SCION

New Zealand Journal of Forestry Science

40 suppl. (2010) S57-S72

www.scionresearch.com/nzjfs

published on-line:
25/02/2010

Pest risk analysis and invasion pathways – insects and wood packing revisited: What have we learned?†

Leland Humble

Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, 506 West Burnside Road, Victoria, British Columbia, Canada V8Z 1M5.

(Received for publication 18 May 2009; accepted in revised form 15 February 2010)

leland.humble@nrcan-rncan.gc.ca

Abstract

The transport of adventive arthropods associated with rapidly expanding global trade has led to an ever increasing list of quarantine pests establishing beyond their native ranges. A significant number of these taxa have become serious forest pests, and some are directly threatening the viability of native tree species across their introduced ranges. The global movement and establishment of bark- and wood-borers such as *Anoplophora glabripennis* (Motschulsky), *Tetropium fuscum* (F.) and *Tomicus piniperda* (L.) in multiple international jurisdictions led to the recognition of the importance of solid wood packing (e.g. crating, pallets) as an introduction pathway. Regulatory inspections and rearing studies targeting wood packing pathways have identified both the diversity of taxa and the potential magnitude of pest movements associated with this route. Concurrently, surveillance programmes initiated to detect invasive bark- and wood-borers in Canada and the United States have identified previously undetected establishment of multiple species of ambrosia- and bark-beetles (Curculionidae: Scolytinae), and woodborers (Cerambycidae) across North America. This paper reviews the lines of evidence that were used to support the development of the first pathway-based international standard for phytosanitary measures (ISPM), that for wood packing (ISPM 15). This standard requires mandatory treatment of wood used as dunnage, packaging, crating or pallets in international trade in order to mitigate populations of bark- and wood-borers potentially present in the raw wood.

Keywords: wood packing; phytosanitary treatment; invasive species; ISPM 15; wood borer.

† *Based on a presentation at the OECD Workshop at the IUFRO International Forestry Biosecurity Conference, 17 March 2009, Rotorua, New Zealand. The Workshop was sponsored by the OECD Co-operative Research Programme on Biological Resource Management for Sustainable Agricultural Systems, whose financial support made it possible for the invited speakers to participate in the Workshop.*

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

Introduction

The transport of adventive arthropods in conjunction with rapidly expanding global trade has led to an ever increasing list of quarantine pests establishing beyond their native ranges. Incursions and establishments of non-indigenous species of bark- and ambrosia-beetles (Coleoptera: Curculionidae: Scolytinae), long-horned wood borers (Coleoptera: Cerambycidae), metallic wood boring beetles (Coleoptera: Buprestidae) and woodwasps (Hymenoptera: Siricidae) continue to be reported globally. More than 25 species of exotic bark- and wood-boring Coleoptera have established in North America since 1985 (Haack, 2006; Hoebeke & Rabaglia, 2008); the European woodwasp (*Sirex noctilio* Fabricius (Hymenoptera: Siricidae)) has established and spread in native and exotic pine forests across both the northern and southern hemispheres (Gilbert & Miller, 1952; Irvine, 1962; Neumann & Minko, 1981; Eldridge & Simpson, 1987; Iede et al., 1988; Tribe, 1995; Hoebeke et al., 2005; Carnegie et al., 2006). Two species of *Anoplophora*, the citrus longhorn beetle (*A. chinensis* (Forster)) and the Asian longhorned beetle (*A. glabripennis* (Motschulsky)) have established in multiple jurisdictions in Europe (Colombo & Limonta, 2001; Tomiczek et al., 2002; Herard et al., 2006; Maspero et al., 2007), with the latter species also having established at multiple locations in North America (Haack et al., 1996; Cavey et al., 1998; Poland et al., 1998; Anon., 2003, 2008a). In Asia, the red turpentine beetle (*Dendroctonus valens* LeConte) quickly became a serious forest pest in native pine stands, after its introduction to China (Britton & Sun, 2002; Cai et al., 2008). While the full impact of many introduced species on forest ecosystems is not yet apparent, recently introduced species (either alone or in association with other vectored organisms) are already directly threatening the viability of native tree species across their introduced ranges. Examples include the emerald ash borer (*Agrilus planipennis* Fairmaire) (Poland, 2007; Poland & McCullough, 2006), and the redbay ambrosia beetle (*Xyleborus glabratus* Eichhoff) with its associated ambrosial fungus *Raffaelea lauricola* T.C. Harr., Fraedrich & Aghayeva (Fraedrich et al., 2008; Hanula et al., 2008; Harrington et al., 2008). Both this global movement of bark beetles and wood borers across multiple international jurisdictions and their establishment in new locations have focused attention on solid wood packing (e.g. crating, dunnage and pallets) as a pathway for the introduction of serious forest pests. In 2002, an international standard for phytosanitary measures (ISPM) that provided guidelines for the regulation of wood packaging material moving in international trade was adopted under the auspices of the International Plant Protection Convention to reduce the risk of movement of bark- and wood-boring arthropods in international trade. A revision of this standard, ISPM No. 15 “Regulation of wood packaging material in international trade” was recently adopted (FAO, 2009a). This standard is unique in that it is the first international standard to regulate a pathway, rather than a commodity. In this paper, I will review evidence that supported the development of ISPM 15, and the data that will be required to assess the effectiveness of it and other pathway-based standards.

What is a pathway?

The glossary of phytosanitary terms of the International Plant Protection Convention defines a **pathway** as “any means that allows the entry or spread of a pest”. **Pest risk analysis** is defined as “the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it” (FAO, 2009b). Pathways describe the processes that result in the transfer of non-indigenous species from one location to another (Hulme et al., 2008). Historically, the primary pathway for the introduction of plant pests has been as contaminants of the commodity being traded (e.g. Tephritidae in fruit). Contamination of conveyances has also been recognised as a potential pathway for introductions (FAO, 2009b), but such non-commodity associated pathways have not historically been regulated globally. Over the past few decades, however, it has become increasingly apparent that non-commodity-based pathways can also present significant risk for the introduction of a wide range of pests. Wood traded as a commodity has long been recognised as pathway for the movement of bark- and wood-boring insects of significance to forestry (Duffy, 1953). More recently, the use of wood to package, crate, brace or support other traded commodities during transport has been demonstrated to provide a major pathway for the introduction of forest pests and pathogens. This is, in part, a consequence of differences between the quality of wood traded as a commodity versus that which is acceptable as disposable (often single use) packaging.

Analyses of pest interception records

Historical establishments

A posteriori analyses of data derived from published records (e.g. checklists, taxonomic revisions, new records), databases or from data associated with voucher specimens in arthropod reference collections (e.g. specimen label data) that document historical establishments of plant pests on woody plants or trees can be used to determine which taxa have established beyond their native ranges. Unfortunately, much of the global pest interception data gathered by national plant protection organisations (NPPOs) is unpublished and, thus, is not readily accessible for such analyses. Consequently, the following summary relies heavily on published information from North America and Europe.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

In some instances, such analyses also provide insights into pathways on which specific pests were transported. For example, Mattson et al. (1994) summarised the non-indigenous insects that established in both Canada and the US from the early 1600s to 1992 and Langor et al. (2009) recently provided a detailed analysis of the arthropods known to have established on woody plants in Canada up to December 2007. Roques et al. (2009) documented the alien terrestrial invertebrates that have established in Europe from the 15th century through to 2007, while Roques (2007) documented the non-indigenous taxa reported from Europe by the European and Mediterranean Plant Protection Organisation (EPPO) between 1995 and 2004 of relevance to forest biosecurity. A number of taxon-specific analyses of historical establishments of bark- and wood-boring beetles have also been published [(Brockerhoff et al., 2003, 2006a (for the period from 1952 to 2000); Haack, 2006 (for the period from 1985 to 2005)]. Of particular interest is the observation that interception records are not always good predictors of species establishment; in Europe, 80% of the Cerambycidae, Scolytinae and Lepidoptera that had established were never intercepted (Roques, 2007). Similar observations have been made for four species of Scolytinae that established in New Zealand between 1952 and 2000 (Brockerhoff, 2006a) and for two species of Buprestidae and 10 species of Scolytinae established in the US between 1985 and 2005 (Haack, 2006).

