United States Department of Agriculture

Animal and Plant Health Inspection Service

Risk Assessment of the Movement of Firewood within the United States

Source: Kosichfirewood.org (artist: Alastair Heseltine)

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Executive Summary

Exotic and native forest pests such as *Agrilus planipennis* (emerald ash borer), *Anoplophora glabripennis* (Asian longhorned beetle), *Dendroctonous ponderosae* (mountain pine beetle), *Ophiostoma novo-ulmi* and *O. ulmi* (pathogens associated with Dutch elm disease), *Cryphonectria parasitica* (pathogen associated with chestnut blight), and *Geosmithia* sp. (pathogen associated with thousand cankers disease of black walnut) cause serious damage to urban and natural forests in the United States. These pests and many others disperse various distances through multiple pathways including movement of nursery stock and firewood. Firewood is a raw forest product that is widely utilized and moved throughout the United States with relatively limited consideration of the potential pests within or the associated risks. We conducted an assessment and examined factors that may affect the risk associated with the movement of firewood such as users, movement, insects and diseases, potential impact to natural and urban forests, and trends in firewood use. From our assessment, we estimate firewood to be a high-risk pathway for the movement of forest pests for the following reasons.

- **Firewood is a well-known pathway for the movement of wood pests.**
- **The United States requires treatment of all imported firewood, with a few exceptions from Canada and Mexico.**
- **Regulations prohibiting the domestic movement of firewood are already justified and in place for several states for five exotic forest pests.**
- **Firewood readily moves commercially and privately throughout the United States.**
- **Urban forests are particularly susceptible and increasing in number.**
- **High diversity and coverage of forests in the United States.**
- **The value of the economic resources in the United States at risk if exotic or native forest pests are spread to additional areas is very high.**
- **High regulatory costs of forest pest management.**

Movement of firewood is a high-risk pathway for spreading non-native and native forest pests in the United States. We recommend that Federal and State regulatory agencies examine the current regulations for firewood movement and coordinate efforts to mitigate the potential risks, with primary focus on long-distance and urban area movement.

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Nature of the Problem

The risks associated with the movement, introduction, and establishment of forest pests in firewood are well recognized, with regulations prohibiting the movement of firewood without treatment or inspection from quarantine areas for forest pests regulated by the Animal and Plant Health Inspection Service (APHIS). Additionally, nearly all firewood imported into the United States is required to have treatments prior to importation to mitigate the risk of pest introduction. The rapid spread of *Agrilus plannipennis*, the emerald ash borer (EAB), in the United States has been attributed primarily to movement of infested nursery stock and firewood (emeraldashborer, 2010). The regulation of ash nursery stock movement was easier to enact due to the identifiable industry and commodity involved; however, regulation of hardwood firewood movement has been more difficult to manage and less effective due to the diverse nature of the firewood industry and the use and movement of firewood by the general public.

Numerous stakeholders representing Federal, State, and private forestery, as well as academia, attended a Firewood Forum for the northeastern United States in New Jersey in 2008. The unanimous message was that firewood is a high-risk pathway for moving exotic forest pests. Groups such as the National Association of State Departments of Agriculture, the National Association of State Foresters, the Southern Group of State Forests, and the Southern Forest Insect Work Conference published position papers recommending strong outreach and educational campaigns, and requesting the regulation of interstate commerce in firewood (NASDA, 2007; NASF, 2009; SFIWC, 2008).

The National Plant Board (NPB) responded by developing a national strategy to mitigate the risks associated with the domestic movement of firewood (NPB, 2007). Resolutions included the following: United States Department of Agriculture (USDA) APHIS and the USDA Forest Service, in cooperation with the NPB and the National Association of State Foresters, will develop a national education and outreach program to inform interstate tourists and travelers that firewood can introduce dangerous and damaging plant pests and as such should not be carried for long distances. The USDA will develop and approve measures (criteria/processes) to mitigate the movement of pests in firewood, and USDA-APHIS should start the process to federally regulate the interstate movement of firewood as a commodity. A National Firewood Task Force (NFTF), a coalition of State and Federal agricultural and natural resource officials, has since been formed to further this process.

Currently, Federal regulations restrict the movement of firewood in several states. As these regulations often pertain to firewood associated with the EAB quarantine, they fail to address the broad risk of firewood movement. This assessment was initiated to examine the risks associated with the domestic movement of firewood in the United States.

Statement of Purpose

The specific objectives of this pest risk assessment are to:

- describe the characteristics of firewood as a pathway for the spread of wood pests,
- assess the potential for movement and establishment of wood pests that may be transported in firewood, and
- estimate the potential economic and environmental consequences these pests may have on forest and tree resources, including the urban environment, if the pests are moved to new areas in the United States.

Although in this assessment we attempt to describe potential risks associated with transport of pests in firewood, there is no way to predict which specific organisms may actually move and cause damage, when such events may occur, or the magnitude of actual damage (Orr et al., 1993). As such, this document presents an analysis of pest risk potential for firewood rather than a pest-specific risk assessment.

Scope of the Assessment

In this document, we evaluate the risk of movement of wood pests in firewood within the United States. Firewood can be composed of nearly all hardwood and softwood species of wood, and numerous pests have been reported to occur on these hosts. Therefore, a comprehensive list of wood pests, hosts, and reported distribution was not generated. Instead, key species of wood pests were selected to illustrate movement potential and probable impacts.

Many organisms in the forest ecosystem work to break down and remove dead or dying trees. These organisms are an essential part of a healthy forest. In this assessment, we are primarily focused on native or exotic organisms associated with firewood that could potentially affect healthy trees in new areas through their movement and establishment.

In describing the firewood pathway, we considered the association of pests with firewood, the amount of firewood, the movement and distribution of firewood within the United States, and the difficulties involved in detecting wood pests in firewood shipments.

In addition to being capable of moving with firewood, an organism must be able to become established in a new environment and cause harm to be considered a pest. Biological characteristics of organisms contribute to their ability to gain entry, become established, and cause harm in new environments. Knowledge of these characteristics can be used to categorize an organism's pest risk threat.

Definition of Firewood

Firewood is defined as "wood that has been cut, sawn, or chopped into a shape and size commonly used for fuel, or other wood intended for fuel" (7 CFR § 301.92, 2010).

Overview of Treatments for Wood Products Entering the United States

The general requirement for any consignment of wood or lumber products is for documentation to accompany each shipment that identifies the commodity, quantity, and its origin. All shipments are subject to inspection and may require other actions deemed necessary by USDA-APHIS Plant Protection and Quarantine (PPQ) as a result of inspection. The universal import option for logs or lumber includes either heat treatment or kiln drying and must be conducted prior to arrival. Treated or dried logs or lumber cannot be commingled with other regulated materials unless all regulated articles in the same hold or container have been heat treated or kiln dried. Heat treated or kiln dried lumber must be marked by permanent marking on each piece of lumber or on the cover of bundles of lumber. Alternatively, the importer document accompanying the shipment must state that the logs or lumber have been heat treated or kiln dried.

Regarding specific types of firewood originating from specific regions or countries, temperate hardwood logs and lumber must be fumigated prior to arrival. If pine originating from Canada moves through an area of the United States quarantined for pine shoot beetle, articles must be shipped in an enclosed vehicle or completely covered. *Fraxinus* spp. from Canada originating in areas regulated for EAB must be debarked or chipped. Raw lumber is not authorized from areas in Asia that are east of 60 degrees east longitude and north of the Tropic of Cancer. Allowable raw lumber from Asia must be completely debarked and cannot be commingled with other regulated materials unless the raw lumber and the other regulated articles are in separate holds or in separate sealed containers. Raw lumber on the vessel's deck must be in a sealed container. (CFR 319.40-6)

Current Federal Treatment Requirements for Firewood

All ash logs and all hardwood firewood from EAB quarantine areas are required to undergo treatment T314-a, specifically, heat treatment at 71.1ºC for 75 minutes[1]. All logs (including firewood) from gypsy moth quarantine areas are required to undergo treatment T314-b, specifically heat treatment at 56ºC for 30 minutes.

The treatment manual also provides treatments premitted for export of oak logs to destroy oak wilt disease (T312-a and -b, methyl bromide) and pine logs to destroy pine shoot beetle [T313-b and D301.50-10(a)[2], methyl bromide].

State Regulations for Firewood

Federal quarantines regulate interstate movement and State quarantines regulate intrastate movement. Twenty-eight states within the conterminous United States have regulations for internal or external quarantines relating to the movement of raw logs. The more recent quarantines cite firewood explicitly as a regulated item, while some cite “logs” and “branches,” of a given species or of multiple species, and firewood is implicit. The organisms that have prompted Federal and State quarantines include EAB, Asian longhorned beetle (ALB), gypsy

[1] Recent thermotolerance studies show that EAB survival is variable depending on the heating conditions, and an internal wood temperature of 60ºC for 60 minutes should be considered the minimum for safe treatment of firewood (Meyers et al., 2009).

[2] This treatment applies only to domestic movement of regulated articles.

moth, pine shoot beetle, sudden oak death, sirex wood wasp, hemlock woolly adelgid, and the European larch canker (Table 1). A number of states are developing regulations to restrict the movement of firewood, among other raw wood products, in connection with thousand cankers disease (Nebraska, Kansas, and Missouri) and laurel wilt disease (Florida). New York was the first state with firewood regulations prohibiting the movement of untreated firewood into the state and within the state over distances of greater than 50 miles. Florida passed regulations in Augut 2010 that require commercial firewood importers to obtain a Master Permit for Wood Products. The Master Permit requires all shippers of firewood to be under compliance with the state of origin indicating that inspections or treatments have been performed. Non-commercial firewood may enter when accompanied by a report of non-commercial (homeowner) firewood. Locally produced untreated firewood is permitted to move up to 50 miles from the point of origin (Florida, 2010)

Table 1. States with regulations relating to the movement of raw wood, including firewood.

Organism	**States with Regulations**
Emerald ash borer (*Agrilus planipennis*)	IL, IN, MD, MI, MN, MO, NY, OH, PA, VA, WI, WV
Asian longhorned beetle (*Anoplophora glabripennis*)	CT, IL, MA, ME, NH, NJ, NY, RI, VT, WI
Gypsy moth (*Lymantria dispar*)	CA, CT, DC, DE, IL, IN, MA, MD, ME, MI, NC, NH, NJ, NY, OH, PA, RI, VA, VT, WI, WV
Pine shoot beetle (*Tomicus perniperda*)	CT, IA, IL, IN, MA, MD, ME, MI, MN, NH, NJ, NY, OH, PA, RI, TN, UT, VA, VT, WI, WV
Sudden oak death (*Phytophthora ramorum*)	CA, OR, WA, WI
European larch canker (*Lachnellula willkommi*)	ME
Hemlock woolly adelgid (*Adelges tsugae*)	ME, MI, NH
Sirex wood wasp (*Sirex noctilio*)	MD, NC
Thousand Cankers Disease (*Geosmithia sp. nov., Pityophthorus juglandis)*	MO

Firewood Use in the United States

Trees utilized for firewood production are often unsuitable for any other purpose. They are often stressed, crooked, damaged, diseased, insect-ridden, or killed, and are removed in urban/ residential areas for aesthetic or safety reasons and in timber stands to improve site conditions for crop trees. As the source of firewood is often stressed or dying trees, it will frequently contain wood pest organism(s) that may have contributed to its demise, thus increasing the risk of firewood. Bark is not purposefully removed from firewood and it frequently remains on the firewood for extended periods of time. The presence of bark increases the ability for wood pests to survive and the suitability and attractiveness of the wood to secondary invading pests. Several characteristics determine whether or not a tree is suitable for lumber or veneer, including diameter, height, branching, and the presence of defects. Urban and yard trees are often utilized as firewood. They are grown in open areas, resulting in short boles and numerous branches, and are often avoided by timber mills because of the risk that they may contain embedded objects (nails, wires, etc.) that could damage equipment and present hazards to sawyers.

