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Risk assessment for the movement of domestic wood packaging material within the United States

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Executive Summary

Domestic wood packaging material (dWPM) provides a suitable habitat for pests that may move internationally in WPM. While direct evidence is lacking (there no studies that describe pests in dWPM), parsimony suggests that wood pests move in dWPM and expand their distributions through this movement. As such, unregulated movement of dWPM represents risk to forestry resources. Relatively higher risks are associated with dWPM containing untreated wood and wood with bark. Despite its potential to transport pests, dWPM does not easily lend itself to regulation because there is a large volume, the wood packaging industry is fragmented, and dWPM is used in almost every aspect of commerce. Also, without direct evidence of the types and quantities of pests associated with dWPM, there is currently no way to develop a targeted regulatory scheme. Additionally, dWPM is difficult to permanently track and it may become reinfested after treatment. These problems present challenges to developing an effective regulatory strategy. This complexity suggests that a systems approach, which combines two or more independent risk management options, could be the most effective. Studies of the actual pests in dWPM could significantly clarify the problem and reduce some uncertainties. These studies could also provide the framework for possible future regulation.

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Nature of the Problem

Wood packaging material (WPM) is loose wood and small wood pieces used to prevent damage to cargo during shipment (7 CFR § 319, 2010). Loose materials such as excelsior, sawdust, and wood shavings and processed wood materials such as plywood, oriented strand board, corrugated paperboard, and resin composites are not considered WPM.

The following are types of WPM:

- *Dunnage* is "wood used to wedge or support cargo" (IPPC, 2007) and often consists of odd, loose boards but may also include whole logs. It is usually layered between units of cargo in a container or ship's hold to prevent motion and chafing of the goods being shipped.
- A *crate* is a box, case, or protective framework for shipping.
- *Skids* may include pairs or sets of timbers designed to slide cargo.
- A *pallet* is a portable platform that facilitates movement of cargo by forklift, truck, or crane.
- *Blocking* and *bracing* are reinforcements to prevent loads from shifting.
- A *spool* is a cylindrical device with a rim on each end and usually an axial hole for a pin or spindle. It is designed to hold wound wire or cable.
- A shipping *drum* is a cylindrical container or barrel.

The risks associated with the movement and introduction of quarantine pests in WPM are well documented (Haack et al., 2007; USDA, 2000). The introduction of destructive tree pests such as the pine shoot beetle (*Tomicus piniperda*, Coleoptera: Curculionidae: Scolytinae), the Asian longhorned beetle (*Anoplophora glabripennis*, Coleoptera: Cerambycidae), and the emerald ash borer (*Agrilus planipennis*, Coleoptera: Buprestidae), all associated with the international movement of WPM, led to the creation of national programs to contain these pests and minimize the destruction of forest resources. International Standard for Phytosanitary Measures No. 15 (IPPC, 2006), Guidelines for Regulating Wood Packaging Material in International Trade, was adopted in 2002 and provides guidelines for mitigating the risk associated with the importation of WPM. This standard has been adopted by over 177 countries.

WPM used in domestic commerce (dWPM) may present the following risks:

- Exotic pests with limited distribution in the United States may be spread to new areas.
- Native pests with limited distribution may be spread to new areas, increasing environmental stressors, which in turn may make our nation's forests more susceptible to these pests.
- Pathogens vectored by established exotic or native insects may spread to new areas.

Currently, movement of dWPM is not regulated except in emerald ash borer and Asian longhorned beetle quarantine areas (7 CFR Part 301 [APHIS, 2007]). Domestic WPM from those areas is regulated under Federal Compliance Agreements, and Federal Certificates are required for interstate shipment of pallets using hardwood materials in quarantine areas for emerald ash borer. However, there are no specific regulations for other types of materials, such as dunnage.

Assumptions and uncertainties

Uncertainty is critical in this analysis because explicit evidence that dWPM transports forest pests that subsequently cause damage is lacking. There is no question that pests such as the emerald ash borer and the Asian longhorned beetle were once absent from the United States and have now become established. These pests were transported by some means and, based on the biology of the pests and border interception records, raw wood, including WPM, is a likely source of introduction. Once an exotic pest is established, it might disperse in a number of ways, including natural spread and human-assisted movement. To accurately assess risk, it is important to understand uncertainty associated with several types of evidence.

The first type of evidence deals with the nature of dWPM material. Specifically, dWPM must be a suitable pest habitat for there to be risk. Ample evidence demonstrates that dWPM harbors wood pests, especially if it contains bark. Unfortunately, the time period and conditions under which wood remains a suitable habitat are not known, especially in a commercial environment. We assume that fresher or greener wood, wood with bark, and a relatively short time in commerce, are all factors associated with an increased likelihood that pests can survive transport and be introduced into new environments.

The second type of evidence deals with movement of pests in dWPM. There are no surveys or significant records of pests in dWPM. Records of overseas interceptions of wood pests in WPM originating from the United States (Appendix 1) and limited domestic interceptions both provide evidence that pests may move in dWPM. However, we do not know the quantity of infested wood, the consistency of the pathway, and the mechanisms required to transfer pests in infested wood to hosts in the environment.

Finally, we do not know whether dWPM has ever been associated with or directly implicated in the dispersal and establishment of a domestic pest (whether native or an established exotic), although there are numerous cases of exotic pests becoming established in discontinuous states or of indigenous pests becoming established far from their native ranges (outlined in Tables 1 and 2, and in Appendix 2). While many forest pests may be associated with wood packaging materials (WPM), their rapid dispersal may result from many causes, including historically incomplete surveys, historically incorrect identification, multiple international introductions, movement of propagative material, or movement of other wood materials, such as logs or Christmas trees. For this analysis, we assume parsimony; while direct evidence may be lacking, a reasonable assessment of risk is possible from available information.

The direct way to reduce these uncertainties would be a survey of the pests present in dWPM. If such a survey or surveys were conducted, risk would need to be reassessed to reflect new data.

Objectives

We initiated this risk assessment to determine if there are sufficient risks to warrant regulation of WPM in domestic commerce.

The specific objectives of this risk assessment are to:

- describe the characteristics of dWPM as a potential pathway for the spread of wood pests.

- assess the potential for movement and establishment of wood pests that may be transported in dWPM.
- estimate the potential economic and environmental impact of these pests on forests and trees, including in the urban environment.

Scope

We evaluate the risk associated with the movement of wood pests in domestically produced or refurbished dWPM within the United States. Wood packaging material is composed of wood from many hardwood and softwood species, and numerous pests occur on these hosts. A comprehensive list of all wood pests that may be associated with dWPM is outside the scope of this assessment, but we have identified key representative species of wood pests to illustrate movement, establishment, and potential impacts. Hitchhiking pests (e.g., gypsy moth, snails, weeds), while capable of being moved on WPM and of significant concern, are not considered explicitly but are discussed within the context of potential mitigations and conclusions.

We do not focus on the potential for new pests to become introduced from other countries into the United States on noncompliant WPM. ISPM 15 has been adopted to mitigate such risks. Although we recognize that infested WPM from foreign sources may enter the domestic supply chain, risks associated with this type of wood are outside the scope of this assessment.

dWPM as a potential pathway for the spread of wood pests

Pallet Industry

The domestic pallet and wood container market is a $7 billion industry consisting of over 3,000 companies and employing over 50,000 individuals (Lefco, 2010). In the United States, 1.9 to 2.0 billion pallets are in use every day (White, 2004). Wood packaging material is usually produced from low-grade wood, often with bark and portions of the vascular cambium remaining (Clarke et al., 2001). Although the majority of raw materials used to produce pallets comes from domestic sources, an estimated 8.7% comes from imported wood (Sanchez, 2010). United States pallet manufacturers have historically used Canadian lumber and more recently have begun using pallet stock from softwoods (e.g., Southern yellow pines[1] and radiata pine) and hardwoods from South America (e.g., *Eucalyptus grandis*) (Brindley, 2004).

Pallets are ubiquitous in domestic commerce and are constantly being moved from region to region. Damaged or otherwise unusable pallets are disassembled, and the parts are then re-used to build or repair pallets (Bush et al., 2002). Because WPM is routinely re-used and re-conditioned, the origin of the WPM is rarely the same as the origin of the commodity with which it is moving. Many tree species are used for WPM (Table 1), each of which is associated with a variety of wood pests. New pallet production is the primary source of revenue within the industry, with an estimated 441 million new pallets produced annually (Bush and Araman, 2009a). Recovered, repaired, and/or remanufactured pallets provide a significant although smaller source of revenue and many within the industry are involved in pallet recovery, repair,

[1] Southern yellow pines include loblolly (*Pinus taeda*), shortleaf (*P. echinata*), longleaf (*P. palustris*), and slash (*P. elliottii*) pines.

and/or remanufacturing (Bush and Araman, 2009b). In general, recycling used pallets has become a low-cost alternative to producing new pallets (Lefco, 2010).