Limitations

National plant protection organisations inspect imported goods for the presence of plant pests and maintain or publish records of plant pests intercepted, often by country of origin and commodity. Analyses of these pest interception records provide insights into the geographic origins of the intercepted species and the frequency of interception, as well as the commodities with which they are associated. Thus, they can be used to identify high-risk commodities or pathways. Unfortunately, interception datasets cannot be used to quantify the diversity and abundance of species associated with an intercepted commodity (Haack & Cavey, 1997; Allen & Humble, 2001; Humble & Allen, 2006; Brockerhoff et al., 2003; Brockerhoff et al., 2006b; McCullough et al., 2006). There are a number of reasons for this:

1. interception data are generally not based on random sampling (NPPOs tend to target high risk commodities or pathways for inspection);
2. negative inspections are not recorded;
3. inspection of individual shipments ceases with the discovery of the first organism of quarantine significance, thus pest loads per shipment cannot be determined;
4. only a small percentage of individual shipments are inspected; and
5. interceptions (especially of immature life stages) are often not fully identified to species.

Interpretation of the risk associated with various invasion pathways identified is also confounded by incomplete identifications of taxa recorded in interception datasets (Brockerhoff et al., 2006a; Haack, 2006; Humble & Allen, 2006; Roques, 2007). Incomplete identifications in interception datasets arise as a consequence of a number of factors and can be taxon specific. Brockerhoff et al. (2006a) considered that the poor condition of intercepted specimens or the presence of only larvae in samples were the main factors contributing to incomplete identifications for 28.5% of the 1505 interceptions of Scolytinae in New Zealand. Haack (2006) documented incomplete identifications ranging from a low of 40% to a high of 100% across families of Coleoptera in the US (Table 1); Humble and Allen (2006) noted serious

TABLE 1: Percentage of Coleopteran interceptions in the US not fully identified and number of interceptions by family (after Haack, 2006).

	Coleoptera[1]							
	SCO	**CER**	**CUR**	**BOS**	**BUP**	**LYC**	**PLA**	**Overall**
Percent not fully identified	50.9	91.1	95.1	40.3	91.0	80.4	100.0	64.8
Total number of interceptions	5008	1642	875	414	245	102	55	8341

[1]*SCO – Curculionidae: Scolytinae; CER – Cerambycidae; CUR – other wood-associated Curculionidae; BOS – Bostrichidae; BUP – Buprestidae; LYC – Lyctidae; and PLA – Curculionidae: Platypodinae*

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

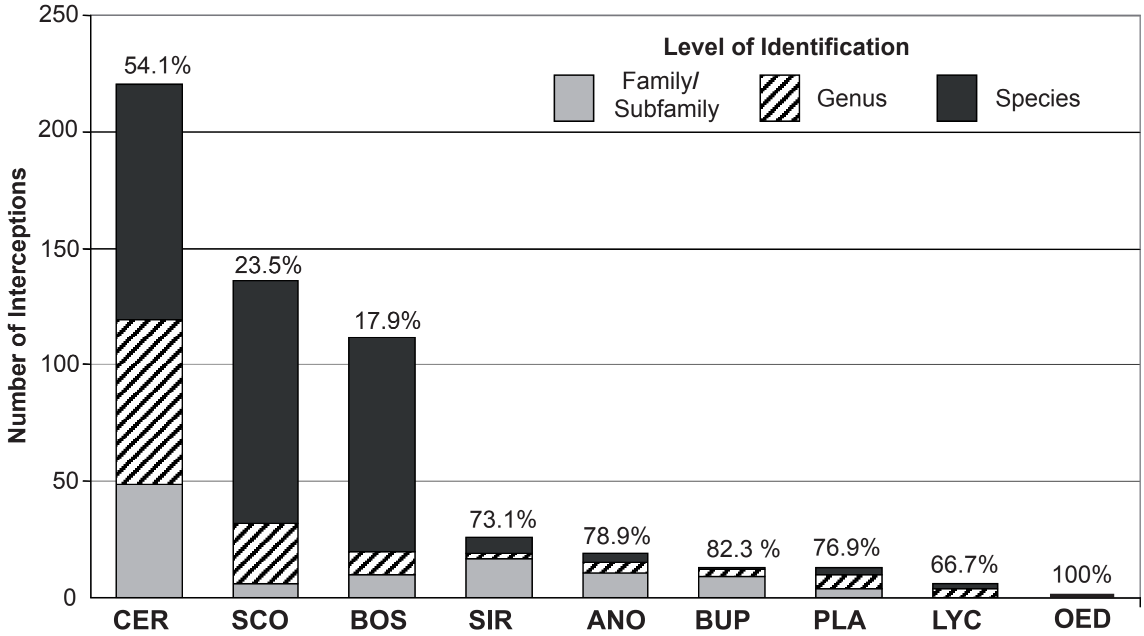

FIGURE 1: Level of identification of bark- and wood-boring taxa intercepted in Canada between 1997 and 2000 (n = 546) (after Humble & Allen, 2006). The number above each bar is the percentage of interceptions of each taxon that were not fully identified to species. CER – Cerambycidae; SCO – Curculionidae: Scolytinae; BOS – Bostrichidae; SIR - Hymenoptera: Siricidae; ANO – Anobiidae; BUP – Buprestidae; PLA – Curculionidae: Platypodinae; LYC – Lyctidae; and OED – Oedemeridae.

deficiencies in the identification of interceptions across two orders of wood associated insect taxa in Canada (Figure 1); and Roques (2007) found that fully 64% of the forestry-related interceptions in Europe between 1995 and 2004 were not fully identified. In the majority of instances, the lack of complete identifications is a consequence of incomplete taxonomic knowledge of the immature stages that are most commonly intercepted (e.g. Cerambycidae, Buprestidae and Siricidae). Other factors contributing to incomplete identifications by NPPOs include lack of taxonomic expertise and/or voucher specimens for the taxa intercepted, and incomplete or inadequate taxonomic knowledge of the fauna in the region of origin of the interception. In general, diagnostic expertise for the flora and fauna transported in trade is more extensive in the region of origin than in the importing region.

General trends

Despite the aforementioned problems, analyses of pest interception records around the world have provided clear evidence that wood packaging is a major pathway for the global movement of forest pests. Interestingly, similar levels of interceptions of pests on wood products have been documented across a number of international jurisdictions. This is despite differences in: inspection intensity and methodology; categorisation of wood products inspected; size of datasets analysed; taxonomic groups included in the analyses; and time period over which data have been collected. Analyses of European interception data for the period 1995 to 2004 identified two pathways (wood packaging materials and bonsais) of equal relative importance to forestry (Roques, 2007). Together these two pathways accounted for almost 73% of the intercepted insects with a potential to become pests of forest and ornamental trees, i.e. they were associated in their native ranges with genera of forest or ornamental trees growing in Europe. Wood packaging comprised 38% of all interceptions related to forests and trees (casewood or crating – 34%, dunnage and pallets – 4%) (Roques, 2007), but only 4% of the total interceptions across all commodities (Roques & Auger-Rozenberg, 2006). Significant proportions of the total European interceptions related to forests and trees were also recovered from sawn timber (16%) and logs (8%), with the remaining 3% being recovered from plants for planting, seeds or miscellaneous categories (Roques, 2007). Similar results were found by Haack and Cavey (1997) in an analysis of United States (US) data for total interceptions on wood products. As in Europe, interceptions on crating predominated (49%), followed by interceptions on dunnage (36%), pallets (6%), lumber (2%) and unassigned sources (7%). In a more specific study, Haack (2006) documented

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

interception levels for six families of Coleoptera on wood from US data collected between 1985 and 2000. Again, interceptions on the wood packaging pathway (crating, dunnage and pallets) predominated (75% of interceptions were from packaging, 16% from wood products, 9% were unassigned). In contrast, an analysis of the Scolytinae interceptions in New Zealand between 1952 and 2000 found that 11% of the all interceptions (73% of the Scolytinae) were from wood packing (dunnage, crating, and pallets), and 3% were recovered from logs and lumber (21% of the Scolytinae). However, fully 84% of all interceptions on wood packaging were represented by taxa other than the Scolytinae (unspecified wood products comprised the remaining 6% of the interceptions of Scolytinae (Brockerhoff et al. 2006a)). These datasets all clearly demonstrate the association of wood packaging with the global redistribution of bark- and wood-boring arthropods.

