Rhus*, *Carpinus*, *Carya* and *Liriodendron* species. Some of these hosts are documented from artificial inoculations (Shear *et al.* 1917, in CABI 2004) and have not been found to be commonly infected in nature. Some hosts are based on artificial inoculations of dead (girdled) trees (Baird 1991, in CABI 2004).

Many species of *Eucalyptus* are susceptible to *Cryphonectria parasitica*, at least to some extent. Several have been ranked for resistance: *Eucalyptus maculata* and *Eucalyptus saligna* are highly susceptible; *Eucalyptus grandis*, *Eucalyptus propinqua* and *Eucalyptus tereticornis* are moderately susceptible; *Eucalyptus microcorys*, *Eucalyptus paniculata* and *Eucalyptus robusta* are moderately resistant; and *Eucalyptus citriodora*, *Eucalyptus torelliana* and *Eucalyptus urophylla* are highly resistant. (Sinclair *et al.* 1987.) Old and Kobayashi (1988) found that *Eucalyptus camaldulensis*, *Eucalyptus haemastoma*, *Eucalyptus microcorys*, *Eucalyptus punctata* and *Eucalyptus robusta* were susceptible to infection by *Cryphonectria parasitica*. They also reported that eucalypts are infected in the field by *Cryphonectria parasitica* in Japan.

Survival of ISPM 15 treatment

Survival of heat treatment

Allen (2001a) demonstrated that heat treatment of 56°C for a minimum of 30 minutes, as adopted in ISPM 15, will not eliminate 1) some stain fungi; 2) many decay fungi; or 3) most thermophilic fungi. The time-temperature schedule that achieves wood core temperature of 56°C for a minimum of 30 minutes would only arrest the development of some fungi of quarantine concern to Australia.

For movement within the European Union or importation into the European Union, wood of *Castanea* is required to be either bark free, originate in an area known to be free of *Cryphonectria parasitica* or to be kiln-dried to below 20% moisture content, expressed as a percentage of dry matter, achieved through an appropriate time/temperature schedule (European Commission 2004). The ISPM 15-approved heat treatment does not effect a reduction in moisture content. Removal of bark would provide a mitigation measure for this pathogen.

Survival of methyl bromide treatment

The ability of methyl bromide to penetrate into wood has been a limitation of efficacy, although removal of bark facilitates the penetration of the fumigant into wood (Ricard *et al.* 1968, in USDA 1991). The use of methyl bromide in managing the risk is uncertain, as the fumigant does not penetrate well through damp or green timber or across the grain of both hardwood and softwood (Banks 1999).

The presence of bark may also be of concern if larger sized timber is treated before being sawn into boards. After treatment, bark would also impede drying of the timber, keeping it greener for longer and making the treated timber more prone to infestation by fungi.

On the pathway

Wood packing materials can be made of both coniferous and non-coniferous wood. Many host species are used in the manufacture of wood packaging material; for example, oak is commonly used in the construction of wood packaging material in Canada (CFIA 2002).

Packing wood is usually inferior-quality timber and, as such, is likely to suffer from various imperfections such as growth abnormalities, physical damage, presence of bark and, most importantly from the forest health point of view, wood pests and diseases (McNamara and Kroeker n.d.).

Cryphonectria parasitica is a bark-inhabiting fungus (EPPO 2005a). Cankers caused by *Cryphonectria parasitica* can occur anywhere on twigs, branches and the trunk, but not roots (Sinclair *et al.* 1987). The fungus colonises bark tissues by the growth of mycelial fans that may be found in several layers of the bark; host cells are killed in advance of colonization (CABI 2004). Mycelial fans may be found throughout the inner and/or outer layers of loose/cracked bark and/or cambium layer (EPPO 2005a). Some annual rings of sapwood can be also infected, although mycelial fans do not form there (EPPO 2005a). Stromata with conidiomata and ascomata are formed in bark cracks (EPPO 2005a).

Debarked wood of *Castanea sativa* can harbour mycelium in (remnants of) the cambium layer and in the sapwood (EPPO 2005a), highlighting the importance of removal of all bark to mitigate this risk. Stromata or bare conidiomata can develop on the sapwood, most commonly at the cut end but also on the sides (EPPO 2005a).

Mycelium can live for up to 10 months in dried bark (EPPO n.d. b).). The highest risk for spread of *Cryphonectria parasitica* comes from the bark, as it harbours the propagules, fruiting bodies and spores of the fungi. Removal of bark would mitigate the risk of survival of this fungus on wood packaging material.

Probability of distribution

The likelihood that *Cryphonectria parasitica* will be distributed in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on) and transferred to a suitable site on a susceptible host: **High**.

Fungi within wood packaging material with bark would remain viable during distribution of commodities with wood packaging material via wholesale or retail trade. Wood packaging material with bark can be expected to contain fungal mycelia and spores. As stated above, mycelium of *Cryphonectria parasitica* can live for up to 10 months in dried bark (EPPO n.d. b).

Infected wood, particularly when cankered bark is attached, could serve as a reservoir for *Cryphonectria parasitica* and provide a pathway to new infection centres when transported internationally, such as might occur with sawn wood packaging material.

Propagules, likely conidia or mycelial fragments, have been associated with insects in Coleoptera and Diptera (Russin *et al.* 1984, Pakaluk and Anagnostakis 1997, in CABI 2004), mites (Wendt *et al.* 1983, Nannelli *et al.* 1998, both in CABI 2004), and slugs (Turchetti and Chelazzi 1984, in CABI 2004).

Probability of entry (importation x distribution)

The likelihood that *Cryphonectria parasitica* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on) and be distributed in a viable state to a susceptible host: **Moderate**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Probability of establishment

The likelihood that *Cryphonectria parasitica* will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High**.

Spread within the host is rapid unless cankers form which temporarily restrict the fungus (EPPO n.d. b). The fungus can exist as a saprobe on broad-leaved trees beyond its parasitic host range (EPPO n.d. b).

Cryphonectria parasitica enters the host through wounds. In the process of colonizing the wound, the fungus forms a hyphal fan with which it invades healthy tissues. After colonizing the bark tissues, a stroma is formed directly beneath the outermost layer of bark, which is comprised of a combination of dead and dying tree tissues and fungal hyphae. Within this stroma, the stromal pustules (pycnidia and perithecia) develop. These structures are the asexual and sexual fruiting bodies. They erupt through the bark and release large numbers of spores into the environment. (Kazmierczak *et al.* 2005.)

Australia has a conducive environment to assist copious production of spores once wood packaging materials with bark containing the fungus enter Australia. Under moist conditions, the stromata of the fungus erupt through the surface of the infected bark (Sinclair *et al.* 1987). Both anamorph and teleomorph fruit bodies may be present simultaneously in the same stroma (Sinclair *et al.* 1987).

Probability of spread

The likelihood that *Cryphonectria parasitica* will spread based on a comparative assessment of those factors in the area of origin and in Australia considered pertinent to the expansion of the geographical distribution of the pest: **High**.

Although insect vectors are not thought to play a very important role in the transmission of the disease, it is noteworthy that chestnut blight cankers have a very large and diverse fauna. In trapping experiments in the USA, 495 species of insect were captured on old blight cankers. A considerable number of insects spent parts of their life cycle on cankers and nearly 69 species were found to carry inoculum of *Cryphonectria parasitica*. (Russin *et al.* 1984.)

The rapid spread of the chestnut blight fungus demonstrates the capability of spores to disperse from infected wood via small animals and insects and wind and rain. Spores from an infected tree are lifted by wind or carried by rain to a healthy tree, entering it through cracks or wounds in the bark (Rellou 2002).

Ascospores are the primary source of virulent inoculum. These spores are released after rain and are adapted for spread by wind. These are produced in abundance on blight-susceptible chestnut trees, and, to a lesser extent, on blight-resistant chestnut trees and oaks. They are disseminated in air currents and have been detected in large numbers as far as 90–120 m from a perithecial source; they were expelled every day for 168 days. (CABI 2004.)

Stromata release millions of conidia embedded in a water-soluble gelatinous matrix. These spores are adapted for spread by rain and are also carried by many insects and birds (Sinclair *et al.* 1987). The smaller conidia are considered less infective than ascospores and are primarily water and insect-borne. Tendrils of conidia in cirrhi, formed in wet weather on a stroma, may contain 100 million conidia (Heald 1926, in CABI 2004). Large numbers of conidia have been recovered from birds (Heald and Studhalter 1914).

Airborne ascospores and conidia carried by birds and insects are primarily responsible for overland spread of chestnut blight at an average 30 km per year (Sinclair *et al.* 1987). The spread potential of *Cryphonectria parasitica* is very high as it produces large numbers of spores (conidia and ascospores), which are airborne and also carried to other susceptible hosts by insects and birds. EPPO (n.d. b) records that beetles in the genus *Agrilus* are involved in transmission. Species of this genus occur in Australia (APPD 2005). Wounds in the bark, of mechanical or biological origin, are the main infection court of *Cryphonectria parasitica* (CABI 2004).

Ascospores have been detected in large numbers as far as 90–120 m from a perithecial source, expelled every day for 168 days (CABI 2004). The optimum temperature range for expulsion of ascospores is 20-27°C (CABI 2004). There will be no vector or climatic limitation for the spread of the fungus in Australia. Australian climatic conditions compare well with countries where the fungus occurs. Availability of hosts (e.g. *Eucalyptus* species) throughout Australia means that the pathogen would easily move from one tree to another.

Probability of entry, establishment and spread

The overall likelihood that *Cryphonectria parasitica* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on), be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Moderate**.

The probability of entry, establishment or spread is determined by combining the probabilities of entry, establishment and spread using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Consequences

Cryphonectria parasitica can have spectacular and long-term effects on forest ecosystems. The fungus is known to cause substantial effects on tree growth and mortality. For example, within 50 years following discovery in 1904 of the chestnut blight in New York City, the disease spread to the extremes of the natural range of the American chestnut, destroying the economic and aesthetic value of one of America's most versatile trees (Sinclair *et al*. 1987). Almost all canopy or 3.5 billion American chestnut trees were killed (CABI 2004). The American chestnut was reduced in most areas to a scattered population of sprout stems in the forest understorey (Sinclair *et al.* 1987).

In Australia, the new and existing chestnut industry would also be significantly affected. In general, the disease would destroy the economic and aesthetic value of some major Australian tree species, possibly including species of *Eucalyptus*. The consequences will be major at regional levels. Also, such introduction into the urban environment in Australia would have serious aesthetic and social loss at local levels.

Consequences (direct and indirect) of *Cryphonectria parasitica*: **Moderate.**

Criterion	**Estimate**
Direct consequences	
Plant life or health	**D** — *Cryphonectria parasitica* is capable of causing direct harm to a wide range of hosts (CABI 2004). Many important native and introduced tree species of Australia are hosts of *Cryphonectria parasitica*, the causal agent of chestnut blight. These tree species include *Eucalyptus* spp., *Castanea* spp., *Quercus* spp. and *Malus*

Criterion	Estimate
	pumila. Some of these are important forestry and amenity tree species.
Any other aspects of the environment	**C** — Damage to amenity trees could cause significant alteration to the urban landscape, especially where *Eucalyptus* species are planted as amenity trees.
Indirect consequences	
Eradication, control, etc.	**C** — Programs to minimise the impact of *Cryphonectria parasitica* are likely to be costly.
Domestic trade	**C** — The presence of this fungus in nursery stock or plantations in chestnut production may result in interstate trade restrictions. These restrictions may lead to a loss of markets.
International trade	**C** — The presence of these fungi in plantations, in nursery stock in chestnut production may have a significant effect at the district level owing to any limitations to access to overseas markets where this pest is absent.
Environment	**B** — Pesticides required to control this fungus are estimated to have consequences that are unlikely to be discernible at the regional level and significant at the local level owing to the cost of treating individual amenity trees or trees for chestnut production.

Note: Refer to Table 6 (The assessment of local, district, regional and national consequences) and text under the 'Method for assessing consequences' section for details on the approach taken to consequence assessment).

Restricted risk estimate

The restricted risk estimate for *Cryphonectria parasitica*, determined by combining the overall 'probability of entry, of establishment and of spread' with the 'consequences' using the risk estimation matrix (Table 7): **Moderate**.

Fusarium circinatum **(pine pitch canker)**

- *Fusarium circinatum* Nirenberg & O'Donnell

  Teleomorph: *Gibberella circinata* Nirenberg & O'Donnell ex Britz, T.A. Coutinho, M.J. Wingfield & Marasas

Probability of importation

The likelihood that *Fusarium circinatum* will arrive in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on): **Moderate**.

Fusarium circinatum occurs in Asia (Iraq, Japan and Philippines), Europe (Italy and Spain), Africa (South Africa and Tanzania), North America (Mexico, USA [Alabama, Arkansas, California, Florida, Georgia, Indiana, Louisiana, Massachusetts, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Virginia and Washington]), Central America (Haiti and Honduras), and South America (Chile) (CABI 2005).

The wide host range within species of *Pinus* that are grown commercially, the wide geographical distribution of the pathogen and the inferior quality of timber usually used for wood packaging material indicate that *Fusarium circinatum* is likely to be in timber destined for the production of wood packaging material. In the United States, the pallet industry uses approximately 1.8 billion board feet of softwood lumber (as well 4.5 billion board feet of hardwood lumber) for the production of 400 to 500 million solid wood pallets annually (North Carolina DNR 2003, Bush and Araman 1997, USDA APHIS 2003, all references cited from Smith *et al.* n.d.).