Table 1. U.S. wood pallet and container manufacturing industry use of lumber, cants, and parts by species or species group and region: 2006.

Species or Species Group	Use by species (% of total reported volume)			
	West	**Midwest**	**Northeast**	**South**
Oak	8.9	19.7	8.8	35.0
Maple	0.0	6.1	11.9	2.7
Mixed hardwoods (no species separation)	6.3	59.3	55.9	40.8
Other North American hardwood species	23.7	3.1	5.9	2.5
Spruce/Pine/Fir Species Group	13.2	6.9	3.5	3.2
Douglas-fir	19.2	0.2	0.0	0.0
Southern Pine Species Group	0.5	3.2	4.8	15.4
Other North American softwood species	28.2	0.5	0.3	0.3
Species imported from outside North America	0.0	1.1	9.0	0.1

Pooled pallets

A significant number of wood pallets in the United States are part of closed-loop systems, where the pallets are rented out by a pallet renting company to various manufacturers then returned for reuse by other manufacturers in the pallet "pool". The two primary wood pooled pallet companies in the United States, CHEP and PECO, issue approximately 262 million and 10 million pallets per year, respectively. These companies use dedicated sawmills, pallet manufacturing facilities, and wood that has been kiln-dried (CHEP) or heat-treated (PECO) prior to pallet assembly. Prior to the pallets being returned for use in the pool they must pass through a repair facility for inspection and repair. The lifecycle of a pallet in the pooled pallet industry can be indefinitely extended with repair and maintenance; however, pallet loss is more common than removal due to wear. All wood used in pallet repair has also been kiln-dried at the supplying sawmills.

Practices followed by these pooled pallet companies will greatly reduce or eliminate organisms associated with dWPM. In particular, the use of kiln-dried wood, which should eliminate many wood pests, and the rapid repair of pallets, which takes infested wood out of circulation, could lower the pest risks associated with pooled pallets compared to white wood pallets.

White wood pallets

The majority of wood pallets (80%) utilized in the United States are part of the “white wood” pallet industry, where roughly equal numbers of new and recycled pallets are sold to industries that need to store or ship their products. The white wood pallet industry is comprised of roughly 3000 manufacturers and recyclers that are widely distributed through the country. The pallet manufacturers obtain timber or cut lumber resources typically within 150 miles of their location and sell pallets on a regional basis due to cost of material transportation (Borchert, 2008a, 2008b). Although pallets are made from different types of wood depending on availability and customer demands, green hardwood lumber was almost exclusively used (95%) at two white wood manufacturing facilities visited. Unlike pooled pallets, which are rented and have distinct ownership, the original purchaser of white wood pallets passes the ownership of pallets with their goods. Empty pallets may be exchanged for loaded pallets or collected at endpoints in consumer supply chains to be reused or recycled as needed. White wood pallet recycling has increased in prevalence and utilization in the supply chain as manufacturers and retailers do not exchange pallets frequently or inspect and repair pallets. The use of recycled or repaired pallets has increased more rapidly than the production of white wood pallets as the consumers are estimated to prefer either lower cost recycled pallets or pooled pallet options instead of higher cost white wood pallets. Pallet recycling or remanufacturing often occurs in conjunction with manufacturing of new pallets with estimates of 85% occurrence.

The white wood pallet industry performs ISPM 15 treatments on a regular basis for customers who require pallets that can be shipped internationally, with around 30% of the pallets produced being treated based on information obtained from site visits.

Based on available information, we believe two main factors associated with white wood pallets increase the risk of associated pest movement when compared to pooled pallets. First, the use of green hardwood materials in the assembly and recycling/repair of white wood pallets increases the risk, because green wood is a more suitable habitat than dried wood for many wood pests. Second, the large volume of new and recycled white wood pallets (a majority of the total pallets in use) in circulation suggests that there is a larger opportunity for pests to move with white wood pallets than with pooled pallets. These combined factors suggest white wood pallets represent both a higher pest risk than pooled pallets and a more difficult-to-manage situation.

Dunnage, crating, and other forms of dWPM

Dunnage and crating materials are often created locally and are not tracked by an industry group or agency. While there are differences between pallets and dunnage, these types of dWPM are similar in that both are loaded and unloaded with cargo. After being unloaded, they must be disposed of or reused in some capacity. However, the low quality of wood used for these functions, especially dunnage, reduces the likelihood that this type of dWPM is recycled. The quantity of these wood materials is unknown but some products, such as cold rolled steel, require sizable quantities of dunnage to prevent shifting and damage while en route.

Pests that may be associated with dWPM

Insect pest interceptions associated with domestically-produced WPM

There are few interception records for dWPM. Interception records from Australia and New Zealand provide some evidence of timber pests associated with WPM originating in the United States (Appendix 1). Significant timber pests intercepted in both countries fall within the orders Coleoptera and Hymenoptera and include bark and ambrosia beetles as well as wood-boring insects from the families Buprestidae, Cerambycidae, Curculionidae (subfamily Scolytinae), and Siricidae.

Surveys and establishments of forest pests known to move on WPM

Researchers in the Pacific Northwest conducted surveys of non-indigenous wood-boring and wood-associated insects in Washington and Oregon over a three-year period (LaBonte et al., 2005). Traps were placed at high-risk sites, including warehouses and businesses importing commodities with WPM, mills importing raw wood products, wood recyclers, port and industrial areas, and urban forests. The collection of many species native to or established in the eastern United States (Table 2) suggests that pest movement on dWPM is common. All of these organisms, either at the species or genus level, are known to move internationally on WPM.

Table 2. Non-indigenous wood-boring beetles established in eastern North America, newly recorded in Oregon and Washington.

Species	Distribution	Intercepted in WPM? What pathway?
Phymatodes testaceus	Europe, North Africa, eastern North America (west to MN and IA)	yes – crating, dunnage, pallets, nonspecific
Xylotrechus sagittatus sagittatus	Native to eastern North America from eastern Canada south to FL and west to NM	Genus level
Monarthrum fasciatum	Native to eastern North America, west to TX, WI and Ontario	Genus level – pallets
Xylosandrus crassiusculus	Exotic; established in eastern USA: SC, FL, GA, LA, MS, NC, TN, TX	yes – crating, pallets
Xylosandrus germanus	Exotic; established in eastern North America	yes – dunnage, also pallets and containers
Gnathotrichus materiarius	Indigenous to eastern North America	yes – nonspecific
Hylastes opacus	Exotic; established in eastern North America	yes – dunnage, pallets, wire (spools)
Xyleborus californicus	Exotic; established in eastern North America	Genus level – pallets, crating, dunnage, nonspecified
Xyleborus xylographus	Indigenous to the Antilles and eastern North America from Ontario to the Gulf Coast	Genus level; species intercepted on ‘wood’

(Source: LaBonte et al., 2005)

Aukema et al. (2010) compiled a list of 455 non-indigenous forest pests with at least one recorded location of establishment in the continental United States. These insects represent 64 families and eight orders. Phloem- and wood-borers comprised 15.4% of established pests (70 of 455, Appendix 2) and represented a number of families within three orders: Coleoptera, Hymenoptera, and Lepidoptera. Most (63 pests, or 90%) were beetles and of these 42 (67%) were bark or ambrosia beetles. Fifteen (21.4%) of the 70 established phloem- and wood-borers are considered to be high impact pests. All are known to be associated with WPM (based on U.S. border interceptions).

There are few port interception records of pathogens with wood or wood products due to the difficulty of visually detecting them as well as the time and expertise required for making accurate and timely identifications (Rogers, 2008; USDA, 2000). One aspect of this group is their association with insects as vectors (Wingfield, 1993). For example, Scolytinae beetles are commonly reported as vectors; however, other beetles in the families Cerambycidae and Buprestidae as well as some mites and moths vector ophiostomatoid fungi (Malloch and Blackwell, 1993). With regard to dWPM, pathogens may be in packing material, in vectors associated with packing material, or both. Examples of forest pathogens with the potential to move on unmitigated dWPM are outlined in Table 3.

Table 3. Examples of forest pathogens with potential to move on unmitigated dWPM.