These analyses also provide insights into the relative importance of the higher taxa transported in association with wood packaging. Beetles dominate recent (1995-2004) European interceptions on wood packaging and fresh wood with the Cerambycidae being the dominant family intercepted on both types of wood products. The sub-family Scolytinae of the Curculionidae also comprised a significant proportion of the interceptions on fresh wood but were less frequently intercepted on wood packing (Roques, 2007). Similarly, in Canadian data for the period 1997-2000 analysed by Humble and Allen (2006), interceptions of Cerambycidae predominated (40% of total interceptions), followed by Scolytinae (25%) and Bostrichidae (almost 21%). In contrast, interceptions by Scolytinae predominated an analysis of longer-term records (1985-2000) for wood products identified as wood packaging (dunnage, pallets and packaging) from the US (Haack, 2006). Scolytinae comprised almost 70% of the interceptions followed by other Curculionidae at 12% and Cerambycidae at 11%. The predominance of interceptions by species of Scolytinae in the US records can be explained, in part, by the inspection process. Wood packaging with bark was often targeted for inspection in the US because internationally, prior to 2002, there was no compulsory treatment for such wood products used in international trade. A combination of targeted inspections, the ease with which bark-feeding Scolytinae can be collected, their preponderance in tree species used for wood packaging, and the presence of adults in association with larval brood galleries (Haack, 2006) has led to the dominance of phloeophagous or phloem-feeding Scolytinae (74% of all interceptions identified to species) in the US dataset. Differences in inspection policy must also be considered when interpreting historical interception data. Xylomycetophagous Scolytinae (ambrosia beetles whose larvae feed in the wood on fungi introduced by adults) and the xylophagous or wood-feeding Anobiidae have not been consistently recorded in the US interception database because they were considered non-actionable pests during the period of the analysis (Haack, 2006). In a similar manner, the establishment of cerambycids like *A. glabripennis* in the US led to an increased emphasis on inspections after 1996 for long-horned wood borers in the US (Haack, 2006).

While the aforementioned analyses all document the preponderance of interception records for Coleoptera, the recent discovery of the introduction of *Sirex noctilio* into North America (Hoebeke et al., 2005) is a reminder of the phytosanitary risks posed by other woodboring taxa associated with wood packing. Between 1985 and 2000, Siricidae were intercepted 103 times in the US. Despite the longstanding importance of this species as a global pest of pines (see Carnegie et al., 2006), only seven of the interceptions were fully identified (all seven were *S. noctilio*) (Hoebeke et al., 2005). In a previous analysis of port interception data for the period 1985 to 1996, Haack & Cavey, (1997) noted that Siricidae comprised slightly more than 1% of the interceptions on wood articles.

Interception databases are also useful in identifying regions of origin of commodities associated with pests. In a detailed analysis of 17 years of US port interception data for possible commodity pathways, McCullough et al. (2006) found that Italy followed by China, West Germany, Spain and Belgium were major sources of pest interceptions on wood products associated with cargo. Their analysis clearly identified the link between foreign trade and invasion pathways; the species richness of intercepted taxa increased linearly with the total number of interceptions for commodity pathways associated with cargo and baggage. Additionally, these authors noted that commodities from those countries frequently recorded as being the origin of pests were more likely to be shipped through numerous ports. In contrast, commodities originating from countries that were infrequent sources of interceptions were shipped through relatively few ports. Analyses of the 1984-2000 interception data from the Port Information Network (PIN) database in the US (McCullough et al., 2006) provide historical insights into the relative importance of commodity groups as invasion pathways. Additionally, they can provide insights into the impact of shifting trade patterns on origin of and rates of interceptions of plant pests. When PIN data for wood-associated Coleoptera were examined for changes in interception patterns over time, Haack (2006) documented shifts in the rate of interceptions originating from source continents. Interceptions from Asia comprised 13% of the total interceptions between 1985 and 1988 but this rose to 40% during the period from 1997 to 2000, while those from Europe dropped from 73% to 34% during the same two periods. Additionally, the dominant taxa intercepted also shifted during the same time frames. Interceptions of Cerambycidae from Asia increased significantly during the latter time period, while interceptions of Scolytinae from Europe

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

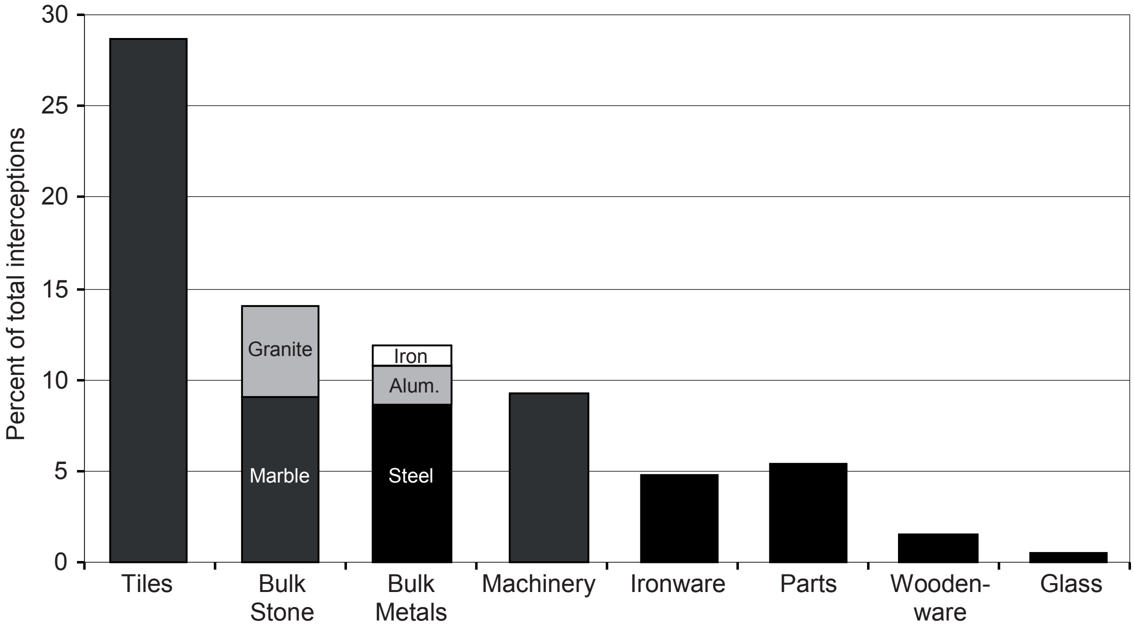

FIGURE 2: Proportion of the total interceptions (n=8341) in the US on all classes of wood packaging from 1985 – 2005 for the top eleven commodities with which they were associated (after data provided by Haack, 2006). The commodity classes "Bulk Stone" and "Bulk Metals" are respectively comprised of two and three of the commodities noted by Haack (2006).

declined dramatically. Factors that contributed to these observed shifts include greatly increased volumes of trade with China and the targeting of inspections for pests associated with wood packing during the latter time period (Haack, 2006).

Specific examples

Analyses of pest interception records also provide insights into which commodities are most often associated with interceptions of bark- and wood-borers as result of international trade. Data provided by Haack (2006) illustrate the association of pest interceptions on wood used to package various types of commodity (Figure 2). High interception rates of bark- and wood-borers were associated with those commodities that are typically packaged with large volumes of wood (Figure 3). While such associations are documented (Haack, 2006, 2007), there is only limited data relating the pest loads (i.e. number of species and individuals) in individual consignments to the amount of wood packaging (volume and/or dimensions of wood). In one such study, Allen and Humble (2001) quantified and compared the pest loads associated with two types of wooden packaging (bolts and spools) used to transport two different commodities, granite blocks and wire rope, respectively. Twenty-nine bolts of Norway spruce (*Picea abies* (L.) H. Karst.) roundwood (with bark) used to brace the granite blocks inside shipping containers and 50 wooden spools constructed from lumber of unidentified coniferous and deciduous species used to transport wire rope from China were sampled. Infested wood was collected from both commodities and insects from the infestations were reared under quarantine to obtain adults for definitive identification.

Bolts - Sixteen species of bark- or wood-boring taxa and at least 24 species of predators, scavengers or parasitoids were reared from the intercepted bolts. The species richness of the bark- and wood-boring fauna varied considerably (Figure 4) between individual bolts, averaging 1.4 ± 0.3 species per bolt (mean ± SE). No single bolt contained more than 38% of the total bark- or wood-boring species reared and 16 (45%) of the bolts contained no pests. While the species richness per bolt was relatively low, significant numbers of individuals of some taxa of quarantine significance were recovered. Had this interception occurred during a phytosanitary inspection, only the first species discovered (likely the Scolytinae) would have been documented before the consignment was destroyed. Wood borers continued to emerge over the entire 2-month period that this packaging was studied.

Spools - the spools were disassembled and individual boards were examined for the presence of both

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

bark- and wood borers. As the spools had been in Canada for 1 – 2 years before analysis, it was not possible to quantify their overall pest load. Some species originally present in the spools may have emerged prior to sampling or have died as larvae during rearing. Despite the lengthy pre-sampling storage time, 24% of spools still contained live wood borers and 31% had some evidence of past wood borer activity. The occurrence of six species of Cerambycidae and one species of Anobiidae was documented. More significantly, there was no external evidence on any of the spools that would indicate the presence of actively feeding wood borers during phytosanitary inspection although there was external evidence of past wood borer activity on some of the spools examined.

