Wood Borer and Bark Beetle Risk Analysis

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EXECUTIVE SUMMARY

Wood borers and bark beetles are among the most serious forest pests world-wide, and many species have become successful invaders beyond their native range. International trade in forest products and, in particular, the widespread use of wood packaging materials have been identified as significant pathways for the introduction of such borers. New Zealand already operates well developed high-risk site and forest health surveillance programmes which should facilitate the detection of new invaders. However, a recent external evaluation of New Zealand's Forest Health Surveillance (FHS) programme, which was commissioned by the Forest Owners Association (NZFOA), recommended the implementation of a network of traps for detecting wood-boring insects across New Zealand on an operational basis. A trap-based surveillance programme may lead to earlier detection and, therefore, an increased likelihood of successful eradication or other emergency response. But such a programme also comes at a cost, and there is some uncertainty among stakeholders whether the risks posed by borers and the benefits of an additional surveillance programme justify this expenditure. The objectives of this report were, therefore, to estimate the risk of establishment of exotic wood- and bark-boring insects and the potential damages that could result, to determine the efficacy of traps for detecting a newly introduced wood- and bark-boring insect and the subsequent probability of successful eradication, and to weigh up the costs and potential benefits of a trap-based surveillance programme.

A review of historical records of interceptions and establishments in New Zealand and overseas indicates that there have been numerous interceptions of borers that pose serious biosecurity risks to New Zealand's plantation forests (and to trees in other production, natural or urban ecosystems). Among the more serious invaders are *Dendroctonus valens* which kills pines in China, and *Ips grandicollis* which currently has serious outbreaks in parts of Australia where it causes mortality of radiata pines. In New Zealand, relatively few establishments of such species have occurred but cases recorded in other countries demonstrate that the risk is high. Border interceptions and establishments of borers have increased in the last two decades as a result of growing international trade, although phytosanitary measures in New Zealand and internationally (e.g., ISPM 15) have counteracted this to some degree. Trap-based surveillance programmes for borers have been implemented in various countries (e.g., Australia, USA), and these have been successful. An ongoing programme in the USA that started in 2001 detected one new species per year, on average, over the following five years. Among the detections was one new species attacking pines (and other Pinaceae), *Hylurgops palliatus.* In New Zealand, a similar programme run by MAF-Biosecurity New Zealand was in operation for three years until 2005 (no new species were detected), but it was discontinued because of a lack of funding. However, a programme is most useful as an early warning system when it operates continuously, so it enables detections of new incursions as early as possible, ideally before any significant spread has occurred. The potential benefits of a reinstated borer surveillance programme, in terms of averted losses, need to be balanced against the costs of a programme. If there were no new establishments, costs would exceed the benefits. Conversely, if a trap-based programme were to lead to the early detection of a new borer with a potentially significant impact on New Zealand's forests and forest industry, then there is a high probability of significant net benefits resulting from the ability to respond more rapidly to this incursion.

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1. Introduction

Wood borers and bark beetles are among the most serious forest pests. Numerous species have become established outside their native range, and some groups are generally regarded to present a high risk to forest biosecurity. Currently there are targeted surveillance programmes for such borers in Australia, the United States, and other countries (see below). In 2007, the New Zealand Forest Owners' Association (NZFOA) commissioned an external evaluation of New Zealand's current Forest Health Surveillance (FHS) programme (Liebhold and Callan 2007). One of the recommendations of the evaluation was *to implement a network of traps for detecting wood-boring insects across New Zealand on an operational basis*. Subsequently the need for further information about the rationale for such a surveillance programme was raised.

Here we present a review of the risks associated with exotic wood- and bark-boring insects that have been recorded on *Pinus* species and other Pinaceae but are not present in New Zealand. Some relevant cases concerning other tree species are also discussed. The review will also discuss the kinds of damage that could potentially occur in New Zealand's plantation forests if an exotic wood- or bark-boring insect did establish, based on experience in other countries. This work will contribute to an evaluation of the potential benefit of carrying out a trapping programme aimed at early detection of wood- and bark-boring insects, based on experience in New Zealand and overseas. The Forest Biosecurity Research Council commissioned this review to address the points above.

Note: this report is <u>not</u> a standard pest risk analysis of wood borers and bark beetles.

The objectives of this study were:

- To estimate the risk of establishment of exotic wood- and bark-boring insects based on historical records of interceptions and establishments in New Zealand and overseas.
- To estimate the potential for 'damage' to trees, forest products, or trade if a wood- and bark-boring insect became established in New Zealand, based on overseas and local experience.
- To determine the efficacy of traps for detecting a newly introduced wood- and bark-boring insect and the subsequent probability of successful eradication.
- To comment on the benefits of carrying out a generic trapping programme based on risk of establishment, potential economic consequences if establishment did occur, and probability of eradication if a detection was made.

2. Background

Wood borers and bark beetles include native species that have co-evolved with their host trees as well as invasive species that were translocated accidentally (e.g., Coulson and Witter 1984, Haack 2001, Liebhold et al. 1995). Globally, the spread of these and other exotic forest insects (and some associated tree pathogens) continues at an unprecedented rate as a result of ever increasing global trade (e.g., Haack 2006, Smith et al. 2007). Wood borers and bark beetles have several features that make them successful invaders. They are easily transported in wood products and wood packaging materials where they are sheltered from detection and, to some degree, adverse climatic effects. Over the last few years such borers were newly detected. For example, in the U.S. new detections since 2000 occurred at a rate of more than one species per year (Rabaglia et al. 2008), and some of these species have serious impacts and are potentially capable of virtually eradicating their newly acquired host tree species (e.g., Haack et al. 2002). These insects can damage trees and timber in various ways, including tunnelling in felled trees and sawn timber, attack of standing trees (sometimes causing mortality by effectively ring-barking trees or by vectoring pathogenic fungi and other organisms), or by introducing sapstain-causing fungi. In addition, the presence of such species on export logs and sawn timber can adversely affect international trade or necessitate fumigation with methyl bromide or other disinfestation measures that are required to comply with trade rules.

As native species many wood borers and bark beetles are a natural element of forests all over the world. Despite this some native species rank among the most damaging forest pests, such as the European spruce bark beetle, *Ips typographus*, the European six-spined engraver beetle, *Ips sexdentatus*, which regularly kill thousands of hectares of spruce and pine forests, respectively, especially during outbreaks following windthrow events. The North American mountain pine beetle, *Dendroctonus ponderosae*, has recently gained world-wide notoriety due to its massive outbreak in British Columbia and adjacent regions causing mortality of lodgepole pine (*Pinus contorta)*, ponderosa pine (*P. ponderosa*), and other pines across an area approaching 150,000 km^2 (Kurz et al. 2008) (Fig. 1).

Should a serious bark beetle or wood borer become established in New Zealand, the consequences for forestry could be severe. As noted earlier, there are numerous precedences of such invasions overseas and a few in New Zealand. As invaders the impacts of such species are often worse than in their native range because they are released from their natural enemies or because their new host trees are not resistant to a pest they have not encountered in their evolutionary history. This is happening in the case of the North American red turpentine beetle, *Dendroctonus valens*, an invader that kills native pines in China (Gao et al. 2005). Another well known case is that of the smaller elm bark beetle, *Scolytus multistriatus*, which introduced the fungal pathogen causing Dutch elm disease (Webber 2000) to North America and, more recently, New Zealand (Gadgil et al. 2000). Together with the disease it spreads, it is responsible for the gradual disappearance of native and introduced elms from much of North America. Longhorn beetles (Cerambycidae) in the genus *Monochamus* are the vectors of the nematode that causes pine wilt disease, which they have spread to several countries, causing mortality of pines not resistant to this nematode (Mamiya 1988).

A number of measures have been taken to reduce the risk of such invasions occurring. The pathway associated with wood packaging has been prioritised, and an International Standard for Phytosanitary Measures, No. 15 (ISPM-15) has been ratified, requiring treatment of wood packaging materials (IPPC 2006). In addition, an 'Import health standard: wood packaging material from all countries' (Biosecurity New Zealand 2006) has been introduced in New Zealand, which appears to have led to some improvements already, although some wood packaging materials continue to arrive untreated (Craighead 2009). New Zealand has a rigorous border quarantine system where all cargo consignments are risk profiled and a subset of high risk cargo is selected for inspection at the port or transitional facility. Any untreated, inadequately treated, non-compliant, or infested material found is immediately treated, destroyed, or returned to the country of origin. Nevertheless, not all infestations are noticed and prevented from entry.