Host range

Major hosts are: *Pinus elliottii* (slash pine), *Pinus palustris* (longleaf pine), *Pinus patula* (Mexican weeping pine), *Pinus radiata* (radiata pine), *Pinus taeda* (loblolly pine), *Pinus virginiana* (scrub pine). Minor hosts are: *Pinus arizonica*, *Pinus attenuata* (knobcode pine), *Pinus ayacahuite* (Mexican white pine), *Pinus canariensis* (Canary pine), *Pinus cembroides* (Mexican pine), *Pinus clausa* (sand pine), *Pinus contorta* (lodgepole pine), *Pinus coulteri* (big-cone pine), *Pinus densiflora* (Japanese umbrella pine), *Pinus discolor*, *Pinus douglasiana*, *Pinus durangensis* (Durango pine), *Pinus echinata* (shortleaf pine), *Pinus estevezii*, *Pinus glabra*, *Pinus greggii* (Gregg's pine), *Pinus halepensis* (Aleppo pine), *Pinus hartwegii* (Hartweg pine), *Pinus leiophylla* (smooth-leaved pine), *Pinus luchuensis*, *Pinus maximinoi*, *Pinus michoacana* (Michoacan pine), *Pinus montezumae* (montezuma pine), *Pinus muricata* (bishop pine), *Pinus oaxacana*, *Pinus occidentalis* (Haitian pine), *Pinus oocarpa* (ocote pine), *Pinus pinaster* (maritime pine), *Pinus pinea* (stone pine), *Pinus ponderosa* (ponderosa pine), *Pinus pringlei*, *Pinus pseudostrobus* (pseudostrobus pine), *Pinus pungens*, *Pinus rigida* (pitch pine), *Pinus sabiniana* (Digger pine), *Pinus serotina* (pond pine), *Pinus strobus* (eastern white pine), *Pinus sylvestris* (Scots pine), *Pinus thunbergii* (Japanese black pine), *Pinus torreyana*, *Pseudotsuga menziesii* (Douglas-fir). The distinction drawn in the list of hosts between 'major' and 'minor' hosts is somewhat arbitrary, and is based primarily on published reports of economic damage. Minor hosts are less damaged because they are either inherently less susceptible to the pathogen, exposed to lower disease pressure because of location, climate or levels of insect vector activity, or found in natural or less intensively managed systems. (CABI 2005.)

Fusarium circinatum affects pines of all ages, cones (seeds), growing points, inflorescence, leaves, roots, stems and the whole plant (CABI 2005). It has recently been recorded in symptomless seedlings of *Pseudotsuga* from California, USA (Ormsby 2004).

Survival of ISPM 15 treatment

Survival of heat treatment

New Zealand's current import requirements for sawn timber of pine pitch canker host material (sawn timber or poles of *Pinus* species or *Pseudotsuga menziesii* originating from areas considered by the Ministry of Agriculture and Forestry not to be free of *Fusarium circinatum* or Pitch Canker disease) require that the material has been heat treated to 70°C (core temperature) for four continuous hours; or kiln dried to less than 20% moisture content at temperatures exceeding 56°C. (Ormsby 2004.)

The California Forest Pest Council's (2000) guidelines for moving pine logs from areas infested with pine pitch canker require that logs being moved from the zone of Infestation have received one of the following treatments: have been stockpiled for one year or more within the zone of Infestation; have been heated to 160ºF [71.1ºC] at the centre of the log for 75 minutes; or, have been completely debarked and all bole cankers removed. Kiln-dried lumber (dried until the centre of the largest dimensional piece reaches 140ºF [60ºC]) can be shipped out of the zone of infestation immediately after treatment.

The ISPM 15-approved heat treatment does not effect a reduction in moisture content. As the fungus occurs in the bark, removal of bark would mitigate the risk if there are doubts about the efficacy of the ISPM 15-approved heat treatment. The presence of bark may also prolong the seasoning process as well as provide a suitable microclimate for fungal spores to germinate and infest ISPM 15-treated timber.

Research carried out by Ridley (pers. comm.) involved growing *Fusarium circinatum* on agar and exposing the cultures to heat. Temperatures used were 40, 50 and 60°C for 10 minute intervals up to 60 minutes. *Fusarium circinatum* survived the 40°C series, there was some death at 50°C when exposed for 50 and 60 minutes but some survived, and at 60°C there was some survival at exposure for 10 and 20 minutes but none after 30 minutes or longer.

In research carried out by Ridley (2004), wood blocks were infested with selected fungi (one of which was *Fusarium circinatum*) and subjected to a range of temperatures and exposure times. In comparing *in vitro* and *in vivo* treatments, heat tolerance increased when *Fusarium circinatum* was grown in wood—70ºC for 10 minutes was required to kill *Fusarium circinatum* in wood blocks after 0, 2, 7 and 28 days desiccation (Ridley and Gardner 2004). Given the variation in temperatures and times necessary to kill this small subset of species tested, 40–70ºC for 10–40 minutes, a broad treatment standard was recommended. In most cases where imported products require treatment the infesting fungi will be unknown, tentatively identified or even misidentified, and likely to be in an unknown physiological state (Ridley 2004). In such cases a broad approach to treatment is recommended. MAF New Zealand's current approach to treatment of moderately high temperature and long exposure time was recommended (Ridley 2004).

The results of the experimental work described above, as well as the temperatures required in the above heat treatments that are higher than that required for the ISPM 15 treatment, indicate that *Fusarium circinatum* could survive the heat treatment required by ISPM 15.

Survival of methyl bromide treatment

The efficacy data of methyl bromide for many pests and pathogens does not exist (USDA 2000, cited in USDA 2002). Penetration of methyl bromide into wood is inversely proportional to the moisture content of the article and, therefore, it does not penetrate as well into wood with high moisture content (e.g. green logs). It also does not penetrate well across the grain of both hardwood and softwood (Banks 1999). These factors could result in *Fusarium circinatum* surviving the methyl bromide treatment required by ISPM 15.

The ability of methyl bromide to penetrate into wood has been a limitation of efficacy, although removal of bark facilitates the penetration of the fumigant into wood (Ricard *et al.* 1968, in USDA 1991). As the fungus is present in the bark, removal of bark would also reduce the risk of survival. The fumigant is also only weakly effective against pathogens of quarantine concern (Rhatigan *et al.* 1995). Methyl bromide requires much higher dosages (ct-products) for activity against nematodes, snails and fungi (typically ct-products exceeding 5000 g h m-3 compared with about 200 g h m-3 for insects) (Banks n.d.).

Biosecurity New Zealand (n.d.) requires that timber (poles, posts or rounds) from *Pinus* species that is being imported from areas not considered by the New Zealand Ministry of Agriculture and Forestry to be free of *Fusarium circinatum* (pine pitch canker), must be heat treated to a core temperature of 70°C for four hours.

On the pathway

Fusarium circinatum is found in the phloem, cambium and xylem (inner bark) of infected hosts (CABI 2004).

The fungus can survive in cut wood or soil for a year or more and insects that carry the fungus may survive in cut wood or chips for many months (California Forest Pest Council 2000). *Fusarium circinatum* spores are known to survive for extended periods within cut wood (Agricultural Commissioner's Office 1998). The fungus can survive in soil for six months and in wood pieces for over 12 months (Ormsby 2004). CABI Crop Protection Compendium (2004) indicates that at moderate temperatures the pathogen can survive for a year or more in infected wood. The fungus is known to survive for long periods (up to one year) in small-diameter wood tissues (Dick and Bain 1997).

Survival of the fungus in timber (as a result of stem cankers) has not been tested but, it has been shown that the fungus survives in chipped infected branch material of *Pinus radiata* (with branches up to 5 cm in diameter with bark retained) (Gadgil *et al.* 2003). Round wood and sawn wood, especially if debarked, are less likely to carry the fungus (EPPO 2005b).

Wood packing materials can be made of both coniferous and non-coniferous raw wood. Many host species are used in the manufacture of wood packaging material, for example, oak is commonly used in the construction of wood packaging material in Canada (CFIA 2002). Wood packaging material and dunnage was considered to be of medium risk as a pathway for *Fusarium circinatum* in the *Management Plan Response to an Incursion of Pine Pitch Canker* (Gadgil *et al.* 2003).

Packing wood is usually inferior-quality timber and, as such, is likely to suffer from various imperfections such as growth abnormalities, physical damage, presence of bark, and (most importantly from the forest health point of view) wood pests and diseases (McNamara and Kroeker n.d.).

With the increase in pine wood becoming available as dead and dying trees in North America are removed as a result of mountain pine beetle attack, there is an increased probability of such material being used as wood packaging materials. Wood from trees of *Pinus radiata* in California killed by *Fusarium circinatum* could also be used in wood packaging. When these packaging materials with bark enter the global trade routes, they could harbour fungal propagules, spores and insect vectors that transmit the fungus.

The fungus is capable of being transported on wood packaging and dunnage, as well as lumber (Mireku and Simpson 2002). Mireku and Simpson (2002) considered that pine pitch canker could be transported on lumber of *Pseudotsuga*.

Probability of distribution

The likelihood that *Fusarium circinatum* will be distributed in Australia with the importation of ISPM 15 compliant wood packaging material (with bark on) and transferred to a suitable site on a susceptible host: **High**.

Fungi within wood packaging material with bark would remain viable during distribution of commodities with wood packaging material via the wholesale or retail trade. Wood packaging material with bark can be expected to contain fungal mycelia and spores. A single piece of timber (e.g. incorporated into a pallet sawn from a stem canker could provide a source of soil inoculum (Gadgil *et al.* 2003). The potential for dunnage and packing material to be disposed of in areas close to ports is high (Gadgil *et al.* 2003).

Fusarium circinatum is known to sporulate prolifically in insect galleries and infested wood and bark. The fungus may be present in insect galleries or in the inner bark of the packaging material and current methods of treatment may not be effective in eradicating these infections and preventing survival in transit to Australia. Furthermore, *Fusarium circinatum* and its vectors may go undetected by visual inspection of wood packaging materials, especially if bark is attached.

Fusarium circinatum spores may be carried by wind, spread by splashing water (fog or rain) (Gadgil *et al.* 2003) and maximum natural dispersal takes place during wet, windy conditions.

Probability of entry (importation x distribution)

The likelihood that *Fusarium circinatum* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on) and be distributed in a viable state to a susceptible host: **Moderate**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Probability of establishment

The likelihood that *Fusarium circinatum* will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **Moderate**.

Fusarium circinatum does not appear to have the ability to infect uninjured tissue (Gadgil *et al.* 2003). However, when provided with a suitable infection site, the pathogen can infect all parts of the tree, including needles and stem tissue, the main stem, roots, cones and seeds (Gadgil *et al.* 2003). It causes lesions that can encircle or girdle branches, roots, and the main stems (Wikler *et al.* 2003).

Fusarium circinatum sporulates on some of the infected tissues, producing salmon pink masses of conidia (Gadgil *et al.* 2003). Insects, water splash or air currents may then disperse spores to new infection sites on the tree. Infected xylem tissues are brown, necrotic and impregnated with resin (Hartman *et al.* 2001). In plantations, shoot dieback and limb cankers predominate (Hartman *et al.* 2001).

Multiple branch infections can cause extensive dieback in the crown of the tree and may lead to tree mortality. The tree produces copious amounts of resin in response to an infection. Flattened or slightly sunken cankers (large infection sites) on the main stem of the tree usually appear after the tree already has multiple branch infections. The fungus is not known to move within the tree; therefore, each canker or lesion is a separate and distinct infection. (Winkler *et al.* 2003.)

Probability of spread

The likelihood that *Fusarium circinatum* will spread based on a comparative assessment of those factors in the area of origin and in Australia considered pertinent to the expansion of the geographical distribution of the pest: **High**.

Fusarium circinatum has a narrow but widely distributed host range of species of *Pinus* and *Pseudotsuga* that covers utility plants and plantation trees. Exotic host trees have been widely planted in temperate Australia since European settlement as amenity trees.

Bark beetles may be found colonising cones, branches, limbs, trunks and roots (Furniss and Carolin 1980). In inoculation tests, where a spore-containing droplet is inserted into the tissue (imitating transmission of the disease through the feeding activity of insects), infection can be initiated with as few as 25 microconidia (Storer *et al.* 1999a).

Insect vectors are another means of natural dispersal of the fungus if contaminated insects are present under the bark, if they emerge, and if their dispersal distance is far enough for them to find susceptible hosts (Gadgil *et al.* 2003). In California, the fungus has been associated with numerous insects, and a number of native bark beetle (Coleoptera: Scolytidae) vectors have been reported (Storer *et al*. 1998). In many cases, these bark beetles have been shown to vector the pathogen to healthy trees (Wood and Storer 2002).

Insects appear to be more important in disease development than does mechanical damage. Potential insect vectors and wounding agents are very common in the forests of south-eastern Australia, so the availability of insect vectors or wounding agents is unlikely to be a limiting factor in the pitch canker fungus' ability to attack pine species in Australia.

The fungus has been isolated from a number of insects, and the following insects are capable of vectoring the pitch canker pathogen: engraver beetles (*Ips* spp.), twig beetles (*Pityophthorus* spp.), cone beetles (*Conophthorus radiata*), and deathwatch beetles (*Ernobius punctulatus*) (Wikler *et al.* 2003). The pathogen has been isolated from *Pityophthorus carmeli*, *Pityophthorus setosus*, *Pityophthorus nitidulus*, *Pityophthorus pulchellus tuberculatus* and *Pityophthorus californicus*. In addition the pathogen has been isolated from *Lasconotus pertenuis* and *Lasconotus nucleatus* (Coleoptera: Colydiidae) which are associates of twig beetles (Storer *et al.* 1999b). Spittlebugs (*Aphrophora canadensis* (Homoptera: Cercopidae)) carry the pathogen. *Fusarium circinatum* has been isolated from *Ips* species (*Ips paraconfusus*, *Ips mexicanus* and *Ips plastographus maritimis*) (Storer *et al.* 1999b).