Pathogens			
Class: Ascomycetes			
Order: Helotiales	**Origin**	**Host genera**	**Pathways for movement**
Gremmeniella abietina var. *abietina* (anamorph: *Brunchorstia pinea*) / scleroderris canker	exotic; (established in eastern U.S.)	Conifers: *Pinus, Picea, Larix, Pseudotsuga, Abies, Tsuga*	Trunk cankers can form on bark—infests and remains latent in host tissues—difficult to detect
Order: Hypocreales			
Fusarium circinatum / pitch canker	native (east)	Conifers: *Pinus, Pseudotsuga*	Vectored by beetles *Pityophthorus, Conophthorus, Ernobius, Ips, Pissodes*; can survive in cut wood for 1+ years
Geosmithia morbida / thousand cankers disease	origin unknown (west)	Hardwoods: *Juglans*	Vectored by bark beetle (*P. juglandis*); likely to be moved in raw wood products
Neonectria faginata / beech bark disease	exotic (found in eastern U.S.)	Hardwoods: *Fagus*	Fungus infects the inner bark of the host into the sapwood, gains access from feeding by the introduced beech scale (*Cryptococcus fagisuga*)
Order: Microascales			
Ceratocystis fagacearum / oak wilt	native? (east)	Hardwoods: *Quercus*	Vectored by sap beetles (Nitiluidae) and occasionally by bark beetles (*Pseudopityophthorus*)
Order: Ophiostomatales			
Leptographium wageneri / black stain root disease	native (west)	Conifers: *Pinus, Pseudotsuga, Abies, Larix, Picea, Tsuga*	Vectored by root feeding beetles (*Dendroctonus, Hylastes, Hylurgops, Ips, Pissodes, Steremnius*); vectors are associated with raw wood
Raffaelea lauricola / laurel wilt disease	exotic (in SE U.S.)	Hardwoods: (Lauraceae)--*Persea, Sassafras, Lindera, Litsaea, Phoebe, Cinnamomum;* (Dipterocarparceae)--*Shorea*; (Fabaceae)--*Leucaena*	Vectored by ambrosia beetle (*X. glabratus*); thought to have been introduced with the vector in WPM
Class: Basidiomycetes			
Order: Russulales			
Heterobasidion annosum / annosum root rot/butt rot	native (east & west)	Conifers: *Pinus, Picea, Pseudotsuga, Tsuga*	Vectored by pine weevil (*Hylobius*); can survive in dead wood for long periods of time

Potential for the movement and establishment of pests transported in dWPM

Many species of bark beetles and wood borers are attracted to recently cut wood and low grade trees, and such low grade trees are frequently used in dWPM applications due to lack of suitability for other applications. The likelihood of an organism becoming established in a new location may increase in relation to the number of individuals imported at a given time or with repeated introductions. Regions with the greatest risk of pest entry are those with high levels of human mobility and trade; therefore, urban areas are more at risk than isolated forests for introduction of exotic forest pests (Liebhold et al., 1995). Skarpass and Økland (2009) observed that timber and other similar WPM storage areas are particularly important points for introduction of pests, as large amounts of material may be stored for long enough for lifecycle completion and local dispersal.

Large volumes of dWPM are moved intermediate and long distances into metropolitan areas, regional or national retail distribution chains, and small communities. The dispersal pathway that most accurately depicts the intermediate and long-distance movement of dWPM is a modified corridor/cultivation pathway (Wilson et al., 2009). The extensive interstate highway and railway transportation system in the United States provides artificial corridors that connect suitable habitat forms facilitating the movement of dWPM.

Resources at risk

United States forests

Approximately 751 million acres (33%) of the United States land area is forest land, with roughly equal amounts found east and west of the central plains. The total forested land area has remained relatively unchanged over the last 100 years. There are 77 million acres (10%) protected from commercial timber harvest in wilderness areas, parks, and other reserved areas. The main forest types are illustrated in Figure 1.

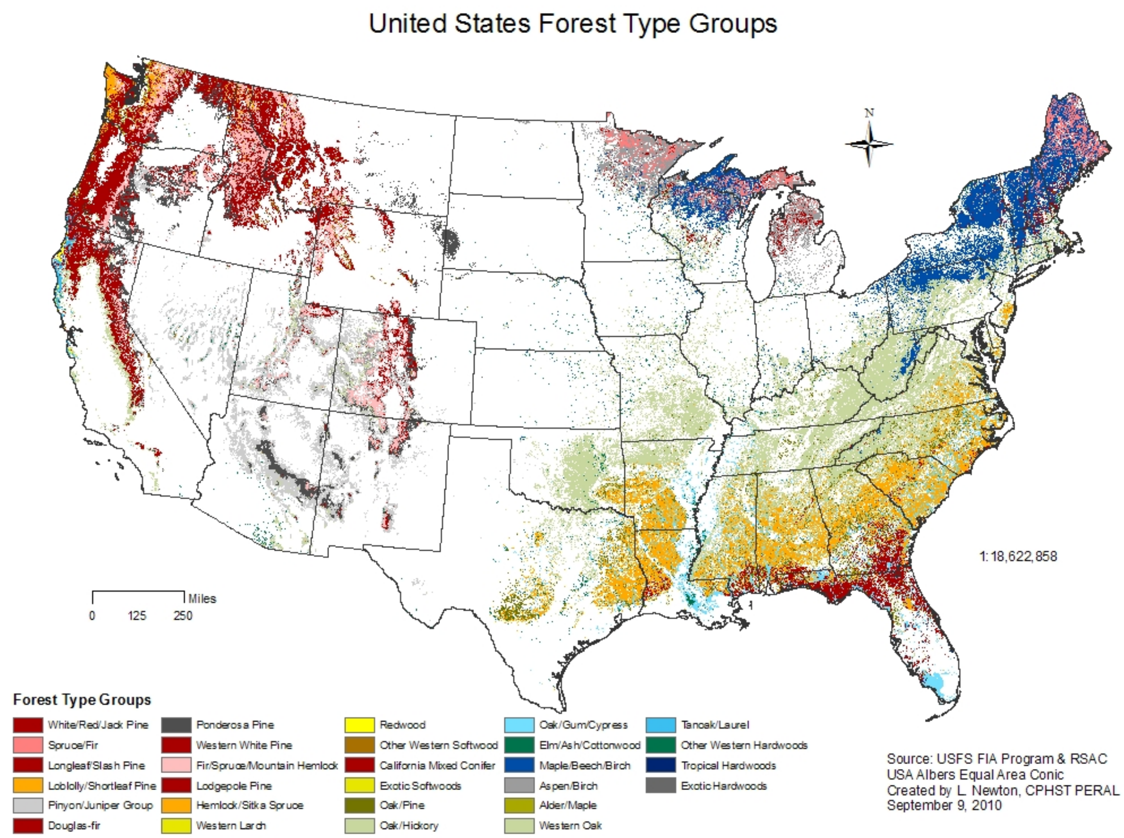

Figure 1. United States forest type groups.

Urban forests

From 1990 to 2000, the urban area of the conterminous United States has increased from 2.5 to 3.1% of the total land volume, an area roughly the size of Vermont and New Hampshire combined. Urban expansion during this period was greatest in forested areas (33.4%), resulting in increased urban-forest interface and the associated potential risks of fire, exotic pest infestation and forest fragmentation (Smith, 2009). Urban areas are predicted to expand up to 8% of the United States by 2050, or roughly the size of Montana, dramatically increasing the urban forest interface (Nowak and Walton, 2005). The close proximity of forests and stored wood products, such as timber, firewood, and pallets can result in an increased likelihood in pest introduction and establishment.

Several factors increase the susceptibility of urban forests to invasion by pest species. Urban forests are located in regions of greater human mobility and trade than non-urban forests (Liebhold et al., 1995). A study on urban forests and levels of herbivory found small forest sites had greater levels of damage than interior forest sites (Christie and Hochuli, 2005). Cregg and Dix (2001) found that urban trees can experience increased moisture stress, heat, or soil compaction that can increase the chance for insect infestation, with hardwood trees more affected than conifers.

The susceptibility and importance of introduction and establishment by forest pests in urban areas can be dramatically magnified by the high costs of management after pest detection. Tree removal, replacement, or treatment can be extremely expensive in public areas, but necessary due to liability issues. Kovacs et al. (2009) estimated the potential costs of emerald ash borer in United States communities from 2009-2019 to be $10.7 billion, with tree removal and replacement or treatment costs calculated over 25 states and 17 million ash trees replaced. The economic costs for Asian longhorned beetle in urban areas over the next 30 to 50 years are estimated as a cumulative non-discounted replacement cost of $669 billion for the entire United States. The discounted cumulative replacement costs for nine selected cities were $1.7 billion (APHIS, 2007).

Economics of forest products and regulatory costs

The forest products industry of the United States is commonly divided into two groups, paper and lumber, with both groups using large amounts of U.S. forest resources. In 2006, the forest products industry harvested 21 billion ft^3 of hardwood and softwood timber with 50% used in construction and building materials and 30% used in pulp and paper (Smith, 2009). The United States is the world production leader in lumber and wood products for residential construction, furniture, and pulp and paper. In 2002, over 50,000 forest product facilities in the United States employed nearly 1.2 million people and produced shipments valued at $405.5 billion (U.S. Census Bureau, 2002).