Surveillance programmes for the early detection of new pests are considered important to allow a timely response to an incursion. Eradication of a new organism may be possible (e.g., Myers and Hosking 2002, Liebhold and Tobin 2008) but usually only if the affected area is not too large. In an interview with Biosecurity, Daniel Simberloff, an internationally recognised expert on invasive pests and Director of the Institute for Biological Invasions at the University of Tennessee, emphasised that early detection (and early intervention) are key to successful incursion responses (Simberloff 2007). For this reason surveillance programmes or 'pest detection surveys' have been and are being carried out in many countries, targeting a wide range of unwanted organisms. In New Zealand a surveillance programme for wood- and bark boring insects was carried out from 2001/02 to 2004/05 (Brockerhoff et al. 2006a). The traps were placed at locations throughout New Zealand, primarily near high risk sites such as ports and airports, as an early warning system for newly introduced exotic insects of significance to the plantation forest industry. Five types of generic lures were used to target a wide range of wood- and bark-boring insects, particularly those that are attracted to conifers. The trapping programme caught many insects (well over 20,000 borers alone) but did not detect any newly introduced insects during the period it was operating. This could be interpreted as meaning that the surveillance programme was not valuable, although the fact that no new borers were found is a positive result and also useful to assure trading partners that there are no serious borers present in New Zealand (and in New Zealand's forest products) that could threaten forest biosecurity in other countries.

A recent review of New Zealand's Forest Health Surveillance (FHS) programme that was commissioned by the Forest Owners Association (NZFOA) recommended:

> "A network of attractant traps for detecting wood-boring insects should be implemented across New Zealand on an operational basis. Ideally this network would consist of traps deployed in high-risk locations coupled with traps in commercial forests."

It is worth noting that such surveillance programmes for wood borers and bark beetles continue in other countries, including Australia (e.g, Wylie et al. 2008) and the U.S. (Rabaglia et al. 2008).

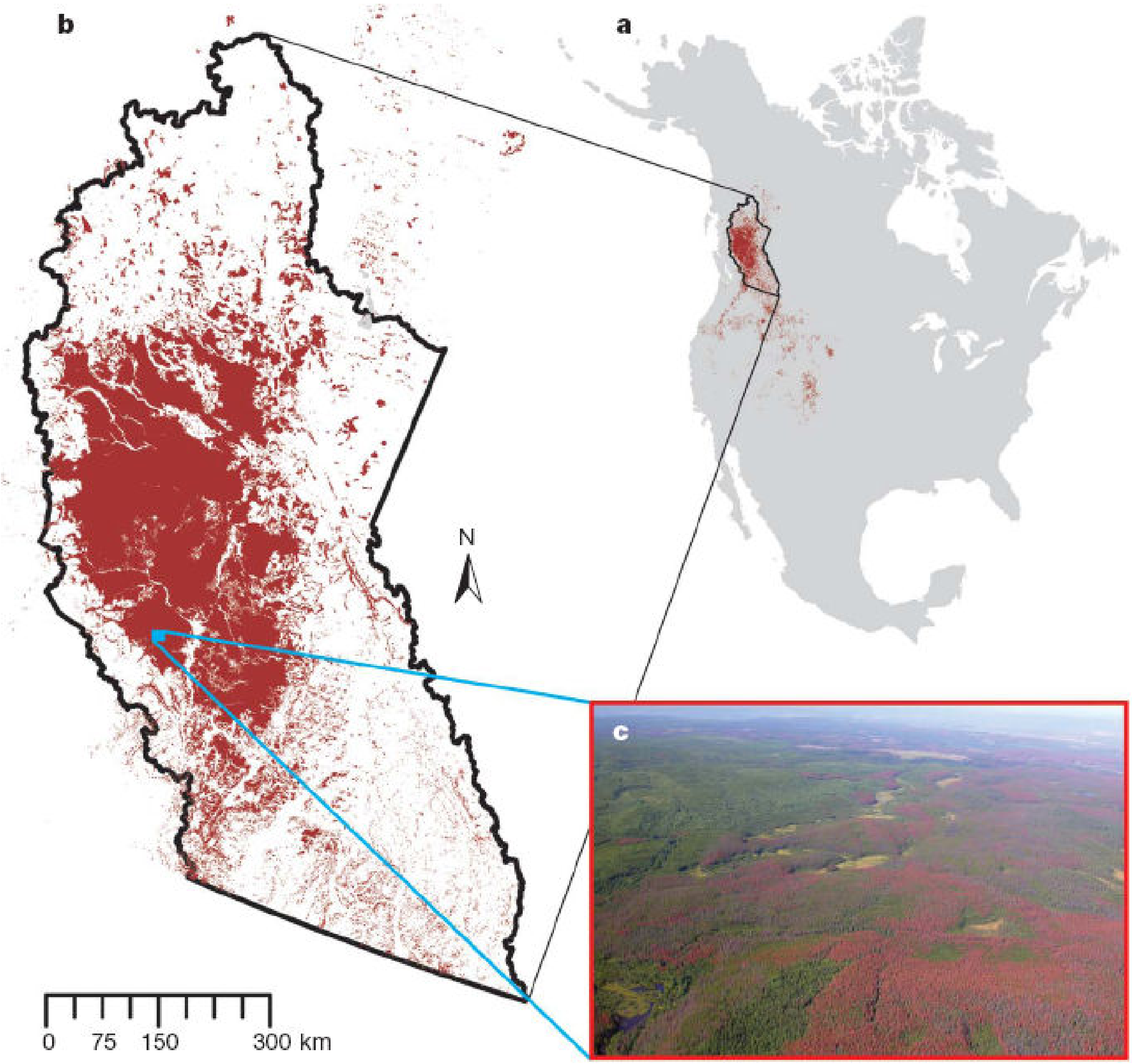

Fig. 1. Extent of the current mountain pine beetle (*Dendroctonus ponderosae*) outbreak in inland British Columbia, Canada, and adjacent regions, which began in the early 2000's and has since spread to well over 100,000 km^2 causing unprecedented mortality of pine trees (c). Reproduced from Kurz et al. (2008).

3. Methods

Wood borers and bark beetles are a group of insects that includes thousands of tree-feeding species. They infest the phloem region of stems, branches, roots and twigs (e.g., true bark beetles – Curculionidae: Scolytinae part) or colonise sapwood and/or heartwood (e.g., ambrosia beetles - Curculionidae: Scolytinae part, longhorn beetles - Cerambycidae, jewel beetles – Buprestidae, wood wasps – Siricidae, carpenter moths – Cossidae, and others) (Wood 1982, Coulson and Witter 1984). These families comprise the most damaging species of such borers, and they are the focus of this study. Note that not all members of these insect families are wood- or bark-boring species; they also include members of various other feeding guilds.

3.1. Risk of establishment:
Historical records of interceptions and establishments of wood- and bark-boring insects in New Zealand and overseas have been compiled from the literature and correspondence with experts overseas. Relevant pathways are discussed. Sources of information are provided in the text.

3.2. Potential damage and economic impacts:
Damage resulting from wood- and bark-boring insects: Examples of the type of 'damage' to trees, forest products, or trade and economic impacts that can result from such insects will be presented as case studies illustrating such damages.

3.3. Surveillance efficacy:
Information about the efficacy of traps for detecting a newly introduced wood- and bark-boring insect will be provided from our experience with a previous operational programme and from more recent research conducted by Scion and associated postgraduate studies as well as information from programmes elsewhere.

3.4. Costs and benefits of a surveillance programme:
The economic costs and benefits of a surveillance programme will be discussed based on risk of establishment, potential economic consequences of an establishment, and economic benefits that could result from an earlier response to an incursion and greater preparedness, including the probability of successful containment or eradication, if this was necessary.

4. Results and discussion

4.1. Risk of establishment of wood- and bark-boring insects and current arrival rate

Exotic species established in New Zealand

There have been several establishments of wood boring and bark boring insects in New Zealand. Species in the families that are typically of the greatest concern include 11 Scolytinae (bark and ambrosia beetles – Curculionidae: Scolytinae), nine Cerambycidae, and the *Sirex* woodwasp, *Sirex noctilio* (Table1; species in other borer families are listed in Brockerhoff and Bain (2000)). Several of these insects caused considerable damage to pines or other trees widely used in plantation forestry in New Zealand. Outbreaks of the *Sirex* woodwasp and its fungal associate, the pathogen *Amylostereum areolatum* (Fries) Boidin., were responsible for widespread mortality of pines in the late 1940s and early 1950s, whereby some stands experienced up to 90% tree mortality (Morgan 1989). Other introduced borers of pines did not normally cause any tree mortality although *Arhopalus ferus* occasionally kills fire-damaged trees that would otherwise have survived (Brockerhoff and Hosking 2001). However, the impact *A. ferus* as a quarantine pest is considerable. Export logs and timber require fumigation with methyl bromide which is costly and increasingly controversial because of environmental impacts and health hazards. Recent protests against methyl bromide fumigation in Picton temporary stopped log exports. The pine bark beetle *Hylastes ater* occasionally attacks and kills seedlings (Milligan 1978, Reay and Walsh 2002), and industry analysts consider this to be the greatest current insect problem in pine plantation forestry in New Zealand. Another pine bark beetle, *Hylurgus ligniperda*, has been reported to attack seedlings in other countries but in New Zealand it appears not to exhibit such behaviour. Several borers of trees other than pines have become established (Table 1).