It is reasonable to conclude that suitable insect vectors present in Australia such as *Ips grandicollis* (five-spined bark beetle), *Hylastes ater* (black pine bark beetle) and *Hylurgus ligniperda* (golden-haired bark beetle) would assist in the establishment of the fungus if it arrives in Australia (Phillips 2001).

Although some of these insects have not been known to visit healthy portions of trees, workers speculate that the insects may 'taste' trees indiscriminately to determine which ones are suitable for colonization. In this exploratory feeding, they may deposit inoculum that they picked up in their brood tree. (Worrall 2005b.)

Injuries from by hail, wind and galls caused by fusiform rust also become infected. The optimum temperature for growth of the fungus is 24ºC. Water stress and fertilisation at high rates may enhance pine susceptibility. Isolates of this fungus vary in virulence, but host-specialised strains among those capable of infecting pines are unknown. Isolates from one pine species can readily infect others. (Sinclair *et al.* 1987).

Once the fungus is established, it could move with pine and Douglas-fir seedlings, young trees, other nursery stock, lumber and wood packaging material with or without bark, woodchips and firewood. It could also move with pine seed or cones from infested sites. It is also spread by contaminated pruning tools (Agricultural Commissioner's Office 1998).

Environmental conditions in areas where pines are grown in Australia could favour spread of the pitch canker fungus. All reports of pitch canker, to date, originate in areas where the climate is warm and humid (a minimum of 14°C with 12–16 hours of free moisture). Typically the weather is rainy with mild winters where the coolest month is above 0°C but below 18°C, and the warmest month is above 10°C. Most areas with radiata pine plantations in Australia will have similar climatic conditions and could be considered at risk of infection by the pitch canker fungus.

All the commercial pine plantations in Australia are susceptible to pitch canker disease (Devey *et al*. 1999). Radiata pine which accounts for about 85% of the commercial plantations in Australia and about half the annual harvest of timber is very susceptible to the pitch canker fungus. Also, radiata pine is grown in regions (New South Wales, Victoria, South Australia and Tasmania) where the temperature and rainfall are suitable for colonisation of the pathogen. No climatic barriers exist in Australia to the establishment and development of pitch canker in Australia. Conditions for the growth of pitch canker disease are likely to be suitable for much of the year.

Probability of entry, establishment and spread

The overall likelihood that *Fusarium circinatum* will enter Australia as a result of trade using ISPM 15 compliant wood packaging material (with bark on), be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Low**.

The probability of entry, establishment or spread is determined by combining the probabilities of entry, establishment and spread using the matrix of 'rules' for combining descriptive likelihoods (Table 5).

Consequences

Pine pitch canker is one of the most serious threats to pine plantations in Australia. Introduction and establishment of *Fusarium circinatum* in Australia could deleteriously affect the current disease status of Australia's exotic plantation forests. This situation could pose serious threats to our current wood production and the potential utilisation of wood in the future. Economic loss in Australia would include tree mortality in plantation forests and amenity stands, reduced wood production and quality, and seed contamination in orchards. It is estimated that annual income losses would be hundreds of millions of dollars. Pitch canker fungus has caused severe damage in native stands and plantations of radiata pine in California and south-eastern USA and could pose a significant economic threat to pine and Douglas-fir plantations in Australia.

Consequences (direct and indirect) of *Fusarium circinatum*: **Moderate**.

Criterion	Estimate

Criterion	Estimate
Direct consequences	
Plant life or health	**D** — *Fusarium circinatum* causes direct harm to a narrow range of economically important hosts, *Pinus* and *Pseudotsuga*.
Any other aspects of the environment	**C** — Damage to amenity trees could cause alteration to the urban landscape.
Indirect consequences	
Eradication, control, etc.	**C** — Programs to minimise the impact of *Fusarium circinatum* are likely to be costly.
Domestic trade	**C** — The presence of these fungi in plantations or in nursery stock may result in interstate trade restrictions. These restrictions may lead to a loss of markets.
International trade	**C** — The presence of these fungi in plantations or in nursery stock may have a significant effect at the district level owing to any limitations to access to overseas markets where these pests are absent.
Environment	**B** — Pesticides required to control this fungus are estimated to have consequences that are unlikely to be discernible at the regional level and significant at the local level owing to the cost of treating individual amenity trees. It is unlikely that trees in the plantation estate would be treated with pesticide.

Note: Refer to Table 6 (The assessment of local, district, regional and national consequences) and text under the 'Method for assessing consequences' section for details on the approach taken to consequence assessment).

Restricted risk estimate

The restricted risk estimate for *Fusarium circinatum*, determined by combining the overall 'probability of entry, of establishment and of spread' with the 'consequences' using the risk estimation matrix (Table 7): **Low.**

11. PEST RISK ASSESSMENT CONCLUSIONS

Table 8 summarises the detailed pest risk assessments and provides restricted risk estimates (based on application of ISPM 15 approved measures) for the selected quarantine pests considered to be associated with imports of wood packaging materials with bark into Australia. Of the selected pests or pest groups (four arthropods and three pathogens), six were assessed to have restricted risk estimates of ‘Low’ to ‘Moderate’. The restricted risk estimates for these pests exceed Australia’s appropriate level of protection. Risk management measures are therefore required in addition to ISPM 15 measures for the importation of wood packaging materials into Australia. The risk management measures are described in Section 13 of this report.

The SPS Agreement defines the concept of an appropriate level of sanitary or phytosanitary protection (ALOP) ‘as the level of protection deemed appropriate by the WTO Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory’. Like many other countries, Australia expresses its ALOP in qualitative terms. Australia’s ALOP, which reflects community expectation through government policy, is currently expressed as providing a high level of sanitary or phytosanitary protection aimed at reducing risk to a very low level, but not to zero. ALOP can be illustrated using a ‘risk estimation matrix’. The Biosecurity Australia import risk analysis handbook provides details of the risk estimation matrix (Commonwealth of Australia 2003).

Table 8 Summary of individual pest risk assessments

Pest Name	Probability of					Overall probability of entry, of establishment and of spread	Consequences	Restricted Risk
	Entry			Establishment	Spread			
	Importation	Distribution	Overall probability of entry					
Arthropods								
Callidiellum rufipenne	Low	Moderate	Low	Moderate	Moderate	Low	Very Low	**Negligible**
Callidium violaceum	High	High	High	High	Moderate	Moderate	Low	**Low**
Gnathotrichus spp.	Moderate	High	Moderate	High	High	Moderate	Low	**Low**
Ips spp.	Moderate	High	Moderate	High	High	Moderate	Low	**Low**
Pathogens								
Ophiostoma/Ceratocystis spp.	High	High	High	High	High	High	Moderate	**Moderate**
Cryphonectria parasitica	Moderate	High	Moderate	High	High	Moderate	Moderate	**Moderate**
Fusarium circinatum	Moderate	High	Moderate	Moderate	High	Low	Moderate	**Low**

12. PEST RISK MANAGEMENT

Risk management describes the process of identifying and implementing measures to manage risks so as to achieve Australia's ALOP, while ensuring that any negative effects on trade are minimised.

To implement risk management appropriately, it is necessary to formalise the difference between 'unrestricted' and 'restricted' risk estimates. Unrestricted risk estimates are those derived in the absence of specific risk management measures, or following only baseline risk management procedures based on commercial production practices. By contrast, restricted or mitigated risk estimates are those derived when 'risk management' is applied, for example, the treatments in ISPM 15.

The conclusions from the preceding pest risk assessments are used to decide whether further risk management in addition to ISPM 15 is required and if so, the strength of measures to be used. Where the risk estimate exceeds Australia's ALOP, risk management measures are required to reduce this risk to a very low level. Since zero-risk is not a reasonable option, the guiding principle for risk management is to manage risk to achieve the required degree of safety that can be justified and is feasible within the limits of available options and resources.

ISPM 11 provides details on the identification and selection of appropriate risk management options and notes that the choice of measures should be based on their effectiveness in reducing the probability of the introduction of the pest.

Examples given of measures commonly applied to traded commodities include:

- *Options for consignments* – e.g. inspection or testing for freedom, prohibition of parts of the host, a pre-entry or post-entry quarantine system, specified conditions on preparation of the consignment, specified treatment of the consignment, restrictions on end use, distribution and periods of entry of the commodity;
- *Options preventing or reducing infestation in the crop* – e.g. treatment of the crop, restriction on the composition of a consignment so it is composed of plants belonging to resistant or less susceptible species, harvesting of plants at a certain age or specified time of the year, production in a certification scheme;
- *Options ensuring that the area, place or site of production or crop is free from the pest* – e.g. pest-free area, pest-free place of production or pest-free production site;
- *Options for other types of pathways* – e.g. consider natural spread, measures for human travellers and their baggage, cleaning or disinfestation of contaminated machinery;
- *Options within the importing country* – e.g. surveillance and eradication programs; and
- *Prohibition of commodities* – e.g. if no satisfactory measure can be found.

An additional risk management measure is identified for each pest or pest group above the ALOP. The pests that are above the ALOP require the use of a risk management measure in addition to those set out in ISPM 15.

Additional Mitigation Measure Required to Maintain Australia's ALOP

Bark Freedom

The importation of solid wood packaging materials is regulated in Australia because these materials present a number of plant pest risks. Wood packaging material is often constructed from green wood, often includes bark, and is often made from low quality wood that sometimes may be of low quality owing to pest damage. Australia's long-standing requirement for freedom of bark for wood packaging materials is a result of the relatively high arthropod pest, pathogen and decay fungi risks associated with wood packaging material.

Australia's concerns about the efficacy of ISPM 15 approved treatment measures are heightened by the fact that the ISPM 15 standard does not require that the wood from which the packaging materials are constructed is to be free of bark before treatment. Many countries, including Australia, New Zealand, and countries in the EU recognise the risk posed by bark on wood packaging materials. Some of the problems associated with bark include:

1. it harbours serious insect pests, decay fungi, pathogens and pathogen vectors;
2. it hampers the inspection process;
3. it impedes fumigation;
4. it delays the seasoning process, and allows timber to remain attractive to timber pests for longer than if bark is removed;
5. it enhances the risk of infestation or re-infestation; and
6. it increases the probability of transmission of soil or hitchhiker pests.

The additional requirement for wood packaging materials to be bark free is a key to improving the efficacy of treatments provided by ISPM 15. As pointed out by Burgess (2005), 'Due account needs to be taken of the fact that neither heat treatment or fumigation can be considered fully effective and that, although there are tests available which can determine whether wood has been exposed to methyl bromide, there are no tests available which can determine whether either treatment has been carried out effectively'.

AQIS' interception records before the implementation of ISPM 15 show that live insects were constantly intercepted on wood packaging materials with bark that are fumigated with methyl bromide. The difficulty in identifying fungi resulted in fewer recorded interceptions of this group of organisms. Similar records are reported from other countries; for example, it was reported that in Austria in 2001, 22 % of inspected wood consignments coming from the USA and Canada had residual bark, and in 50 % of these live insects or nematodes were found (Burgess 2005). These findings confirm the risks of transmitting serious pests in wood that retains some or all of its bark, especially if there are compliance issues relating to the ISPM 15 treatments. A bark free requirement provides an additional protection. Preliminary data from AQIS' current survey (AQIS unpublished data) demonstrates no overall improvement in interception rates of invertebrates as a result of the implementation of ISPM 15.

Heat treatment with temperature of 71°C at the centre of the wood for 75 minutes (APHIS universal treatment) is also considered to be an effective treatment for wood products against all pests including the fungi identified in the PRAs in this document. In most cases, infesting fungi will be unknown, tentatively identified or even misidentified, and likely to be in an unknown physiological state; in such cases a broad approach to treatment is recommended (Ridley 2004). Dwinell (2005a) notes that he would have preferred, for technical and biological reasons, to have seen ISPM 15 set 61ºC as the target core temperature for pasteurisation of green wood. In the absence of the requirement that all wood packaging materials be made from bark free wood, Australian quarantine treatments would have to be restricted to heat treatment at higher temperatures alone which provides the broadest and safest approach to the wood imports issue. In general, heat treatments do not have any significant deleterious effects on wood quality because controlled heat treatments help reduce wood damage caused by uneven drying (US EPA 2002). In fact, temperatures up to 82.2°C (180°F) for periods up to one hour do not appreciably affect wood properties (US EPA 2002). The industry in Australia has commented that the present technology can meet the 56°C for 30 minutes requirement in addition to Australia's longstanding bark free requirements.

Restricting quarantine treatments to heat treatments alone (either 56ºC or 71ºC) does not subsequently deal with the infestation post-treatment issue. Many forest pests, including those identified in these PRAs are attracted to the volatiles released from sawn timber over a period of time after harvesting; for example, many of these insects lay eggs into bark crevices with larvae developing and feeding under the bark, in the cambial layer. Removal of bark reduces these infestation problems after quarantine treatment and addresses the risks associated with pests using bark as shelter sites.

Australia's plant and animal health status is maintained through the implementation of measures to facilitate the importation of products while protecting the health of people, animals and plants. Australia bases its national measures on international standards where they exist and where they deliver the appropriate level of protection from pests and diseases of quarantine concern. However, where such standards do not achieve Australia's ALOP, or relevant standards do not exist, Australia exercises its right under the SPS Agreement to take appropriate measures, justified on scientific grounds and supported by pest risk analysis.