A standard cord is the amount of firewood contained in 128 cubic feet of space when the firewood is tightly stacked (80 cubic feet of solid wood). A cord of firewood is a pile which measures 4 feet wide, 4 feet high, and 8 feet long. The number of trees in a cord of wood depends on the size of the tree–for example, one mature tree with a 22-inch diameter at breast height (DBH, 4.5 feet from ground level) is all that is needed for a cord of firewood, while it would take 50 trees with a 5-inch DBH to comprise a cord (Patmos, 2005). Another common measurement is the "face cord" or "rick" which is a pile of firewood measuring 4 feet by 8 feet by 24 inches (or whatever length each stick is cut), approximating one-half of a standard cord. Firewood bundles, often seen at supermarkets or other retail outlets, represent between 1/100 of a cord (a bundle weighing 36 pounds) and 1/64 of a cord (a bundle measuring 1 foot by 1 foot by 2 feet) (Slusher, 1985). Individuals selling firewood may sell it by the truckload, in which case determining the true volume of wood is difficult.

The fuel value of wood varies by the type of wood and depends on its density and moisture content. Denser (heavier) woods, if properly dried, will deliver more Btu per cord (Table 2). Hardwoods are more desirable for firewood because they have a higher fuel value (Table 3), burn longer, and tend to produce more coals that last longer when compared to softwoods. Each of the tree species noted in the tables below is commonly utilized as firewood. Each is associated with a variety of native organisms that could become pests in a new environment, and each could serve as host for any number of forest pests.

Table 2. Approximate weight per standard cord of various woods and potential heat of air-dried wood.

	Pounds green[1]	**Pounds air-dried**[2]	**Million Btu available**[3]
Ash	3,940	3,370	23.6
Basswood	3,360	2,100	14.7
Box elder	3,500	2,500	17.5
Cottonwood	3,920	2,304	16.1
Elm (American)	4,293	2,868	20.1
Elm (Red)	4,480	3,056	21.4
Hackberry	4,000	3,080	21.6
Hickory (shagbark)	4,980	4,160	29.1
Locust (black)	4,640	4,010	28.1
Maple (silver)	3,783	2,970	20.8
Maple (sugar)	4,386	3,577	25.0
Oak (red)	4,988	3,609	25.3
Oak (white)	4,942	3,863	27.0
Osage orange	5,480	4,380	30.7
Pine (shortleaf)	4,120	2,713	19.0
Red cedar	3,260	2,700	18.9
Sycamore	4,160	2,956	20.7
Walnut (black)	4,640	3,120	21.8

[1] Approximate weight of standard cord, for the first two columns of figures.
[2] To 20% moisture content.
[3] Potential available heat from standard cord with 100% unit efficiency. Heat at 20% moisture content.

Source: *Wood fuel for heating* (Slusher, 1985).

Table 3. Ratings for popular firewood species.

	Relative amount of heat	Easy to burn?	Easy to split?	Have heavy smoke?	Pop or throw sparks?	General rating and remarks
Hardwood Trees						
Ash, red oak, white oak, beech, birch, hickory, hard maple, pecan, dogwood	High	Yes	Yes	No	No	Excellent
Soft maple, cherry, walnut	Medium	Yes	Yes	No	No	Good
Elm, sycamore, gum	Medium	Medium	No	Medium	No	Fair–too much water when green
Aspen, basswood, cottonwood, yellow poplar	Low	Yes	Yes	Medium	No	Fair–but good for kindling
Softwood Trees						
Southern yellow pine	High	Yes	Yes	Yes	No	Good, but smoky
Cypress	Medium	Medium	Yes	Medium	No	Fair
Eastern red cedar	Medium	Yes	Yes	Medium	Yes	Good–good for kindling

Source: (Slusher, 1985).

Description of Firewood Pathways

Firewood imported from other countries

From 2005 to 2009, the United States received imports of firewood ("fuelwood": billets, twigs, and faggots), with values exceeding $39 million. The majority (64.4%) came from Canada; 33.9% was imported from Central and South America, Europe, or Asia; and a little less than 2% from Mexico. This firewood comes into the United States through multiple districts and is then distributed throughout the country. Imports received in 2009 were valued at just under $7.1 million (Table 4), primarily going into the northeast (NY, ME, VT) at $2.5 million, the Pacific Northwest (WA) at $2 million, and the south (TX, FL, LA, VA) at $2 million. As with the five-year data, most firewood is imported into the United States from Canada, Honduras, and Estonia.

Table 4. United States firewood imports by custom districts (2009).

Country of Origin	U.S. Customs District	Total (US$)
Argentina	Houston TX (District)	45,414
Canada	Anchorage AK (District)	28,476
	Buffalo NY (District)	85,054
	Detroit MI (District)	108,449
	Ogdensburg NY (District)	366,794
	Portland ME (District)	313,956
	Seattle WA (District)	2,047,937
	St Albans VT (District)	467,895
China	Columbia-Snake (District)	11,039
Colombia	Houston TX (District)	6,006

El Salvador	New Orleans LA (District)	30,636
Estonia	Baltimore MD (District)	2,138
	Los Angeles CA (District)	74,855
	New York City NY (District)	1,080,695
Honduras	Houston TX (District)	154,053
	Los Angeles CA (District)	163,196
	Miami FL (District)	1,538,685
	New Orleans LA (District)	135,922
	Norfolk VA (District)	32,738
	San Francisco CA (District)	45,221
Indonesia	New York City NY (District)	12,300
Japan	Los Angeles CA (District)	2,305
Latvia	Los Angeles CA (District)	20,710
	Miami FL (District)	23,812
	New York City NY (District)	148,554
Mexico	El Paso TX (District)	53,626
	Laredo TX (District)	29,932
	Nogales AZ (District)	19,548
Netherlands	New York City NY (District)	8,837
Sweden	New York City NY (District)	7,007
	San Francisco CA (District)	13,904
Switzerland	New York City NY (District)	18,042
Grand Total		7,097,736

Source: U.S. Bureau of the Census: Foreign Trade Division USA Trade® Online;
U.S. Import and Export Merchandise trade statistics.

In general, imported firewood must undergo heat treatments of 71ºC for 75 minutes prior to entrance into the United States, although regulations vary for wood from Canada and Mexico[3]. If proof of treatment cannot be provided, the entire shipment is rejected; however, firewood is not inspected upon entry into the United States as long as the importing country provides proof of treatment, (Jones, 2010). Much of the material imported is in single bundles for personal use (for fireplace ambiance or camping) and these single bundles are shrink-wrapped. Some are entirely wrapped in plastic and some have only the center portion of the bundles wrapped, open at both ends. Firewood double-bagged entirely (but loosely) in contractor grade 4 mil plastic bags is an inexpensive and effective method for preventing the spread of emerald ash borer (Poland et al., 2008) and most likely other forest pests as well.

[3] Conifer firewood from Canada (with the exception of *Pinus* firewood from pine shoot beetle-infested areas) and all firewood from Mexican states adjacent to the United States are exempt from treatment requirements.

Canada also exports large quantities of “hog fuel” into the United States. Hog fuel, defined by the Harmonized Tariff Codes of the United States[4] as “wood waste,” often comes in the form of 5-foot slabs cut from logs prior to processing at the sawmill (Jones, 2010). These slabs, taken from any number of tree species, are often sent into the Pacific Northwest. During 2009, Canada exported 189.7 thousand metric tons of hog fuel to the United States. This material may not be covered within the existing regulatory structure, as it is not considered “firewood” and, as such, does not require treatment. Because these slabs are likely to contain bark and outer sapwood, the importation of hog fuel from Canada may be a pathway for the introduction of forest pests into the United States.

Firewood distributors

Firewood dealers range from individuals selling wood locally from the back of a truck to very large distributors that ship firewood from coast to coast. Logs and other materials utilized for firewood are cheap (often free) and easily obtained through sawmills, logging operations, tree service companies, land clearing companies, construction companies, and homeowners. Forest landowners often produce firewood as an added benefit of managing woodlots for timber production. Wood can be cut and kept to save fuel costs or sold to generate income, and this improves timber quality, species composition, and growth rate by removing undesirable trees (Gardner, 1997). As discussed above, firewood is also imported from other countries and distributed throughout the United States, particularly into urban areas.

Commercial firewood, particularly if sold by large distributors, may be moved long distances. For example, firewood sold in Ohio may come from Missouri, brokered by a firm in Texas (Buck, 2008). Given the ubiquitous nature of this industry, the exact number of firewood dealers is unknown and any estimate will include a great deal of uncertainty. We obtained data on firewood distributors (dealers) from an organization that collects information on businesses throughout the United States. As of January 2010, this database contained 1093 businesses that reported the sale of firewood as their primary source of income. Annual sales range from $163,000 to over $16 million, with the majority (82%) earning less than $500,000 (Figure 1) and consisting of one to three employees. The total sales volume reported by these companies exceeds $619 million. These firewood dealers are scattered throughout the country, particularly clustered on the West Coast and in the northeastern United States, which represents 23 and 26 percent of the total sales volume reported, respectively.