TABLE 1. Origin, year and location of first detection, and host genera of exotic bark and ambrosia beetles (Scolytinae), longhorn beetles (Cerambycidae), and wood wasps (Siricidae) established in New Zealand. Notes about hosts focus on pines and other plantation forest trees. Compiled mainly from Brockerhoff and Bain 2000 (all taxa), Brockerhoff, Bain and Knizek 2003 and Painting 2007 and Painting et al. (in prep.) and Zondag and Nuttall 1977 (for Sirex).

Species	**Origin**	**First detected (year and location)**	**Host tree genera (main hosts underlined) and notes**
Scolytinae			
Amasa truncata (Erichson)	Australia	1930, Canterbury	*Eucalyptus*, ***Pinus***, ***Pseudotsuga***, other exotic & native, usually in dead wood, causes branch dieback in eucalypts
Ambrosiodmus compressus (Lea)	Australia	1972, Kawerau, Bay of Plenty	*Prunus*, ***Pinus***, ***Pseudotsuga***, others, breeding in peach only
Coccotrypes dactyliperda (Fabr.)	Sub-tropics and tropics	2002, Auckland	Seeds of small-seeded palms
Coptodryas eucalyptica (Schedl)	Australia	1975, Auckland	*Acacia, Melicytus, Ulmus*, other exotic and native (not *Eucalyptus*)
Cryphalus wapleri Eichhoff	Australia	1946, North Auckland	*Ficus*
Hylastes ater (Paykull)	Europe	1929, Foxton, Wanganui	***Pinus***, occasionally other Pinaceae
Hylurgus ligniperda (Fabricius)	Europe	1974, Whitford	***Pinus***
Phloeosinus cupressi Hopkins	N. America	1943, Auckland	*Cupressus*, *Chamaecyparis*
Scolytus multistriatus (Marsham)	Europe	1990, Auckland	*Ulmus*, *Populus*
Xyleborinus saxesenii (Ratzeburg)	Europe	1963, Mamaranui, Northland	***Pinus***, *Acacia*, *Eucalyptus*, *Malus*, many others
Xylosandrus pseudosolidus (Schedl)	Australia	1978, Noises Is., Auckland	Establishment uncertain, NZ hosts not known. In NZAC as '*Hadrodemius solidus* (Eichhoff)'
Cerambycidae			
Arhopalus ferus (Mulsant) (*A. tristis* (Fabricius)*)	Europe	1963, Orua Bay, Auckland	***Pinus*** (Note: First NZ record in Orua Bay, Auckland, see Kuschel 1990)
Aridaeus thoracicus (Donovan)	Australia	1954, New Plymouth	*Eucalyptus*, *Pyrus*, *Cryptocarya*, *Leptospermum*
Bethelium signiferum (Newman)	Australia	1940, North Island	*Acacia* and related genera
Callidiopsis scutellaris (F.)	Australia	1935, Waipawa, Hawkes Bay	*Eucalyptus*
Coptocercus rubripes (Boisduval)	Australia	1931, Nelson	*Crataegus*, *Eucalyptus*
Didymocantha obliqua Newman	Australia	1960, Tauranga	*Acacia*
Nathrius brevipennis (Mulsant)	Europe	1993, Christchurch	*Ulmus*
Phoracantha semipunctata (F.)	Australia	1873, Christchurch	*Eucalyptus*
Tessaromma undatum Newman	Australia	1902, Auckland	*Eucalyptus*
Siricidae			
Sirex noctilio Fabricius	Europe	Ca. 1900	***Pinus***, occasionally other Pinaceae

* In the New Zealand literature, *Arhopalus ferus* (Mulsant) is often reported as *Arhopalus tristis* (Fabricius). Currently *A. ferus* is assumed to be the correct name.

These include the smaller elm bark beetle *Scolytus multistriatus*, the vector of Dutch elm disease (Gadgil et al. 2000), and *Phoracantha semipunctata*, which can kill eucalypts, although it is not as problematic in New Zealand as in some other countries. The last time an establishment of a wood-boring or bark-boring insect was detected in New Zealand was in 1993, that of the eucalypt borer *Nathrius brevipennis*. However, there were numerous interceptions of borers at the border and at warehouses, etc. (see below), and overseas trends do not suggest that the risk of establishment of such species is lower than in the past (see below).

Exotic species established overseas

Many invasive forest pests and diseases have become established in other countries and some of the more notable examples are listed in Table 2. The two insects that are considered to be the most significant introduced forest insect pests in Australia are both borers: the *Sirex* woodwasp and the pine bark beetle *Ips grandicollis* (Wylie 2001, see also Neumann 1979). Like in New Zealand, *Sirex noctilio* has caused much damage in pine plantations and also in farm woodlots and windbreaks. A *Sirex* outbreak in south-eastern Australia in 1987 killed nearly 2 million trees and caused damages of about $5 million (Wylie 2001). *Sirex noctilio* now occurs in most southern-hemisphere regions where large pine plantations occur (Table 2).

Ips grandicollis is thought to have been introduced to Australia with pine crating from the U.S. (Wylie 2001). It usually attacks dead wood and logging debris of pines but when populations are at outbreak levels attack of live trees occur, particularly trees stressed by fire or drought. Attacks also greatly reduce the time available for salvage harvesting. In its native USA, *Ips grandicollis* and two other *Ips* species are important pests of pines in the southern USA, where the largest pine plantations occur. According to the US Forest Service these beetles caused losses of 6.6 million board feet and 1.1 million cords of pine timber between 1973 and 1979 (Connor and Wilkinson 1983). Another North America *Ips* species attacking pines, *Ips calligraphus*, has become established in the Philippines (Browne 1979). *Ips calligraphus* is able to attack living trees but there appears limited information about its impact in pine plantations in the Philippines.

The European pine bark beetle *Tomicus piniperda* was detected in the U.S. in 1992 and the following year in Canada (Table 2, Haack 2006). Because *T. piniperda* is one of the most serious bark beetles in European pine forests, its establishment in North America caused great concern among foresters and forest biosecurity specialists. Although damages have so far remained less serious than expected, the federal quarantine and Canadian quarantine implemented to prevent or reduce the spread from the north-eastern US and the provinces of Ontario and Quebec had significant impacts on trade of pine logs, Christmas trees, nursery stock and other forest products (Haack and Poland 2001). In northern Spain, a part of the native range of *T. piniperda*, it is considered the most serious bark beetle of *Pinus radiata* plantations. More recently the European *Orthotomicus erosus* (Wollaston) was detected in California in 2004 (Table 2). This species infesting pines has previously been introduced to Chile and S. Africa.

Until 1998 there was only one species of *Dendroctonus* that was known to be invasive, the European spruce beetle *Dendroctonus micans*. It was first found in the UK in 1982, and an eradication attempt was initiated but it had already spread too far through much of Wales and adjacent counties, and the management objective was changed to containment (Burgess 2001). A new infestation was more recently discovered in Kent, suggesting that further spread may occur. The second invader affecting pines is the red turpentine beetle, *Dendroctonus valens*, which is native to the south-western USA. In 1998 this species was discovered in Shanxi Province in northern China, where an outbreak developed that killed the native Chinese pine, *Pinus tabuliformis* (Yan et al. 2005, Gao et al. 2005). The fact that it kills pine trees is rather unusual because in its native region it rarely does this. However, there are in fact more and more such examples of invading species that exhibit a changed behaviour and are more damaging than on their natural hosts.

Since about 2000 the mountain pine beetle, *Dendroctonus ponderosae*, has been responsible for damage of unprecedented magnitude centred in the interior of British Columbia, Canada, affecting primarily lodgepole pine but also other pines in the region. This is one of the largest insect outbreaks ever recorded (see above and Fig. 1), and is apparently the result of warmer than average winters, which enabled greater survival of the population, and fire suppression which increased the forests' susceptibility. Although this outbreak occurs primarily in the native region of *D. ponderosae*, it is also considered 'invasive' because it is spreading beyond the Rocky Mountains into northern Alberta where it has now become established. It is feared that it could now spread further east through the jack pine, *Pinus banksiana*, belt of the boreal forest. Although the invasion of *D. ponderosae* is not related to trade, it illustrates the magnitude of potential impacts that can result from such insects.