These two examples illustrate the differing risk profiles associated with various types of wood packaging. A greater taxonomic diversity of potential pest species (sixteen species from five Families and two Orders) was found in the bolts compared with spools (seven species from two Families of Coleoptera). In addition to the greater taxonomic diversity of potential pest species found in the bolts, larger numbers of individuals of the dominant taxa were intercepted in the bolts than from the spools. Phloem-feeding species with annual life cycles [all of the Scolytinae and Cerambycidae (Bense, 1995) and likely the Anobiidae)] dominated the taxa recovered from bolt interceptions; only two of the 16 bark or wood-borers recovered, *Sirex juvencus* (L.) and *Serropalpus barbatus* (Schaller), complete their life cycles within the xylem. In contrast, all but one of the species reared from spools fed within xylem. The single phloem-feeding species, *Ptilineurus* sp. (Coleoptera: Anobiidae), recovered from spools was associated with a bark strip on the milled lumber. While milled lumber reduced the incidence of phloem feeding taxa, it does not eliminate risk but rather shifts the risk to those taxa feeding within xylem.

With the exception of the wood borer, *Rhagium inquisitor* (L.), which has a Holarctic distribution, only

FIGURE 3: Various uses of wood packaging used to ship: stone products (A, B); manufactured iron and steel products (C); or as dunnage on vessels (D). *Images courtesy of D. Holden, Canadian Food Inspection Agency.*

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

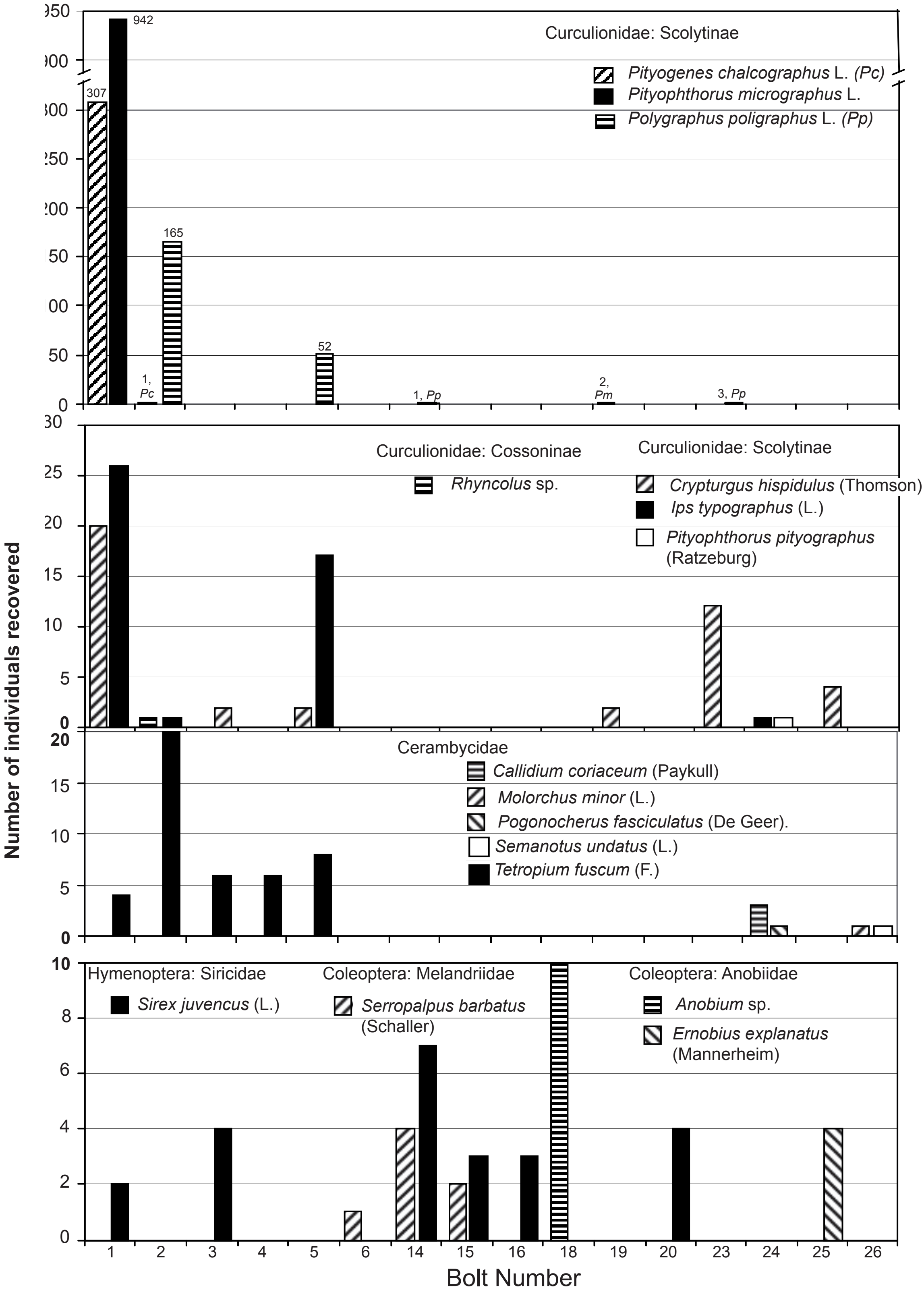

FIGURE 4: Distribution of species of bark- and wood-boring Hymenoptera and Coleoptera reared from 16 Norway spruce bolts by individual bolt. Live insects were reared from 16 of the 29 bolts recovered from the consignment.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

two of the species recovered from these rearings, *Sirex juvencus* (H. Goulet, Agriculture and Agrifoods Canada, Ottawa, pers. comm.) and *Tetropium fuscum* (F.) (Smith & Hurley, 2000), are currently established in North America. Of the other species recorded, the Asian species *Psacothea hilaris* (Pascoe) (Coleoptera: Cerambycidae) has been reported in Italy (Jucker et al., 2006) and the United Kingdom (Anonymous, 2008b). Surprisingly, *Anoplophora glabripennis* was not reared from the spools even though it had previously been recovered from warehouses housing spools. It is also of interest to note that wire rope is not identified as one of the top 11 commodities associated with interceptions in the US (Haack, 2006).

Surveillance programmes for non-indigenous bark- and wood-borers

The implementation of surveillance programmes for non-indigenous introductions has provided additional evidence of the risks posed by the wood packaging pathway both regionally (Humble, 2001; Mudge et al., 2001; Pennacchio et al., 2003; LaBonte et al., 2005) and nationally (Brockerhoff et al., 2006c; Rabaglia et al., 2008). Insects that were first detected by surveillance programmes include four bark beetles (Curculionidae: Scolytinae) and four ambrosia beetles (Curculionidae: Scolytinae) (Haack, 2006), as well as *S. noctilio* (Hoebeke et al., 2005) and *Xiphydria prolongata* (Geoffroy) (Hymenoptera: Xiphydriidae) (Mudge et al., 2001) in the US. In Canada, surveillance programmes in forest habitats in and around port facilities led to the first national records for three species of ambrosia beetles and the first regional records for an additional two species of ambrosia beetles (Humble, 2001). Similarily, Pennacchio et al. (2003) reported the presence of *Xylosandrus crassiusculus* (Motschulsky) in Italy from the results of a regional surveillance programme. In contrast, Brockerhoff et al. (2006c) recovered no new non-indigenous taxa during nationwide surveys from 2002-2004 in New Zealand. These surveillance programmes all employed flight-intercept traps baited with various combinations of kairomones[1] or pheromones[2], which targeted specific taxa of concern (e.g. *Ips typographus* (L.) for Canada) (CFIA, 2006, 2009). In general, kairomones attract a greater diversity of species in surveillance trapping than do the more species specific pheromones. Haack (2006) observed that these chemicals are most effective for Scolytinae.

While surveillance programmes have been successful in early detection (Haack, 2006), they are not equally effective either within or across all taxonomic groups (Figure 5). Current surveillance programmes rely on a limited suite of semiochemicals (compounds emitted by a plant or animal that evoke a behavioural or physiological response in another organism) such as host-produced volatile chemicals (such as ethanol or α-pinene) and/or species-specific pheromones, which are used as lures to target species of regulatory concern. Species capture is dependent on the response of the target species to these semiochemicals. The limited efficacy of the trapping systems become evident when the species richness detected in surveillance trapping studies is evaluated against the known diversity of bark- and wood-borers potentially present in the area under surveillance. At best, only about a third of the species of Scolytinae that are attracted to ethanol or α-pinene were recovered in five years of trapping (Figure 5). The species trapped were predominantly ambrosia beetles and secondary bark beetles like *Hylastes* spp. and *Hylurgops* spp. Unfortunately, these trap-and-lure systems were relatively ineffective for recovering the majority of Cerambycidae and Buprestidae species across the study sites. Additionally, little is known of the efficacy of these lure systems for the detection of indigenous species of bark- and wood-borers present in the source areas.