[4] The Harmonized Tariff Schedule of the United States defines the term "wood waste" as residual material other than firewood resulting from the processing of wood, including scraps, shavings, sawdust, veneer clippings, chipper rejects, and similar small wood residues, as well as larger or coarser solid types of residual wood such as slabs, edgings, cull pieces, and veneer log cores

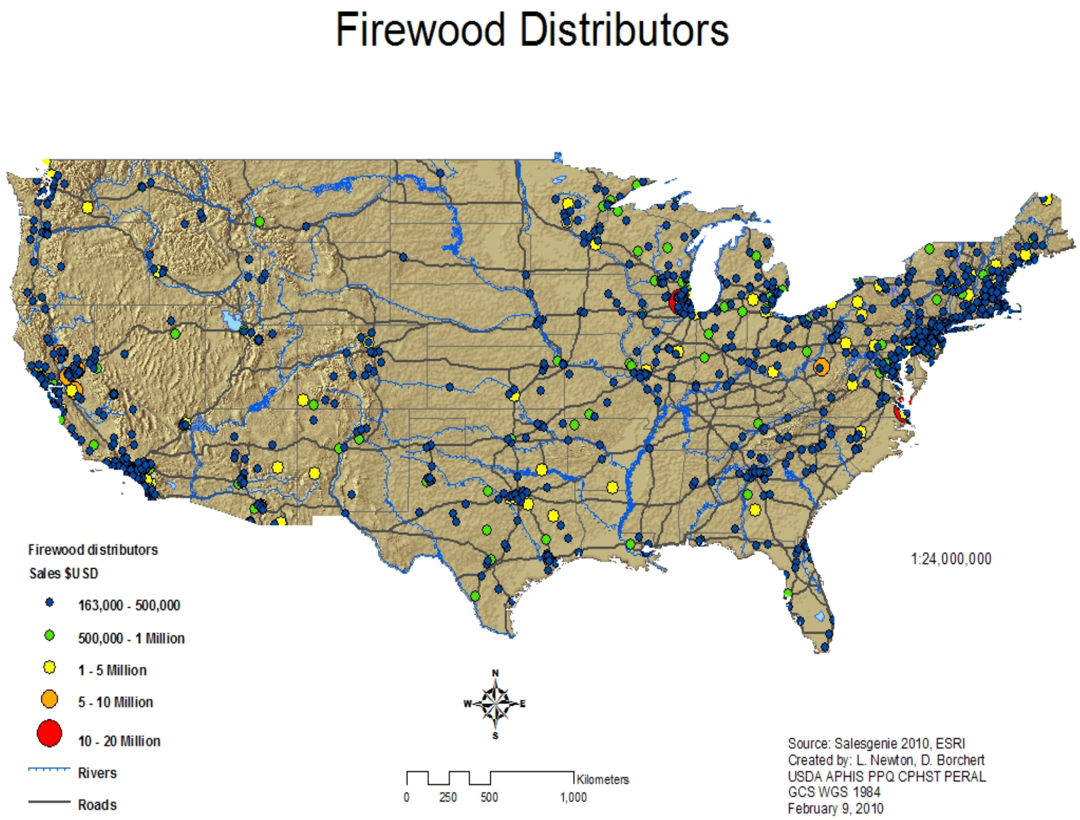

Figure 1. Firewood distributors advertising firewood and reporting over $163,000 in annual sales.

Regarding acquisition of wood for sale, distributors may produce the wood themselves, obtain local firewood, travel several hours to collect it (Buck, 2008), or, as is the case in some western states, they may travel hundreds of miles (Jacobi, 2007). Firewood is sold “green,” “seasoned,” or “kiln dried.” Green firewood is freshly cut and should be dried prior to burning. The risk associated with green firewood is high, as any insect or pathogen present in the wood will have a greater probability of surviving transport into a new habitat. Seasoned wood has been allowed to air dry for a time, generally six months to a year, although under the right conditions (cut during the winter and allowed to air dry), wood may be considered “seasoned” after three months. While these periods may allow the wood to dry sufficiently to burn well, insects and pathogens may still be present and living within the wood. For example, wood infested with the emerald ash borer may contain both newly initiated and fully developed larvae and it may take two successive emergence periods (i.e., two summers) for all EAB adults to emerge (Petrice and Haack, 2007). Wood dwelling nematodes like the pine wood nematode (*Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle) are able to survive in chipped wood for 20 months

(Panesar et al., 1994). Further, the fruiting bodies of fungi may remain viable in firewood for more than three years.

Treatment practices by some firewood distributors may reduce the risk of pests associated with firewood. For example, a site visit to a large firewood production facility in Pennsylvania (Chaloux, 2008) revealed that incoming inventories of stock are purchased from sawmills within a 25 to 30 mile radius. Raw logs (approx. 20 feet long) are transported to the lumber yard, cut to firewood length and split into firewood. Prior to stacking, wood is either screen cleaned to remove loose bark and dirt or kiln dried. The piled wood is utilized to fuel the kilns during periods of high demand or sold locally by the cord. This distributor routinely kiln-dries the wood to produce firewood that burns cleanly and easily; their protocol calls for a 36-48 hour run in the kiln at 110-115ºC, a treatment that would likely destroy any potential pests.

Firewood users

Home heating

There are an estimated 41 million wood stoves and wood-burning fireplaces in homes throughout the United States (EPA, 2009). Residential wood combustion meets 9% of the nation's space-heating energy needs and wood is burned regularly in approximately 30 million homes (Houck et al., 1998). As prices for home heating oil rise and the cumulative acquisition of fireplaces and woodstoves rises, it becomes more likely that people will supplement their home heating with firewood (Figure 2).

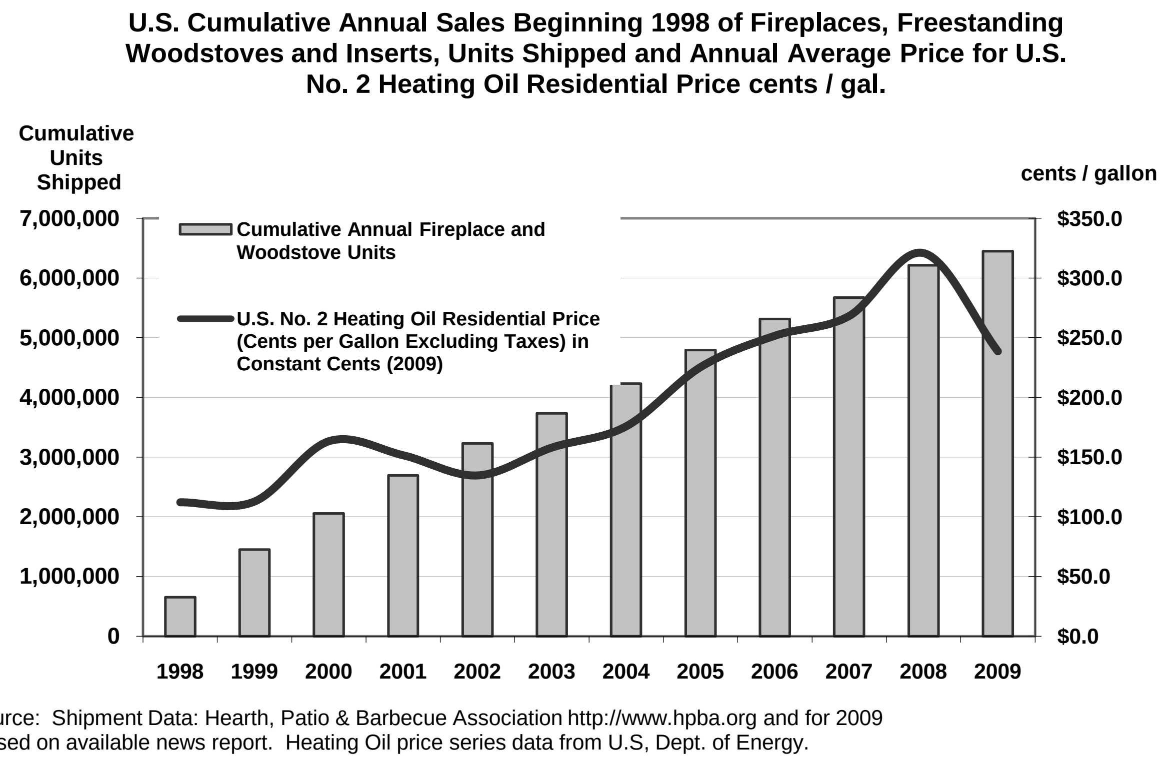

Figure 2. Trends in oil prices and the cumulative annual sales (11 years) of fireplaces and woodstoves.

Firewood consumption for home heating varies throughout the country and is affected by other fuel costs, air pollution regulations, the availability of firewood, and population density. In Michigan, for example, utilizing wood for home heating may require up to 7 cords per winter (Pentico, 2010), while in Oklahoma, only 3 or 4 cords may be required (Marcoullier and Anderson, n.d.).

Houck et al. (1998) estimate that 20.4 million households utilize wood for residential space-heating in the United States and consume 27.4 million cords of wood per year. This equates to approximately 219 million pole-sized trees (8-inch DBH). A second estimate of the quantity and value of firewood utilized for home heating, based on research conducted by Skog and Watterson (1983), is found in Table 5.

Table 5. Estimated quantity and value of firewood utilized for home heating in the United States.

Total U.S. households 2002 (U.S. Census)	107,366,878
28% of households using firewood 1980/81 heating season (Skog and Watterson 1983)	30,062,726

Number of cords consumed @ 1.91 cords/household (Skog and Watterson 1983)	57,419,806
Cubic feet of solid wood @ 80 cubic feet solid wood / cord	4,593,584,508
Estimated Value @$80 per cord	$4.593 billion

Firewood for home heating may be obtained locally or transported long distances. Buck (2008) estimated that the potential spread is frequently 150-200 miles. Firewood is a significant resource on public lands in the western United States. Between 2003 and 2007 fuel wood sales from Bureau of Land Management (BLM) lands roughly doubled (Table 6)[5]. Interestingly, the majority of tree harvest permits requested in one forest region in 2008 were requested by individuals residing less than one hundred miles from the harvest area. However, some applicants resided nearly 2000 miles from the harvest area (Figure 3) and it is reasonable to assume these individuals, if granted permits, transported the cut wood over large distances.

Table 6. Fuelwood (cords) removed from public (BLM) lands 2003-2007.

Fuelwood Cords Fiscal Year (October - September)		2003	2004	2005	2006	2007
Alaska		713	481	705	1,232	1,032
Arizona		443	285	468	214	589
California		556	482	453	796	950
Colorado		1,384	1,759	2,630	5,126	6,469
Idaho		507	362	498	313	445
Montana		381	3,455	1,046	1,589	1,857
Nevada		4,356	3,368	4,459	4,604	3,759
New Mexico		1,954	2,815	4,552	6,506	7,496
Oregon		4,576	4,788	4,508	5,442	7,192
Utah		3,239	2,967	4,356	2,641	5,616
Wyoming		855	289	676	975	2,070
	Total	18,964	21,051	24,351	29,438	37,475

[5] Includes volumes related specifically to fuelwood sales during the fiscal year. The unit of measure used is cords, the traditional standard for fuelwood. Two cords are approximately equal to one MBF = one thousand board feet; one board foot measures 1 foot in length by 1 foot in width by 1 inch in thickness. Volumes and values associated with BLM's Stewardship Contracting authority are not included.

Source: U.S. Department of the Interior, Bureau of Land Management, Public Land Statistics 2003 through 2007.