Among the longhorn beetles that have been recorded as invaders in other countries, two *Arhopalus* species occur in Australia (Table 2). One of these, *Arhopalus rusticus* was detected in 2000, and it may be implicated in the spread of an invasive pine wood nematode in Melbourne (Smith et al. 2008). An infestation of the European house borer *Hylotrupes bajulus* was confirmed in 2004 in Western Australia. This species infests particularly seasoned pine and other softwoods, and its impacts on houses with wooden framing can be devastating. An eradication campaign is underway (van Schlagen and Bain 2009) which involves various detection and delimitation efforts and the felling and destruction of pine trees in affected areas. Authorities estimate that eradication can be declared from urban areas by 2010 and from plantation forests by 2015. The European brown spruce longhorn, *Tetropium fuscum*, infests primarily spruce but it has also been recorded from pines, mainly Scots pine. In 1999 this species was found infesting and killing red spruce near the port of Halifax, Nova Scotia, Canada. This is another case of an invader having a greater impact on its new host than on its normal host in its native area where it attacks mainly Norway spruce, without causing tree death. Several other Cerambycidae are known as successful invaders that cause much damage to trees in their exotic range (Table 2). Although most of these other species are not associated with pines, they serve to illustrate the risks of such invasions in general terms. Among these is the so-called Asian longhorned beetle, *Anoplophora glabripennis*, in the north-eastern U.S. and parts of Ontario, Canada. It often kills its new hosts, a wide range of native hardwoods, whereas it is normally more benign in its native range (Nowak et al. 2001). *Anoplophora chinensis* has a similar behaviour in Italy where it has become established in the area around Milan. Eradication programmes for these infestations have been ongoing for several years and the prospects are very good for *A. glabripennis* in Chicago and around New York City, although the discovery of a more recent, larger infestation in Massachusetts seems beyond eradication.

Xyleborus glabratus is an Asian ambrosia beetle infesting redbay, sassafras, and avocados in the SE U.S. where it was detected in 2002. It too kills its new hosts (Haack 2006), in conjunction with a fungal pathogen it vectors. Finally, the invasive emerald ash borer, *Agrilus planipennis*, is perhaps the most serious recent invader among the borers. Its impact on ash trees in Michigan and surrounding areas is devastating (Haack et al. 2002), and it is spreading fast. North American ashes have no resistance to this insect whereas it has no such effect on native ashes in its native China. Efforts to limit the spread and impact of this insect in North America do not show much promise, and it is likely that ashes will largely disappear because of this insect. This is particularly tragic because ashes are common trees throughout much of the U.S. and they were also widely planted in urban areas following the demise of North American chestnut and elms which succumbed to chestnut blight and Dutch elm disease, respectively.

The invasion trend of wood- and bark-boring insects in the U.S. is summarised in Fig. 2. This indicates the rate of detections is not declining despite the efforts to curb the arrival and establishment of such species. In New Zealand, new detections of borers appear to have levelled off (Fig. 3), although the smaller size and volume of trade means that such events are likely to occur less evenly distributed over time. It is acknowledged that U.S. borders are perhaps more 'leaky' than New Zealand's.

Table 2. Examples of invasive wood- and bark-boring insects outside New Zealand that are relevant for this review, with information about the origin, invaded area and host trees of bark and ambrosia beetles (Scolytinae), longhorn beetles (Cerambycidae), jewel beetles (Buprestidae), and wood wasps (Siricidae). Host trees relevant to plantation forestry in New Zealand are underlined. Compiled from Brockerhoff et al. 2006a, Haack 2006, Hoebeke et al. 2005, Painting 2007 and Painting et al. (in prep.) and other sources.

Species	Origin	Country where established and (if known) year of detection	Host tree genera (main hosts underlined) and notes
Scolytinae			
Dendroctonus valens LeConte	North America	China (1998)	<u>***Pinus***</u>
Ips calligraphus (Germar)	North America	Philippines (?)	<u>***Pinus***</u>
Ips grandicollis (Eichhoff)	North America	Australia (1943)	<u>***Pinus***</u>
Orthotomicus erosus (Wollaston)	Eurasia	U.S. (2002), also Chile, South Africa, Swaziland	<u>***Pinus***</u>
Tomicus piniperda (L.)	Eurasia	U.S. (1992), Canada (1993)	<u>***Pinus***</u>, other Pinaceae
Xyleborus glabratus Eichhoff	Asia	U.S. (2002)	*Persea* (redbay), *Sassafras*, *Lindera*, *Litsea*, *Shorea*, other hardwoods
Cerambycidae			
Anoplophora chinensis (Forster) (= *A. malasiaca*)	Asia	Italy (2000)	*Citrus*, *Acer*, *Populus*, *Salix*, other hardwoods
Anoplophora glabripennis (Motschulsky)	Asia	U.S. (1996), Canada (2003)	*Acer*, *Populus*, *Salix* and other hardwoods
Arhopalus rusticus rusticus (L.)	Europe (this subspecies)	Australia (2000?), Argentina (2000)	<u>***Pinus***</u>, *Picea*
Arhopalus syriacus (Reitter)	Europe	Australia (1950s)	<u>***Pinus***</u>, *Picea*
Callidiellum rufipenne (Motschulsky)	Asia	U.S. (1997), Italy (1980s?), Spain (?), Argentina (2003)	*Thuja*, other Cupressaceae, attacks ***Cupressus macrocarpa*** in Spain
Hylotrupes bajulus (L.) (European House Borer)	Europe and North Africa	Western Australia (2004), South America, South Africa, Israel	<u>***Pinus***</u>, *Picea, Abies*, other Pinaceae, Podocarpaceae, etc. (seasoned softwoods)
Phoracantha recurva (Newman)	Australia	U.S. (1995), Southern Europe, Chile, Argentina,	<u>*Eucalyptus*</u>
Phoracantha semipunctata (Fabricius)	Australia	Southern Europe, USA, Hawaii, South America	<u>*Eucalyptus*</u>
Tetropium fuscum (Fabricius)	Europe	Canada (Nova Scotia) (1999)	<u>*Picea*</u>, ***Pinus***, other Pinaceae
Buprestidae			
Agrilus planipennis Fairmaire	Asia	U.S. (2002)	<u>*Fraxinus*</u>
Siricidae			
Sirex noctilio	Europe	NZ, Australia (1952), South America, South Africa	<u>***Pinus***</u>, *Pseudotsuga*, other Pinaceae

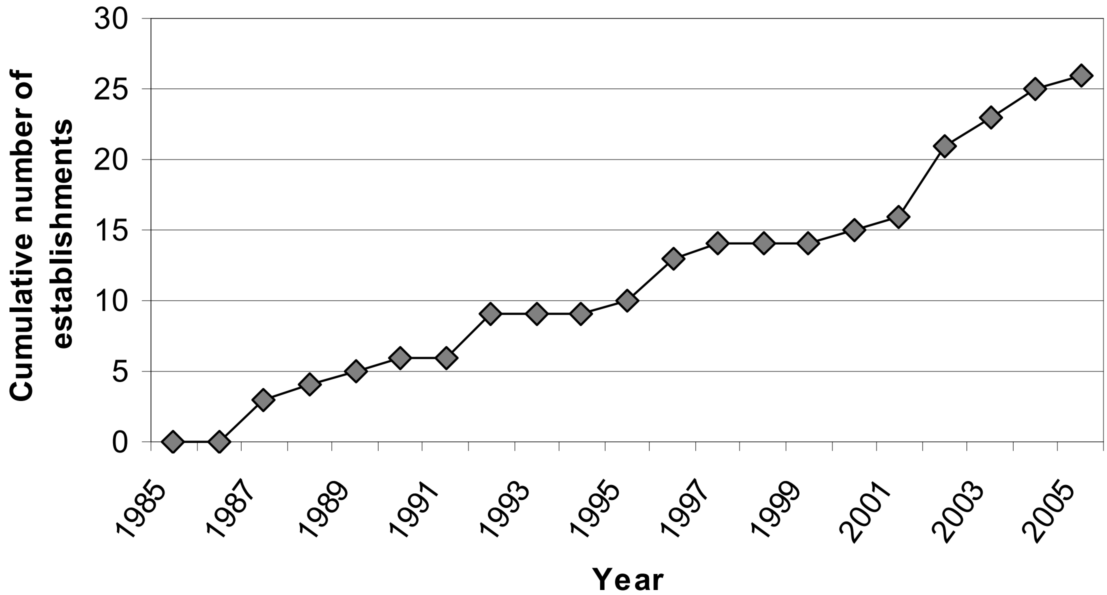

Fig. 2. Recent establishments of wood-boring and bark-boring insects (Scolytinae, Cerambycidae, Buprestidae, and Siricidae) in the U.S. between 1985 and 2005. Years of detection based on Haack (2006) and Hoebeke et al. (2005).