The average cost of Federal forest pest regulatory programs in the United States by USDA-APHIS-PPQ from 2004 to 2008 was approximately $279 million (Lewis, 2008). In addition, there are regulatory programs and costs for management of forest pests borne by state departments of agriculture. The high cost of regulatory response combined with the difficulty of forest pest eradication (Moore, 2005) emphasizes the need to prevent the spread of forest pest species to new areas.

Treatments for WPM

A variety of methods have been proposed by exporters or government regulatory agencies to reduce the risk of invasive pests in WPM (Table 4, detailed in Appendix 3). Those methods range from intensive inspection programs, through various kinds of controls (e.g., fumigation, heat treatment, and irradiation), to the use of substitute packing materials (prohibition of WPM). Many of those methods are more efficacious against one type of organism than another, and no single method (with the exception of substitute packing materials, if hitchhiking pests are not included) can eliminate the risk from all types of invasive pests. Some of the materials available for control, such as methyl bromide used in fumigations, are believed to be associated with environmental degradation, and their use is diminishing (USDA MRP 2003).

Table 4. Treatment alternatives and their component methods.

Alternatives	Inspection	Heat treatment	Fumigants	Wood preservatives	Irradiation	Controlled atmosphere	Substitute packing materials	Disposal
1. No Action	•	•[1]	•[1]	•[1]				
2. Extension of China Interim Rule	•	•	•	•				
3. Adoption of IPPC Guidelines	•	•	•					
4. Comprehensive Risk Reduction	•	•	•	•	•	•	•	•
5. Substitute Packing Materials Only	•						•	

[1] For China and Hong Kong only. (Source: USDA MRP, 2003)

The adoption of ISPM 15 allowed for an internationally harmonized approach to WPM. The International Plant Protection Convention (IPPC) guidelines provide that WPM imported from all countries to the United States would be required to be heat treated (to a minimum wood core temperature of 56°C for a minimum of 30 minutes) or fumigated with methyl bromide (treatment schedule per the IPPC guidelines), and then marked to show that it has been treated.

Heat treatments have proven to be highly effective for subcortical insects and pathogens. The ISPM 15 approved treatment of 56°C for 30 minutes appears to control most wood pests (Graham, 1924; Mushrow et al., 2004; Myers and Bailey, 2010; USDA-APHIS, 2008). However, this treatment is not always effective at treating all life stages (particularly prepupae) of the emerald ash borer (*Agrilus planipennis*, Coleoptera: Buprestidae) (Goebel et al., 2010; McCullough et al., 2007; Myers et al., 2009; Nzokou et al., 2008). Recent research has shown that a heat treatment of 60°C for 60 minutes is the recommended minimum treatment for preventing the spread of emerald ash borer in wood products (Myers et al., 2009).

Heat treatments are also effective for controlling wood pathogens. Fungi are killed more rapidly when wood is at a high moisture content and, although many pathogens are killed by the 56°C for 30 minute treatment, higher temperatures are often required for heartwood fungi and some species of sap-rot and blue stain fungi (Ramsfield et al., 2010; Uzunovic and Khadempour, 2007). Heat treatments can be accomplished through steam treatments, hot water baths, microwave irradiation, or kiln-drying. Kiln-drying, especially at conventional kiln schedules, is a very effective way to sterilize wood, and kiln-dried wood (moisture content < 20%) is generally accepted by trading partners as requiring no further treatment (Hosking, 2007).

Heat-treating green wood may lead to the development of surface molds, so heat treatments in combination with additional kiln-drying are an effective way to meet phytosanitary requirements and minimize the growth of surface molds (Hamner, 2007).

Fumigation provides effective control, but many of the compounds (e.g., methyl bromide, phosphine, carbonyl sulfide) are highly toxic to workers, leave dangerous residues, and, particularly in the case of methyl bromide, contribute to the depletion of the ozone layer (Butler, 1995; Serca et al., 1998). Sulfuryl fluoride may provide an effective alternative to methyl bromide (Vermeulen and Kool, 2006), although it does not appear to be as effective in controlling the egg stage of many insect species (USDA-APHIS, 2003). A patented new fumigant, Ethanedinitrile (cyanogen), appears to be promising as a quarantine treatment for timber (O'Brien et al., 1999; Viljoen and Ren, 2001; Wright et al., 2002).

Irradiation treatments include gamma radiation, microwaves, and radio frequency treatments, all of which have been shown to eliminate pests in wood (Csupor et al., 2000; Fleming et al., 2004; Henin et al., 2008; Kundstadt, 1998; Tubajika et al., 2007). With gamma radiation, insects, if not killed, may be sterilized and incapable of breeding. They would, however, still be able to vector pathogens and nematodes. Microwave treatments are effective, but increased moisture content requires increased exposure time to reach desired internal temperatures. Radio frequency has been proven to destroy decay and sap-stain fungi in wood.

Controlled atmosphere treatments are effective but require very long periods (about nine days), so they may be inefficient for large quantities of WPM (Vermeulen and Kool, 2006). Vacuum technology shows promise for treatment of pallet components, killing pests by removing moisture from their bodies (Brindley, 2005). Although the vacuum removes enough moisture to kill the pest, it does not significantly remove moisture from the wood or cause any noticeable lumber degradation. Additionally, the process appears to be environmentally benign because it involves little use of energy and avoids the release of toxic and ozone-damaging gases into the atmosphere (Chen et al., 2006).

Substitute packaging materials include plywood, oriented strand board, particle board, corrugated paperboard, plastics, resin composites, metal, rubber, and fiberglass. Any of these materials would likely reduce the risks associated with the movement of wood pests in wood to almost zero but would have little effect on hitchhiking pests.

Reinfestation of treated wood

Wood treatment, whether by heat or chemicals, is intended to kill organisms currently within the wood, but treated wood can be reinfested (Evans, 2007; Haack and Petrice, 2009). Interception of pests on ISPM 15 treated wood may be an indication of reinfestation, although pest presence could also be from pest insusceptibility to the treatment, false treatment (untreated wood is marked as treated), or untreated wood was used to refurbish a pallet/crate. Haack and Petrice (2009) heat-treated wood from trees in good health to ISPM 15 specifications, left the wood exposed in a Michigan forest, and then sampled the wood for pests. A variety of Cerambycidae and Scolytinae beetles were able to infest and develop in the treated wood (Appendix 4). Some of the beetles they found are important wood pests that attack a wide range of economically important hosts or vector fungi/nematodes that further contribute to tree decline (see Appendix 4 for details). A study by the International Forestry Quarantine Research Group (IFQRG) in the United Kingdom also found heat-treated wood is suitable for colonization by a range of bark beetles [e.g., *Tomicus piniperda* (Linnaeus), *Hylurgops pallidatus* (Gyllenhal), *Orthotomicus* *laricis* (Fabricius), *Hylastes* sp., and *Ips sexdentatus* (Boerner)] (Evans, 2007). In both of these studies greater numbers of some beetle species were found on the heat-treated wood than on the untreated wood.

Factors for reinfestation of treated wood depend on variables such as moisture content and presence of bark (Allen 1995; Evans, 2007; Haack and Petrice, 2009). For ambrosia beetles, the wood needs to be beyond the fiber saturation point (> 30%) for the beetles to be able to successfully attack and colonize (Allen, 1995). Regarding presence and size of bark on treated wood, Haack and Petrice (2009) found that Cerambycidae and bark beetles readily infested heat-treated logs with bark intact as well as heat-treated lumber with residual bark patches. Exit holes of Cerambycidae were only found in heat-treated lumber with bark patches of 1,000 cm^2, while exit holes from Scolytinae bark beetles were found on bark patches as small as 250 or 100 cm^2 (Haack and Petrice, 2009).

Based on these studies, reinfestation is a possibility with treated wood, particularly if large pieces of residual bark are present and wood is stored in areas of high moisture.

Mitigation Strategy

The presence of some indefinable risk in dWPM suggests that a mix of systems approach strategies may be beneficial. Heat and chemical treatments, regardless of their exact schedule, are single-point treatments and mitigate pests that are present in the wood at the time of treatment. They do not prevent reinfestation or control pests that may have used the wood prior to treatment. These types of treatments may be most beneficial for wood that has a limited commercial lifetime, such as dunnage, or wood that has limited interaction with the environment after treatment (Appendix 5). Various levels of debarking, from debarked wood to bark free, can reduce or largely eliminate the habitat for many wood pests (Haack and Petrice, 2009). However, this can come at a significant increase in material costs (White, 2004). A systems approach or a push-pull strategy (described in Appendix 3) may be beneficial for long-term control, but it may not deliver the complete pest elimination possible with certain other treatments. These treatments are not mutually exclusive and may be combined to provide the most control for the least cost. A detailed description of treatment strategies, including type, site, and potential efficacy, is in Appendix 3.