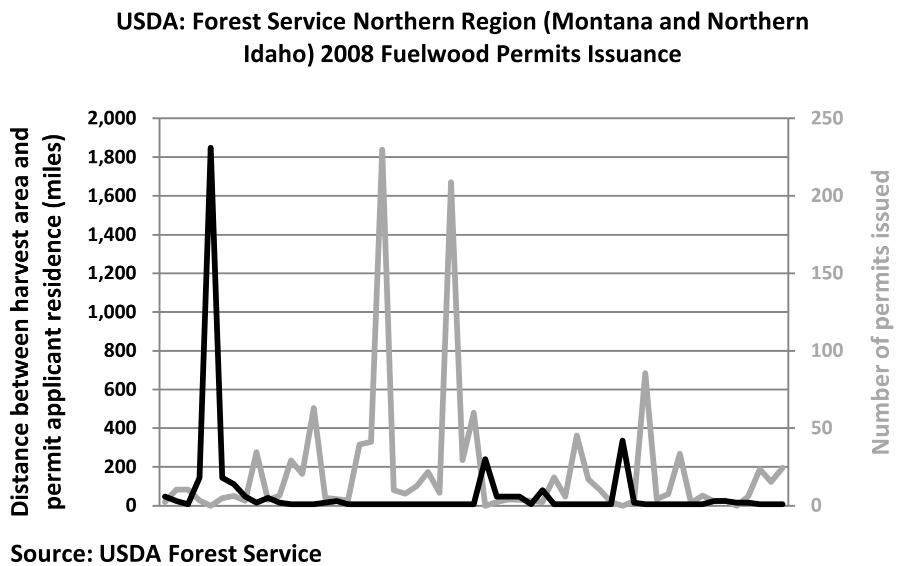

Figure 3. Fuelwood permits from Federal lands.

The graph below highlights the individual states that consume wood for residential heating and also the average number of miles that states ship firewood and other raw wood (Figure 4). States such as Indiana, Rhode Island, New Hampshire, Missouri, and Idaho rank higher than others in average shipment miles (over 500 miles). Homeowners frequently cut and haul their own firewood making this specific pathway very difficult to assess.

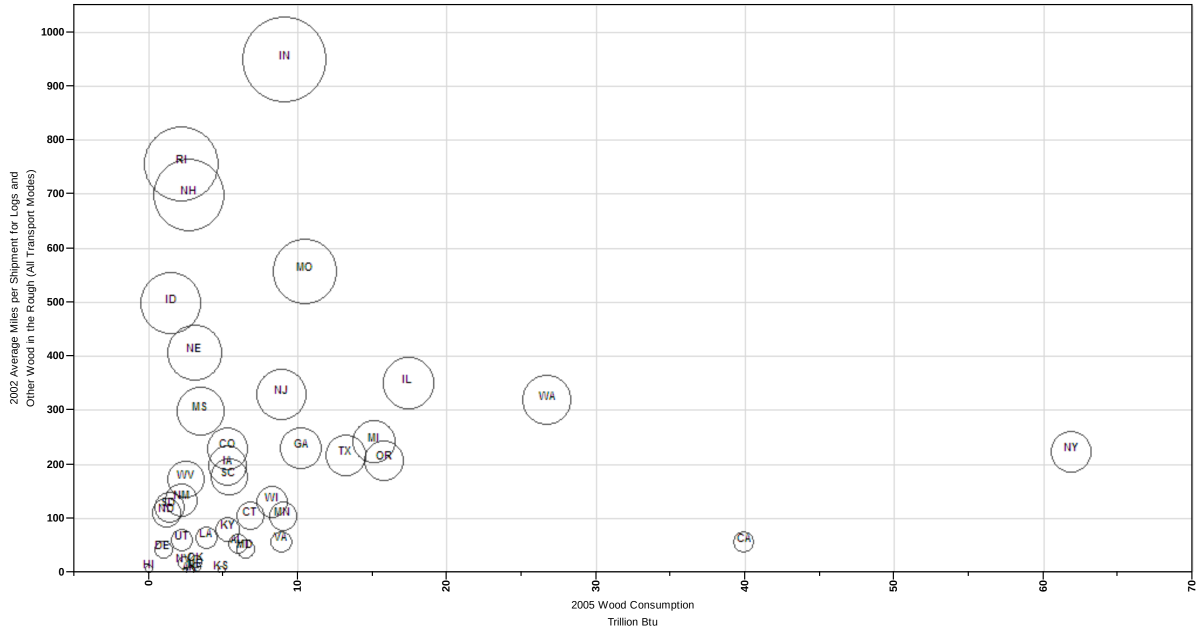

Figure 4. Residential Sector 2005 - Energy consumption from fire/fuel wood and 2002 average miles per shipment for logs and other wood in the rough (all transport modes).[6]

Camping

Thousands of campgrounds are scattered throughout the United States (Figure 5) and camping is a popular recreational activity for millions of people each year. Campfires are an integral part of camping, and campers often bring their own firewood due to the cost and quality of firewood provided at or near campgrounds. Surveys from the west and the northeast indicate that 8 to 57% of campers may bring firewood from home, often travelling 100 to 200 miles and frequently crossing state lines (Jacobi, 2007; Jacobi et al., 2009; Weimer, 2008). Research conducted in the western states estimates that 330,000 campers (RVs, trailers, tents) are moving firewood into national parks every year (Jacobi et al. 2010). Although most national park campers buy firewood inside the park, some campers have been known to bring firewood from one side of the country to another—for example, from California to New Hampshire (NHDR, 2006).

[6] Source: U.S. Department of Energy, Energy Information Administration, Table S4. Residential Sector Energy Consumption Estimates, 2005 2002 Commodity Flow Survey, Transportation-Commodity Flow Survey, Bureau of Transportation Statistics and U.S. Census Bureau, 2005 Economic Census. Table 5a. Shipment Characteristics by Two-Digit Commodity for State of Origin: 2002.

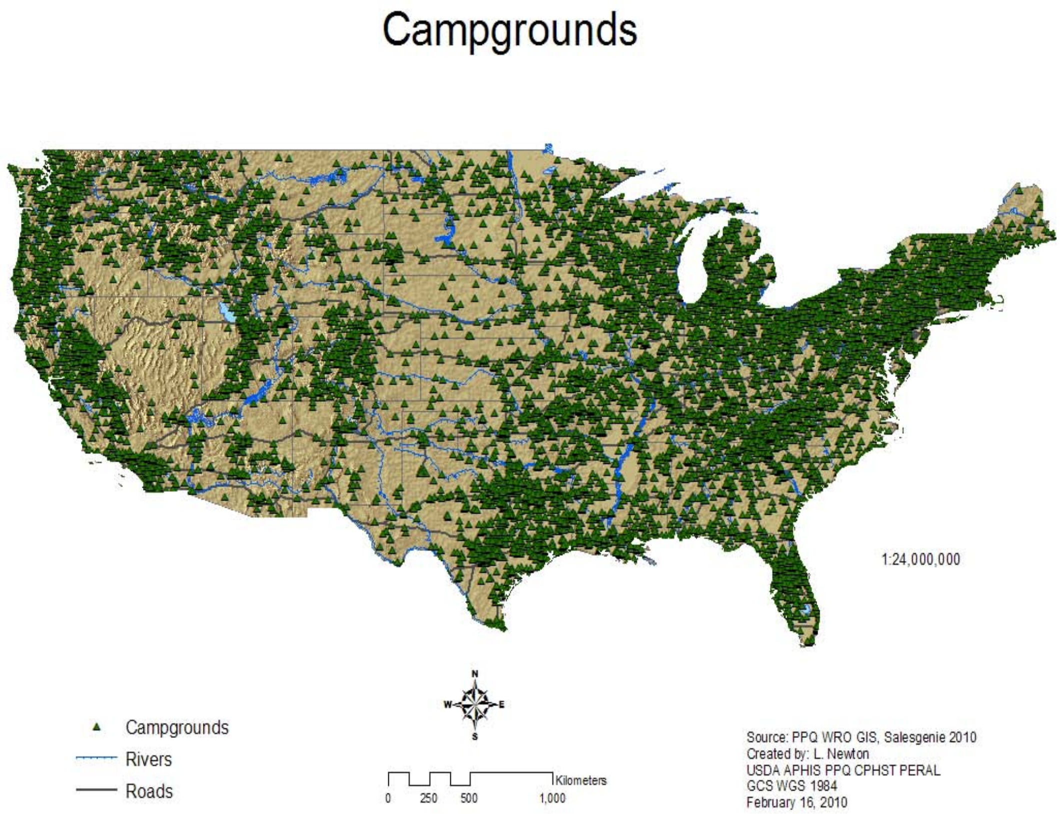

Figure 5. Federal, State, and public campgrounds throughout the United States.

In connection with the EAB program, PPQ conducted firewood surveys during two peak holiday periods (Memorial Day and Labor Day) in Michigan and Ohio during the summer of 2004. The Michigan survey was targeted towards reducing the amount of firewood moved out of EAB quarantine areas and the Ohio survey was targeted toward reducing the amount of firewood coming from quarantined areas into Ohio. In Michigan, within a two-day period (Thursday/Friday), there were 128 referrals for firewood with 101 quarantine violations. There were 4871 pieces of firewood seized; only eight of these pieces were ash, but of these, six were infested with EAB. Because the insect of interest was EAB, no survey was done of any other wood pests that may have been present on the seized wood. The Labor Day survey in Ohio resulted in fewer seizures (7 seizures totalling 254 pieces of firewood, and no EAB observed), but it was noted in the report that although the firewood originated in Michigan near the Ohio border destinations included Indiana, Ohio, and Pennsylvania (APHIS PPQ EAB Program 2004).

As an example of a specific camping-related activity, stockcar racing is a popular spectator sport for millions of people in the United States. Races take place from February through November at venues scattered throughout the country and many fans camp while traveling the circuit. In 2006, after an employee at Great Smoky Mountains National Park noticed a visitor with firewood coming from an EAB-quarantined area, PPQ conducted a firewood survey in eastern Tennessee, including Sullivan County, where the Bristol Motor Speedway is located. Campgrounds near the speedway hosted campers from 40 different states; campers from 14 states had transported firewood to the race. Four seizures were made in violation of EAB quarantines, approximating 120 pieces of firewood (Pentico, 2006). The hardwood firewood seizures came from Michigan, Indiana, and the Canadian province of Ontario, localities over 500 miles from the campgrounds. Additionally, most of the out of state visitors with firewood came from from Florida, North Carolina, Georgia, and other southern states. This is noteworthy because the redbay ambrosia beetle, *Xyleborus glabratus*, is associated with a fungal pathogen, *Raffaelea lauricola*, which causes laurel wilt disease (LWD) and kills trees in the Lauraceae family, including redbay, sassafrass, and others. These tree species occur in LWD-infected areas and are often utilized as firewood. Similar blitzes were conducted in the Bristol, TN, area in 2007 and 2008. In 2008, a total of 29 firewood seizures occurred. Of these seizures, 75% of the people moving firewood knew about the quarantines, but moved the wood out of the quarantined areas anyway. Conversely, people who made reservations at campgrounds that expressly directed people not to bring firewood with them did not bring firewood, thus demonstrating the potential efficacy of citizen outreach programs (Cooley, 2008).

A 2008 survey of campers in Wisconsin revealed that most campers (87%) felt strongly that fires were an important part of the camping experience; while some (27%) continued to bring firewood from home or from some other distant location, this was a marked reduction from their 2006 survey, in which 44% of campers brought their own firewood (Peterson and Nelson, 2009). Most campers (75-78%) used 4-6 armload size bundles or more of firewood during their camping experience.