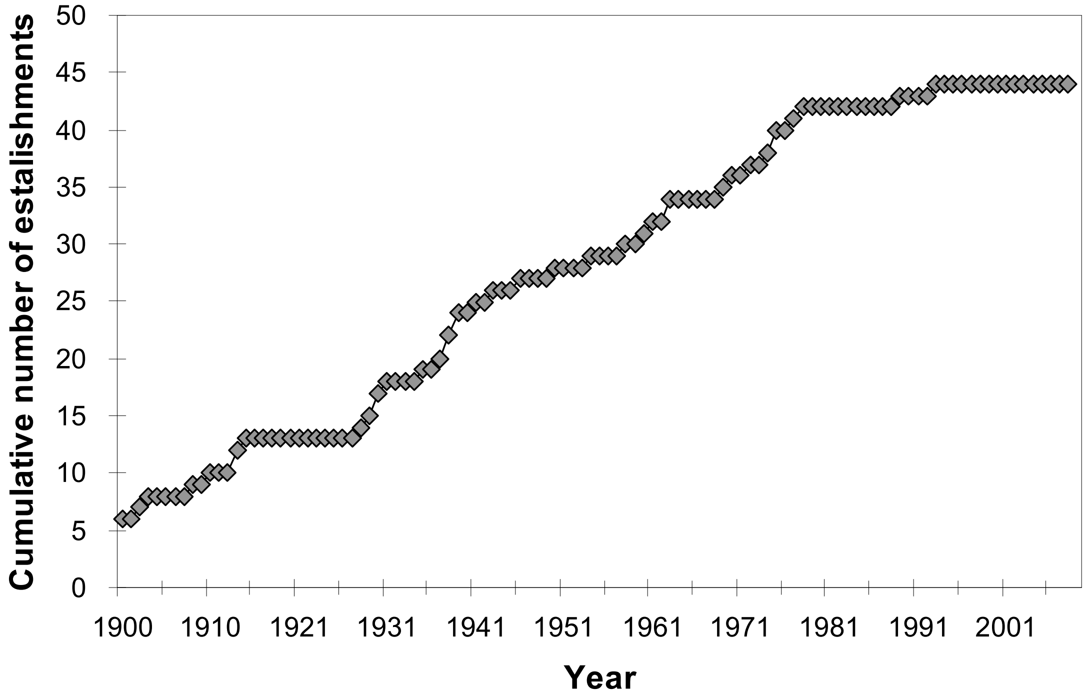

Fig 3. Cumulative establishments of wood-boring and bark-boring insects (Scolytinae, Cerambycidae, Siricidae, and other taxa) in New Zealand between 1900 until 2008. (Scion data)

Historical and recent border interceptions in New Zealand and overseas

Since 1948, border interceptions of wood- and bark-boring insects were recorded in the BUGS database in conjunction with diagnostic services at Scion (Bulman 1990). Thousands of intercepted specimens are held in the National Forest Insect Collection at Scion, and over the years this has become a most useful reference collection of borers from overseas that are associated with wood packaging, dunnage, timber, furniture, etc. Much additional information about interceptions is also held in the BUGS database. From 1948 until 2000 interceptions records amounted to ca. 1500 bark and ambrosia beetles (Curculionidae: Scolytinae), ca. 2700 longhorn beetles (Cerambycidae), 200 jewel beetles (Buprestidae), ca. 300 weevils (other Curculionidae), ca. 370 wood wasps (Siricidae) and many other taxa. These interceptions were compiled from shipments originating from about 60 countries from all continents (except Antarctica), and so represent a remarkable record of wood- and bark-boring insects that arrived at our border, primarily as a result of trade, and a very useful resource for the analysis of invasions and the relationship between arrivals and establishments (Brockerhoff et al. 2006a). Although many wood- and bark-borers have been intercepted at our ports, most have been of little risk to *P. radiata* plantations. Carter (1989) classified the interceptions listed in the BUGS database as high, medium, or low threats to *P. radiata*. Between 1958 and 1988, on average just under 3.5 high risk wood- and bark-borers were intercepted per year, although interceptions are thought to represent only a small fraction of the actual number of arrivals. Insects considered to be low risk were intercepted more frequently at over 50 per year. Furthermore, as a result of the substantial increase in trade with NE Asia, the species complement arriving in New Zealand and, consequently, the associated risk profile has changed.

Since 2000, when the provision of standard diagnostics moved to MAF's IDC Laboratories, ca. 350 additional interceptions were recorded in MAF-BNZ's databases, and these were kindly provided by Alan Flynn. Note that today specimens from infested wood packaging and cargo are no longer routinely subjected to identification and are only occasionally recorded. Instead, such shipments are either fumigated or refused entry. Because of this change in policy, the reduced number of interceptions recorded per year cannot be interpreted as an indication of a reduced arrival rate of such organisms. However, a number of targeted surveys exist that can give an indication of current infestation rates of wood packaging and cargo, for example furniture (see below).

Long-term data sets of detailed interception records for wood- and bark-boring insects exist only for few countries. Apart from New Zealand, detailed interception records were held from about 1900 in the USA. Interceptions were also documented in Australia, Chile, Canada, and the UK, although, to our knowledge, these are generally less comprehensive and mostly do not include detailed taxonomic identification. Since the late 1990s interceptions are being recorded in Europe, and as of 2005, over 300 Cerambycidae and ca. 100 Scolytinae are included, but few records were identified to the species level (Alain Roques, INRA, pers. Comm. 2006).

Interception records of such borers in the USA are held in two data bases, "PIN" (now "Pest ID") and "AQIM", and these were analysed in much detail by Bob Haack of the US Forest Service and collaborators (Haack 2001, 2006). The PIN (Pest ID) data base holds information about interceptions recorded since 1985. However, earlier interceptions were published, usually annually, and are available in hard copy. As part of a project on 'Trade and invasions of forest insects' at the National Centre for Ecological Analysis and Synthesis (NCEAS) at the University of California, Santa Barbara, a team of forest entomologists and economists (including Bob Haack, Sandy Liebhold, James Turner, Ecki Brockerhoff and others) are in the process of capturing US interception data before 1985, going back to 1950. This is to provide a basis for further analysis of arrivals and establishments of wood- and bark-boring insects in the U.S. and world-wide, and to improve our understanding of the economic impact of such invasions and of the benefits of measures that have been, or could be, implemented to reduce the arrival and establishment of such organisms (e.g., ISPM 15 (IPPC 2006)). Presently the work is still in progress but initial results are expected to become available later in 2009.

Analyses of interception records from New Zealand (e.g., Brockerhoff et al. 2006a) and U.S. (Haack 2001, Haack 2006, Work et al. 2005) have shown that establishments of wood- and bark-boring insects do reflect historic interception rates, to a considerable degree, despite the fact that interception records are not ideal for statistical analysis because of a lack of randomisation of sampling and recording of negatives (Work et al. 2005, Brockerhoff et al. 2006a). Particularly for species where the level of identification is good, such as for Scolytinae, most species that have become established were intercepted frequently (Brockerhoff et al. 2006a, Haack 2006) (Fig. 4). Similar results were obtained for Cerambycidae and other taxa when analyses were restricted to the genus level, (Haack 2006, Painting 2007, Painting et al. (in prep.)). The trend of invasive borers increasingly originating from north-east Asia is also apparent in interceptions and clearly related to changing trade patterns (Brockerhoff et al. 2006a, Haack 2006). North-east Asia is of particular concern as a source region of invaders because it is part of the Palaearctic region where many closely related species of the common European and North American tree species occur, including pines and other Pinaceae. Many of the high-impact examples of invasions noted above involve more or less host-specific insects that are naturally associated with a closely related tree species, where their impact is less serious, whereas their new hosts, which often lack resistance, are highly susceptible (e.g., *Dendroctonus valens*, *Ips grandicollis*, *Tetropium fuscum*, *Sirex noctilio*, *Anoplophora glabripennis*, *Xyleborus glabratus*, *Agrilus planipennis*).

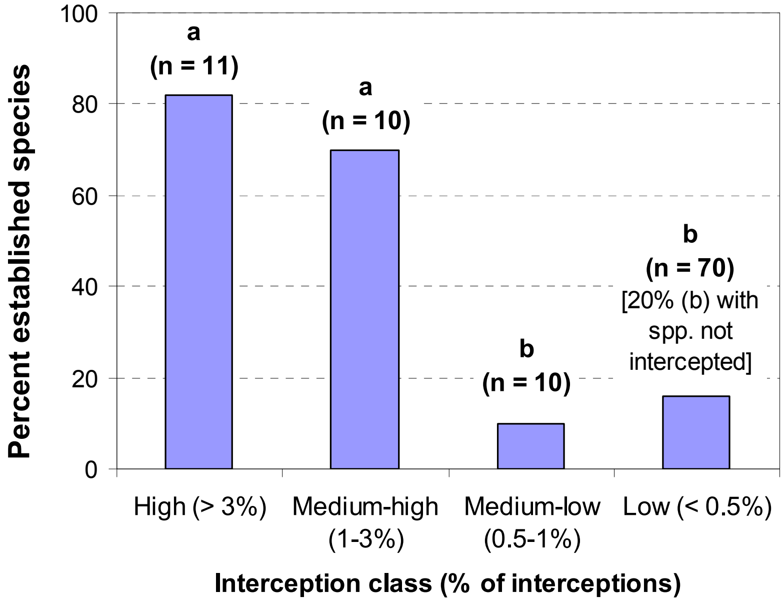

Fig. 4. Proportions of true bark beetle species that have become established worldwide in relation to their interception frequency in New Zealand and the United States. The most frequently intercepted species which each represent at least 3% of all interceptions are grouped in the 'high' interception class, and about 80% of these have become established, whereas only 10-20% of those species have become established that are less frequently intercepted (see Brockerhoff et al. 2006a for further details).