Biosecurity Australia believes that the risk management measures examined below for the pests listed in Table 3 (p. 26) (which does not include fungi) and those dealt with in the PRAs, are commensurate with the identified risks. It should be emphasised that inspection is not a measure that mitigates the risk of a pest. It is the remedial actions or treatment that can be taken based on the results of the inspection that would reduce a pest risk.

Summary of Australia's entry requirements for wood packaging material before ISPM 15

Australia has regulated standards for wood packaging materials including dunnage for many years. The following import requirements were being enforced before the ISPM 15 (AQIS 2004, ICON database):

1. freedom from bark;
2. methyl bromide fumigation at 48 g/m^3 for 24 hours. The timber at the time of treatment should be no greater than 200 mm in diameter in the smallest plane, and treatment be applied within 21 days of export or containerisation; and
3. where packaging is imported in containerised cargo it must be accompanied by a packaging declaration stating compliance with Australian requirements.

Australia's entry requirements for wood packaging material after implementation of ISPM 15 approved measures

The quarantine alert released by AQIS on 2 April 2004 advised that ISPM 15 would be inserted into Australia's existing import requirements for wood packaging material. On 21 June 2004, AQIS notified the World Trade Organisation (WTO) Committee on Sanitary and Phytosanitary Measures regarding the implementation. From 1 September 2004, AQIS accepted wood packaging material that is treated in accordance with ISPM 15.

In addition to the ISPM 15 approved measures, Australia has maintained the following existing requirements in order to meet its ALOP:

- freedom from bark (mandatory); and

- where packaging is imported in containerised cargo it should be accompanied by a packaging declaration stating compliance with Australian requirements to facilitate clearance (non-mandatory).

Section 3.3 of ISPM 15 states 'subject to technical justification, countries may require that imported wood packaging material subjected to an approved measure be made from debarked wood'. Commercial debarking processes are highly variable in their effectiveness, depending upon the age of the machinery, the type of wood being milled (thick- or smooth-barked logs), the individual growth characteristics of species and individual stands, as well as time of and since harvesting (p. 13).

As a signatory to the IPPC, Australia is obliged to provide technical justification for its bark free requirement. According to ISPM 15, 'NPPOs may accept any measures other than those listed in Annex I by arrangement with their trading partners, especially in cases where the measures listed in Annex I cannot be applied or verified in the exporting country. Such measures should be technically justified and respect the principles of transparency, non-discrimination and equivalence'.

ISPM 15 Approved measures are not sufficient to maintain Australia's ALOP

Table 8 provides results of the individual pest risk assessments for four arthropod pests and three fungi. The pests considered in these PRAs and with a restricted risk estimate above Australia's ALOP are listed in the Table 9.

Table 9 Pest and pest groups considered in this PRA that require risk management measures.

Insects	Fungi
Callidium violaceum	*Ophiostoma/Ceratocystis* spp.
Gnathotrichus spp.	*Cryphonectria parasitica*
Ips spp.	*Fusarium circinatum*

The results of the pest risk assessment of the importation into Australia of wood packaging materials with bark showed that the pests selected for assessment (Table 11) have restricted risk estimates of 'Low' to 'Moderate'. These restricted risk estimates exceed Australia's appropriate level of protection (ALOP) and an additional risk management measure is required for the importation into Australia of wood packaging materials. Removal of bark from wood packaging material will serve to mitigate the risk by:

- reducing the likelihood that wood packaging material is infested/infected with quarantine pests;
- improving the efficiency of ISPM 15-approved treatments and therefore reducing the risks of pests surviving;
- reducing the risk of infestation after treatment; and
- increasing the efficacy of inspection and any consequent treatment.

Heat treatment

According to ISPM 15, where wood packaging material has been treated by one of the approved ISPM 15 measures (heat treatment or methyl bromide fumigation), the treatment is considered to eliminate members of the pest groups listed in Table 1. By this, the IPPC guidelines have acknowledged that the wood is being treated to only control the pests as listed in the standard. As shown in Table 11 above, all the fungi identified in these pest risk assessments as requiring risk management measures are not listed in the ISPM 15 standard. Consideration of insects' ability to infest wood after treatment is also not considered. This means that the approved ISPM treatment measures are not sufficient to control at least these pests of concern to Australia.

Allen (2001a) stated that heat treatment of 56°C for 30 minutes, as adopted in ISPM 15, will not eliminate: 1) some stain fungi; 2) many decay fungi; 3) most thermophilic fungi; 4) some insects; and 5) some viruses. In most cases where imported products require treatment, the infesting fungi will be unknown, tentatively identified or even misidentified, and likely to be in an unknown physiological state (Ridley 2004). In such cases, a broad approach to treatment is recommended (Ridley 2004). The APHIS universal treatment option requires a 71°C at the centre of the wood for 75 minutes (Federal Register 1995), although, APHIS argues that the universal treatment option was not established with wood packaging material in mind. According to a recommendation made by the Council of the American Phytopathological Society (APS 1999), '71°C at the centre of the wood for 75 minutes provides the broadest and safest documented effective treatment for wood products including wood packaging materials'.

The removal of bark would facilitate the seasoning process, reduce the availability of shelter that may allow insects to infest or hitch hike or allow fungal spores to germinate and infest ISPM 15-heat treated timber, as well as facilitate inspection procedures.

Fumigation with methyl bromide

The current ISPM 15 approved methyl bromide fumigation schedule is 48 g/m^3 at a temperature of 21°C for at least 16 hours. Methyl bromide fumigation at a minimum dosage of 48 g/m^3 for 24 hours is recognised around the world as being effective against many insects including bark beetle, borers and some fungi. Despite large numbers of treatment failures, as evidenced by high rates of interception of live insects on fumigated wood products (PDI 2004), Australia has relied on this schedule as a standard treatment for the control of insect pests associated with wood products. This is owing to the recognition that many of the failures are caused by poor commercial fumigation practices rather than the efficacy of the fumigation schedule (Australian Accredited Fumigation Scheme 2005).

It is noted that, if applied properly, methyl bromide fumigation at the rate of 48 g/m^3 for 16 hours may be efficacious against most arthropod pests associated with the timber at the time of fumigation. However, recent discussion and research papers indicate that methyl bromide fumigation under the schedules outlined in the ISPM 15 may not be effective against the fungal pests considered in these PRAs (e.g. Burgess 2005), as ISPM 15 was developed to deal with a specific group of insect pests and the pine wood nematode.

The ISPM 15 approved fumigation treatment measures have not been proven effective against fungi, and do not address the issue of infestation after treatment by either fungi or invertebrate pests. Therefore, the fungi and invertebrate pests analysed in these PRAs and other similar pests may not be controlled by the approved fumigation treatment measures in ISPM 15. In addition, efficacy data for methyl bromide and heat treatment for many pests and pathogens does not exist (USDA 2003), as well as their potential to infest treated timber. An additional risk management measure is therefore warranted for the importation of wood packaging materials into Australia.

The removal of bark would facilitate the penetration of methyl bromide, facilitate the seasoning process, reduce the availability of shelter that may allow insects to infest or hitch hike or allow fungal spores to germinate and infest timber treated with the methyl bromide schedule in ISPM 15, as well as facilitate inspection procedures.

13. CONCLUSIONS

- The PRA has provided detailed individual risk assessments for seven pests (four arthropod pests and three fungi) considered to be associated with imports of wood packaging materials with bark (Table 8). Three of the arthropods and three of the fungi had restricted risk estimates above Australia's ALOP. The assessments showed that these pests have a restricted risk estimate of 'Low' to 'Moderate'. The restricted risk estimates for the pests exceed Australia's appropriate level of protection and risk management measures are required for the importation of wood packaging materials with bark into Australia.
- ISPM 15 approved treatment measures have been adopted by Australia and incorporated into Australian quarantine requirements for the importation of wood packaging materials into Australia. Presently, the only internationally accepted treatment options for wood packaging material under the ISPM 15 are heat treatment or fumigation with methyl bromide. These approved treatments are considered to be inadequate to control the entry, establishment and spread of quarantine pests identified in these PRAs.
- Biosecurity Australia considers that the adoption of the IPPC Guidelines (ISPM 15) for wood packaging materials does not prevent Australia from maintaining additional measures to ensure that the pests identified in these PRAs and other similar pests of concern do not become established in Australia. Consequently, Australia will retain its long-standing requirement that all wood packaging materials imported into Australia be free of bark as additional requirement to the ISPM 15 approved treatment measures. The information provided in this report clearly demonstrates that it is unsafe to rely only on either heat treatment of 56°C for 30 minutes or methyl bromide fumigation schedule of $48 g/m^3$ at a temperature of 21°C for 16 hours to maintain/ensure Australia's appropriate level of protection against the pests of concern considered in these PRAs.
- In the absence of the requirement that all wood packaging materials be made from bark free wood, Australian quarantine treatments would have to be restricted to heat treatment at higher temperatures; for example, a temperature of 71°C at the centre of the wood for 75 minutes is considered to be documented effective treatment for wood products against all pests including fungi identified in this PRA.
- Australia's long-standing requirement that wood packaging materials be bark free is fully justified because it:
    - minimises the risk of entry and establishment of the quarantine pests identified in these PRAs and other similar pests that depend on bark for food, shelter and one or more stages of development;
    - compensates for the effects of bark on heat treatment and methyl bromide fumigation and minimises treatment failures;
    - enhances the visual inspection process;
    - reduces the risk of infestation and re-infestation after treatment; and
    - controls the risk of introduction and spread of soil-borne pests and some hitchhiker pests.
- Biosecurity Australia considers that the risk management measures examined above for the quarantine pests identified in these PRAs are commensurate with the identified risks.

- Australia remains committed to further development of ISPM 15 and its refinement, including review of the fumigation rates to ensure effective treatment for the broad spectrum of quarantine pests that can use the wood packaging materials pathway, and to explore alternative treatment options to facilitate trade and reduce the quarantine reliance on methyl bromide.

14. REFERENCES

AFFA (2001). Guidelines for Import Risk Analysis, draft September 2001. Agriculture, Fisheries and Forestry - Australia, Canberra, Australia. http://www.daff.gov.au/content/publications.cfm?Category=Biosecurity%20Australia&ObjectID=85B98CC3-86DE-48AE-8A76D4A40F33245A; accessed 16 March 2006.

Agricultural Commissioner's Office (1998). Pest Alert. Pitch Canker of Pines. Agricultural Commissioner's Office, Santa Barbara County, CA. http://www.countyofsb.org/agcomm/pcanker.htm; accessed 1 July 2004.

Allen, E.A. (2001a). Efficacy of heat treatment for solid wood packaging materials. Draft report for the IPPC Working Group on Wood Packaging Meeting, Mexico City, February 2001.

Allen, E. (2001b). Solid Wood Packing Material as a Pathway for Nonindigenous Species. Exotic Forest Pests Online Symposium. http://www.apsnet.org/online/exoticpest/Papers/allen.htm; accessed 18 October 2005.

APHIS (2004). Plant Protection and Quarantine. Wood Packaging Materials. http://www.aphis.usda.gov/ppq/wpm/import.html; accessed 17 October 2005.

APPD (2005). Australian Plant Pest Database. Plant Health Australia. http://www.planthealthaustralia.com.au/APPD/legal.asp (password access only).

APS (1999). Council of The American Phytopathological Society, Resolution on Wood Importation. http://www.apsnet.org/media/ps/woodimport.asp; accessed 21 October 2005.

AQIS (1988). *Plant Quarantine Manual*. Australian Quarantine and Inspection Service.

AQIS (1999a). Australian Quarantine and Inspection Service. Canberra. *Imported packaging materials, addressing the quarantine risks*. 17 pp.

AQIS (1999b). Joint AQIS Industry visit to USA and Canada. Timber Trip Report August 1999. 21 pp.

AQIS (2004). Australian Quarantine and Inspection Service, Import conditions database. http://www.aqis.gov.au/icon32/asp/homecontent.asp.

AQIS (2005). Import conditions for wood packaging materials. ICON database. http://www.aqis.gov.au/icon.

AQSIQ and NPQS (2003). Effects of methyl bromide fumigation on pine wood nematode, *Bursaphelenchus xylophilus* (S & B) in naturally infected pine logs. The China-Korea Joint Experiment Report presented to the International Forestry Research Quarantine Group, February 2004, Rome.

Armed Forces Pest Management Board (1990). Technical Information Memorandum No. 5 Defense Pest Management Information Analysis Center, Forest Glen Section, Walter Reed Army Medical Center Washington. http://www-nehc.med.navy.mil/nepmu2/pmttoolbox/ENTOMOLOGY_files%5CShipboard%20Pest%20Control%20Manual%5C03%20DATA%20FILES%20(R)%5CAFPMB%20TECHNICAL%20INFORMATION%20MEMORANDA%5CTIM%2005%20(JUN90).pdf.; date accessed 21 November 2005.

Aukema, B.H., Richards, G.R., Krauth, S.J. and Raffa, K.R. (2004). Species assemblage arriving at and emerging from trees colonised by *Ips pini* in the Great Lakes Region: partitioning by time since colonisation, season and host species. *Annals of the Entomological Society of America* 97: 117–129.

Australian Accredited Fumigation Scheme (2005). http://www.daff.gov.au/content/output.cfm?ObjectID=953B6214-FEEB-45FA-95552C43ED1E0A31; accessed 6 March 2006.

Banks, H.J. (1999). Is methyl bromide a good fumigant for timber and timber products?, *in* Anon., *National Stakeholder Timber Pest Conference Proceedings*. AQIS, 20–22 April 1999, Canberra, Australia.

Banks, H.J. (n.d.). Alternatives to methyl bromide for durables and timber. http://europa.eu.int/comm/environment/%20ozone/conference/durables_timber.pdf; accessed 7 December 2004.