Scientists from Colorado State University conducted surveys of state park campers in Colorado and National Park campers in Wyoming, Colorado, Utah and Nevada from 2007-2009 to determine camper home states, firewood presence, firewood state sources, and the risk of harboring pests (Jacobi et al., 2010b). They surveyed campers in 15 state and 30 Federal campgrounds (from 7 state and 13 National Parks) and found that 66% of state and 60% of Federal campers interviewed had firewood at the campsites. Tent campers were more likely to have firewood than those with other means of camping (e.g., tent trailers, RVs, trailers). In Colorado state campgrounds, 4% of campers brought firewood from out-of-state sources, or, when weighted with visitor statistics, 2,358 campers per year. In Federal campgrounds, 39% of campers brought firewood from out-of-state sources, or, when weighted with National Park visitor statistics, 329,919 campers per year. Firewood type was primarily conifer and the majority of both conifer and hardwood firewood had bark attached. On out-of-state firewood, signs of prior insect infestation and fungal infection were present on 41% and 13%, respectively.

Much work has been done to raise awareness of the issues surrounding the movement of firewood by campers, and it does appear that people are becoming aware of the associated risks and that some are altering their habits. Many campgrounds and state forestry agencies are adding their assistance and urging visitors to parks and campgrounds to leave firewood at home and purchase it locally. Shenandoah National Park has just issued a ban on firewood purchased or brought from outside the park and will allow campers to gather dead and downed firewood in the park or purchase it at Park Camp Stores (NPS, 2010).

In general, the movement of firewood by campers is associated with the spread of forest pests. During the initial spread of EAB infestations in the northeast, 75% of new infestations were found in campgrounds or parks–these included campgrounds in Michigan, Ohio, Indiana, and West Virginia (Buck, 2008; Ellis, 2008). Firewood is often made from diseased or insect-ridden or killed trees, and curing or drying times for firewood can be as little as three months. People camp more often during the summer and early fall months, and insects or other pests are most active during these seasons. Movement of firewood by campers is often limited to 100 or 200 miles, presenting a substantial risk for exacerbating the spread of pests locally. Because some campers move firewood long distances, this is a greater risk for new long distance spread infestations.

Initiation, Approach, and Distribution of Pest Risk

Pest Interceptions Associated with Firewood

Border Interceptions

Forest pests accompany firewood by becoming associated with the wood in several ways. Pests present on the exterior surface of trees may be transported as hitchhikers, particularly if the bark is not removed. Forest pests that attack live trees often survive tree felling, rough processing, and shipping of firewood (e.g., many bark, longhorned, and buprestid beetles, as well as fungal pathogens). Pests may attack the wood after the tree is felled, in the landing, during transport, or while lying in a lumber or firewood yard.

In general, firewood imported from other countries must undergo heat treatment of 71.1ºC for 75 minutes prior to entrance into the United States (Jones, 2010). Exporting countries are required to provide proof of treatment or the firewood is refused entry. For this reason, there are no records in the PPQ database (PestID) specifying interceptions on firewood from any country other than Canada and Mexico. Recent border inspections of firewood from Canada and Mexico provide documentation that reportable pests may be moving into the United States via this pathway (APHIS, PestID queried 3/15/2010). Between July 2006 and February 2010, there were 93 interceptions on firewood from Canada and 17 from Mexico. Although these detections were rarely identified to species, the families Buprestidae, Cecidomyiidae, Cerambycidae, Curculionidae (including bark beetles within Scolytinae), Lonchaeidae, and Tortricidae were represented.

Domestically, there are numerous reports of various organisms detected in firewood at California state agricultural inspection stations. Focused inspections of firewood moving from other states into California between August 15, 2006, and August 19, 2009, resulted in 1071 interceptions from 48 states (CDFA, 2009). The majority (60%) were from states west of the Mississippi River, but 428 interceptions (40%) were from the east, many from states along the Eastern Seaboard (Figure 6). The interception data from California demonstrates that many types of live organisms are readily moved in firewood.

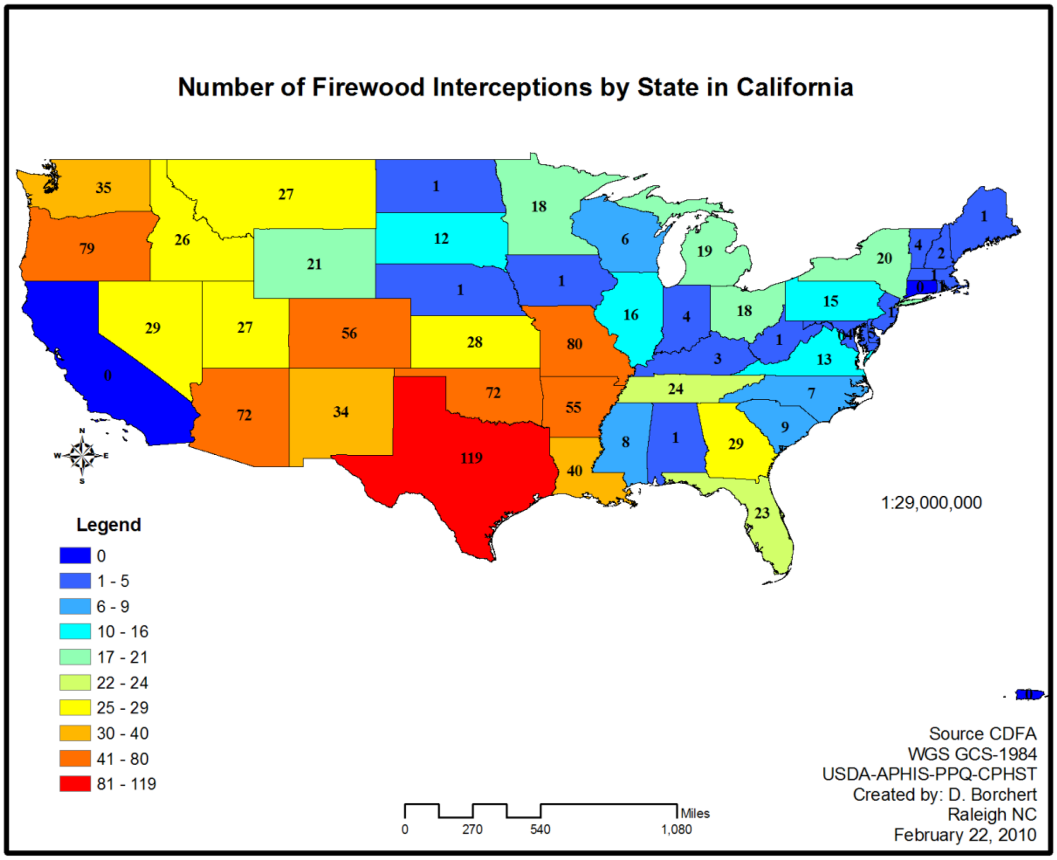

Figure 6. Firewood interceptions by state.

Table 7. Orders of insects detected on firewood at California inspection stations.

Order	Interceptions	Order	Interceptions
Blattodea	9	Lepidoptera	47
Coleoptera[1]	547	Neuroptera	2
Collembola	28	Orthoptera	1
Dermaptera	6	Psocoptera	28
Diptera	51	Raphidioptera	3
Embioptera	1	Thysanoptera	9
Hemiptera[2]	73	Thysanura	4

Hymenoptera	179	Trichoptera	1
Isoptera	13	**TOTAL**	**1002**

[1]There were beetles from 43 families found on firewood. The most frequently intercepted families were Cerambycidae (110), Tenebrionidae (88), Curculionidae (86 [78% were scolytids]), and Buprestidae (77).
[2]This order includes the piercing-sucking insects formerly classified as the order Homoptera.

Firewood Surveys and Studies

Over the past few years, a number of surveys and studies have focused on the domestic movement of firewood.

Haack et al. (2010) conducted a survey on firewood surrendered in 2008 at the Mackinac Bridge in Michigan and found that of the 1045 pieces of wood examined, 23% contained live borers and 41% more had evidence of previous infestations. The live borers included species from three orders and seven superfamilies or families including Bostrichoidea, Brentidae, Buprestidae, Cerambycidae, Cossidae, Curculionidae (Scolytinae and non-Scolytinae), and Siricidae. The wood pieces represented 21 genera of trees, with all genera reported to be currently or previously infested except *Salix* and *Thuja* (both of which had a very small sample size). The percentage of infested wood was 15, 16, and 33%, during the survey periods in April, July, and September, respectively. Live Buprestidae, Cerambycidae, and ambrosia (Curculionidae: Scolytinae) beetles were found during all three survey periods, while true bark beetles (Curculionidae: Scolytinae) were found only in the later two periods. Nearly half of the wood inspected was estimated to be cut from live trees the proceeding year and bark was present on 73% of all firewood pieces. This information indicates firewood transported by the public could easily transport wood pests that infest live or recently dead trees. Detailed interviews with people surrendering firewood on the bridge over four years found that most (75%) of vehicles that surrendered firewood originated from 61 counties in the Michigan lower peninsula, while 7% came from 10 counties in the upper peninsula. Sixteen percent of the vehicles surrendering firewood came from 17 other U.S. states (Indiana, Ohio, Wisconsin, Illinois, Minnesota, New York, Pennsylvania, Iowa, North Carolina, South Carolina, Tennessee, Kentucky, Louisiana, New Jersey, New Mexico, Texas, and Virginia), while 1% came from Canada (Ontario, Alberta, and Newfoundland).

A Pennsylvania survey of firewood producers and sellers revealed that most customers were private buyers who utilized the wood for home heating. These producers did not think that treating firewood was feasible, nor did they think that customers would be willing to pay more for treated wood (Ellis, 2008). The Kansas Department of Agriculture (KDA, 2007) found that firewood for retail sale in Kansas came from as far as California and New York and, although many of the bundles were labeled as “dried,” after being placed in boxes for a period of weeks, a third produced adult longhorned and bark beetles (Coleoptera: Cerambycidae and Cucurlionidae: Scolytinae). Surveys in New York State campgrounds in 2007 revealed differences in the percentage of campers who are likely to bring firewood from home–27% of people camping in the Catskills were likely to bring firewood with them, while 51% of people camping in the

Adirondacks bring firewood from home; overall, 36% of campers in New York campgrounds routinely brought firewood from home (Williamson, 2008).

From firewood retail surveys conducted over two summers, Jacobi et al. (2009; 2010a) found that in the west (Colorado, New Mexico, Utah, Wyoming), up to 75% of firewood still had bark attached and the majority (68-91%) exhibited evidence of preexisting insect infestation or fungal infection. Firewood bundles purchased from urban retail operations were labeled as having come from multiple states, including Arizona, California, Florida, Georgia, Idaho, Kentucky, Louisiana, Minnesota, Missouri, Montana, Nebraska, Oregon, Pennsylvania, Texas, and Washington. Some were labeled as having come from British Columbia. Most (75%) of the retailers were reported as selling firewood in both winter and summer. These firewood bundles were placed into enclosed bins (1-2 bundles per bin), and the bins were checked every 4-6 weeks. The first assessments found that of 196 bins, 67 (34%) had insects. These included scolytids, cerambycids, buprestids, wasps, carpenter ants, leaf beetles, parasitic flies, and predatory beetles. Walnut with thousand cankers disease was purchased, which highlights the risk associated with this particular disease complex moving on firewood.