Conclusions

We do not know whether dWPM has ever been directly implicated in the dispersal and establishment of a domestic pest. However, we have demonstrated that dWPM material provides a suitable habitat for many pests and that pests are known to move in WPM. While direct evidence may be lacking, parsimony suggests that wood pests move in dWPM and expand their distributions through this movement. As such, unregulated movement of dWPM represents a risk to a variety of valuable resources.

Relatively higher risks are associated with dWPM containing untreated wood, wood with bark, and crafted from infested trees. Pooled pallets appear to pose less of a risk than white-wood pallets, primarily because pooled pallets use kiln-dried materials and are meant to be used multiple times. In comparison, white-wood pallets, which constitute the majority of new and recycled pallets, often use green hardwood and are designed for short-term uses. Additionally, pooled pallets stay within a system of usage and are repaired with kiln-dried materials, while white-wood pallets are used as determined by individual owners and can be shipped to any location and are repaired/recycled with green wood. Dunnage is the most likely type of dWPM to be untreated and to contain bark, which increases its associative risks.

Despite its potential to transport pests, dWPM does not easily lend itself to regulation because the wood packaging industry is fragmented and of variable composition due to the large volume of dWPM. Domestic WPM is difficult to permanently track and it may become reinfested after treatment. In addition, the inability to distinguish between various potentially regulated (i.e., dWPM) pathways and non-regulated pathways (raw logs, railroad ties, etc.) creates confounding issues for regulation. For these reasons, development and implementation of efficacious regulatory oversight may not be feasible for dWPM. However, a variety of risk reduction mitigations could be applied on a voluntary or focused regulatory basis.

Future research may resolve some of the uncertainties associated with specific risks posed by movement of dWPM. Surveys of dWPM could provide information about the quantity, types, and circumstances surrounding pests in dWPM. Studies to determine how and when pests enter wood and their ability to survive processing are also important. Finally, data that describes how long pests can survive in all forms of wood packaging material (pallets, crating, dunnage, spools, drums, etc.) and under what conditions pests leave WPM would identify circumstances that are more amenable to pest introduction and establishment. Results from these types of research efforts would help determine, as precisely as possible, the true nature of the problem while informing potential mitigation strategies.

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Appendices

Appendix 1. Interceptions of timber pests in Australia and New Zealand (1948-2003) on WPM from the United States[1]

Country	Order: Family	Species	Origin / Mode of Entry / No. interceptions, if known	Source[1]
AUSTRALIA				
	Coleoptera: Bostrichidae	*Heterobostrychus aequalis*	USA / nonspecified WPM / 2	(3)
		Lyctus brunneus	USA / nonspecified WPM / 2	(3)
		Lyctus planicollis	USA / nonspecified WPM / 1	(3)
		Lyctus sp.	USA / nonspecified WPM / 7	(3)
		Minthea rugicollis	USA / nonspecified WPM / 1	(3)
		Sinoxylon anale	USA / nonspecified WPM / 3	(3)
		Xinoxylon conigerum	USA / nonspecified WPM / 3	(3)
		Xylothrips religiosus	USA / nonspecified WPM / 1	(3)
	Coleoptera: Buprestidae	No species listed	USA / nonspecified WPM / 1	(3)
	Coleoptera: Cerambycidae	*Arhopalus rusticus*	USA / nonspecified WPM / 1	(3)
		Cerambycinae (no species listed)	USA / nonspecified WPM / 1	(3)
		Monochamus sp.	USA / nonspecified WPM / 1	(3)
		Palaeocallidium rufipenne	USA / nonspecified WPM / 1	(3)
		Xylotrechus sp.	USA / nonspecified WPM / 1	(3)
	Coleoptera: Curculionidae: Scolytinae	*Gnathotrichus retusus*	USA / nonspecified WPM / 1	(3)
		Gnathotrichus sp.	USA / nonspecified WPM / 1	(3)
		Ipini (tribe)	USA / nonspecified WPM / 1	(3)
		Ips grandicollis	Eastern USA / machine crates	(1)
		Scolytinae (no species listed)	USA / nonspecified WPM / 5	
		Pseudohylesinus nebulosus	USA / nonspecified WPM / 1	(3)
		Xyleborus celsus	USA / nonspecified WPM / 1	(3)
	Hymenoptera: Siricidae	*Sirex juvencus*	USA / nonspecified WPM / 1	(3)
		Sirex noctilio	USA / nonspecified WPM / 1	(3)
		Urocerus augur	USA / nonspecified WPM / 1	(3)
NEW ZEALAND				
	Coleoptera: Curculionidae: Scolytinae	*Carphoborus ponderosae*	USA / pine pallets; pine & unspecified casewood & pallets / 3	(1 & 2)
		Crypturgus borealis	USA, North America / spruce dunnage & sawn timber / 2	(1 & 2)
		Dendroctonus ponderosae	USA / pine casewood & dunnage / 3	(2)
		Dendroctonus rufipennis	North America / spruce casewood & sawn timber / 2	(2)
		Dryocoetes affaber	USA / spruce casewood & dunnage	(1 & 2)
		Dryocoetes americanus	USA/Spruce dunnage	(1)
		Dryocoetes autographus	USA, North America / spruce, pine, and unspecified casewood & dunnage / multiple	(2)
		Gnathotrichus materiarius	USA, North America / pine & Douglas-fir dunnage and casework / 5	(1 & 2)
		Gnathotrichus retusus	USA, North America / pine and Douglas-fir pallets, casewood & sawn timber / 5	(1 & 2)
		Gnathotrichus sulcatus	North America / Douglas-fir, cedar, and hemlock cable drums, casewood, pallets,	(2)

			poles & sawn timber / 10	
		Hylastes nigrinus	USA / Douglas-fir dunnage & sawn timber / 2	(2)
		Hylurgops rugipennis	North America / pine casewood / 1	(2)
		Ips avulsus	North America / pine casewood / 2	(2)
		Ips borealis	North America / 1 spruce dunnage / 1	(2)
		Ips calligraphus	North America / pine casewood & dunnage / 11	(2)
		Ips grandicollis	North America / pine dunnage & pallets / multiple	(2)
		Ips pini	North America / pine casewood & dunnage / 6	(2)
		Orthotomicus caelatus	North America / spruce & pine dunnage, pallets, sawn timber & stanchions / 7	(2)
		Phloeosinus pini	USA / spruce dunnage / 1	(1 & 2)
		Pityogenes hopkinsi	North America / pine casewood & dunnage / 3	(2)
		Pityokteines sparsus	USA / unspecified softwood dunnage / 2	(1 & 2)
		Polygraphus rufipennis	North America / fir, spruce & pine casewood, dunnage & pallets / 22	(2)
		Pseudohylasinus nebulosus	USA / unspecified dunnage / 1	(1)
		Pseudopityophorus minutissimus	USA / Oak dunnage	(1)
		Scolytus multistriatu s[2]	North America / elm casewood, dunnage, pallets & sawn timber / multiple	(2)
		Trypodendron lineatum	USA, North America / spruce, pine, Douglas-fir, and cedar cable drums, casewood, dunnage, pallets & sawn timber / multiple	(2)
		Trypodendron rufitarsus	USA / spruce dunnage / 1	(1 & 2)
		Xyleborus inermis	Eastern USA/Pine pallets overlaying hardwood dunnage	(1)
		Xyleborus rileyi	USA/Pine casewood	(1)
		Xyleborinus saxesenii [2]	USA / hardwood & softwood casewood, dunnage & sawn timber / multiple	(2)
		Xyleborus affinis	USA / pine dunnage, pallets & sawn timber / mutltiple	(2)
		Xyleborus intrusus	USA / Douglas-fir dunnage / 1	(2)
		Xyleborus volvulua	USA / pine casewood / 1	(2)
		Xyloterinus politus	North America / oak dunnage & pallets / 3	(2)

[1]This list was derived from the following sources:
(1) Marchant and Borden (1976): Study conducted by the Canadian Forest Service of worldwide introductions and establishment of bark and timber beetles (Coleoptera: Curculionidae: Scolytinae). The report included interception summary data from 1948-1965 and 1965-1971 but did not include frequency of interceptions.
(2) Brockerhoff et al. (2003): Study of interceptions of exotic bark and ambrosia beetles intercepted on WPM in New Zealand between 1952 and 2000.
(3): Interception data shared by the Australian government. Data were collected between 1986 and 2003.
[2]*Scolytus multistriatus* and *Xyleborinus saxesenii* are exotic and now established in the United States; *S. multistriatus* is now in 48 states and *X. saxesenii* has been collected in 35 states (Rabaglia 2010, pers. comm.).