Pathways

Many of the recent invasions were traced back to wood packaging materials used with various imports. An ever increasing range of products are being freighted in shipping containers, very often with some kind of wood packaging inside. A recent study conducted by Biosecurity New Zealand found that 91% of containers carrying "freight of all kinds" (FAK) contained some wood packaging materials (Craighead 2009). Most of this was in the form of pallets and wooden materials for holding goods, with some wooden bracing materials, dunnage, and cable reels. Bulman (1999) found that 44% of 1,526 randomly selected full container loads (FCL)s contained wood packing or products. Many of the manifest packing descriptions did not list wood when it was present.

A review of interceptions of bark and ambrosia beetles (Brockerhoff et al. 2006a) revealed that dunnage and case wood accounted for most positive samples (Table 3).That study covered not only finds in containers but also all kinds of other shipments as well as sawn timber and logs. Analysis of interception data does not account for differences in the quantity of various types of packing imported, or differences in inspection intensity. However, findings of Brockerhoff et al. (2006a) are supported by earlier studies on the incidence of bark, insect damage, fungi, and insects in containers where interceptions were most often recorded for crates, cases and pallets (Tables 4 and 5) (Bulman 1992, 1998). Other relevant studies that examined the quarantine risk associated with containers are those by Gadgil et al. (2002) for air cargo containers, Stanaway et al. (2001) for empty containers arriving in Australia, and Haack (2001, 2006) as an example for interceptions in the USA, covering various wood packaging and other materials.

Table 3. Representation of various wooden goods and packaging materials in which Scolytinae were intercepted in New Zealand between 1948 and 2000 (from Brockerhoff et al. 2006a)

Material	No. (%) of interceptions
Dunnage	522 (34.7%)
Casewood (crating)	427 (28.4%)
Sawn timber	266 (17.7%)
Pallets	156 (10.4%)
Logs	48 (3.2%)
Other materials or not recorded	86 (5.7%)

Table 4. Interceptions of various materials of quarantine significance for forest biosecurity (from Bulman 1992)

Packing type	No. of consignments	Material intercepted (%)				Infested consignments (%)	
		Bark (%)	Insect damage (%)	Fungi (%)	Insects (%)	Actual mean (%)	Adjusted mean (%)
Crates	136	5.1	6.6	3.7	10.3	20.6	22.3a
Cases	613	4.7	5.9	0.3	4.7	13.7	16.3ab
Pallets	576	5.4	4.9	1.0	2.8	12.2	15.3 b
Skids	41	4.9	4.9	2.4	0.0	9.8	13.2 b
Others	230	7.8	9.6	0.4	0.0	10.0	12.8 b
Bales	75	0.0	0.0	1.3	8.0	8.0	9.8 bc
Packages	99	2.0	2.0	0.0	3.0	6.1	6.6 bc
Pieces	37	0.0	0.0	5.4	0.0	5.4	3.5 bc
Rolls	32	0.0	0.0	0.0	3.1	3.1	3.7 bc
Cartons	708	0.6	0.8	0.1	0.0	1.1	2.1 c
TOTAL	**2547**	**3.7**	**4.1**	**0.7**	**2.7**	**9.1**	

Adjusted means with the same letter not significantly different at the 5% level. Goods types are regarded as significantly different if the standard error of their difference exceeds twice the difference of the means.

Table 5. Interceptions of various materials of quarantine significance for forest biosecurity (from Bulman 1998).

Packing type	No. of consignments	Material intercepted (%)				Average contaminated consignments (%)	
		Bark	Insects	Insect damage	Fungi	Actual FCL	Predicted FCL
Skids	129	12.4	0.8	5.4	3.1	14.0	15.6a
Crates	374	11.8	5.1	8.3	0.3	14.7	13.6a
Cases	430	5.8	1.2	2.6	0.5	7.7	10.5 b
Others	315	9.2	2.2	4.1	1.3	11.1	10.1 b
Pallets	6983	2.7	0.4	0.9	0.2	3.2	4.6 c
Bales	28	0.0	0.0	3.6	0.0	3.6	3.2 c
Packages	288	2.1	0.0	1.4	0.7	3.1	3.1 c
Cartons	153	1.3	0.0	0.0	0.0	1.3	1.1 c
Pieces	255	0.4	0.0	0.4	0.0	0.4	0.7 c
Rolls	46	0.0	0.0	0.0	0.0	0.0	0.1 c
TOTAL	**9001**	**3.5**	**0.7**	**1.5**	**0.3**	**4.2**	

Adjusted means with the same letter are not significantly different at the 5% level. Packaging types are regarded as significantly different if the difference of the means exceeds twice the standard error of the means.

As noted earlier, the introduction in May 2006 of New Zealand's 'Import health standard: wood packaging material from all countries' (Biosecurity New Zealand 2006) which is based on the International Standard for Phytosanitary Measures, No. 15 (ISPM 15), essentially requires that wood packaging materials are treated to ensure they are free from live wood- and bark-boring insects. This is expected to reduce the risk associated with wood packaging materials, and a recent study by Biosecurity New Zealand confirmed that the rate of wood packaging materials not bearing the the ISPM 15 stamp is very low, perhaps some 10% on average for different kinds of wood packaging (Craighead 2009). However, a study of wood packaging materials in Australia (Zahid et al. 2008) found that about a third of ISPM 15-stamped materials were non-compliant. About 10% of still had bark present, which greatly increases the risk of bark beetle presence. This indicates that although ISPM 15 is a huge improvement, there is still risk associated with wood packaging materials.

It is also worth noting that the import of sawn timber has increased recently in New Zealand, and at least historically sawn timber was an important source of interceptions (Bulman 1998, Brockerhoff et al. 2006a). However, much of today's imported timber is tropical hardwood which is probably somewhat less risky from a biosecurity point of view because most tropical insects (and diseases) of tropical trees are unlikely to persist in New Zealand's climate. Another pathway that has much increased over the last decade or so is the import of furniture (for example, about 40,000 sofas were imported from China and Malaysia in 2005, according to Thompson et al. (2007)). In the past a much greater proportion of furniture used to be manufactured in New Zealand and from local timber. A study assessing the kind of timber used in imported sofas (Thompson et al. 2007) determined that timber from Pinaceae (including pine and spruce) was the second most common. This furniture originated from Malaysia and China, and the latter is part of a region where significant pests of our plantation forests could originate. The inspection of 51 sofas revealed 95 cases of contamination on 39 sofas, including bark (30 cases), insects (19 cases), fungi (11), and borer holes (32), mostly in sofas from China. The author is also aware of reports of exotic beetles emerging from imported sofas that have already been in use in residences in New Zealand. Importers voluntarily fumigate upholstered furniture so the risk is considered to be low, providing they maintain this effort.

Other, probably more minor pathways are tourists bringing wooden souvenirs, etc., and live plants. Several wood borer incursions in the U.S. have been traced back to live plant imports, with the citrus longhorn beetle, *Anoplophora chinensis*, being an example of this. However, those pathways are of less significance in New Zealand due to quarantine actions at ports and strict import standards, although some illegal imports might still occur.

Carter (1989) listed insects that were considered to have the potential to attack living *P. radiata* and classified them according to impact and likelihood of introduction. Of the 217 insects, 6% were classified high impact. Less than 30% of the 217 insect species listed were wood- or bark-borers. Scion records show that over 500 insects not recorded in New Zealand have been recorded attacking *P. radiata*.

4.2. Potential damage and economic impacts

The various kinds of 'damage' to trees, forests, forest products, the effects on trade, and other economic impacts that have resulted from the establishment of wood- and bark-boring insects have been illustrated above (in the sections on 'exotic species established in New Zealand / overseas'). In order to synthesise this further, these kinds of damages can be categorised as follows:

- Tunnelling in felled trees: This is the most common type of damage, whereby there is usually no direct damage or effect on tree health. However, the tunnelling itself can devalue logs and timber cut from infested trees, which can greatly reduce their value.

- Attack of sawn timber: Numerous borers are capable of attacking timber that is already sawn, primarily when the timber is still 'fresh' and the moisture content is relatively high. However, others can attack even dry timber in service such as the house borer (*Anobium* *punctatum*, not covered otherwise in this review) and the European house borer (*Hylotrupes bajulus*, see above).