What are we missing?

One of the most significant deficiencies in both interception data and surveillance monitoring is the absence of information on organisms vectored by the taxa intercepted in the monitoring programmes. A lack of specific knowledge relating to the range of organisms potentially vectored by intercepted insects or the possible impacts of these organisms on novel hosts within their introduced range are extremely difficult to evaluate *a priori* (Humble & Allen, 2006). The risk posed by vectored organisms is difficult to evaluate since plant protection agencies generally do not survey for such organisms. This is amply illustrated by the impact on native Lauraceae of the laurel wilt fungus, *Raffaelea lauricola*. This disease was introduced into the southeastern US in association with an ambrosia beetle of Asian origin, *Xyleborus glabratus* (Harrington et al., 2008; Hanula et al., 2008). While twenty species of xylomycetophagous ambrosia beetles (*Trypodendron domesticum* (L.) and 19 spp. of Scolytinae: Xyleborina) have been introduced into North America (Canada and the US) since 1817 (Haack, 2001; Humble, 2001), only *X. glabratus* is known to have arrived with a serious plant pathogen.

[1] *compounds such as ethanol and α-pinene that are released by stressed, dying or recently dead deciduous or coniferous trees and are used by bark- or wood-boring insects to detect host material suitable for attack;*

[2] *species-specific compounds used to attract mates or induce aggregation of conspecifics on suitable hosts.*

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

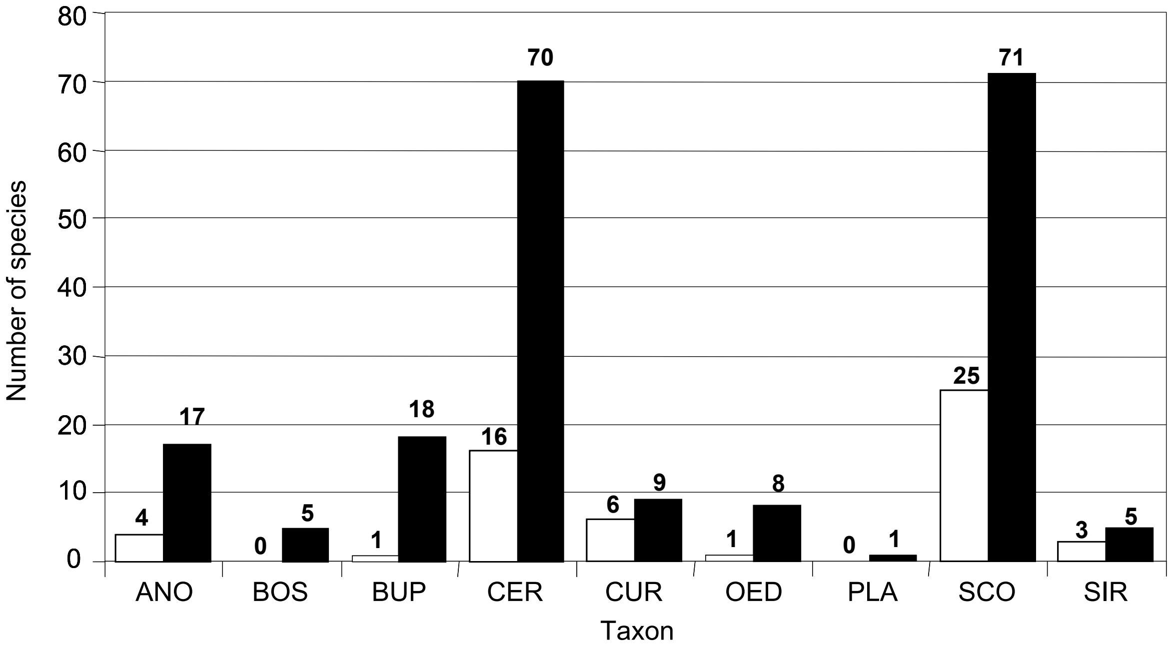

FIGURE 5: Numbers of species of bark- and wood-borers grouped by family[1] recovered in surveillance trapping at 14 locations[2] in natural forest habitats in the greater Vancouver area of British Columbia, Canada for the five years between 1995 and 1999 inclusive (open bars) versus the total number of species estimated[3] to be present at the locations trapped (filled bars).

In a review of the vectored organisms associated with bark- and wood-borers intercepted during wood packaging audits in Canada between 1997 and 2000, Humble and Allen (2006) documented 39 species of fungi recorded in the literature as being associated with nine species of bark-beetles (Scolytinae). More than 56% of the fungal taxa recorded, including serious Eurasian pathogens such as *Ceratocystis laricicola* Redfern & Minter and *Ceratocystis polonica* (Siemaszko) C. Moreau, had not been recorded previously from North America.

From a regulatory perspective, the presence of a species capable of vectoring pathogenic organisms in more than one biotic region can be problematic, if a different suite of organisms is associated with the vector in each biotic region. Thus, the Holarctic species, *Dryocoetes autographus* (Ratzeburg), could potentially vector novel fungi when transferred between hemispheres (Figure 6). Such vector species would not be subject to phytosanitary restrictions since they are already present within the region to which they have been transported via trade items.

Of even more serious concern, is the potential for exotic vectored organisms to be introduced even though their natural vector species does not establish in the new area. At least some of the novel vector-pathogen relationships created by such transfers are having serious impacts on forest health. This is amply illustrated by the multiple introductions of pinewood nematode beyond its native North American range (see Humble & Allen, 2006 and references therein). Thus, in the pine forests of Japan, China and Portugal, the pinewood nematode is vectored by native species of *Monochamus,* rather than by its native North American vectors.

[1] ANO – Anobiidae; BOS – Bostrichidae; BUP – Buprestidae; CER – Cerambycidae; CUR – wood boring Curculionidae (excluding Scolytinae and Platypodinae); OED – Oedemeridae; PLA – Curculionidae: Platypodinae; SCO – Curculionidae: Scolytinae; and SIR - Hymenoptera: Siricidae.

[2] The number of locations trapped and the lures employed in each year were as follows: 1995 – 1 site, 6 lures [α-pinene, α-pinene + ethanol, ethanol, lineatin, sulcatol and *Ips typographus* lure]; 1996 – 2 sites, 4 lures [*Tomicus piniperda* lure, ethanol, α-pinene + ethanol, and *Ips typographus* lure]; 1997 – 2 sites, 5 lures [*T. piniperda* lure, ethanol, α-pinene + ethanol, α-pinene, and *I. typographus* lure]; 1998 – 1 site, 8 lures [*T. piniperda* lure, *I. typographus* lure, ethanol, α-pinene, green leaf volatiles, lineatin, sulcatol and retusol]; and 1999– 12 sites, 11 lures [*T. piniperda* lure, *I. typographus* lure, chalcogran, ethanol, α-pinene, birch oil distillation, experimental buprestid lure, experimental cerambycid lure, dipentene, lineatin and sulcatol].

[3] The total number of species potentially occurring across all locations was estimated by determining the number of species in each family that had been recorded from the study area.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