Appendix 2. Nonindigenous forest pests established in the continental United States

Order	Family	Species (Common name)	Date	Host breadth	High Impact	Intercepted on WPM
COLEOPTERA						
	Anobiidae	*Ernobius mollis* (pine bark anobiid)	1899	Polyphagous		yes
	Buprestidae	*Agrilus cyanescens*	1920	Polyphagous		Genus level
		Agrilus pilosivittatus		Monophagous		Genus level
		Agrilus planipennis (emerald ash borer)	2002	Monophagous	x	Genus level
		Agrilus prionurus (soapberry borer)	2003	Monophagous	x	Genus level
		Agrilus sinuatus		Oligophagous		Genus level
		Agrilus sulcicollis	2003	Monophagous		yes
	Cerambycidae	*Anoplophora glabripennis* (Asian longhorned beetle)	1996	Polyphagous	x	yes
		Callidellum rufipenne (Japanese cedar longhorned beetle)	1954	Oligophagous	x	yes
		Callidium violaeum (violet tanbark beetle)	1907	Polyphagous		yes
		Chlorophorus annularis		Monophagous		yes
		Hylotrupes bajulus (old house borer)	1850	Oligophagous		yes
		Phoracantha recurva (eucalyptus borer)	1995	Monophagous	x	yes
		Phoracantha semipunctata (eucalyptus longhorned borer)	1985	Monophagous		yes
		Phymatodes lividus		Polyphagous		---
		Phymatodes testaceus (tanbark borer)	1903	Monophagous		yes
		Saperda populnea (poplar longhorn beetle)		Monophagous		Genus level
		Sybra alternans	1992	Monophagous		---
		Tetropium castaneum (black spruce beetle)	2001	Oligophagous		yes
		Tetrops praeusta	1996	Oligophagous		---
	Curculionidae	*Cryptorhynchus lapathi* (poplar and willow borer)	1882	Polyphagous	x	Genus level
	Curculionidae: Scolytinae	*Ambrosiodmus lewisi* (ambrosia beetle)	1990	Polyphagous		---
		Ambrosiodmus (Xyleborus) pelliculosus (ambrosia beetle)	1987	Polyphagous		---
		Coccotrypes cyperi (ambrosia beetle)	1934	Polyphagous		Genus level
		Dryoxylon onoharaensum (ambrosia beetle)	1977			---
		Euwallacea fornicatus (ambrosia beetle)	2002			---
		Euwallacea (Xyleborus) validus (ambrosia beetle)		Polyphagous		yes
		Hypocryphalus mangiferae (ambrosia beetle)	1949	Monophagous		Genus level
		Hypothenemus javanus	1975	Polyphagous		Genus level

		(ambrosia beetle)				
		Monarthrum mali (ambrosia beetle)	1906	Polyphagous		Genus level
		Trypodendron domesticum (European hardwood ambrosia beetle)	1997	Polyphagous		yes
		Xyleborinus alni	1995	Polyphagous		Genus level
		Xyleborinus saxesenii (Asian ambrosia beetle)	1915	Polyphagous		yes
		Xyleborus atratus (ambrosia beetle)	1987	Polyphagous		Genus level
		Xyleborus californicus	1944	Polyphagous		Genus level
		Xyleborus dispar (European shothole borer)	1817	Polyphagous		Genus level
		Xyleborus glabratus (red bay ambrosia beetle)	2002	Oligophagous	x	Genus level
		Xyleborus pfeilii (ambrosia beetle)	1992	Oligophagous		Genus level
		Xyleborusrubricollis (ambrosia beetle)	1942	Polyphagous		Genus level
		Xyleborus seriatus (ambrosia beetle)	2005	Polyphagous		Genus level
		Xyleborus similis (shot-hole borer)	2002	Polyphagous		yes
		Xylosandrus compactus (black twig borer)	1941	Polyphagous		Genus level
		Xylosandrus crassiusculus (granulate ambrosia beetle)	1974	Polyphagous		Genus level
		Xylosandrus germanus (ambrosia beetle)	1931	Polyphagous		yes
		Xylosandrus mutilatus (ambrosia beetle)	1999	Polyphagous		Genus level
		Crypturgus pusillus (bark beetle)	1868	Oligophagous		yes
		Hylastes opacus (bark beetle)	1987	Oligophagous	x	yes
		Hylurgops palliatus (bark beetle)	2001	Oligophagous		yes
		Hylurgus ligniperda (bark beetle)	2000	Monophagous	x	yes
		Hypothenemus areccae (bark beetle)	1960	Polyphagous		Genus level
		Hypothenemus birnamus	1951	Polyphagous		Genus level
		Hypothenemus brunneus (bark beetle)	1915	Polyphagous		Genus level
		Hypothenemus californicus (bark beetle)	1915	Polyphagous		Genus level
		Hypothenemus columbi	1951	Polyphagous		Genus level
		Orthotomicus erosus Mediterranean pine engraver	2004	Oligophagous	x	yes
		Phloeosinus armatus (bark beetle)	1989	Monophgaous		Genus level
		Pityogenes bidentatus (bark beetle)	1988	Monophagous		Genus level
		Premnobius cavipennis	1939	Monophagous		---

		(bark beetle)				
		Scolytus mali (large shothole borer)	1868	Polyphagous		Genus level
		Scolytus multistriatus (smaller European elm bark beetle)	1909	Monophagous	x	yes
		Scolytus rugulosus	1878	Polyphagous		yes
		Scolytus schevyrewi (banded elm bark beetle)	2003	Polyphagous	x	yes
		Tomicus piniperda (pine shoot beetle)	1991	Monophagous	x	yes
HYMENOPTERA						
	Siricidae	*Eriotremex formosanus* (Formosan horntail)	1974	Polyphagous		---
		Sirex noctilio (old world wood wasp)	2002	Monophgaous	x	yes
LEPIDOPTERA						
	Agonoxenidae	*Chrysoclista linneella*	1928	Monophagous		---
	Cossidae	*Zeuzea pyrina* (Leopard moth)	1882	Polyphagous		Family level
	Gelechiidae	*Anarsia lineatella* (peach tree borer)	1872	Monophagous	x	Family level
	Sesiidae	*Sesia apiformis* (hornet moth)	1880	Polyphagous		Family level
		Synanthedon tipuliformis (currant borer)	1825	Polyphagous		Genus level

(Source: Aukema et al., 2010)

Appendix 3. Summary of available treatments for wood packaging materials

A variety of treatments and alternatives are available to reduce the risk of invasive pests in wood packaging materials, including heat treatments, fumigation, irradiation, controlled atmosphere, vacuum treatments, push-pull strategies, and substitute packing materials.

Heat treatments can be accomplished through steam treatments, hot water baths, microwave irradiation, or kiln-drying. Kiln-drying, especially at conventional kiln schedules, is a very effective way to sterilize wood, and kiln-dried (moisture content < 20%) wood is generally accepted by trading partners as requiring no further treatment (Hosking, 2007). The ISPM 15 approved heat treatment of 56°C for 30 minutes appears to control most wood pests (Graham, 1924; Mushrow et al., 2004; Tamblyn and Kent, 1951; USDA-APHIS, 2008; Myers and Bailey, 2010; Forbes and Ebeling, 1987; Quarles, 2006; Goebel et al., 2010), including:

- bark beetles (Coleoptera: Curculionidae: Scolytinae) (e.g., the pine engraver *Ips pini*)
- longhorned beetles (Coleoptera: Cerambycidae) (e.g., the whitespotted sawyer [*Monochamus scutellatus*] and the Asian longhorned beetle [*Anoplophora glabripennis*])
- some metallic wood borers (Coleoptera: Buprestidae) (e.g., the flatheaded borer [*Chrysobothris dentipes*])
- woodwasps (Hymenoptera: Siricidae) (e.g., *Sirex noctilio*)

However, the 56°C/30 minute treatment is not always effective at treating all life stages (particularly prepupae) of the emerald ash borer (*Agrilus planipennis*) (Coleoptera: Buprestidae) (McCullough et al., 2007; Nzokou et al., 2008; Myers et al., 2009). Recent research has shown that the recommended heat treatment for EAB in wood products is 60°C for 60 minutes (Myers et al., 2009) or 65°C for 30 minutes (Nzokou et al., 2008).

Heat treatments are also effective for controlling wood pathogens. Fungi are killed more rapidly when wood is at a high moisture content and, although many pathogens are killed by the 56°C for 30 minute treatment, higher temperatures are often required for heartwood fungi and some species of sap-rot and bluestain fungi (Uzonovic and Khadempour, 2007; Ramsfield et al., 2010). From the studies outlined in this section, it appears that higher temperatures, even for a very short time (< 1 minute) are very effective in killing multiple species and types of fungi. The pinewood nematode (*Bursaphelenchus xylophigus*) is killed by the 56°C/30 minute treatment (Dwinell, 1990, 1997; Dwinell et al., 1995).

Heat-treating green wood may lead to the development of surface molds, so heat treatments in combination with additional kiln-drying are an effective way to meet phytosanitary requirements and minimize the growth of surface molds (Hamner, 2007).