BioMat Net (2005). Biological Material for Non-Food Products. Sustainable wood/new clean technology methods for the control of fungal stains in wood. http://www.biomatnet.org/secure/Fair/S805.htm; accessed 17 November 2005.

Biosecurity New Zealand (n.d.). Import Health Standard Sawn Wood from all Countries. http://www.biosecurity.govt.nz/imports/forests/faq.htm; accessed 9 August 2005.

Brasier, C.M. (1981). Laboratory investigation of *Ceratocystis ulmi*, *in* R.J. Stipes and R.J. Campana (eds), *Compendium of elm diseases*, pp. 76–79. The American Phytopathological Society, St. Paul, MN, USA.

Brasier, C.M. (1996). New Horizons in Dutch Elm Disease Control. Report on Forest Research 1996. London, U.K.: HMSO, Forestry Commission. pp. 20–28.

Brasier, C.M. (2001). Rapid evolution of introduced plant pathogens via interspecific hybridization. *BioScience* 51 (2):123–133.

Burgess, R. (2005). Debarking (bark freedom): Additional requirement under section 3.3 ISPM 15 – Technical justification. A Discussion Paper to be presented at the ISPM 15 workshop in Vancouver, 28 February–4 March 2005.

Byers, J.A. (1989). Chemical ecology of bark beetles. *Experientia* 45: 271–283.

Byers, J.A. (2000). Wind-aided dispersal of simulated bark beetles flying through forests. *Ecological Modelling* 125:231–243.

Byers, J.A. (2004). Chemical ecology of bark beetles in a complex olfactory landscape, Chapter 8, *in* F. Lieutier, K.R. Day, A. Battisti, J.-C. Grégoire and H.F. Evans, *Bark and wood boring insects in living trees in Europe, a synthesis*, pp. 89–134. Kluwer Academic Publishers, Dordrecht.

CABI (2003a). Crop Protection Compendium. *Gnathotrichus retusus* datasheet http://www.cabicompendium.org; accessed 11 May 2004.

CABI (2003b). Crop Protection Compendium. *Gnathotrichus sulcatus* datasheet http://www.cabicompendium.org; accessed 11 May 2004.

CABI (2003c). Crop Protection Compendium. Pest datasheets for individual *Ophiostoma* and *Ceratocystis* species. http://www.cabicompendium.org.

CABI (2004). Crop Protection Compendium – Global Module. CAB International. Wallingford, UK.

CABI (2005a). Crop Protection Compendium – Global Module. CAB International. Wallingford, UK.

CABI (2005b). Forestry Compendium, individual pest datasheets. http://www.cabicompendium.org; accessed 15 September 2005.

CABI and EPPO (1997). *Ips sexdentatus*, *in* I.M. Smith, D.G. McNamara, P.R. Scott, M. Holderness and B. Burger (eds), *Quarantine Pests for Europe*, 2nd edn, pp. 344–346. CAB International, University Press, Cambridge.

Cade, S.C., Hrutfiord, B.F., and Gara, R.I. 1970. Identification of a primary attractant for *Gnathotrichus sulcatus* isolated from western hemlock logs. *Journal of Economic Entomology* 63: 1014–1015.

California Forest Pest Council (2000). Guidelines for handling woody material infected with pitch canker fungus. Research & Reports. Pitch Canker Task Force. http://frap.cdf.ca.gov/pitch_canker/research/woody_guidelines.htm; accessed 21 November 2005.

California Oak Mortality Task Force (2004). *Phytophthora ramorum* overview. http://www.cnr.berkeley.edu/comtf/html/; accessed 25 October 2005.

Canadian Forestry Service (2005). Summary of brown spruce longhorn beetle research projects 2003/2004. Natural Resources Canada. http://www.atl.cfs.nrcan.gc.ca/index-e/what-e/science-e/entomology-e/bslb-e/summary-e.html; accessed 12 September 2005.

Cannon, C.A. (1998). Nutritional ecology of the carpenter ant *Camponotus pennsylvanicus* (de geer): macronutrient preference and particle consumption. PhD Dissertation Virginia Polytechnic Institute and State University. http://scholar.lib.vt.edu/theses/available/etd-110398-001812/unrestricted/Dissertation-etd.PDF; accessed 17 June 2004.

CFIA (1998). Summary of plant quarantine pest and disease situations in Canada. www.inspection.gc.ca/english/sci/surv/sit98e.shtml; accessed 21 November 2005.

CFIA (2001a). *Callidiellum rufipenne* (Motschulsky) – Japanese cedar longhorned beetle, Plant Pest Information. http://www.inspection.gc.ca/english/sci/surv/data/calrufe.shtml; accessed 22 September 2005.

CFIA (2001b). Summary of plant quarantine pest and disease situations in Canada. http://www.inspection.gc.ca/english/sci/surv/sit2000e.shtml#top; accessed 23 November 2005.

CFIA (2002). *Ceratocystis fagacearum* (Bretz) Hunt - Oak Wilt**.** Canadian Food Inspection Agency Factsheet http://www.inspection.gc.ca/english/sci/surv/data/cerfage.shtml; accessed 10 May 2005.

CFIA (2005). Entry requirements for Wood Packaging Materials produced in all areas other than the Continental United States. D-98-08. http://www.inspection.gc.ca/english/plaveg/protect/dir/d-98-08e.pdf; accessed 17 October 2005.

Chamberlain, W.J. (1953). Insects affecting forest products and other materials. Oregon State College Cooperative Association, Corvallis, Oregon. 159 pp.

Commonwealth of Australia. (2003). *Import risk analysis handbook*. Department of Agriculture, Fisheries and Forestry, Canberra, Australia.

Conifer Gardens Nursery (2006). Conifer list. http://www.conifergardens.com.au/prod01.htm accessed 27 February 2006.

Connor, M.D. and Wilkinson, R.C. (1983). *Ips* bark beetles in the south. Forest insect and disease leaflet 129, U.S. Department of Agriculture Forest Service. http://www.na.fs.fed.us/spfo/pubs/fidls/ips/ipsfidl.htm; accessed 21 November 2005.

COST, Multidisciplinary Chestnut Research (n.d.). Workgroup 4. Silviculture. http://www.unitus.it/dipartimenti/dpp/progetti/cost/wp4.htm; accessed 1 March 2006.

Covey, C. (16 November, 2005). Bluestain on treated wood. Email to ispm-15-L@mailserv.fao.org. Unit Pallets Limited & TIMCON/FEFPEB.

Cree, L.A. (2002) *Phytophthora ramorum* (sudden oak death). Canadian Food Inspection Agency Factsheet. http://www.inspection.gc.ca/english/plaveg/protect/pestrava/sodmsc/sodfacte.shtml; accessed 21 November 2005.

Cross, D.J. (1991). Penetration of methyl bromide into *Pinus radiata* wood and its significance for export quarantine. *New Zealand Journal of Forestry Science* 21: 235–245.

Cutter, B.E. (1994). Considerations in drying hardwood lumber. University of Missouri, Extension publication G5507. http:/muextension.missouri.edu/xplor/agguides/forestry/g05507.htm; accessed 26 April 2005.

Das, S.C. and Gope, B. (1985). Palliative control of tea chest panel borer by heating. *Two & A Bud* 32: 43–44.

Daterman, G.E. and Overhulser, D.L. (2002). Ambrosia beetles of western conifers. Forest insect and disease leaflet 170, Forest Service United States Department of Agriculture. http://www.fs.fed.us/r6/nr/fid/fidls/fidl170.pdf; accessed 4 May 2004.

De Beer, Z.W., Wingfield, B.D. and Wingfield, M.J. (2003). The *Ophiostoma piceae* complex in the Southern Hemisphere: a phylogenetic study. *Mycological Research* 107: 469–476.

Defense Supply Center Columbus (n.d.). Non-manufactured Wood Packaging Material Notice and FAQs. http://www.dscc.dla.mil/Offices/Packaging/NMWPMnotice.html#NCMR; accessed 1 March 2006.

De Hoog, G.S. (1993). *Sporothrix*-like anamorphs of *Ophiostoma* species and other fungi, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma*. Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 53–60. APS Press, St Paul, Minnesota, USA. (First printing 1999.)

Denlinger, D.L. and Yocum, G.D. (1998). Physiology of heat sensitivity, *in* G.J. Hallman and D.L. Denlinger (eds), *Temperature sensitivity in insects and application in integrated pest management*, pp. 7–57. Westview studies in insect biology. Westview Press Boulder Colorado.

Devey, M., Matheson, C. and Gordon, T. (1999). Current and potential impacts of pitch canker in radiata pine. *CSIRO Forestry and Forest Products Technical Report* 112, 120 pp.

Dick, M. and Bain, J. (1997). The threat to Australasia. A discussion paper. New Zealand Forest Research Institute. Rotura, New Zealand.

Di-Ioro, O.R. (2004). Exotic species of cerambycidae (coleoptera) introduced in Argentina. Part 2. New records, host plants, emergence periods, and current status. *Agrociencia* 38: 663–678.

Dowding, P. (1969). The dispersal and survival of spores of fungi causing bluestain in pine. *Transactions of the British Mycological Society* 52 (1): 125–137.

Dowding, P. (1970). Colonization of freshly bared pine sapwood surfaces by staining fungi. *Transactions of the British Mycological Society* 55 (3): 399–412.

Dowding, P. (1973). Effects of felling time and insecticide treatment on the interrelationships of fungi and arthropods in pine logs. *Oikos* 24: 422–429.

DPI (2004). Management of elm pests and diseases in Australia. Department of Primary Industries, Science, Research and Development. http://www.dpi.vic.gov.au/dpi/nrenktri.nsf/FID/-BBB0C655C71008AECA256BE9008122B3?OpenDocument; accessed 28 October 2005.

Duncan. R.W. (1991). The golden buprestid a wood boring beetle. Forest pest leaflet, Pacific Forestry Centre, Canadian Forest Service.

Duryea, M.L., Huffman, J.B., English, R.J. and Osbrink, W. (1999). Will subterranean termites consume landscape mulches? *Journal of Arboriculture* 25: 143–150.

Dwinell, L.D. (2001). Potential use of elevated temperature to manage pests in transported wood. Risks of Exotic Forests Pests and Their Impact on Trade. An International Online Workshop to reduce movement of forest pests with a minimal impact on trade held April 16–29, 2001. http://www.apsnet.org/online/ExoticPest/Papers/dwinell_temperature.htm; accessed 20 July 2005.

Dwinell, L.D. (2002). Mitigating the pinewood nematode and its insect vectors in transported coniferous wood. Pre-publication copy of paper for proceedings of a symposium on the Epidemiology of Pine Wilt Disease presented at the 4th International Congress of Nematology, Tenerife, Spain, 8–13 June 2002. http://www.dscc.dla.mil/downloads/packaging/PinewoodNematodeWhitePaper.pdf; accessed 27 October 2005.

Dwinell, L.D. (2005a). Review: A discussion paper. Debarking (bark freedom): Additional requirement under section 3.3 ISMP [ISMP] 15 – technical justification by Roddie Burgess (January 2005). Papers presented at the 2nd meeting of the IFQRG, Victoria/Canada 21–23 February 2005.

Dwinell, L.D. (2005b). Exploratory study on colonization of heat-treated pine bolts, cants, slabs, and boards with bark by the pinewood nematode and its *Monochamus* vectors. Papers presented at the 2nd meeting of the IFQRG, Victoria/Canada 21–23 February 2005.

Ebeling, W. (1975). Urban entomology. University of California, Division of Agricultural Sciences. 695 pp.

Ebeling, W. (1994). Heat penetration of structural timbers. *IPM Practitioner* XVI (2) February, 9–10.

EC (2004). Council Directive 2000/29/EC of 8 May 2000. On protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. http://europa.eu.int/eur-lex/pri/en/oj/dat/2000/l_169/l_16920000710en00010112.pdf; accessed 17 October 2005.

EPPO (no date b). *Cryphonectria parasitica*. Datasheets on quarantine pests. Prepared by CABI and EPPO for the EU under Contract 90/399003.

EPPO (no date c). *Ceratocystis fagacearum* and its vectors. Datasheets on quarantine pests. Prepared by CABI and EPPO for the EU under Contract 90/399003.

EPPO (2005a). *Cryphonectria parasitica*. OEPP/EPPO Bulletin 35: 295–298. http://www.blackwell-synergy.com/doi/abs/10.1111/j.1365-2338.2005.00836.x; accessed 17 March 2006.

EPPO (2005b). *Gibberella circinata*. OEPP/EPPO Bulletin 35: 383–386. http://www.blackwell-synergy.com/doi/abs/10.1111/j.1365-2338.2005.00905.x; accessed 17 March 2006.

Ertelt, P. (1994). Studies on controlled thermal treatment in pest-infested wood. Diploma Thesis, Department of Wood Technology, Rosenheim Technical College.

European Commission (2001). Commission Decision 2001/219/EC of 12 March 2001. Health & Consumer Protection Directorate-General. Frequently Asked Questions. http://www.pflanzenschutzdienst.de/pdf/be/Gesundheit/FAQ.pdf; accessed 1 March 2006.

European Commission (2004). Commission Directive 2004/102/EC of 5 October 2004. http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2004/l_309/l_30920041006en00090025.pdf; accessed 2 March 2006.

Evans, H.F., Moraal, L.G. and Pajares, J.A. (2004). Biology, ecology and economic importance of buprestidae and cermabycidae. Chapter 20, *in* F. Lieutier, K.R. Day, A. Battisti, J.-C. Grégoire, and H.F. Evans (eds), *Bark and wood boring insects in living trees in Europe, a synthesis*, pp. 447–498. Kluwer Academic Publishers, Dordrecht.