Potential for Movement and Establishment of Pests in Firewood

The likelihood that an organism will move to and become established in a new environment is related to the chance of the organism being associated with the host or commodity, its ability to survive transport, its ability to locate and colonize suitable hosts, and its ability to reproduce and spread. The likelihood of introduction will vary with biology, origin, time, and destination.

For untreated firewood, the likelihood of a potential pest being associated with the wood depends primarily on the population levels in the area of origin and the habits and seasonalities of the life stages of the organism. Potential pests may be present at the time of harvest or may colonize before shipment. Many species of bark beetles and wood borers are attracted to recently cut wood and low grade trees, which may have pest infestations. Forest insects and pathogens of nearly every kind that have life stages closely associated with tree trunks, bark, and branches (such as wood borers, bark beetles, and pathogens) pose the greatest risk of infesting firewood. A potential pest infesting firewood must be able to survive transit conditions. Since firewood is minimally processed (cut and possibly split) and transit time is typically short duration, pests are likely to survive.

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. Many factors affect the ability of invasive species to establish, such as climate, suitable hosts, competition with native species, and extinction of small populations. Regions with the greatest risk of pest entry are those with high levels of human mobility and trade; therefore, urban areas (Figure 7) are more at risk than isolated forests for introduction of forest pests (Liebhold et al., 1995).

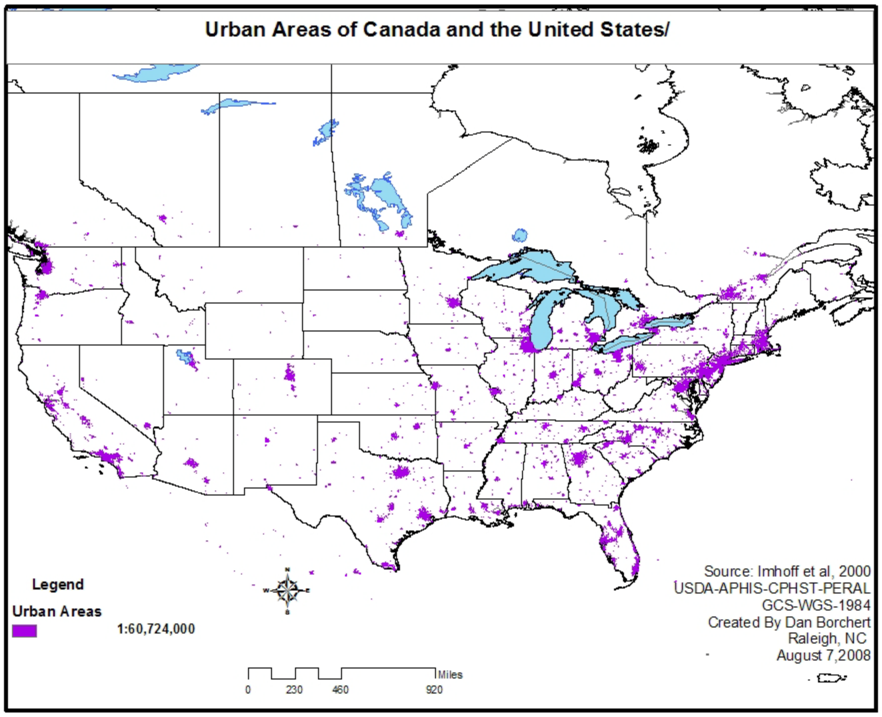

Figure 7. Urban areas of the United States and Canada depicted using city lights data (Imoff et al., 2004)

Biological invasions of non-native and native organisms are believed to be heavily influenced by, and associated with human mediated activities (Wilson et al., 2009), (Valery et al., 2009). The nature of the human involvement can be used to estimate the possible type of impact and pattern of dispersal as well as the risks associated with the movement. The frequency and volume of material moved and introduced into new areas, such as firewood, increases the likelihood of pest introduction.

We classified firewood movement into three main patterns characterized primarily by distance moved: local, intermediate, and long-distance. This is similar to the stratified dispersal of gypsy moth described by Sharov and Liebhold (1998), which involves local and long-distance dispersal. The distance, volume, and likely endpoint of the firewood are the main risk points associated with firewood dispersal pathways. The most frequent dispersal pathway for firewood is local or leading-edge dispersal, due to the general availability of the resource, the cost of transportation, and the relatively low value of the commodity. Leading edge dispersal can be natural or human-mediated dispersal, which involves gradual range expansion into new areas with near-continuous introduction frequency (Wilson et al., 2009). The local movement of firewood can increase the speed of the leading edge movement compared to natural dispersal. If the pest organisms are native, the range expansion of the pest is typically mirrored by natural enemies in leading edge dispersal.

The intermediate and long-distance movement of firewood is estimated to occur less frequently than local movement. Large volumes of firewood can be moved intermediate and long distances by commercial firewood distributors into metropolitan areas and regional or national retail distribution chains. Both of these markets have high demand for the resources and may pay higher prices. Lower volumes of firewood can also be moved intermediate and long distances by non-commercial entities such as campers, recreational event participants, and second home owners, primarily for convenience and cost savings, but the destination endpoints can be widely dispersed. The dispersal pathway that most accurately depicts the intermediate and long-distance movement of firewood is a modified corridor/cultivation pathway (Wilson et al., 2009). The extensive interstate highway and railway transportation system in the United States (Figure 8) provides artificial corridors that connect suitable habitat forms facilitating the movement of firewood. Firewood contains the organisms that are collected from and distributed to many different regions. The organisms are within a suitable host that will often allow for development and possible establishment to occur. It is important to recognize that there are many impediments to the establishment of organisms when introduced into new areas. One of the most notable impediments are Allee effects, which are factors that cause extinction in low-density populations due to problems with mate location, host defense, inbreeding depression, and natural enemies. Allee effects vary depending on the biology of the pest, volume, and frequency of introduction and susceptibility of the habitat (Contarini et al., 2009).

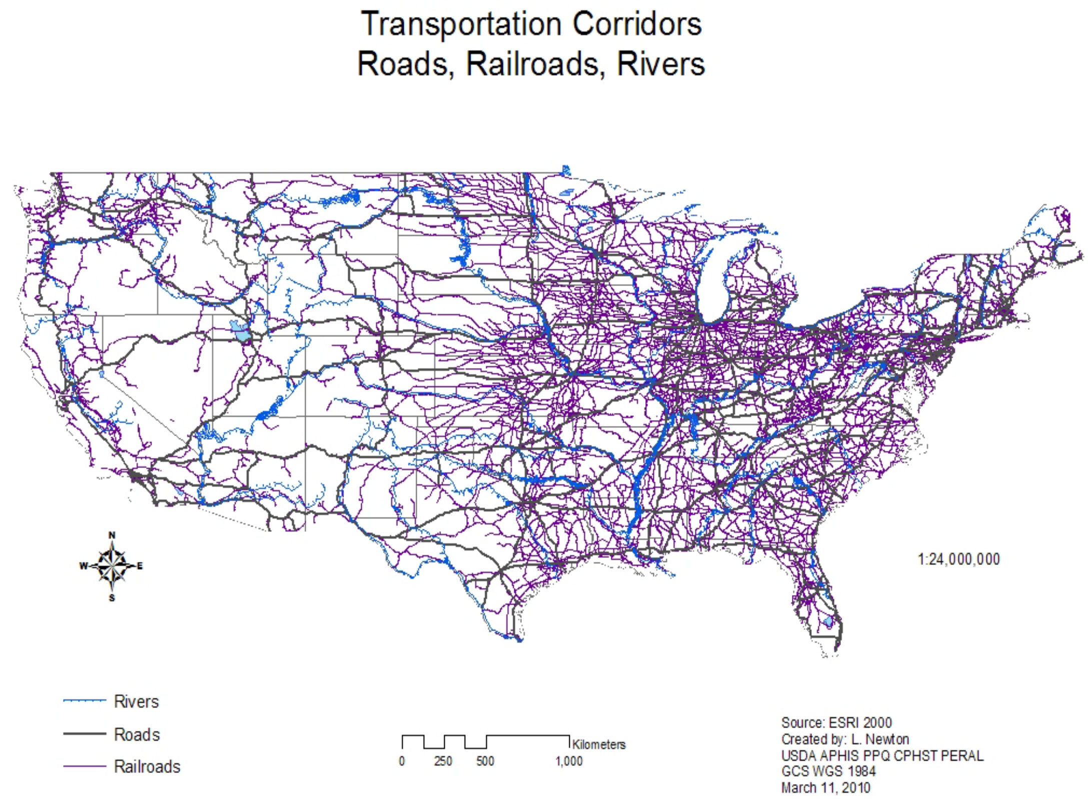

Figure 8. Transportation corridors throughout the United States.

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 forests contain over 800 species of trees, of which 82 are reported as non-native (Smith et al., 2009). 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.

For purposes of classification by the U.S. Forest Service, the country is divided into four main regions (Figure 9): North, South, Rocky Mountain, and Pacific Coast. Additionally, there are sub-regions (North East, North Central, South East, South Central, Great Plains, Intermountain, Pacific Northwest, and Pacific Southwest). Roughly 40% of the North, South, and Pacific Coast regions are forested land, while 20% of the Rocky Mountain region is forested. Private ownership accounts for 57% of the overall forested land in the United States, but the percentage by region is 76% in the North, 88% in the South, 25% in the Rocky Mountain region, and 57% in the Pacific Coast.

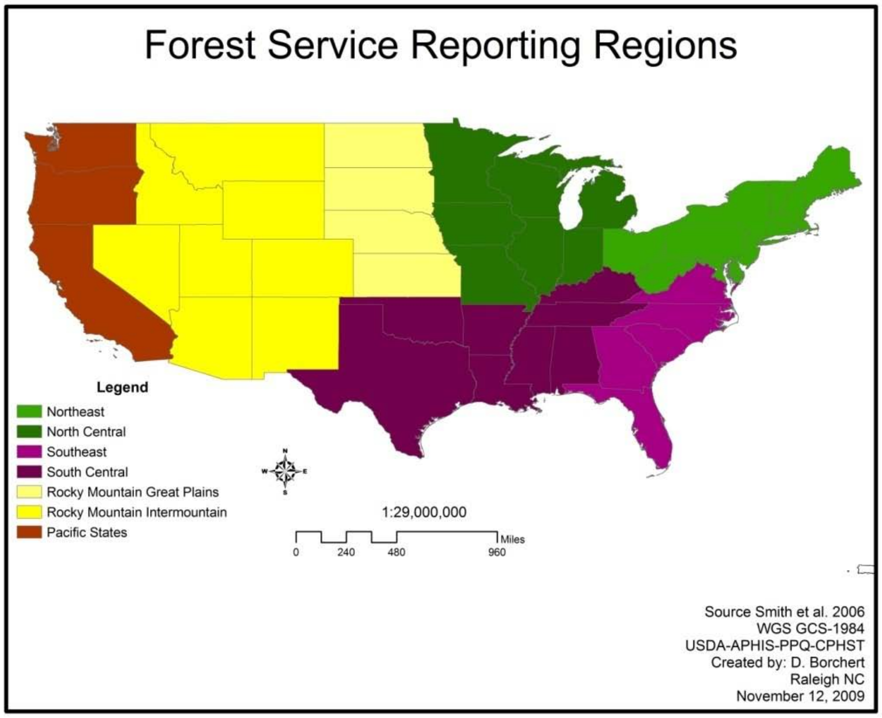

Figure 9. United States Forest Service reporting regions.