Fumigation provides effective control, but many of the compounds (e.g., methyl bromide, phosphine, carbonyl sulfide) are highly toxic to workers, leave dangerous residues, and, particularly in the case of methyl bromide, contribute to the depletion of the ozone layer (Serca et al., 1998; Butler, 1995). Sulfuryl fluoride may provide an effective alternative to methyl bromide (Vermeulen and Kool, 2006), although it does not appear to be as effective in controlling the egg stage of many insect species (USDA-APHIS, 2003). A patented new fumigant, Ethanedinitrile (cyanogen), appears to be promising as a quarantine treatment for timber (O'Brien et al., 1999; Viljoen and Ren, 2001; Wright et al., 2002).

Irradiation treatments include gamma radiation, microwaves, and radio frequency treatments, all of which have been shown to eliminate pests in wood (Kunstadt, 1998; Fleming et al., 2004; Henin et al., 2008; Tubajika et al., 2007). With gamma radiation, insects, if not killed, may be sterilized and would be incapable of breeding. They would, however, still be able to vector pathogens and nematodes. Microwave treatments are effective, but increased moisture content requires increased exposure time to reach desired internal temperatures. Radio frequency has been proven to destroy decay and sap-stain fungi in wood.

Controlled atmosphere treatments are effective but require very long periods (about nine days) (Vermeulen and Kool, 2006), so they may be inefficient for large quantities of WPM.

Vacuum technology shows promise for treatment of pallet components, killing pests by removing moisture from their bodies (Brindley, 2005). Although the vacuum removes enough moisture to kill the pest, it does not significantly remove moisture from the wood or cause any noticeable lumber degradation. Additionally, the process appears to be environmentally benign because it involves little use of energy and avoids the release of toxic and ozone-damaging gases into the atmosphere (Chen et al., 2006).

A “push-pull” strategy is utilized in integrated pest management and refers to the use of attractive and deterrent stimuli that, in combination, modify the behavior of pest species. Deterrents are used to push unwanted insects away from a resource while highly attractive pull stimuli are used in tandem to lure potential pests away from desired resources ., New Zealand researchers are testing the use of various light spectra to reduce wood borer beetle populations from illuminated areas during peak flight periods (Pawson and Watt, 2009). This technique could also include separation of treated wood from barked wood and limitations of the storage of wood Pawson and Watt, 2009).

Substitute packaging materials include plywood, oriented strand board, particle board, corrugated paperboard, plastics, resin composites, metal, rubber, and fiberglass. The use of any of these materials would likely reduce the risks associated with the movement of wood pests in WPM to almost zero.

Bark and wood-boring beetles can reinfest heat-treated WPM if bark remains on the wood and patches of bark greater than or equal to 100 cm^2 provide suitable habitat for the complete development of reinfesting bark beetles (Haack and Petrice, 2009). The use of debarked or, ideally, bark-free material will minimize the opportunities for reinfestation. In fact, removing bark from EAB-infested logs has been shown to result in the removal of 99.9% of EAB larvae from logs, including both sawlogs and reject[2] logs (McCullough et al., 2010).

[2] Logs that are rejected because of poor quality – these are often the logs that supply lumber for pallets.

Appendix 4. Reinfestation of treated wood

Wood treatment, whether by heat or chemicals, is intended to kill organisms currently within the wood; however, studies have shown that treated wood can be reinfested (Evans, 2007; Haack and Petrice, 2009). Interception of pests on ISPM 15 treated wood may be an indication of reinfestation; however, pest presence could also be from pest resistance to the treatment, false treatment (untreated wood is marked as treated), or untreated wood used to refurbish a pallet/crate. To test the possibility of treated wood re-infestation, Haack and Petrice (2009) conducted a study where they ensured the heat treatments were applied to the wood (from trees in good health, with no sign of borer attack, and treatment was conducted to ISPM 15 specifications), left the wood exposed in a Michigan forest, and then sampled the wood for pests (Haack and Petrice, 2009). In their study, a variety of Cerambycidae and Scolytinae beetles were able to infest and develop in the treated wood (see table below). Some of the beetles they found are important wood pests that attack a wide range of economically important hosts or vector fungi/nematodes that further contribute to tree decline (see table below for details).

A study by the International Forestry Quarantine Research Group (IFQRG) in the United Kingdom also found heat-treated wood is suitable for colonization by a range of bark beetles (e.g., *Tomicus piniperda*, *Hylurgops pallidatus*, *Orthotomicus laricis*, *Hylastes* sp., and *Ips sexdentatus*) (Evans, 2007). In both of these studies, greater numbers of beetles were found on heat-treated wood as compared with untreated wood.

Reinfestation of treated wood is dependent on variables such as moisture content, presence of bark, and size of bark patches (Allen, 1995; Evans, 2007; Haack and Petrice, 2009). Longhorned and bark beetles readily infested heat-treated logs with bark intact as well as heat-treated lumber with residual bark patches. Exit holes of Cerambycidae were only found in heat-treated lumber with bark patches of 1,000 cm^2, while exit holes from Scolytinae beetles were found on bark patches as small as 250 or 100 cm^2 (Haack and Petrice, 2009).

From these studies, it is clear that reinfestation is a possibility with treated wood, particularly if large pieces of residual bark are present and wood is stored in areas of high moisture.

Pests found infesting heat-treated wood from study by Haack and Petrice (2009).

Pest Name	Family	Pest Behavior
Acanthocinus obsoletus (Oliver)	Cerambycidae	Attacks recently killed pine and balsam fir (Baker, 1972)
Dryocoetes autographus (Ratzeburg)	Scolytinae	Reported in association with *Ophiostoma piceaperdum* (Rumbold) Arx (Haberkern et al., 2002) and certain *Leptographium* species (Jacobs et al. 2010); found in lower portions of dying or injured trees, stumps, or felled trees (Baker, 1972)
Hylastes opacus (Erichson)	Scolytinae	Frequent pest in nurseries and pine plantations; kills young trees and wounds older trees making them susceptible to disease (Bridges, 1995)
Ips grandicollis (Eichhoff)	Scolytinae	Attacks weakened, dying, or recently felled trees and fresh logging debris (Baker, 1972; Connor and Wilkinson, 1983); associated with bluestain fungus *Ophiostoma ips* (Rumbold) Nannf. (syn. *Ceratocystis ips* (Rumbold) C. Moreau) (Adams et al., 2009; Baker, 1972; Connor and Wilkinson, 1983); trunks and limbs of healthy trees can be attacked; adults strongly

		attracted to freshly cut/injured trees; spot kills in healthy stands of pine have occurred (Baker, 1972)
Gnathotrichus materiarius (Fitch)	Scolytinae	Breeds in dead and dying conifers (Baker, 1972)
Monarthrum mali (Fitch)	Scolytinae	Attacks recently injured or recently cut hardwoods; highly destructive to green lumber and fresh logs of gum in Gulf States (Baker, 1972)
Monarthrum fasciatum (Say)	Scolytinae	Attacks recently injured or recently cut hardwoods; highly destructive to green lumber and fresh logs of gum in Gulf States (Baker, 1972); considered one of the most serious scolytid pests of hardwoods in Indiana (Deyrup, 1978)
Monochamus notatus (Drury)	Cerambycidae	Breeds in dead/dying white pine and balsam fir and "windthrown" red spruce (Baker, 1972); associated with pinewood nematode (*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle) (Bergdahl et al., 1991; Dwinell and Nickel, 2004)
Orthotomicus caelatus (Eichhoff)	Scolytinae	Breeds in the base of weakened or dying conifers, or thick bark of stumps and logs (Baker, 1972)
Polygraphus rufipennis (Kirby)	Scolytinae	Reported to kill spruce trees if populations are high enough or trees are already weakened (Baker, 1972; Bowers et al., 1996); also reported in associated with the blue stain fungus *Leptographium abietinum* (Peck) Wingf. (Haberkern et al., 2002; Ohsawa et al. 2000) and *Ophiostoma bicolor* Davidson & Wells, *O. piceaperdum* (Rumbold) Arx and *O. ips* (Rumbold) Nannf. (Haberkern et al., 2002).
Urographis fasciatus (DeGeer)	Cerambycidae	Attacks weakened, stressed or dying hardwoods (Nebeker et al., 2005)
Xyleborinus saxeseni (Ratzeburg)	Scolytinae	Generally associated with weakened or dead trees (Doerr et al., 2008; Walker, 2008); attacks hardwood and softwoods (Baker, 1972)
Xylosandrus germanus (Blandford)	Scolytinae	Recognized as a key pest in nurseries; able to attack healthy trees (Ranger and Reding, 2008); wide host range includes apple, walnut, ash, grape, pine, pecan, willow, plum, rhododendron, and black cherry (ODA, 2005); reports of association with *Fusarium* sp. (Kessler, 1974)
Xylotrechus colonus (F.)	Cerambycidae	Species reported with dead or dying hardwoods (Eaton and Kaufman, 2007); recently killed trees are preferred (Baker, 1972)

Appendix 5. Mitigation Strategy

A “domestic” ISPM 15 has been suggested as the treatment for WPM. ISPM 15 is an international measure designed to prevent the spread of wood insect pests and disease by requiring that wood packing be debarked, treated with heat or methyl bromide, and stamped to prove that it has been treated. Wood packaging lacking the ISPM 15 seal is considered non-compliant and can be destroyed or re-exported. The goal is to remove at least a portion of the exotic pests before entry into the United States. The treatment is done only once and is not inspected afterwards (APHIS, 2010).