Farr, D.F., Bills, G.F., Chamuris, G.P. and Rossman, A.Y. (1989). *Fungi on plants and plant products in the United States*. APS Press, St Paul, USA. 1252 pp.

Farrell, R. (2001). Identification of fungal infections in imported timber. MBS 304. Research Results 1999/2000 Research Final Report Summaries. MAF Policy Information Paper 01/42. http://www.maf.govt.nz/mafnet/rural-nz/research-and-development/research-results/1999-2000/1999-2000-research-results-02.htm#P580_61458; accessed 23 November 2005.

Federal Register (1995). May, 25, 1995. Department of Agriculture. Animal and Plant Health Inspection Service. 7 CFR Parts 300 and 319. Importation of Logs, Lumber, and Other Unmanufactured Wood Articles. *Federal Register* 60 (101): 27665–27682.

Federal Register (2004). September 14, 2004. Department of Agriculture. Animal and Plant Health Inspection Service. 7CFR Part 319. Importation of Wood Packaging Material. *Federal Register* 69 (179): 55719–55733.

Feist, W.C., Springer, E.L. and Hajny, G.J. (1971). Viability of parenchyma cells in stored green wood. *Tappi* 54: 1295–1297.

Flora of China (n.d.). Castanea. Flora of China, Volume 4. Fagaceae. http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=105816; accessed 2 March 2006.

Florida Department of Agriculture & Consumer Services (2004–2005. Forest Management. Division of Forests. Forest Recovery Information after a Hurricane. http://www.fl-dof.com/forest_management/cfa_hurricane.html; accessed 18 November 2005.

Foltz, J.L. (2001). Pine Bark Beetles in Florida. http://eny3541.ifas.ufl.edu/pbb/PBB_ID.htm; accessed 20 September 2001.

Furniss, R.L. and Carolin, V.M. (1980). Western Forest Insects. Miscellaneous publication No. 1339. U.S. Department of Agriculture, Forest Service, Washington, D.C. 654 pp.

Gadgil, P., Dick, M., Simpson, J., Bejakovich, D., Ross, M, Bain, J., Horgan, G. and Wylie, R. (2003). *Management Plan Response to an Incursion of Pine Pitch Canker*. Prepared for the Forestry and Forest Products Committee. Forest Health Committee.

Glassey, K. (1999). New Zealand Experiences in Regulating Imported Forest Produce. *Proceedings of the National Stakeholder Timber Pest Conference 20–22 April Canberra.* Timber Pest Co-ordination Unit. Australian Quarantine and Inspection Service. Commonwealth of Australia.

Haack, R.A. (2003). Intercepted Scolytidae (Coleoptera) at U.S. ports of entry: 1985–2000. *Integrated Pest Management Reviews* 6: 253–282 (2001).

Haack, R.A. and Cavey, J.F. (1997). Insects intercepted on wood articles at ports-of-entry in the United States: 1985–1996. *Newsletter of the Michigan Entomological Society* 42 (2–4): 1–6.

Haack, R.A. and Slansky, F. Jr. (1987). Nutritional ecology of wood-feeding Coleoptera, Lepidoptera and Hymenoptera, *in* F. Slansky Jr and J.G. Rodriguez (eds), *Nutrutional Ecology of Insects, Mites and Spiders*. John Wiley and Sons Inc.

Haack, R.A., Petrice, T.R., Nzokou, P. and Kamdem, D.P. (n.d.). Suitability of heat-treated and borate-treated green logs with bark to bark- and wood-borer attack. Poster presented at Annual US Department of Agriculture symposium on introduced forest pests. 1 p. Papers presented at the 2nd meeting of the IFQRG, Victoria, Canada 21–23 February 2005.

Hagle, S.K., Gibson, K.E. and Tunnock, S. (2003). *A field guide to diseases and insect pests of northern and central rocky mountain conifers*. United States Department of Agriculture, Forest Service http://www.fs.fed.us/r1-r4/spf/fhp/field_guide/PDFs/PinonEngraverBeetle61.pdf; accessed 20 September 2005.

Halik, S. and Bergdahl, D.R. (1992). Survival and infectivity of *Bursaphelenchus xylophilus* in wood chip soil mixtures. *Journal of Nematology* 24: 495–503.

Hammond, H.E.J., Langor, D.W. and Spence, J.R. (2001). Early colonisation of *Populus* wood by saproxylic beetles (Coleoptera). *Canadian Journal of Forest Research* 31: 1175–1183.

Hanks, L.M. (1999). Influence of the larval host plant on reproductive strategies of cerambycid beetles. *Annual Review of Entomology* 44: 483–505.

Hansen, L.D. and Akre, R.D. (1985). Biology of Carpenter ants in Washington State (Hymenoptera:Formacidae:*Campanotus*). *Melanderia* 43: 1–62.

Hansen, M. and Lewis, K.J. (eds). (1997). *Compendium of Conifer Diseases.* American Phytopathological Society, St. Paul, Minn., USA.

Harrington, T.C. (1993). Diseases of conifers caused by species of *Ophiostoma* and *Leptographium*, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma. *Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 161–172. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Harrington, T.C., and Wingfield, M.J. (1998). The *Ceratocystis* species on conifers. *Canadian Journal of Botany* 76: 1446–1457.

Harris, E.C. (1963). Methyl bromide fumigation and wood-boring insects. *Record of the Annual Convention British Wood Preservers' Association* 1963: 159–175.

Hartman, J., Hodges, C. and Barnard, E. Pine diseases, *in* R.K. Jones and D.M. Benson (eds), *Diseases of Woody Ornamentals and Trees in Nurseries*, pp. 280–297. APS Press, St Paul, Minnesota, USA.

Harvey, J. (2005). PalletLink Datasheet – Bluestain. Email to ISPM-15-L@mailserv.fao.org 18/11/05.

Heald, F.D. (1926). Manual of Plant Diseases. New York. McGraw-Hill. 891 pp.

Heald, F.D. and Studhalter, R.A. (1914). Birds as carriers of the chestnut blight fungus. *Journal of Agriculture Research*, 2:405–422.

Hicks, M. (2004). Changing regulations on packing material: Will you be affected? FAS Online. http://www.fas.usda.gov/info/agexporter/2001/jan/PackingRegulations.htm; accessed 1 November 2005.

Hinds, T.E. (1972). Insect transmission of *Ceratocystis* species associated with aspen cankers. *Phytopathology* 62: 221–225.

Hoebeke, R.E. (1999). Japanese cedar longhorned beetle in the eastern United States. Pest Alert USDA-APHIS. http://www.aphis.usda.gov/lpa/pubs/jclbpale.pdf; accessed 28 September 2005.

Hosking, G.P. (1978). *Prionoplus reticularis* White (Coleoptera: Cerambycidae). Huhu beetle. *Forest and Timber Insects in New Zealand, No 35*. Forest Research Institute, New Zealand Forest Service.

Humble, L.M., Allen, E.A. and Bell, J.D. (2002). Exotic wood-boring beetles in British Columbia. Interceptions and establishments. Natural Resources Canada. Canadian Forest Service. http://www.pfc.forestry.ca/biodiversity/exotics/; accessed 23 November 2005.

Humphreys, N. and Allen, E. (2000). Lesser cedar longicorn beetle - *Callidiellum rufipenne*. Exotic Forest Pest Advisory - Pacific Forestry Centre, Canadian Forest Service, No. 4: 4 pp.

Hutcheon, N.B. and Jenkins, J.H. (1967). Some basic characteristics of wood, CBD-85. Canadian Building Digest, National Research Council Canada. http://irc.nrc-cnrc.gc.ca/cbd/cbd085e.html; accessed 27 April 2005.

Hutchison, L.J. and Reid, J. (1988). Taxonomy of some potential wood-staining fungi from New Zealand 1. Ophiostomataceae. *New Zealand Journal of Botany* 26: 63–81.

Index Fungorum (2005). Index Fungorum. http://www.speciesfungorum.org/Names/Names.asp

IPPC (2002). International standards for phytosanitary measures: guidelines for regulating wood packaging material in international trade. Secretariat of the International Plant Protection Convention, Food and Agriculture Organization of the United Nations, Rome. https://www.ippc.int/servlet/BinaryDownloaderServlet/ISPM_15_English.pdf?filename=1055161712885_ISPM15_e.pdf; accessed 10 May 2005.

Ivarsson, P., Tittiger, C., Blomquist, C., Borgeson, C.E., Seybold, S.J., Blomquist, G.J. and Högberg, H-E. (1998).Pheromone precursor synthesis is localized in the metathorax of *Ips paraconfusus* Lanier (Coleoptera: Scolytidae). *Naturwissenschaften* 85: 507–511.

Jacobs, S.B. (2003). The old house borer. Entomological notes, Department of Entomology, Pennsylvania State University. http://www.ento.psu.edu/extension/factsheets/pdfs/oldHouseBorer.pdf accessed November 2005.

Jactel, H. (1991). Dispersal and flight behaviour of *Ips sexdentatus* (Coleoptera: Scolytidae) in pine forest. *Annales des Sciences Forestieres* 48(4): 417–428 (abstract only cited).

Jactel, H. and Gaillard, J. (1991). A preliminary study of the dispersal potential of *Ips sexdentatus* Boern (Coleoptera: Scolytidae) with an automatically recording flight mill. *Journal of Applied Entomology* 112: 138–145.

Karasev, V.G. (1974). Reasons for differences in damage to softwoods by *Callidium violaceum* (Coleoptera, Cerambycidae). *Zoologicheskii-Zhurnal* 53 (8): 1196–1199 (abstract only seen).

Kazmierczak, P., Kim, D.H., Turina, M. & Van Alfen, N.K. (2005). A hydrophobin of the chestnut blight fungus, *Cryphonectria parasitica*, is required for stromal pustule eruption. *Eukaryotic Cell* 4 (5): 931–936.

Kieran, M. and Allen, E. (2004). Keeping forest pests from moving around the world. http://www.fao.org/documents/show_cdr.asp?url_file=//docrep/007/y5507e/y5507e08.htm; accessed 25 October 2005.

Kile, G.A. (1993). Plant diseases caused by species of *Ceratocystis sensu stricto* and *Chalara*, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma*. Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 173–183. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Kliejunas, J.T., Tkacz, B.M., Burdsall, H.H., DeNitto, G.A., Eglitis, A., Haugen, D.A., and Wallner, W.E. (2001). Pest Risk Assessment of the Importation into the United States of Unprocessed Eucalyptus Logs and Chips from South America. General Technical Report FPL-GTR-124. Forest Products Laboratory, Forest Service, US Department of Agriculture, Madison, WI, USA.

Kolk, A. and Starzyk, J.R. (1996a). Violet tanbark beetle – *Callidium violaceum* (L.) in Atlas skodliwych owadów lesnych (The Atlas of Forest Insect Pests) Multico Warszawa. 705 pp. English translation by Dr Lidia Sukovata for http://www.forestpests.org/poland/violettan.html; accessed 6 October 2005.

Kolk, A. and Starzyk, J. R. (1996b). Six-toothed bark beetle - *Ips sexdentatus* (Börn.) in Atlas skodliwych owadów lesnych (The Atlas of Forest Insect Pests) Multico Warszawa. 705 pp. English translation by Dr. Lidia Sukovata for http://www.forestpests.org/poland/sixtoothedbark.html; accessed 20 September 2005.

Kooper, B.J., Klepzig, K.D. and Raffa, K.F. (2004). Components of antagonism and mutualism in *Ips pini* – fungal interactions: relationship to a life history of colonizing highly stresses and dead trees. *Environmental Entomology* 33: 28–34.

Kuhnholz, S., Borden, J.H. and McIntosh, R.L. (2000). The ambrosia beetle *Gnathotrichus retusus* (Coleoptera: Scolytidae) breeding in red alder, *Alnus rubra* (Betulaceae). *Journal of the Entomological Society of British Columbia* 97: 103–104 (abstract only seen).

Lane, C.L. (1998). *Log Export and Import Restrictions of the US Pacific Northwest and British Columbia: Past and Present*. USDA, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-435, August 1998.

Leahy, P., Feinstein, D., Jeffords, J., Levin, C., Clinton, H., Schumer, C. and Boxer, B. (2002). Letter to Ann M. Veneman, Secretary of Agriculture, U.S. Department of Agriculture. APHIS registration 35-4211933. Pages A87–A88 in USDA (2003). Importation of solid wood packing material. Final environment impact statement – August 2003. U.S. Department of Agriculture, Marketing and Regulatory Programs, Animal and Plant Health Inspection Service, Riverdale Maryland USA. http://www.aphis.usda.gov/ppd/es/pdf%20files/swpmfeis.pdf; accessed 21 November 2005.

Lindelöw, Å., Risberg, B. and Sjödin, K. (1992). Attraction during flight of scolytids and other bark- and wood-dwelling beetles to volatiles from fresh and stored spruce wood. *Canadian Journal of Forest Research* 22: 224–228.

López, J.F. and Alía, R. (2005). Chestnut (*Castanea sativa*) genetic resource cons. European Forest Genetic Resources Programme. http://www.ipgri.cgiar.org/networks/euforgen/Networks/Scattered_Broadleaves/NHStrategies/CastaneaSppConsStrategy.htm; accessed 2 March 2006.

Lui, Y.B. and McLean, J.A. (1993). Observations on the biology of the ambrosia beetle *Gnathotrichus retusus* (Leconte) (Coleoptera: Scolytidae). *Canadian Entomologist* 125 (1): 73–83.

McLean, J.A. and Borden, J.H. (1975). *Gnathotrichus sulcatus* attack and breeding in freshly sawn lumber. *Journal of Economic Entomology* 68: 605–606.