The main forest types (Figure 10) in the east are oak-hickory (35.9%), loblolly-shortleaf pine (14.5%), maple-beech birch (13.9%), oak-pine (7.7%), oak-gum cypress (5.7%), elm-ash-cottonwood (5.2%), Aspen-birch (4.5%), Spruce Fir (3.9%), and white-red jack pine (2.8%), with other forest types and non-stocked comprising the remaining 5.9%.

The main forest types in the western regions are fir-spruce (20.5%), other softwoods (19.4%), pinyon-juniper (14.9%), western hardwoods (13.9%), Douglas fir (10.7%), ponderosa pine (6.7%), hemlock-sitka spruce (4.7%), lodgepole pine (4.3%). Western white pine, larch, redwood, and non-stocked comprise the remaining 4.9%.

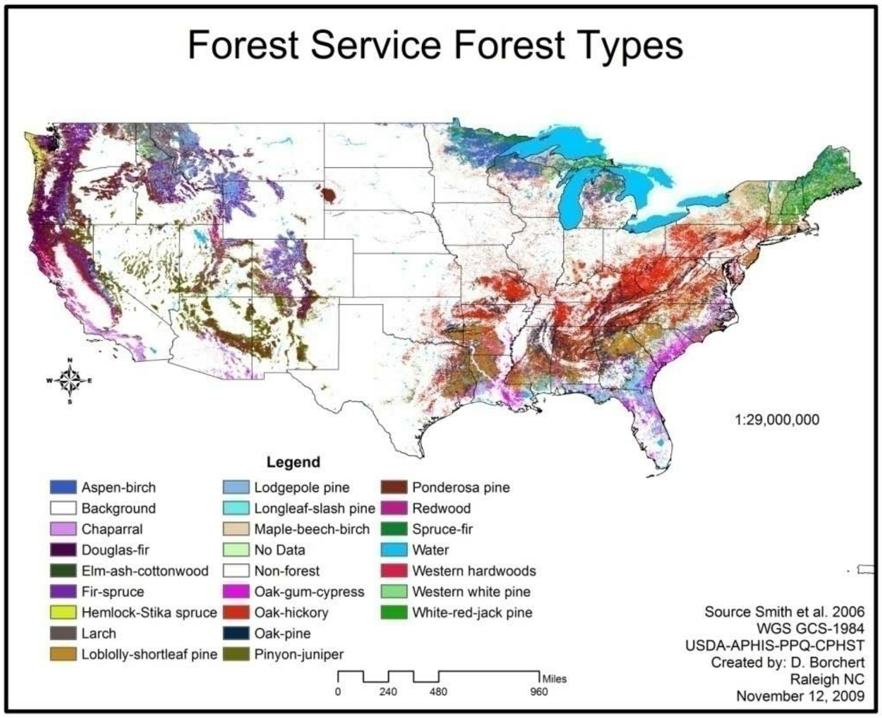

Figure 10. United States Forest Service forest types.

In a recent forest products report (Smith et al., 2009), fuelwood products are defined as wood used for conversion to some form of energy, primarily in residential use. For the entire United States, 9.3% of the roundwood product is designated as fuelwood, with 6.2% listed as hardwoods source and 3.2% listed as softwoods source, but there are substantial differences in percentages by region. For the North region 18.9% of all roundwood products harvested were designated as fuelwood, with 17.8% listed as hardwoods and 1.1% softwoods. For the South region, 4.3% was designated as fuelwood, with 3.9% listed as hardwoods and 0.4% softwoods. For the Rocky Mountain region 17.5% was designated as fuelwood, with 5.8% hardwood and 11.7% softwoods. For the Pacific Coast Region, 12.6% was fuelwood, with 0.6% hardwoods and 12% softwoods.

A national woodland ownership survey determined that family forest ownership accounts for 35% of all forest land in the United States (Butler, 2008). Most family forest owners (63%) have less than 10 acres of forest land, but of the total acreage held by family forests, 53% have 100 or more acres, and that forest has been owned on average for 26 years or more. Of the 12 reasons rated for owning forest land, firewood production was rated 11th with 15% of the family forest area represented, but there were future plans in 28% of the area to harvest firewood. Insects and plant diseases were the number one concern of family forest owners, accounting for nearly 58% of the family forest area.

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 et al., 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. A study of bark beetle movement in timber found that storage time and proximity of the material to forests had the greatest impact on likelihood of introduction and establishment of the beetles (Skarpaas and Okland, 2009). The most urbanized areas of the United States are in the Northeast and Southeast, which are also the areas where the percentage of urbanization increase is the greatest (Smith et al., 2009).

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 EAB 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 ALB 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).

Forest Pest Damage Examples and Estimates

Mortality from insects was detected by aerial survey on 5.3 million acres of the 400 million acres surveyed in 2006, with 50% of the mortality attributed to *Dendroctonus ponderosae*, the indigenous mountain pine beetle, but the estimates do not include acres where mortality is sparse. Insect-caused defoliation was reported on 8.5 million acres of forests, with forest tent caterpillar, budworms (western spruce, spruce, and jack pine), aspen leaf miner, and gypsy moth accounting for most of the defoliation (more than 90 percent) (Smith et al., 2009). Diseases caused by dwarf mistletoes, root pathogens, and canker fungi are not easily detected by aerial survey, but may be present on millions of acres of forest causing loss of growth, mortality or increasing the mortality caused by other organisms such as bark beetles. In 2006, the Forest Health Technology Enterprise Team estimated 25 percent or more of the standing live trees larger than 1 inch in diameter would die in the next 15 years, representing 58 million acres (Smith et al., 2009).

In addition, evidence suggests that changes in environmental conditions and forest ecosystems have resulted in increased susceptibility of forests to invasion by forest pests. This has been observed primarily with indigenous forest pests like the mountain pine beetle, *Dendroctonus ponderosae* (Hopkins), which is affecting nearly 1.5 million acres of forest since 1996 in Colorado (Colorado State FS, 2008). The epidemics of mountain pine beetle are attributed to lack of cold temperatures, drought, and the increased availability of mature hosts.

A study of climate change and 134 individual tree species in the northeastern region of the United States found that a large change in forest species composition was likely to occur as a result of climate change. Iverson et al. (2008) estimated that the mature trees will eventually be in climates less suitable for their growth leading to increased susceptibility to pests and pathogens. Similarly forest pests would be able to develop more rapidly with increasing temperatures and expand their potential range (Iverson et al., 2008).

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 the forest resources in the United States. In 1998, the forest products industry harvested 19 billion ft^3 of hardwood and softwood timber with 50% used in construction and building materials and 30% used in pulp and paper. The United States is the world production leader in lumber and wood products for residential construction, furniture, and pulp and paper. In 1997, there were over 44,000 forest product facilities in the United States employing nearly 1.3 million people and producing shipments valued at $262 billion (US DOE, 2000).

There is considerable uncertainty about the potential economic impact of new forest pest establishment on the forests and the forest products industry. Losses could be substantial during pest outbreak situations or if impacts are severe on particular ecosystems (i.e, redbay or thousand canker disease of walnut). The size of area, rate of spread, and type of impact are the primary factors that would influence the potential economic impact. Many different forest pests are present in the United States that cause significant damage to forested areas, but losses to these areas may be managed or tolerated, such as with southern pine beetle and *Cronartium comandrae* Peck (comandra blister rust of pine).

The average cost of Federal forest pest regulatory programs in the United States by USDA-APHIS-PPQ from 2004-08 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.

Pests Associated with Firewood

Native insects and diseases are important components in healthy forest ecosystems and at endemic levels help to remove stressed trees and to maintain species diversity. Native trees generally exhibit a certain level of resistance to native pests and are able to tolerate infestations at low levels. However, overcrowding, overmaturity, drought, and other stressors appear to have now placed North American trees and entire forest populations at a higher risk for infestation and outbreaks. A national estimate from 2006 (Figure 11)[7] places approximately 58 million forest acres at risk from native and introduced pests, many of which are known to move on firewood. Half (29 million acres) are at risk from bark beetles (Coleoptera: Curculionidae: Scolytinae).

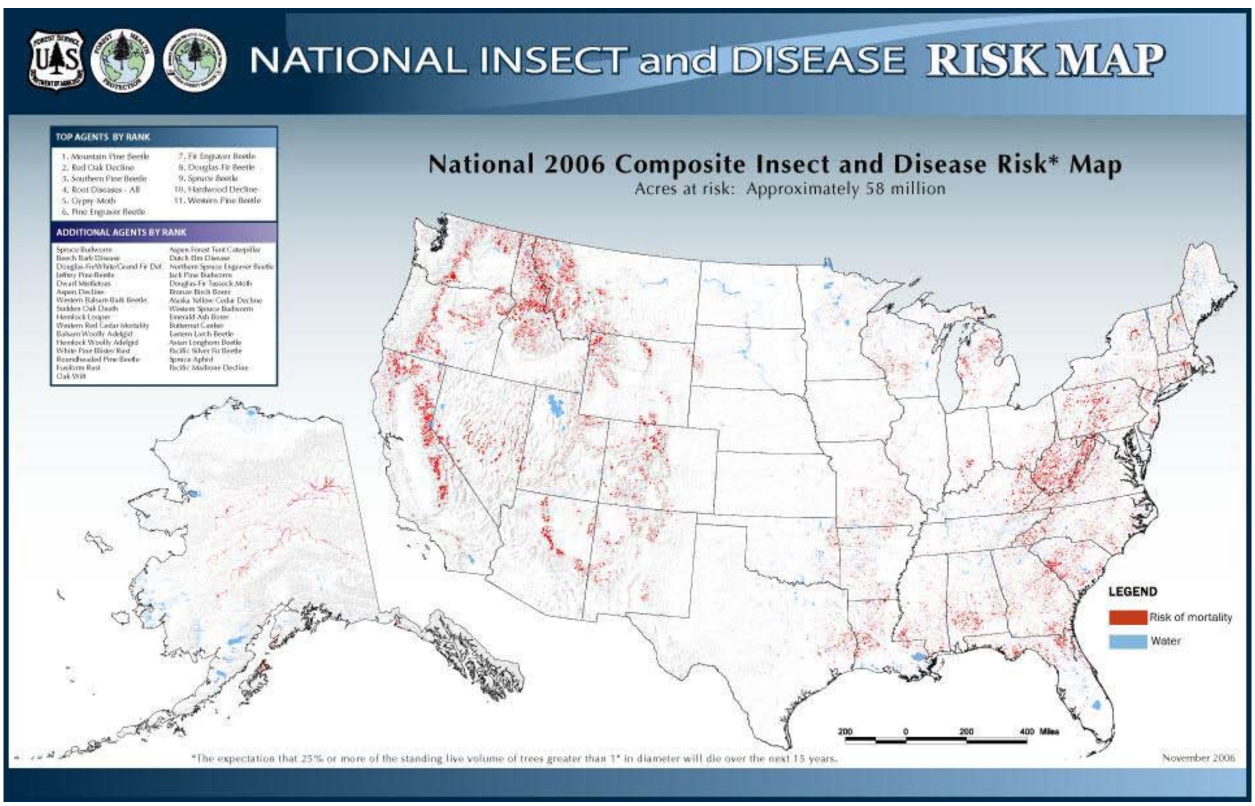

Figure 11. National insect and disease risk map for the United States.