However, the domestic environment has some important differences that could affect the utility of an ISPM 15 strategy. The area being controlled is the entire United States, rather than a single point and a single time, such as entry at a port for international WPM. Therefore, a treatment should give some long lasting protection due to the risk of reinfestation and treatment failures. This issue must be balanced against the concept that ISPM 15 is, and was never, meant to be perfect; rather, it is a “risk reduction” strategy. Thus, the critical question is balance between the number and types of pests eliminated, when treatment is applied, the longevity of the treatment, and its costs. The answer to that question depends on what treatment or strategy is being applied and when it is applied versus the type of pests that may escape mitigation and costs. An examination of the treatment types and potential management points versus potential risks may help decide what the efficacious strategy is. The wood treatments are in three main categories: heat treatments (with several different ways to heat wood), chemical treatments, and alternative treatments.

Heat Treatment – Pallets

Where	Positives	Negatives	Costs of Treatment
At the saw mill	* The wood will leave the mill treated regardless of the end-use	* The wood can be re-infested in commerce, especially if it contains bark. * The mill does not know the end-use. * Not all wood needs to be treated. * Places the expense on the sawmill.	56/30 Energy=$0.03-.0.15 per pallet 60/60 Energy=$0.6-0.30 Per pallet Costs assoc.w/time also x2
At the pallet factory	* Pallets leave treated. * May be closer in time to the period of use, lessening the opportunity for re-infestation.	* Green wood at the pallet factory my become focus of infestation. * Has the same potential for re-infestation as treatment at the mill * Not clear when dunnage would be treated. Will pallet factories produce or treat that wood also?	56/30 Energy=$0.03-.0.15 per pallet 60/60 Energy=$0.6-0.30 Per pallet Costs assoc.w/time also x2
Periodic treatments	* Retreating wood would reduce the opportunity for infestation and may even	* Major increase in expense. * May not be practical. * Other forms of WPM not	56/30 Energy=$0.03-.0.15 per pallet

	eliminate some infested pallets	affected.	60/60 Energy=$0.6-0.30 Per pallet Costs assoc.w/time also X2

Heat Treatment- Dunnage + Crating

Where	Positives	Negatives	Costs of Treatment
Mill	* Best coverage of likely materials. * Could remove or reduce the number of pests obtained in the field.	* Increasing costs may reduce compliance. * Dunnage and crating can be made from any source of wood. It is not clear how we can make treated supply chain for dunnage. * Reinfestation still possible	Same as pallet
After the mill	* Lessens the opportunity for reinfestation in commerce or during movement	* Increases costs in a low value commodity * Not clear when or where treatment would occur	Same as pallet
Periodic treatments	* Retreating wood would reduce the opportunity for infestation and may even eliminate some infested wood	* Dunnage is frequently single use so periodic treatment is pointless and unenforceable * Disposal is an issue	Same as pallet

Chemical Treatments – Pallets, Dunnage, Crating

Where	Positives	Negatives	Cost of Treatment
Mill	* Removes pests obtained in the field	* Many chemicals do not penetrate deeply into logs * Can only be used on cut lumber	Unknown
After the mill/pallet factory	* Removes pests from field and picked during moving	* Allows for the movement of infested green wood	Unknown
Periodic retreatment	* Retreating wood would reduce the opportunity for infestation and may even eliminate some infested wood	* Dunnage is frequently single use so periodic treatment is pointless and unenforceable * Disposal is an issue	Unknown

Alternative management – Pallets, Dunnage, Crating

Where	**Positives**	**Negatives**	**Cost of Treatment**
Field Survey wood Rapid removal from the field Push-Pull	* Lessens the main opportunities for infestation	* Wood piles in the field are an economic necessity * Which treatment may prevent infestation is not clear, other than minimizing field storage	Unknown
Mill Survey Rapid Removal	* Lessens the main opportunities for infested logs to release pests into	* Wood piles in the field are an economic necessity	Unknown

Limit size of pile of cut and green wood Separate green and treated wood Push-Pull	the environment		
Pallet factory Separate green wood and processed wood Push-Pull	* Lessens interaction between green wood and treated wood or the environment	* Difficult to enforce * Does nothing about dunnage	Unknown

Bark Free – Pallets, Dunnage, Crating

Where	Positives	Negatives	Costs of Treatment
Mill	* Would remove or kill most pests present in the wood * Would prevent reinfestation	* Expensive, decreases the amount of wood available, unlikely to be used in dunnage/ crating	Unknown
Pallet factory	* Wood unlikely to be re-infested	* Does not include dunnage * Expensive	15-+30% increase of rejected cants. As much as 50% of wood can be rejected

Compiling a Mitigation Strategy

From a pest management perspective, the optimum strategy would to combine bark-free wood with a high temperature/long duration heat treatment and wood management once the wood is in commerce. However, the combination of all these measures may be so expensive that the commodity cannot support the costs of these mitigations, in which case, any regulation would be composed of pieces of different mitigations. The opposite is also possible. A minimal approach would be a single 56/30 treatment which would provide pest reduction to a point. The actual strategy will depend on the acceptable level of treatment, convenience, and expense. One way to help decide is to lay out the options with their positive and negatives, as presented in the strategy menu below. This menu summarizes the major treatment options, potential benefits and limitations for pest management, and when they might be applied. Options can be selected alone or coupled together to develop a coherent strategy.

Treatment Menu Summary

Treatment		+/-	Reinfestation	Application Strategy	
				At the mill +/-	At the factory +/-
Heat	56/30 **1 pt. treatment**	+ Creates a single logistic chain for WPM - Does not kill all wood pests, such as EAB	Possible for both insects and ambrosial fungi	+ Eliminates field acquired pests - Does not prevent pests acquired in trade	+ Eliminates field and some pests acquired by green wood - May not apply to dunnage, allows green wood to move
	60/60 **1 pt.**	+Does kill more wood pests than	Possible for both insects and	+ Eliminates field acquired pests	+ Eliminates field and some pests

	treatment	54/30, such as EAB -Creates a second logistic chain for wood, cost at least twice as much pre treatment	ambrosial fungi	- Does not prevent pests acquired in trade	acquired by green wood - May not apply to dunnage, allows green wood to move
Chemical	Methyl Bromide **1 pt. treatment**	+ Already in use for commodity treatments - Schedule for removal from the market, doesn't penetrate wood well	Not tested but likely	+ Eliminates field acquired pests - Does not prevent pests acquired in trade	+ Eliminates field and some pests acquired by green wood - May not apply to dunnage, allows green wood to move
	Other **1 pt. treatment**	+ May lessen the use of methyl bromide - None of the chemicals available have been certified or used on a large scale	Not tested but likely	+ Eliminates field acquired pests - Does not prevent pests acquired in trade	+ Eliminates field and some pests acquired by green wood - May not apply to dunnage, allows green wood to move
Alternatives	Push Pull **Long term treatment**	+ May be the cheapest option, if applied throughout the logistic chain - Decreases populations but does not eliminate pests, effectiveness unclear	Possible for both insects and ambrosial fungi	+ May reduce populations at the mill - May not be efficacious by itself	+ May reduce populations at the factory - May not apply to dunnage - May not be efficacious by itself, allows green wood to move
	De-barked **Long term treatment**	+removes many opportunities for bark beetles to infest -can still survive and reproduce with patches the size of a credit card	Possible for both insects and ambrosial fungi	+ Eliminates some but not all field acquired pests -Does not prevent pests acquired in trade	+Eliminates some field and some pests acquired by green wood -May not apply to dunnage, allows green wood to move
	Bark free **Long term treatment**	+ Removes almost any opportunity for bark beetles to reproduce in wood - May decrease pallet yield per cant load by almost half	Unlikely for bark beetles and probably wood borers	+ Eliminates field acquired pests	+ Eliminates field and some pests acquired by green wood - May not apply to dunnage, allows green wood to move
Repeated treatment application **Long term treatment**		+ Likely to give better control than a single treatment - Increase costs, unenforceable, impossible to track or schedule	Possible but would be eliminated by the repeat treatments	Probably can't be applied here	+ Eliminates pests acquired in trade at least periodically - Does not apply to dunnage

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