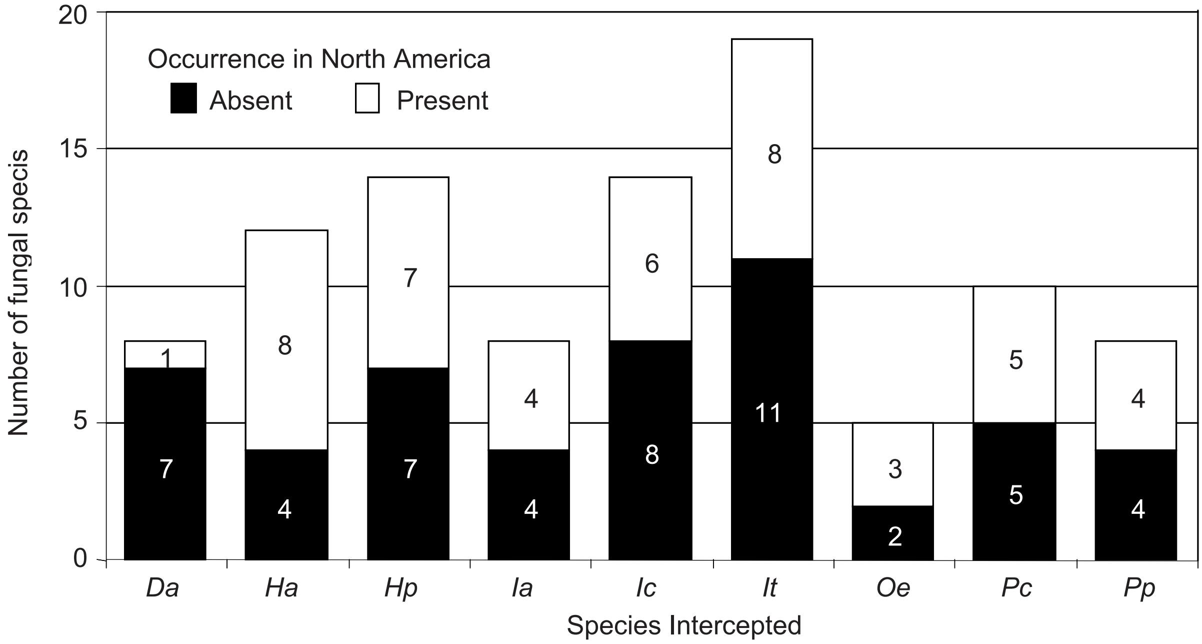

FIGURE 6: Number of fungal species recorded within and outside of North America (Canada and the US) associated with nine species of bark- beetles (Curculionidae: Scolytinae) that were intercepted in association with wood packaging in Canada between 1997 and 2000 (after Humble & Allen, 2006). *Da – Dryocoetes autographus* (Ratzeburg)*; Ha – Hylastes ater* (Paykull); *Hp –Hylurgops palliatus* (Gyllenhal)*; Ia – Ips acuminatus* (Gyllenhal); *Ic – cembrae* (Heer) *; It – Ips typographus* (L.)*; Oe – Orthotomicus erosus* (Wollaston); *Pc – Pityogenes chalcographus* (L.)*; and Pp – Polygraphus poligraphus* (L.).

Another example is that three of the five remaining native stands of Monterey pine, *Pinus radiata* D.Don, in California are threatened by pine pitch canker, *Fusarium circinatum* Nirenberg and O'Donnell, a non-indigenous pathogen which is vectored by a diversity of insects (Wikler et al., 2003).

There are also examples of transference of introduced pathogens to native vectors as a consequence of the lack of fidelity between vectors and their associated fungi. In North America, elms growing in both urban environs and natural forests have been decimated by introduced pathogens *Ophiostoma ulmi* (Buisman) Nannf. and *O. novo-ulmi* Brasier (Bright, 1976) which were vectored in large part by a bark beetle *Hylurgopinus rufipes* (Eichhoff) native to the continent. Westwood (2003) noted that, although the vector with which Dutch elm disease was first introduced, *Scolytus multistriatus* (Marsham) was present, it was not the primary vector of the disease in Manitoba and Saskatchewan in Canada or North Dakota in the US. In those areas, *H. rufipes* constituted more than 99% of the vector population

Instances of pathogens acquiring additional vectors with the introduction and establishment of additional non-indigenous vectors into a habitat have also been documented (Negrón et al., 2005; Jacobi et al., 2007; Wingfield et al. 2010).

Haack (2006) has observed that the both the initial date of establishment and the exact mode of entry is not known for any of the recently established insect species in the US. He suggested that the wood packaging pathway is the most likely mode of entry as many of the taxa were frequently intercepted on such materials. Solid wood packaging is the only plausible pathway for the introduction and establishment of wood borers such as *T. fuscum* into countries, such as Canada, that have long prohibited the import of untreated coniferous wood products (lumber, logs, etc.).

New invasive species are still being discovered in forest habitats (see Jendek & Grebbenikov, 2009) that have likely been introduced during the transport of commodities packaged with wood. This indicates that the full legacy of introductions resulting from global trade has probably not yet been determined. The two rearing studies decribed earlier (Allen & Humble, 2001) provided some insights into both the potential abundance and diversity of species transported in association with wood packaging. These studies suggested the pest loads associated with individual interception records collected by plant protection organisations are most likely significantly underestimated. Work et al. (2005) estimated that inspections of maritime cargo (which often include large volumes of wood packaging) likely detect only

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

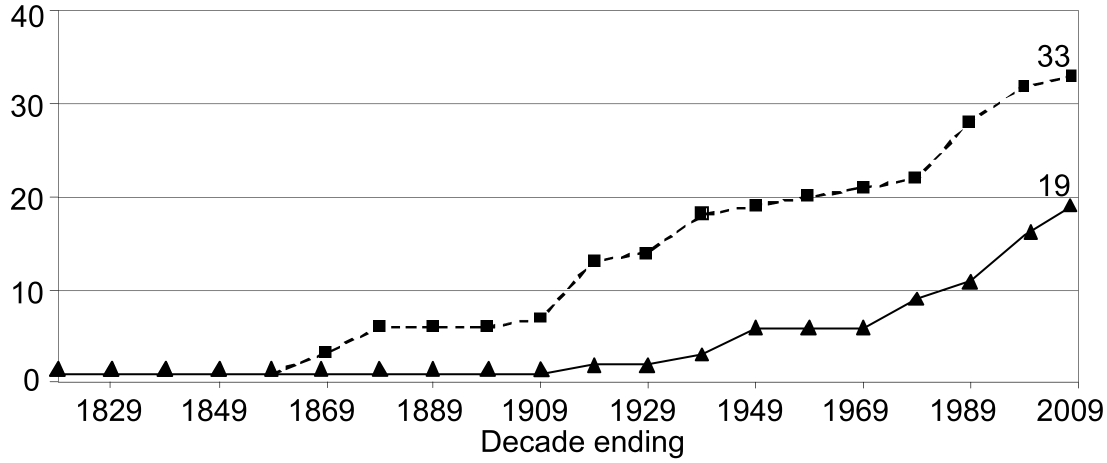

FIGURE 7: The cumulative number of establishments of species of ambrosia beetles (solid line) and bark beetles (dashed line) (Curculionidae: Scolytinae) by decade in the continental United States (after data in Haack, 2006).

19 – 28% of the actual species arriving with the cargo. When coupled with the overall low rate of inspection of imports (Brockerhoff et al., 2006a; Haack, 2006), and the potentially long lag time between initial establishment and first discovery of the introduced pest populations (Smith & Hurley, 2000; Poland & Haack, 2003), the available information suggests that numerous populations of invasive bark- and wood-boring species have yet to be discovered.

Continued surveillance of new, high-risk sites is necessary for two reasons (as is intermittent monitoring of locations at which non-indigenous species are known to be present). The first is to detect new populations of non-indigenous species and the second is the need for ongoing evaluation of known, locally established populations that do not currently exhibit invasive tendencies.

The recent identification of the pheromone components for species of two subfamilies of Cerambycidae (Cervantes et al., 2006; Ray et al., 2006; Hanks et al., 2007) suggests that lures could be developed for use in future surveillance programmes for long-horned wood borers. Trap-and-lure systems that effectively sample the diversity of Buprestidae have not been developed, however.

Non-commodity based pathways

Evidence accumulated from analysis of phytosanitary interceptions records, regional and national inventories of established invasive species and surveillance programmes for new introductions have each provided clear evidence of the importance solid wood packaging as a major pathway for the introduction of forest pests globally. With the implementation of compulsory treatment of wood packaging, significant reductions in the rates of establishment of bark- and wood-borers moving on this pathway can be expected. However, evaluation of the degree of reduction of the rates of establishment resulting from the compulsory treatments will be difficult to ascertain. This is mainly due to the lack of fully quantified and identified background datasets documenting the infestation levels of wood packaging and pest loads per unit volume of wood. The only datasets that may be useful in demonstrating the effectiveness of ISPM are rates of accumulations of taxa associated primarily with the wood packaging pathway. Data provided by Haack (2006), supplemented by records from other literature, show a steady increase in the accumulation of ambrosia beetles between 1969 and 2008 (Figure 7). Future declines in the decadal rates of accumulation would be indicative of the effectiveness of wood packaging treatments. Care should be taken to ensure that fully quantified interception data are available during the development and prior to the implementation of any future, non-commodity-based or commodity-based standards. The adoption of statistically valid (randomised) sampling protocols for the detection of nonindigenous pests during inspections would greatly improve the ability of NPPOs to evaluate the effectiveness of any standard through post-implementation audits of pest interceptions. Such a protocol was recently adopted in the US (see Work et al., 2005).

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

Acknowledgments

The Organisation of Economic Co-operation and Development is thanked for their financial support towards attending the workshop. This work was also supported by funding from the Forest Invasive Alien Species Program, Natural Resources Canada, Canadian Forest Service. This manuscript was greatly improved by comments received from the editors and two anonymous reviewers.