- Vectoring of organisms causing sapstain and increased decomposition: Numerous borer species are known to vector fungi that cause sapstain and, possibly, rot which greatly reduces the value of timber.

- Attack of standing, live trees: This tends to be the most damaging attack associated with borer species as some of these can cause tree mortality, usually by effectively ring-barking trees or by vectoring pathogenic fungi and other organisms. Widespread tree mortality caused by borers often results in considerable environmental impacts as well, potentially affecting forest biodiversity, increasing run-off and erosion, loss of carbon, etc.

- Vectoring and spread of disease-causing organisms: Many significant tree "diseases" are directly linked with attack by borers which spread the disease between trees and geographically within a country. In addition, insects associated with such disease-causing organisms can be directly involved with the primary introduction into a new territory with wood packaging or by other means. Examples of such insect-pathogen relationships are the following (others are referred to above):
  - *Amylostereum areolatum* is vectored by *Sirex noctilio* in New Zealand and elsewhere. It is the joint action of the insect and pathogen mutualism that can cause tree mortality;
  - Pine pitch canker, *Fusarium circinatum*, is vectored by several bark beetle species, and at least in California this is thought to be the primary cause of tree infection;
  - Pine wood nematode, *Bursaphalencus* spp., a feared pathogen that can cause pine wilt disease and kill some pines, but *P. radiata* is considered resistant. It is typically vectored by pine sawyer longhorn beetles in the genus *Monochamus*. To our knowledge there are no establishments of exotic *Monochamus* species anywhere but the recent introduction of pine wood nematode in Portugal is likely to be related to the arrival of infected *Monochamus* beetles. Native *Monochamus* beetles are apparently the primary vectors in Portugal. There has been a recent outbreak of another pine wood nematode species in Melbourne. There are no *Monochamus* beetles in Australia but the introduced *Arhopalus rusticus* (a close relative of the burnt pine longhorn beetle present in New Zealand) was found in dead trees. It has been suspected that it contributed to the spread of the disease (Smith et al. 2008) although is not known with certainty. However, it seems *B. hunanensis* was successfully eradicated around Melbourne.

- Cost of losses to pests: All of the above types of damage incur costs that can range from minor (in the case of a benign dead wood infesting organism) to severe (in the case of an organism such as the mountain pine beetle).

- Increased cost of trade: The presence of wood- and bark-boring insects in or on export logs and sawn timber can adversely affect international trade due to phytosanitary regulations and trade bans as many countries do not allow the import of infested logs or timber. For example, log and sawn timber exports from New Zealand need to be fumigated to ensure they are free of live burnt pine longhorn beetles, *Arhopalus ferus*.

- Emergency response costs: The establishment of a new pest can be very costly as it often requires activities such as pest risk assessment, delimitation, monitoring, and, if deemed necessary, an emergency response to eradicate or contain the new organism. Eradication or containment incur costs for treatments of the affected areas, quarantine measures to reduce the further spread of the organism, community consultation, and other activities. Early detection greatly reduces these costs because the cost of size of the affected area.
- Increased pest management and forest management costs: Should eradication not be possible and a damaging pest becomes permanently established, a wide range of potential pest management and associated forest management costs can be incurred.

- Other costs: Various other costs may be incurred, such as loss of property value due to damage or loss of urban amenity trees, costs of tree replacement, and loss of opportunity, for example, if the planting of certain tree species is no longer possible or advisable due to the presence of damaging pests. Depending on the identity of the organism, there could also be effects on biodiversity and conservation values, with associated economic impacts due to losses from reduced ecosystem services, for example. Some studies even consider loss of aesthetic value due to an invader as a cost. Such indirect 'costs' are difficult to estimate.

The total loss from such organisms is difficult to estimate since this would vary from species to species. Also, this would depend on the actual damages resulting in New Zealand, given that invaders often behave differently in different countries, depending on factors such as the climate in the region where the organism has become established and the susceptibility of local host tree species and varieties. However, some information exists from economic impact assessments in New Zealand Turner et al. (2004, 2007,) and several overseas countries (e.g., Colautti et al. 2006, Krcmar 2008).

Turner et al. (2004) estimated the annual expected losses due to new forest pests, including "costs of eradication and control programmes, reduced harvest value, household expenditures to control the exotic pest, and replacement of affected trees in the urban forest". Several scenarios were used and incorporated different estimates of "the likelihood of pest arrival, detection, eradication, and successful control, and the effect of biosecurity research on these" and a range of discount rates. Without incorporating the benefit from research, net present economic losses between 2000 and 2040 from new establishments of pests of trees ranged from $3.75 billion to $20,27 billion (Turner et al. 2004). However, damages to urban forests and pathogens accounted for a large proportion of those losses, and wood- and bark-boring insects affecting plantation forests were not considered specifically. Turner et al. (2007) focused on the economic impact of export trade restrictions and increased costs resulting from the establishment of an exotic forest pest.

The projected economic impacts of exotic forest pest establishments on the forest sector in Canada, based on case histories for seven invasive species, is estimated at between CAD$7.7 billion and CAD$20,1 billion per annum (Colautti et al. 2006). This estimate includes figures for one borer affecting spruce and, to a lesser degree, pines, the brown spruce longhorn beetle (see above). It ranked among the highest impact species in that analysis (spruces are the principal timber trees across much of Canada). The projected annual impact of this species on timber sales, domestic exports, and spruce pulp ranges from ca. CAD$3.0 billion to CAD$7.5 billion per annum (Colautti et al. 2006). An earlier study estimating the potential economic impact of a successful establishment of the European bark beetle *Ips typographus* in the western U.S. estimated losses of timber harvest value (1990 values) of US$0.2 to US$1.5 billion (USDA Forest Service 1991).

4.3. Surveillance methods and efficacy

Surveillance for wood borers and bark beetles can be done using a range of methods. Ground-based and aerial surveys of forests and urban areas are being undertaken already (e.g., Carter 1989, Bulman et al. 1999, Bulman 2008), and these can detect incursions of wood- and bark-boring insects. However, because these surveys rely on easily noticeable symptoms of damage, they may not lead to early detections during the initial stages of an establishment. This is less of a problem with high-risk site surveys which focus on sites near ports, air ports, and devanning sites that are most likely to be at the centre of new establishments. Here, surveys are more intensive and involve close examination of woody plants, whereas forest surveys are more extensive and rely on coverage from a moving vehicle, or aircraft.

Another method that is potentially more successful than inspection in early detection relies on the use of traps baited with specific insect attractants. Attractants can include pheromones, such as sex pheromones or aggregation pheromones, and kairomones, such as host volatiles that are normally used by insects to locate their host plants. Surveillance using traps baited with attractants as lures has the advantage of potentially detecting new establishments during the earliest stages of an establishment, before damage symptoms are noticeable.

Much progress has been made in the research and development of lures and trapping systems for wood- and bark boring insects. Powerful attractants are now available for many wood- and bark boring insect species (Table 6). For example, a review of pheromones used by longhorn beetles (Cerambycidae) has recently been published by Millar et al. (2009), and new information about attractants for red turpentine beetle (*Dendroctonus valens*) and the wood wasp *Sirex juvencus* is given by Erbilgin et al. (2007) and Costello et al. (2008), respectively. Comprehensive information on insect lures can be accessed at the Pherobase website (www.pherobase.com). These lures are most commonly used in funnel traps or panel traps.

Table 6. Common, generally available lures for wood- and bark boring insects affecting pines and other conifers

Lures	Examples of target genera
Alpha-pinene and ethanol	*Hylastes*, *Dendroctonus (D. valens)*, *Monochamus*, *Sirex*, *Tomicus*,
3-Carene or Beta-pinene and ethanol	*Dendroctonus (D. valens)*
Frontalin and ethanol	*Dendroctonus* (e.g., *D. ponderosae*)
Ipsdienol	*Ips*, *Orthotomicus*
Ethanol	*Xyleborus*

Routine surveillance programmes using traps baited with attractants for common wood- and bark boring species are now undertaken in several countries that are biosecurity conscious. For example, a large-scale programme has been in operation in the USA since 2001 (Rabaglia et al. 2008), and pilot studies have taken place in several Australian states (e.g., Bashford 2008, Wylie et al. 2008). As mentioned earlier, a New Zealand-wide trapping programme to detect new wood- and bark boring insects occurred over three seasons until 2005 (Brockerhoff et al. 2006b), and more follow-up work refining lure choice and trap design on a smaller scale is ongoing as part of FRST-funded activities (Brockerhoff et al., unpublished) and associated postgraduate projects.