McLean, J.A., and Borden, J.H. 1977. Attack by *Gnathotrichus sulcatus* (Coleoptera: Scolytidae) on stumps and felled trees baited with sulcatol and ethanol. *Canadian Entomology* 109:675–686.

McNamara, D and Kroeker, G. (n.d.) International Measures for Solid Wood Packing Material. Exotic Forest Pests Online Symposium http://www.apsnet.org/online/exoticpest/Papers/mcnamara_mesures.htm; accessed 22 April 2005.

MAFF (2003). Methyl Bromide Fumigation Schedules for Wood packing Materials Infested with Pine Wood Nematode (*Bursaphelechus xylophilus*). Plant Protection Division, Food and Safety and Consumer Affairs Bureau, Ministry of Agriculture, Forestry and Fisheries, Japan. Technical Report Presented to the International Quarantine Forestry Research Group Conference, 19 February 2004, Rome.

MAF NZ (2003). Import Health Standard - Bark from all countries. Ministry of Agriculture and Forestry, New Zealand. http://www.biosecurity.govt.nz/imports/forests/standards/non-viable-forest-produce/bark.htm; accessed 22 November 2005.

Maier, C.T. and Lemmon, C.R. (2000). Discovery of the small Japanese cedar longhorned beetle, *Callidiellum rufipenne* (Motschulsky) (Coleoptera: Cerambycidae), in live Arborvitae in Connecticut. *Proceedings of the Entomological Society of Washington* 102 (3):747–754.

Malloch, D. and Blackwell, M. (1993). Dispersal biology of the ophiostomatoid fungi, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma*. Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 195–206. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Matsuura H. Fujita K. (1997). Termination of adult diapause by chilling in the small cedar longicorne beetle, *Callidiellum rufipenne* (Motschulsky) (Coleoptera, Cerambycidae). *Research Bulletin of the Plant Protection Service*, Japan, 33: 43–48.

Middlekauf, W.W. (1960). The siricid wood wasps of California (Hymenoptera: Symphyta). *Bulletin of the California Insect. Survey* 6 (4): 59–77. University of California Press Berkeley and Los Angeles.

Milligan, R.H. (1979). *Leanobium flavomaculatum* (Coleoptera: Anobiidae) Espanol. A Native House Borer. Forest and Timber Insects in New Zealand, Forest Health Leaflet No. 36. Forest Research Institute, New Zealand Forest Service. http://www.forestresearch.co.nz/PDF/Ent36Leanobiumflavomaculatum.pdf; accessed 15 June 2004.

Mireku, E. and Simpson, J.A. (2002). Fungal and nematode threats to Australian forests and amenity trees from importation of wood and wood products. *Canadian Journal of Plant Pathology* 24: 117–124.

Monné, M.A. and Hovore, F.T. (2002). Checklist of the Cerambycidae and Disteniidae (Coleoptera) of the Western Hemisphere. Part One: Parandrinae through Lepturinae, Electronic Version 2002. http://hovore.com/pdf/Electronic_Checklist_Pt.1_05_03.pdf; accessed 6 October 2005.

Moore, B.A. (2005). Alien Invasive Species: Impacts on Forestry and Forests. Working paper FBS/8E. Forestry Department, Forest Resources Division, Forest Resources Development Service, FAO, Rome. http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/008/j6854e/J6854E03.htm; accessed 6 March 2006.

Morgan, F.D. (1961). The comparative biologies of certain New Zealand Cerambycidae. *The New Zealand Entomologist* 2: 26–34.

Morgan, F.D. (1968). Biomics of Siricidae. *Annual Review on Entomology* 13: 239–256.

Morrell, J.J. (1995). Importation of unprocessed logs into North America: a review of pest mitigation procedures and their efficacy. *Forest Products Journal* 45: 41–49.

Munro, J. (1928). *Beetles Injurious to Timber*. Forestry Commission Bulletin No. 9. His Majesty's Stationary Office, Adastral House, Kingway, London.

Murdoch, C.W. (1992). Alternatives to Petroleum-Based Biocides for Protecting Hardwood Lumber and Manufactured Products, *Transferring Technologies for Industry, No. 4*. http://www.nal.usda.gov/ttic/industry/hrdwood4.htm#methyl; accessed 26 October 2005.

Mussen, E.C. (2000). Wood wasps and horntails. Pest Notes, University of California, Division of Agriculture http://www.ipm.ucdavis.edu/PDF/PESTNOTES/pnwoodwaspshorntails.pdf; accessed 1 July 2005.

Nannelli, R. and Turchetti, T. (1989). Preliminary observations on the association of some species of corticolous Acari with Cryphonectria parasitica (Murr.) Barr. *Redia*, 72(2): 581–593.

Nag Raj, T.R. and Kendrick, W.B. (1993). The anamorph as generic determinant in the holomorph: the *Chalara* connection in the Ascomycetes, with special reference to the ophiostomatoid fungi, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma*. Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 61–70. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Natural Resources Canada (2005) Our forests under threat. Canadian Forest Service. http://www.cfl.scf.rncan.gc.ca/CFL-LFC/publications/activites/menace_e.html; accessed 21 November 2005.

Nuorteva, P. and Nuorteva, S.L. (1955). Das auftreten holzzerstorender insek-ten in einigen scharenkirohspielen Sudwestfinnlands [The occurrence of wood-destroying insects in certain parishes in south-west Finland]. *Annales Entomologici Fennici* 20 (4): 164–171 (abstract only seen).

Old, K.M. & Kobayashi, T. (1988). Eucalypts are susceptible to the chestnut blight fungus, *Cryphonectria parasitica*. *Australian Journal of Botany* 36: 599–603.

Ormsby, M. (2004). Report on the interception of *Fusarium circinatum* (Pitch Canker) on imported seedlings of Douglas fir (*Pseudotsuga menziesii*) 11 February 2004. http://www.fas.usda.gov/ffpd/wto_sps_tbt_notifications/forest_products/NNZL280_Report.pdf; accessed 1 July 2004.

Owen, D. and Adams, D. (1999). Overview of Pitch Canker in California, *in* Devey, M., Matheson C. and Gordon, T. *Current and Potential Impacts of Pine Pitch Canker in Radiata Pine*. Proceedings of the Impact Monterey Workshop. Monterrey, California, 30 November to 3 December 1998. CSIRO Forestry and Forest Products. Technical report No. 112

Paine, T.D., Raffa, K.F. and Harrington, T.C. (1997). Interactions among scolytid bark beetles, their associated fungi, and live host conifers. *Annual Review of Entomology* 42: 179–206.

Pakaluk, J. and Anagnostakis, S.L. (1997). *Acoptus suturalis* LeConte (Coleoptera: Curculionidae: Zygopinae), a potential vector of the chestnut blight fungus, *Cryphonectria parasitica* (Murrill) Barr, in the Eastern United States. *Proceedings of the Entomological Society of Washington*, 99(3): 583–584.

Parkin, E. (1937). The kiln-sterilization of timber infested by *Lyctus* powder-post beetles. *Forestry Quarterly* 11: 32–39.

Pastoret, J. (1993). Air seasoning (drying) of wood. University of Missouri, Extension publication G5550. http:/muextension.missouri.edu/xplor/agguides/forestry/g05550.htm; accessed 26 April 2005.

PDI (2004). Pest and Disease Information Database. Biosecurity Australia, Department of Agriculture, Fisheries and Forestry, Canberra, Australia.

Phillips, C. (2001). Pine pitch canker – *Fusarium subglutinans* f. sp. *pini*. *Forest Health* Number 31. Forestry South Australia. Government of South Australia. http://www.forestry.sa.gov.au/privateforestry/insect_fact_sheets/Fact_Sheet_html/FHS%2031%20PFG78%20Pine%20Pitch%20Canker.htm; accessed 26 September 2005.

Plant Health Survey Unit (2005). *Tetropium fuscum* (Fabricius) Brown Spruce Longhorn Beetle, Canadian Food Inspection Agency, Plant pest information sheet. http://www.inspection.gc.ca/english/sci/surv/data/tetfuse.shtml; accessed 12 September 2005.

Reay, S.D., Thwaites, J.M. and Farrell, R.L. (2005). A survey of *Ophiostoma* species vectored by *Hylastes ater* to pine seedlings in New Zealand. *Forest Pathology* 35: 105–113.

Rhatigan, R.G., Morrell, J.J. and Filiip, G.M. (1995). Toxicity of methyl bromide to four pathogenic fungi in larch hardwood. *Forest Products Journal* 49: 63–67.

Redmer, J.S., Wallin, K.F. and Raffa, K.F. (2001). Effect of host tree seasonal phenology on substrate suitability for the pine engraver (Coleoptera: Scolytidae): implications for population dynamics and enemy free space. *Journal of Economic Entomology* 94 (4): 844–849.

Rellou, J. (2002). Chestnut blight fungus. *Cryphonectria parasitica*. http://www.columbia.edu/itc/cerc/danoff-burg/invasion_bio/inv_spp_summ/Cryphonectria_parasitica.htm; accessed 7 March 2006.

Rexrode, C.O. and Brown, D. (1983). Oak wilt. Forest Insect & Disease Leaflet 29. US Department of Agriculture Forest Service. http://www.na.fs.fed.us/spfo/pubs/fidls/oakwilt/oakwilt.htm; accessed 22 November 2005.

Ridley, G. (2004). Fungi heat tolerances, MBS 331, in MAF NZ, *Research Results 2003/04 Research Final Report Summaries*. MAF Policy information Paper 55. December 2004. http://www.maf.govt.nz/mafnet/rural-nz/research-and-development/research-results/2003-2004/; accessed 9 August 2005.

Ridley, G.S. and Gardner, J.F. (2004). Temperatures and exposure times to eliminate fungi from infested wood. Heat Treatment pp. 1–7. Document provided by MAF NZ.

Rose, A.H. (1957). Some notes on the biology of *Monochamus scutellatus* (Say) (Coleoptera: Cerambycidae). *The Canadian Entomologist* 89: 547–553.

Rudinsky, J.A. (1962). Ecology of scolytidae. *Annual Review of Entomology* 7: 327–348.

Russin, J.S., Shain, L. and Nordin, G.L. (1984). Insects as carriers of virulent and cytoplasmic hypovirulent isolates of the chestnut blight fungus. *Journal of Economic Entomology* 77: 838–846.

Salom, S.M. and McLean J.A. (1989) Influence of wind on the spring flight of *Trypodendron lineatum* (Olivier) (Coleoptera: Scolytidae) in a second-growth coniferous forest. Canadian Entomology 121(2): 109–119.

Salvage, R. (1999). Timber importation from an AQIS operational perspective, *in* Anon., *National Stakeholder Timber Pest Conference Proceedings*, AQIS, 20–22 April 1999, Canberra, Australia.

Sathyapala, S. (2004). Pest risk analysis. Biosecurity risk to New Zealand of pinewood nematode (*Bursaphelenchus xylophilus*). Ministry of Agriculture and Forestry. New Zealand.

Sauvard, D. (2004). General biology of bark beetles. Chapter 5, *in* F. Lieutier, K.R. Day, A. Battisti, J.-C. Grégoire and H.F. Evans, *Bark and wood boring insects in living trees in Europe, a synthesis*. pp. 529–534. Kluwer Academic Publishers, Dordrecht.

Scheffrahn, R.H., Su, N.-Y. and Hsu, R.-C. (1992). Diffusion of methyl bromide and sulfuryl fluoride through selected structural wood matrices during fumigation. *Material und Orhanismen* 27: 147–155.

Schmidt (n.d.). Penetration of fumigants into logs for pest eradication and stain prevention. http://www.epa/ozone/mbr/airc/1997/090schmidt.pdf; accessed 22 April 2005.

Schröder, T. (2005). Reinfestation of spruce logs and planks (*Picea abies*) with bark-beetle *Pityogenes chalcographus* after heat treatment according to the ISPM No. 15. Papers presented at the 2nd meeting of the IFQRG, Victoria, Canada, 21–23 February 2005.

Searles, T.D. (2005). Letter to Mr Roddie Burgess dated 24 January 2005; from T.D. Searles, President, American Lumber Standard Committee, Incorporated. Papers presented at the 2nd meeting of the IFQRG, Victoria, Canada 21–23 February 2005.

Seifert, K.A. (1993). Sapstain of commercial lumber by species of *Ophiostoma* and *Ceratocystis*, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma. *Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 141–151. APS Press, St Paul, Minnesota, USA. (Reprint 1999.)

Seifert, K.A. and Okada, G. (1993). *Graphium* anamorphs of *Ophiostoma* species and similar anamorphs of other Ascomycetes, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma. *Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 27–41. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Seifert, K.A., Webber, J.F. & Wingfield, M.J. (1993a). Methods for studying species of Ophiostoma and Ceratocystis, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma. *Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 255–259. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Seifert, K.A., Webber, J.F. & Wingfield, M.J. (1993b). A nomenclator for described species of *Ceratocystis*, *Ophiostoma*, *Ceratocystiopsis*, *Ceratostomella* and *Sphaeronaemella*, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma. *Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 269–287. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Shibata E. (1994). Population studies of *Callidiellum rufipenne* (Coleoptera: Cerambycidae) on Japanese cedar logs. *Annals of the Entomological Society of America*, 87(6): 836–841.

Shore, T.L. (2000). Ambrosia beetles. *Forest Pest Leaflet* 72, Pacific Forestry Centre, Natural Resources Canada, Canadian Forest Service. PDF copy http://warehouse.pfc.forestry.ca/pfc/5011.pdf; accessed 6 May 2004.

Simpson, J.A. (1999). Fungi on wood imported into Sydney. AQIS study. Department of Agriculture Fisheries and Forestry, Canberra, Australia.