References

Allen, E. A., & Humble, L. M. (2001). Nonindigenous species introductions: a threat to Canada's forests and forest economy. *Canadian Journal of Plant Pathology, 24,* 103-110.

North American Plant Protection Organization Phytosanitary Alert System. (2003). *Asian longhorned beetle (*Anoplophora glabripennis*) infestation found in Ontario, Canada/ Infestation par le longicorne asiatique (*Anoplophora glabripennis*) en Ontario, au Canada. 09/12/2003.* Retrieved 10 April 2009, from http://www.pestalert.org/opr_search.cfm

American Plant Protection Organization Phytosanitary Alert System. (2008a). *Asian longhorned beetle,* Anoplophora glabripennis*, confirmed in Worcester County, Massachusetts. North*. Retrieved 10 April 2009, from http://www.pestalert.org/opr_search.cfm

EPPO Reporting Service PARIS (2008b). 2008/201 Psacothea hilaris *detected in the United Kingdom: addition to the EPPO Alert List NO. 10, 11-12.* Retrieved 10 May 2009, from http://archives.eppo.org/EPPOReporting/2008/Rse-0810.pdf

Bense, U. (1995). *Longhorn beetles: Illustrated key to the Cerambycidae and Vesperidae of Europe.* Nördlingen, Germany: Druckerei Steunmeier.

Bright, D.E. (1976). *The insects and arachnids of Canada. The bark beetles of Canada and Alaska (Coleoptera: Scolytidae). Part 2.* Canada Department of Agriculture Publication 1576. Ottawa, ON, Canada: Canada Department of Agriculture.

Britton, K. O., & Sun, J. H. (2002). Unwelcome guests: Exotic forest pests. *Acta Entomologica Sinica, 45*(1), 121-130.

Brockerhoff, E. G., Knízek, M., & Bain, J. (2003). Checklist of indigenous and adventive bark and ambrosia beetles Curculionidae: Scolytinae and Platypodinae) of New Zealand and interceptions of exotic species 1952-2000. *New Zealand Entomologist, 26,* 29-44.

Brockerhoff, E. G., Bain, J., Kimberley, M., & Knizek, M. (2006a). Interception frequency of exotic bark and ambrosia beetles Coleoptera: Scolytinae) and relationship with establishment in New Zealand and worldwide. *Canadian Journal of Forest Research, 36,* 289-298.

Brockerhoff, E. G., Liebhold, A. M., & Jactel, H. (2006b). The ecology of forest insect invasions and advances in their management. *Canadian Journal of Forest Research, 36,* 263-268.

Brockerhoff, E. G., Jones, D. C., Kimberly, M. O., Suckling, D. M., & Donaldson, T. (2006c). Nationwide survey for invasive wood-boring and bark beetles (Coleoptera) using traps baited with pheromones and kairomones. *Forest Ecology and Management, 228,* 234-240.

Cai, Y. W., Cheng, X. Y., Xu, R. M., Duan, D. H., & Kirkendall, L. R.. (2008). Genetic diversity and biogeography of red turpentine beetle *Dendroctonus valens* in its native and invasive regions. *Insect Science, 15,* 291-301.

Carnegie, A. J., Matsuki, M., Haugen, D. A., Hurley, B. P., Ahumada, R., Klasmer, P., Sun, J., & Iede, E. T. (2006). Predicting the potential distribution of *Sirex noctilio* Hymenoptera: Siricidae), a significant exotic pest of *Pinus* plantations. *Annals of Forest Science, 63*, 119-128.

Cavey, J. F., Hoebeke, E. R., Passoa, S., & Lingafelter, S. W. (1998). A new exotic threat to North American hardwood forests: an Asian longhorned beetle, *Anoplophora glabripennis* Motschulsky) Coleoptera: Cerambycidae). I. Larval description and diagnosis. *Proceedings of the Entomological Society of Washington, 100,* 373-381.

Cervantes, D. E., Hanks, L. M., Lacey, E. S., & Barbour, J. D. (2006). First documentation of a volatile sex pheromone in a longhorned beetle (Coleoptera: Cerambycidae) of the primitive subfamily Prioninae. *Annals of the Entomological Society of America, 99,* 718-722.

Canadian Food Inspection Agency (CFIA). (2006). *2006 Plant protection survey report.* Retrieved 28 February 2010, from http://www.inspection.gc.ca/english/plaveg/pestrava/surv/sit2006e.shtml#exo

Canadian Food Inspection Agency (CFIA). (2009). D-02-12: *Import requirements for non-processed wood and other non-propagative wood products, except solid wood packaging material, from all areas other than the continental United States.* Retrieved 28 February 2010, from http://www.inspection.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

gc.ca/english/plaveg/protect/dir/d-02-12e.shtml

Colombo, M., & Limonta, L. (2001). *Anoplophora malasiaca* Thomson (Coleoptera Cerambycidae Laminae Lamiini) in Europe. *Bollettino di Zoologia Agraria e di Bachicoltura, Ser II, 33,* 65-68.

Duffy, E. A. J. (1953). *A monograph of the immature stages of British and imported timber beetles (Cerambycidae).* Norwich, UK: Jarrold and Sons Ltd.

Eldridge, R. H., & Simpson, J. A. (1987). Development of contingency plans for use against exotic pests and diseases of trees and timber. 3. Histories of control measures against some introduced pests and diseases of forests and forest products in Australia. *Australian Forestry, 50,* 24-36.

Food and Agriculture Organisation (FAO). (2009a). *Regulation of wood packaging material in international trade ISPM No. 15.* Rome, Italy: FAO.

Food and Agriculture Organisation (FAO). (2009b). *Glossary of phytosanitary terms ISPM No. 5.* Rome, Italy: FAO.

Fraedrich, S. W., Harrington, T. C., Rabaglia, R. J., Ulyshen, M. D., Mayfield, A. E., III, Hanula, J. L., Eickwort, J. M., & Miller, D. R. (2008). A fungal symbiont of the redbay ambrosia beetle causes a lethal wilt in redbay and other Lauraceae in the southeastern United States. *Plant Disease, 92,* 215-224.

Gilbert, J. M., & Miller, L. W. (1952). An outbreak of *Sirex noctilio* F. in Tasmania. *Australian Forestry, 16,* 63-69.

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

Haack, R. A. (2006). Exotic bark- and wood-boring Coleoptera in the United States: recent establishments and interceptions. *Canadian Journal of Forest Research, 36,* 269-288.

Haack, R. A., & 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), 1-5.

Haack, R. A., Cavey, J. F., Hoebeke, E. R., & Law, K. R. (1996). *Anoplophora glabripennis*: A new tree-infesting exotic cerambycid invades New York. *Newsletter of the Michigan Entomological Society, 41*(2-3), 1-3.

Hanks, L. M., Millar J. G., Moreira, J. A., Barbour, J. D., Lacey, E. S., McElfresh, J. S., Reuter, F. R., & Ray, A.M. (2007). Using generic pheromone lures to expedite identification of aggregation pheromones for the cerambycid beetles *Xylotrechus nauticus*, *Phymatodes lecontei*, and *Neoclytus modestus modestus. Journal of Chemical Ecology, 33,* 889–907.

Hanula, J. L., Mayfield, A. E., Fraedrich, S. W., & Rabaglia, R. J. (2008). Biology and host associations of redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae), exotic vector of laurel wilt killing redbay trees in the southeastern United States. *Journal of Economic Entomology, 101,*1276-1286.

Harrington, T. C., Fraedrich, S. W., & Aghayeva, D. N. (2008). *Raffaelea lauricola*, a new ambrosia beetle symbiont and pathogen on the Lauraceae. *Mycotaxon, 104,* 399-404

Hérard, F., Ciampitti, M., Maspero, M., Krehan, H., Benker, U., Boegel, C., Schrage, R., Bouhot-Delduc, L., & Bialooki, P. (2006). *Anoplophora* species in Europe: infestations and management processes. *EPPO Bulletin, 36*(3), 470-474.

Hoebeke, E. R., Haugen, D. A., & Haack, R. A. 2005. *Sirex noctilio*: discovery of a Palearctic siricid woodwasp in New York. *Newsletter of the Michigan Entomological Society, 50*(1-2), 24-25.

Hoebeke, E. R., & Rabaglia, R. J. (2008). *Xyleborus seriatus* Blandford Coleoptera: Curculionidae: Scolytinae), an Asian Ambrosia Beetle New to North America. *Proceedings of the Entomological Society of Washington, 110,* 470-476.

Hulme, P. E., Bacher, S., M. Kenis, M., Klotz, S., I. Kühn, I., D. Minchin, D., Nentwig, W., Olenin, S., Panov, V., Pergl, J., Pyšek, P., Roques, A., Sol, D., Solarz, W., & Vilà, M. (2008). Grasping at the routes of biological invasions: a framework for integrating pathways into policy. *Journal of Applied Ecology, 45,* 403-414.