Modelling approaches can be used to enhance the efficiency of such surveillance programmes (e.g., Coulston et al. 2008). Bulman et al. (1999) revised the approach to calculate and compare the efficiency of various drive-through and plot-based surveillance methods, and Kriticos et al. (2008) found that if a pest established in a forest a surveillance system based on a regular or stratified sampling system would detect pests at eradicable population sizes. Success depended on survey intensity and the visibility of the damage the pest creates.

4.4. Costs and benefits of a surveillance programme

To weigh up the respective costs and benefits of a surveillance programme for wood- and bark-boring insects it is important to consider a number of aspects that incur costs and benefits. Each of these is characterised by a particular probability of occurrence, and these probabilities are difficult to predict with any certainty. Without engaging in a sophisticated modelling exercise, which is beyond the scope of this report, some scenarios are explored here that will affect the major cost and benefit factors.

Costs of a surveillance programme

The costs of a surveillance programme using attractant-baited traps include costs for planning such a programme, purchase of traps and lures, deployment and maintenance of traps, identification of specimens, curation of specimens, data analysis and reporting. The actual cost of this greatly depends on the number of locations surveyed and on the number of traps used.

Depending on the scope of such a programme the cost is estimated to range from less than $100,000 up to $300,000 annually.

Potential benefits of a surveillance programme
The benefits of such a programme will vary greatly depending on the aggregate of the following:
- Arrival rate of each particular species,
- Risk of their establishment,
- Potential economic and ecological consequences of their establishment, and
- Probability of successful containment or eradication due to surveillance.

Additional benefits from such a programme include, for example:
- Better knowledge of abundance, distribution, and phenology of established insect pests,
- Increased certainty about area freedom from pests.

Arrival rate
The arrival rate of wood- and bark borers can only be estimated from our knowledge of border interceptions in New Zealand and overseas (see sections on interception records and pathways under 4.1., above). We know that many borers have arrived in the past and that some of these have become established (above). One of the main pathways for the arrival of wood- and bark-borers, the use of solid wood packaging materials in international trade, has been addressed to some degree by phytosanitary measures including ISPM15 (IPPC 2006) and New Zealand's 'Import health standard: wood packaging material from all countries' (Biosecurity New Zealand 2006). As mentioned earlier, this appears to have led already to some improvements in the infestation rate of wood packaging materials (Craighead 2009), and therefore a reduction in risk. Nevertheless, some risk remains, as demonstrated by the ongoing interception of wood- and bark boring insects. The increase in trade over time and the increasing use of containers may also have offset some of the gains made by phytosanitary policy.

Furthermore, it is also important to keep in mind that many species have long lag phases between the initial establishment of a small founder population and the eventual increase of their population to a level where they are more easily detected (as illustrated in Fig. 5). This suggests that it is possible that some recently established, but as yet undetected, borer species are already present in New Zealand, stemming from arrivals that occurred before phytosanitary measures were implemented.

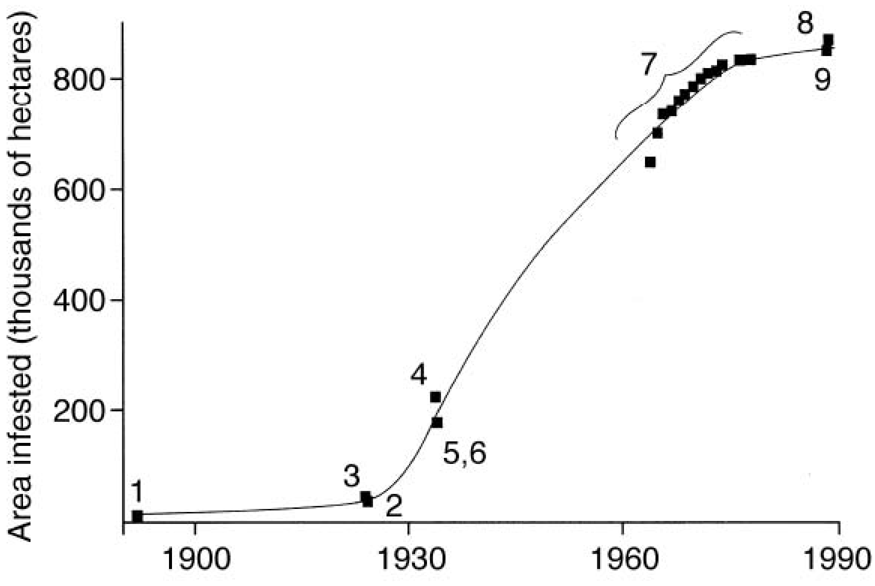

Fig. 5. Illustration of the 'lag' and 'log' phases often exhibited by invaders (here the plant *Opuntia aurantiaca* in South Africa) (from Moran and Zimmerman 1991).

Risk of establishment
The probability of establishment of wood- and bark-borers is influenced by numerous species-specific biological and site factors (e.g., Bartell and Nair 2003, Liebhold and Tobin 2008). There is an abundance of species that have already become established outside their native range (e.g., see Table 2 and sections on established species under 4.1.), and many others are likely to be able to colonise new areas. We have to assume that the risk of establishment in New Zealand of borers affecting pines and other conifers is relatively high, given the relatively mild climate and the widespread occurrence and general abundance of suitable host trees. However, others believe the risk is not so high, given the relatively small number of successful establishments of insects affecting pines to date.

Averted costs due to surveillance
Costs potentially incurred by invading wood- and bark-boring insects are covered in detail above (under 4.2.). In a worst-case scenario, annual losses from a serious borer pest could amount to many millions or even billions of dollars (see examples under 4.2.; the projected annual impact of the brown spruce longhorn on Canadian forestry was estimated at CAD$3.0 - CAD$7.5 billion), but for most species losses are likely to be lower. If a surveillance programme enabled the early detection and, as a result, the successful eradication of a serious borer species, then the net savings would be the averted losses less the costs of the surveillance programme. One could argue that the costs of the eradication programme should also be subtracted from the savings although, in the case of a serious invader, an eradication programme is likely to take place with or without a surveillance programme. However, if a surveillance programme leads to earlier detection, then the probability of eradication will be greater because this is generally inversely related to the infested area. If the invader was found to be too widespread for successful eradication, the response may be limited to risk assessment and delimitation surveys. Therefore, there is a trade-off between the cost of surveillance and the cost (and likely success) of eradication. In other words, a very intensive (and expensive) surveillance programme is likely to reduce the cost of eradication, whereas a small (and inexpensive) surveillance programme would lead to greater expenditure for eradication (e.g., Bogich et al. 2008. However, even if detection as a result of a surveillance programme is not early enough for successful eradication, there may still be an increased probability of containment, restricting damages at least temporarily to a smaller affected area, with associated savings. Such 'slow-the–spread' responses can buy time to allow the development of cheaper long-term control and damage mitigation practices. Ultimately, all these cost items would differ among species and incursion responses.

Other benefits
Maintaining a surveillance programme for wood- and bark boring insects will have other benefits, beyond the potentially earlier detection of a new invader, before symptoms become easily detectable. Such a programme can provide increased certainty about area freedom from particular pests. This was an issue, for example, during the debate about the US log import injunction in the late 1990s, when it was argued by some opponents that New Zealand logs could be a source of dangerous borers that were alleged to be present here. Furthermore, a surveillance programme can be expected to lead to better knowledge of abundance, distribution, and phenology of species that are already known to be established, and it will improve our ability and preparedness to conduct pest detection surveys for delimitation, should this become necessary during an incursion.

Conclusions

The evidence compiled in this report supports the view that wood- and bark-borers pose considerable biosecurity risks to pines and other trees used in plantation forestry in New Zealand. There are numerous significant pests overseas that are highly unwanted in New Zealand, and there are many precedences of such species becoming established outside their native range. In addition, it needs to be considered that some invaders have a much greater impact in their area of introduction than in their native range. The considerable increases in trade and globalisation have expanded the volume and number of species arriving at our borders, although improvements in quarantine and border protection have counteracted this to some degree. Recent establishments in several countries and the recognition that phytosanitary regulations such as ISPM 15 (which prescribes treatments to ensure wood packaging materials are pest free) are not 'bullet proof' indicate there is still some risk. A surveillance programme could be implemented for wood- and bark borers, based on traps baited with attractants. This is likely to lead to an earlier detection of newly established borers, compared with the current high-risk site surveillance and general forest health surveillance methods, and this would be expected to increase the probability of successful eradication. However, the benefits gained from such a programme, in terms of averted losses, need to be balanced against the costs of a surveillance programme. In the absence of any new establishments, the costs of a surveillance programme would exceed the benefits. Conversely, if a trap-based surveillance programme were to lead to the early detection of a new borer with a potentially significant impact on New Zealand's forests and forest industry, then there is a high probability of significant net benefits resulting from the ability to respond more rapidly to this incursion. It is difficult to predict what the exact magnitude of these benefits would be, although a scenario modelling approach could be useful to explore this further.

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