Simpson, J.A. Manuscript accepted for publication in *Australian Forestry*.

Sinclair, W.A., Lyon, H.H. and Johnson, W.T. (1987). *Diseases of trees and shrubs*. Comstock Publishing Associates, Cornell University Press, Ithaca, USA.

Six, D.L. and Paine, T.D. (1997). *Ophiostoma clavigerum* is the mycangial fungus of the Jeffrey pine beetle, *Dendroctonus jeffreyi*. *Mycologia* 89: 858–866.

Smith, T.M., Reichenbach, M., Molina-Murillo, S.A. & Smith, R. (n.d.). Potential effect of international phytosanitary standards on use of wood packaging material. Technical Paper. http://www.agctr.lsu.edu/enr/palletsanitation/articles/article1.pdf; accessed 3 March 2006.

Snyder, T.E. (1923). High temperatures as a remedy for *Lyctus* powder-post beetles. *Journal of Forestry* 21: 810–814.

Society of American Foresters (2005). Here's How to Salvage Beetle-Killed Trees. From the January 2005 issue of *The Forestry Source*. http://www.safnet.org/archive/0205_howtobeetle.cfm; accessed 18 November 2005.

Solomon, J.D. (1995). Guide to insect borers of North American broadleaf trees and shrubs. Agricultural Handbook. 706. Forest Service, U.S. Department of Agriculture, Washington, DC. 735 pp.

Soma, Y., Naito, H., Misumi, T., Mizobuchi, M., Tsuchiya, Y., Matsuoka, I., Kawakami, F., Hirata, K. and Komatsu, H. (2001). Effects of some fumigants on pine wood nematode *Bursaphelenchus xylophilus* infecting wooden packages. 1 Susceptibility of pine wood nematode to methyl bromide, sulfuryl fluoride and methyl isothiocyanate. *Research Bulletin of the Plant Protection Service, Japan* 37: 19–26.

Soma, Y., Naito, H., Misumi, T., Tsuchiya, Y., Mizobuchi, M., Matsuoka, I. and Kawakami, F. (2002) Effects of some fumigants on pine wood nematode, *Bursaphelenchus xylophilus* infecting wooden packages 2, Mortality of pine wood nematode by methyl bromide tent fumigation. *Research Bulletin of the Plant Protection Service, Japan* 38: 13–19.

Soma, Y., Goto, M., Naito, H., Ogawa, N. and Kawakami, F. (2003) Effects of some fumigants on pine wood nematode, *Bursaphelenchus xylophilus* infecting wooden packages 3. *Research Bulletin of the Plant Protection Service Japan* 39: 7–14.

Stone, C. and Simpson, J.A. (1987). Influence of *Ips grandicollis* on the incidence and spread of bluestain fungi in *Pinus elliottii* billets in north-eastern New South Wales. *Australian Forestry* 50 (2): 86–94.

Stone, C. and Simpson, J.A. (1991a). Influence of cell viability of freshly felled *Pinus elliottii* on the subcortical community associated with *Ips grandicollis* (Coleoptera: Scolytidae). *Canadian Journal of Forest Research* 21 (7): 1006–1011.

Stone, C. and Simpson, J.A. (1991b). Effect of six chemicals on the insects, mites, nematodes and fungi associated with *Ips grandicollis* (Eichhoff) (Coleoptera: Scolytidae) in northeastern New South Wales. *Journal of the Australian Entomological Society* 30: 21–28.

Storer, A.J., Gordon, T.R. and Clark, S.L. (1998). Association of the pitch canker fungus, *Fusarium subglutinans* f. sp. *pini*, with Monterey pine seeds and seedlings in California. *Plant Pathology* 47: 649–656.

Storer, A.J., Bonello, P., Gordon, T.R. and Wood, D.L. (1999a). Evidence of resistance of the pitch canker pathogen (*Fusarium subglutinans*) in native stands of Monterey pine (*Pinus radiata*). *Forest Science* 45: 500–505.

Storer, A.J., Wood, D.L. and Gordon, T.R. (1999b). Insect vectors of *Fusarium circinatum* in California, and their potential for the spread of pitch canker disease, *in* M.E. Devey, A.C. Matheson and T.R. Gordon, *Current and Potential Impacts of Pitch Canker in Radiata Pine*, pp. 45–48. CSIRO Australia.

Spitzer, E., Lockyer, B., Blumenthal, R and Madigan, L. (2005). States sue for better control of invasive pests. Press Release, Office of New York State Attorney General Eliot Spitzer, September 15. Http://www.oag.state.ny.us/press/2005/sep/sep15b_05.html; accessed 22 November 2005.

Strang, T.J.K. (1992). A review of published temperatures for the control of pest insects in museums. *Collection Forum* 8: 41–67.

Tainter, F.H. and Baker, F.A. (1996). *Principles of Forest Pathology*. John Wiley and Sons, Inc., xvi + 805 pp.

Technical Panel on Forest Quarantine (2005). Report of the Technical Panel on Forest Quarantine, Victoria, Canada, 7–11 March 2005. IPPC. https://www.ippc.int/servlet/BinaryDownloaderServlet/75879_09.doc.doc?filename=1118403101637_Report_TPFQ_1st_meeting_draft_2005_06_09.doc&refID=75879; accessed 26 October 2005.

Thwaites, J.M., Farrell, R.L., Duncan, S.M., Reay, S.D., Blanchette, R.A., Hadar, E., Hadar, Y., Harrington, T.C. and McNew, D. (2005). Survey of potential sapstain fungi on *Pinus radiata* in New Zealand. *New Zealand Journal of Botany* 43: 653–663.

Thwaites, J.M., Farrell, R.L., Hata, K., Lausberg, M. and Carter, P. (no date). Sapstain fungi: from harvesting to an export destination. The University of Waikata & fibre-gen, Carter Holt Harvey Limited.

Tkacz, B.M. Burdsall, H.H., Jr. DeNitto, G.A. Eglitis, A. Hanson, J.B. Kliejunas, J.T. Wallner, W.E. O'Brien, J.G. Smith, E.L. (1998). Pest risk assessment of the importation into the United States of unprocessed *Pinus* and *Abies* logs from Mexico. General Technical Report FPL–GTR–104. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 116 pp.

Tragardh, J. (1947). Final Survey of the wood destroying insects in public buildings in Sweden. *Bulletin of Entomological Research* 38: 117–122 (abstract only seen).

Turchetti, T. and Chelazzi, G. (1984). Possible role of slugs as vectors of the chestnut blight fungus. *European Journal of Forest Pathology*, 14(2): 125–127.

UN Atlas of the Oceans (n.d.). Dry Cargo Ships. General Cargoes and Bulk Carriers. Ships of the World, Maritime transportation, Transportation and Telecommunications, Uses of the Oceans. http://www.oceansatlas.com/unatlas/uses/transportation_telecomm/maritime_trans/shipworld/cargo_car/drycargo/dry_cargo_ships.htm; accessed 6 March 2006.

USAToday (2005). Katrina turned lush forests into wastelands. http://www.usatoday.com/money/industries/2005-09-13-katrina-timber_x.htm; accessed 18 November 2005.

USDA (1991). Pest risk assessment of the importation of larch from Siberia and the Soviet Far East. Forest Service Miscellaneous Publication No. 1495.

USDA (1992). Pest risk assessment of the importation of *Pinus radiata* and Douglas-fir logs from New Zealand. Miscellaneous Publication 1508. Forest Service, U.S. Department of Agriculture, Washington, DC.

USDA (1999). United States Department of Agriculture. Air drying of lumber. Forest Products Laboratory, General Technical Report FPL-GTR-117.

USDA (2000). Pest risk assessment for importation of solid wood packing materials into the United States. U.S. Department of Agriculture, Animal and Plant Health Inspection Service and Forest Service. Raleigh, North Carolina, USA. http://www.aphis.usda.gov/ppq/pra/swpm/intro.pdf; accessed 23 November 2005.

USDA (2003). Importation of solid wood packing material. Final environment impact statement – August 2003. U.S. Department of Agriculture, Marketing and Regulatory Programs, Animal and Plant Health Inspection Service, Riverdale Maryland USA. http://www.aphis.usda.gov/ppd/es/pdf%20files/swpmfeis.pdf accessed 21 November 2005.

US EPA (1994). Environmental Protection Agency. Heat treatments to control pests on imported timber. http://www.epa.gov/spdpublc/mbr/casestudies/volume2/heatlog2.html; accessed 26 October 2005.

Uzunović, A., Webber, J.F., Pearce, A.J. and Dickinson, D.J. (1999). The role of mechanized harvesting in the development of bluestain in pine. *Canadian Journal of Forest Research* 29(2): 242–251.

Viljoen, J. and Banks, J. (2002). Stock-take of timber treatments and their efficacy. Technical Working Group Report, Risk analysis for the importation of sawn coniferous timber from New Zealand, Canada and USA. CSIRO Division of Entomology.

Viitasaari, M. and Heliövaara, K. (2004). Siricidae (horntails), Chapter 22 (8), *in* F. Lieutier, K.R. Day, A. Battisti, J.-C. Grégoire and H.F. Evans, *Bark and wood boring insects in living trees in Europe, a synthesis*, pp. 529–534. Kluwer Academic Publishers, Dordrecht.

Webber, J.F. (1990). Relative effectiveness of *Scolytus scolytus*, *S. multistiatus* and *S. kirschi* as vectors of Dutch elm disease. *European Journal of Forest Pathology* 20: 184–192.

Webber, J.F. (2000). Insect vector behaviour and the evolution of Dutch elm disease, *in*: C.P. Dunn (ed.), *The elms—Breeding, Conservation and Disease Management*, pp. 47–60. Kluwer Academic Publishers, Boston, USA.

Wendt, R., Weidhaas, J., Griffin, G.J. and Elkins, J.R. (1983). Association of *Endothia parasitica* with mites isolated from cankers on American chestnut trees. *Plant Disease*, 67: 757–758.

Whitehead, P.F. (1988). Two rare Cerambycidae (Col.) from Worcestershire. *Entomologists Monthly Magazine* 124 (1484–1487): 79 (abstract only seen).

Whyte, C. (2003). Sea container Biosecurity. An overview of New Zealand's new biosecurity arrangements for sea containers. Ministry of Agriculture and Forestry, New Zealand. http://www.cbfca.com.au/fiji2003/_upload/report/09_Dr_Carolyn_Whyte_Presentation.pdf; accessed 23 November 2005.

Wichmann, L. and Ravn, H.P. (2001). The spread of *Ips typographus* (L.) (Coleoptera, Scolytidae) attacks following heavy windthrow in Denmark, analysed using GIS. *Forest Ecology and Management* 148: 31–39.

Wikler, K., Gordon, T.R., Storer, A.J. and Wood, D.L. (2003). Pitch Canker. University of California Statewide IPM Program. http://www.ipm.ucdavis.edu/PMG/PESTNOTES/pn74107.html; accessed 1 July 2004.

Wilson, L.F. (1962). White-spotted sawyer. Forest insect and disease leaflet 74, United States Department of Agriculture Forest Service. 6 pp. http://www.na.fs.fed.us/spfo/pubs/fidls/ws_sawyer/ws_sawyer.htm; accessed 19 April 2004.

Wingfield, M.J. (1993). *Leptographium* species as anamorphs of *Ophiostoma*: progress in establishing acceptable generic and species concepts, *in* M.J. Wingfield, K.A. Seifert and J.F. Webber (eds). Ceratocystis *and* Ophiostoma*. Taxonomy, Ecology, and Pathogenicity*, second printing, pp. 43–51. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Wingfield, M.J., Harrington, T.C. and Solheim, H. (1997). Two species in the *Ceratocystis coerulescens* complex from conifers in western North America. *Canadian Journal of Botany* 75: 827–834.

Wingfield, M.J., Seifert, K.A. and Webber, J.F. (eds). (1993). Ceratocystis *and* Ophiostoma*. Taxonomy, Ecology, and Pathogenicity*, second printing. APS Press, St Paul, Minnesota, USA. (Reprinted 1999.)

Wood, D.L. (1982a). The role of pheromones, kairomones and allomones in the host selection and colonization behaviour of bark beetles. *Annual Review of Entomology* 27: 411–446.

Wood, S.L. (1982b). The bark and ambrosia beetles of North and Central America (Coleoptera: Scotytidae), a taxonomic monograph. *The Great Basin Naturalist Memoirs* No. 6. 1359 pp.

Wood, M.S., Stephens, N.C., Allison, B.K. and Howell, C.I. (2001). *Plantations of Australia – A report from the National Plantation Inventry and the National Farm Forest Inventory.* National Forest Inventory, Bureau of Rural Sciences, Canberra.

Wood, D.L. and Storer, A.J. (2002). Bark beetles infesting California's conifers. *Fremontia* 30 (3–4): 19–25.

Worrall, J. (2005a). Forest and shade tree pathology. Wood decay. http://www.forestpathology.org/decay.html; accessed 18 October 2005.

Worrall, J. (2005b). Pitch canker. Forest and shade tree pathology. Wood decay. http://www.forestpathology.org/dis_pitch.html; accessed 22 November 2005.

Yan, Z., Sun, J., Owen, D. and Zhang, Z. (2004). The red turpentine beetle, *Dendroctonus valens* LeConte (Scolytidae): an exotic invasive pest of pine in China. *Biodiversity and Conservation* (in press) http://www.kluweronline.com/article.asp?PIPS=5270697&PDF=1; accessed 12 October 2004).

15. APPENDIX 1. Inter-national Standards for Phytosanitary Measures Publication No. 15 - Guidelines for Regulating Wood Packaging Material in International Trade