Humble, L. M. (2001). Invasive bark and wood-boring beetles in British Columbia, Canada. In E. Alfaro, K. Day, S. Salom, K.S.S. Nair, H. Evans, A. Liebhold, F. Lieutier, M. Wagner, K. Futai, & K. Suzuki (Eds.), *Protection of world forests from insect pests: advances in research Vol. 11* (pp. 69–77). Vienna, Austria: IUFRO World Series.

Humble, L. M., & Allen, E. A. (2006). Forest biosecurity: alien invasive species and vectored organisms. *Canadian Journal of Plant Pathology, 28,* S256–S269.

Iede E., Penteado, S., & Bisol, J. (1988). Primeiro registro de ataque de *Sirex noctilio* em *Pinus taeda* no Brasil. EMBRAPA-CNPF, *Circular Técnica, 20,* 1-12.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

Irvine, C. J. (1962). Forest and timber insects in Victoria. *Victoria's Resources, 4,* 40-43.

Jacobi, W. R., Koski, R. D., Harrington, T. C., & Witcosky, J. J. (2007). Association of *Ophiostoma novo-ulmi* with *Scolytus schevyrewi* (Scolytidae) in Colorado. *Plant Disease, 91,* 245-247.

Jendek, E., & Grebennikov, V. V. 2009. *Agrilus sulcicollis* (Coleptera: Buprestidae), a new alien species in North America. *Canadian Entomologist, 141,* 236-245.

Jucker, C., Tantardini, A., & Colombo, M. (2006). First record of *Psacothea hilaris* (Pascoe) in Europe (Coleoptera Cerambycidae Lamiinae Lamiini). *Bollettino di Zoologia Agraria e di Bachicoltura, Ser. II, 38*(2), 187-191.

LaBonte, J. R., Mudge, A. D., & Johnson K. J. R. (2005). Nonindigenous woodboring Coleoptera (Cerambycidae, Curculionidae: Scolytinae) new to Oregon and Washington, 1999–2002: consequences of the intracontinental movement of raw wood products and solid wood packing materials. *Proceedings of the Entomological Society of Washington, 107,* 554-564.

Langor, D. W., DeHaas, L. J., & Foottit, R. G. (2009). Diversity of non-native terrestrial arthropods on woody plants in Canada. *Biological Invasions, 11,* 5-19.

Maspero, M., Jucker, C., & Colombo, M. (2007). First record of *Anoplophora glabripennis* Motschulsky) Coleoptera Cerambycidae Lamiinae Lamiini) in Italy. *Bollettino di Zoologia Agraria e di Bachicoltura, Ser. II, 39*(2), 161-164.

Mattson, W.J., Niemela, P.. Millers, I., & Inguanzo, Y. (1994). *Immigrant phytophagous insects on woody plants in the United States and Canada: an annotated list.* USDA Forest Service General Technical Report, NC-GTR- 169. Washington DC, USA: USDA Forest Service.

McCullough, D. G., Work, T. T., Cavey, J. F., Liebhold, A. M., & Marshall, D. (2006). Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17-year period. *Biological Invasions, 8,* 611-630.

Mudge, A. D., LaBonte, J. R., Johnson, K. J. R., & LaGasa, E. H. (2001). Exotic woodboring Coleoptera (Micromalthidae, Scolytidae) and Hymenoptera (Xiphydriidae) new to Oregon and Washington. *Proceedings of the Entomological Society of Washington, 103,* 1011-1019.

Negrón, J. F., Witcosky, J. J., Cain, R. J., LaBonte, J. R., Duerr II, D. A., McElwey, S. J., Lee, J.C., & Seybold, S. J. (2005). The banded elm bark beetle: a new threat to elms in North America. *American Entomologist, 51*(2), 84-94.

Neumann, F. G., & Minko, G. (1981). The sirex wood wasp in Australian radiata pine plantations. *Australian Forestry, 44,* 46-63.

Pennacchio, F., Roversi, P. F., Francardi, V., & Gatti, E. (2003). *Xylosandrus crassiusculus* (Motschulsky) a bark beetle new to Europe. *Redia, 86,* 77-80.

Poland, T. M., Haack, R. A., & Petrice, T. R. (1998). Chicago joins New York in battle with the Asian longhorned beetle. Newsletter of the Michigan. *Entomological Society, 43*(4), 15-17.

Poland, T. M., & Haack, R.A. (2003). Exotic forest insect pests and their impact on forest management. In *Proceedings, Society of American Foresters 2002 National Convention; 2002 October 5-9; Winston-Salem, NC. SAF Publication 03-01*, (pp 132-141). Bethesda, MD, USA: Society of American Foresters.

Poland, T. M. (2007). Twenty million ash trees later: current status of emerald ash borer in Michigan. *Newsletter of the Michigan Entomological Society, 52*(1-2), 10-14.

Poland, T. M., & McCullough, D. G. (2006). Emerald ash borer: Invasion of the urban forest and the threat to North America's ash resource. *Journal of Forestry,* (April-May), 118-124.

Rabaglia, R., Duerr, D., Acciavatti, R., & Ragenovich, I. (2008). *Early detection and rapid response for non-native bark and ambrosia beetles: summary of the 2001-2005 pilot project. United States Department of Agriculture, Forest Service, Forest Health Protection.* May 2008. Retrieved 10 May 2009, from http://www.fs.fed.us/foresthealth/publications/EDRRProjectReport.pdf

Ray, A. M., Lacey, E. S., & Hanks, L. M. (2006). Predicted taxonomic patterns in pheromone production by longhorned beetles. *Naturwissenschaften, 93,* 543–550.

Roques, A. (2007). Old and new pathways for invasion of exotic forest insects in Europe first results of the Euopean project DAISIE. In H. F. Evans & T. Oszako, (Eds.), *Alien invasive species and international trade* (pp. 80-88). Warsaw, Poland: Forest Research Institute (Instytut Badawczy Lesnictwa).

Roques, A., & Auger-Rozenberg, M.-A. (2006). Tentative analysis of the interceptions of non-indigenous organisms in Europe during 1995-2004, *Bulletin OEPP, 36*(3), 490-496.

Roques, A., Rabitsch, W., Rasplus, J.-Y., Lopez-Vaamonde, C., Nentwig, W., & Kenis, M. (2009). Alien terrestrial invertebrates of Europe. In D. Simberloff (Series Ed.) & DAISIE

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)

(P. E. Hulme, W. Nentwig, P. Pyšek & M. Vilà) (Vol. Eds.), *Invading Nature - Springer Series in Invasion Ecology Vol. 3. Handbook of Alien Species in Europe* (pp. 63-79). Heidelberg, Germany: Springer.

Smith, G., & Hurley, J. E. (2000). First North American record of the Palearctic species *Tetropium fuscum* (Fabricius) (Coleoptera: Cerambycidae). *The Coleopterists Bulletin, 54*(4), 540.

Tomiczek, C., Krehan, H., & Menschorn, P. (2002). Dangerous Asiatic longicorn beetle found in Austria: new danger for our trees? *Allgemeine Forstzeitschrift für Waldwirtschaft und Umweltvorsorge, 57*(2), 52-54.

Tomiczek, C. (2002). *First occurrence of the "Asian longhorned beetle",* Anoplophora glabripennis *(Motschulsky) in Europe.* Vienna, Austria: Federal Forest Research Centre.

Tribe, G. D. (1995). The woodwasp *Sirex noctilio* Fabricius Hymenoptera: Siricidae), a pest of *Pinus* species, now established in South Africa. *African Entomology, 3,* 215-217.

Westwood, A. R. (1991). A cost benefit analysis of Manitoba's integrated Dutch elm disease management program 1975–90. *Proceedings of the Entomological Society of Manitoba, 47,* 44-59.

Wingfield, M. J., Slippers, B., & Wingfield, B. D. (2010). Novel Associations Between Pathogens, Insects And Tree Species Threaten World Forests. *New Zealand Journal of Forestry Science, 40 suppl.,* (in press)

Wikler, K., Storer, A. J., Newman, W., Gordon, T. R., & Wood, D. L. (2003). The dynamics of an introduced pathogen in a native Monterey pine (*Pinus radiata*) forest. *Forest Ecology and Management, 179,* 209-221

Work T. T., McCullough D. G., Cavey J. F., & Komsa R. (2005). Arrival rate of nonindigenous insect species into the United States through foreign trade. *Biological Invasions, 7,* 323-332.

ISSN 0048 - 0134 (print)
ISSN 1179-5395 (on-line)