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[7] Risk is defined as the expectation that 25% or more of the standing live volume of trees greater than 1" in diameter will die over the next 15 years. Source: U.S. Forest Service (Available at http://www.fs.fed.us/foresthealth/technology/images/RiskMap_agents_hillshade_md.jpg)

Since firewood is derived from a large number of woody taxa and may contain bark, it is likely that many species of insects and wood pathogens could move with the commodity. Many forest pathogens utilize insects as vectors. Scolytid beetles are commonly reported as vectors; however other beetles in the Cerambycidae, Curculionidae, and Buprestidae, as well as some mites, scales, wasps, and moths, are also effective vectors of forest pathogens (Haugen and Hoebeke, 2005; Houston and O'Brien, 1983), (FDACS, 1983; Malloch and Blackwell, 1993). This movement ranges from external associations to intricate symbiotic interactions (Malloch and Blackwell, 1993). In some instances the insect is believed to utilize the fungus to overcome host plant defense mechanisms (Eckhardt et al., 2004; Horntvedt et al., 1983) or use by-products of the fungus for brood development within the tree (Eckhardt et al., 2004).

Insects

Examples of insects known to move on raw wood and firewood are outlined below (Table 8). Fact sheets for the majority of these insects are in Appendix B.

Table 8. Examples of insects known to move on raw wood/firewood.

Insects			
Order: Coleoptera			
Family: Bostrichidae			
Species/	**Origin**	**Host genera**	**Pathways for movement**
Scobia declivis / lead cable borer	native (west)	Hardwoods: *Quercus, Acer, Acacia, Eucalyptus, Umbellularia*	Intercepted in CA in firewood from MO and CO; detected in FL in 2000
Family: Buprestidae			
Agrilus coxalis / goldspotted oak borer	native (west)	Hardwoods: *Quercus*	Expanding native range in western states; a pest in CA; likely introduced into CA on firewood from Mexico
Agrilus planipennis / emerald ash borer	Exotic	Hardwoods: *Fraxinus, Juglans, Pterocarya, Ulmus*	Wood packing material (WPM) (introduction); domestic spread traced to movement of logs, firewood, nursery stock
Agrilus sulcicollis / European oak borer	exotic (now in Canada)	Hardwoods & possibly conifers: *Quercus, Castanea, Carpinus, Fagus*; possibly *Pinus*	Believed introduced into Great Britain in imported timber; common in cut wood piles in forests for later use as fuel
Buprestis aurulenta / golden buprestid	native (west)	Conifers: *Abies, Picea, Pinus, Pseudotsuga, Thuja*	Intercepted in CA on firewood
Chrysobothris trinervia / metallic woodboring beetle	native (west)	Conifers: *Picea, Pinus*; also *Larix, Pseudotsuga*	Found in MN on barked logs of *Larix occidentalis* from the west
Melanophila drummondi / flathead pine borer	native (west/east)	Conifers: *Abies, Larix, Picea, Tusga, Pseudotsuga, Pinus*	Found in MN on barked logs of *Larix*; introduced into China on unprocessed logs imported from western U.S.
Family: Cerambycidae			

Anoplophora glabripennis / Asian longhorned beetle	Exotic	Hardwoods: *Populus, Salix; also Acer, Aesculus, Alnus, Betula, Fraxinus, Hibiscus, Liriodendron, Malus, Morus, Platanus, Prunus, Pyrus, Robinia, Rosa, Sophora, Ulmus*	WPM (introduction)
Megacyllene antennata / mesquite borer	native (southwest)	Hardwoods: *Prosopis*	Intercepted in CA in firewood from TX
Monochamus obtusus / the obtuse sawyer	native (west)	Conifers: *Abies, Pinus, Pseudotsuga*	Vectors *Bursaphelenchus xylophilus*, pine wilt nematode; intercepted in CA in firewood from WA and MI
Neoclytus muricatulus / ---	native (east and west)	Conifers & Hardwoods: *Abies, Larix, Picea, Pinus, Pseudotsuga; Quercus*	Found in MN on barked logs of *Larix occidentalis* from the west
Phymatodes decussatus / ---	native (west)	Hardwoods: *Quercus*	Intercepted in CA in firewood
Phymatodes dimidiatus / spruce bark borer	native (west and north)	Conifers: *Abies, Larix, Picea, Pseudotsuga, Tsuga*	Found in MN on barked logs of *Larix occidentalis* from the west
Phymatodes lecontei / ---	native (all of U.S.)	Conifers: *Pinus, Larix, Abies, Picea*	Genus has been intercepted at U.S. border in dunnage and firewood; found in MN in barked logs of *Larix occidentalis* imported from the western U.S.
Tetropium velutinum / western larch borer	native (west)	Conifers: *Abies, Picea, Pinus, Larix, Pseudotsuga, Tsuga*	Found in MN in barked logs of *Larix* imported from western U.S.
Xylotrechus longitarsus / zebra beetle	native (west)	Conifers: *Pseudotsuga*	Found in MN in barked logs of *Larix* imported from western U.S.
Xylotrechus nauticus / oak cordwood borer	native (west)	Hardwoods: *Quercus, Arbutus, Eucalyptus, Prunus, Salix, Juglans*	Intercepted in CA in firewood from PA
Xylotrechus sagittatus / arrowhead borer	native (east)	Conifers: *Abies, Picea, Pinus*	Likely introduced into OR in WPM and other raw wood products
Family: Cucuijidae			
Cucujus clavipes / cucujid beetle	native (east and west)	Hardwoods: *Fraxinus, Populus*	Intercepted in CA on firewood from MI and OK
Family: Curculionidae: Scolytinae			
Dendroctonus ponderosae / mountain pine beetle	native (west)	Conifers: *Pinus; Picea*	WPM; intercepted in CA on firewood from OR
Dendroctonus pseudotsugae / Douglas-fir beetle	native (west)	Conifers: *Pseudotsuga, Larix, Tsuga*	Found in MN on barked logs of *Larix occidentalis*; most likely WPM or other raw products from the west; intercepted in Great Britain on timber from Canada
Dendroctonus valens / red turpentine beetle	native (US except for Gulf States)	Conifers: *Pinus, Picea, Abies, Larix, Pseudotsuga*	Found in MN on barked logs of *Larix occidentalis*; most likely WPM or other raw products from the west; intercepted in Great Britain on timber from Canada

Dryocoetes confuses / western balsam bark beetle	native (west)	Conifers: *Abies, Picea, Pinus*	
Hylesinus californicus / ---	native (west)	Hardwoods: *Fraxinus, Olea*	Recent detection in east most likely the result of its introduction in WPM and other raw wood products
Hylesinus criddlei / ---	native (west and midwest)	Hardwoods: *Fraxinus*	Recent detection in east most likely the result of its introduction in WPM and other raw wood products
Ips mexicanus / Monterey pine ips	native (west)	Conifers: *Pinus*	Intercepted in CA in firewood from AZ; vectors *Fusarium circinatum* (pitch canker)
Monarchrum fasciatum / yellow banded timber beetle	native (east to Texas)	Conifers & Hardwoods: *Pinus, Tsuga; Betula, Quercus, Carya, Malus, Mimosa, Nyssa, Populus, Prunus, Acer, Castanea, Liquidambar*	Likely introduced into OR in WPM and other raw wood products
Pityophthorus juglandis/ walnut twig beetle	native (west)	Hardwoods: *Juglans*	Vectors *Geosmithia* sp. (thousand cankers disease); likely to move on raw wood; has been observed in walnut firewood for sale in CO
Polygraphus rufipennis / four-eyed spruce bark beetle	native (broadly distributed)	Conifers: *Pinus, Larix, Abies, Picea*	Intercepted at U.S. border in dunnage & firewood; found in MN on barked logs of *Larix occidentalis* from western U.S.
Pseudopityophthorus pubipennis / western oak bark beetle	native (west)	Hardwoods: *Quercus, Lithocarpus, Castanea, Aesculus*	Intercepted in CA in firewood from TX
Scolytus laricis / larch engraver	native (west)	Conifers: *Larix*	Found in MN in barked logs of *Larix* from western U.S.; intercepted in Great Britain on timber from Canada
Tomicus piniperda / pine shoot beetle	exotic (in NE/Central U.S.)	Conifers: *Pinus, Picea, Abies, Larix*	Vectors blue-staining fungi; intercepted on WPM (especially dunnage) at U.S. borders; logs containing overwintering adults pose a risk
Xyleborus glabratus / redbay ambrosia beetle	exotic (in SE U.S.)	Hardwoods: (Lauraceae)--*Persea, Sassafras, Lindera, Litsaea, Phoebe, Cinnamomum;* (Dipterocarparceae)--*Shorea*; (Fabaceae)--*Leucaena*	Vectors *Raffaelea lauricola* (laurel wilt disease); thought to have been introduced into U.S. in WPM; firewood is indicated in spread in southeastern states
Xyleborus xylographus / ambrosia beetle	native (east)	Hardwoods: *Quercus, Corylus, Prunus, Malus, Alnus, Acer, Abies, Juglans*	WPM implicated in spread from eastern U.S. into OR
Xyloterinus politus / ambrosia beetle	native (primarily east but also in WA and AK)	Hardwoods & Conifers: *Acer, Alnus, Betula, Carya, Castanea, Fagus, Fraxinus, Magnolia, Populus, Prunus, Quercus, Ulmus; Picea, Pinus, Tsuga*	Potential vector for *Ophiostoma ulmi* (Dutch elm disease); WPM implicated in spread from eastern U.S. into WA
Family: Lyctidae			

Lyctus cavicollis / western lyctus beetle	native (widespread)	Hardwoods: *Eucalyptus, Carya, Fraxinus, Quercus, Citrus, Ulmus, Prunus, Platinus, Robinia, Juglans*	Intercepted in CA in oak firewood from MN; introduced into Europe on consignments of sawn hardwood from the U.S.
Family: Micromalthidae			
Micromalthus debilis / telephone pole beetle	native (east)	Conifers & Hardwoods: *Pinus, Tsuga, Castanea, Quercus*	Articles of wood - dunnage and other WPM implicated for introduction from eastern U.S. into OR and WA
Order: Hymenoptera			
Family: Siricidae			
Sirex noctilio / European (sirex) woodwasp	exotic (established in northeast)	Conifers: *Pinus*; also *Abies, Larix,Picea, Pseudotsuga*	Symbiotic fungus, *Amylostereum areolatum*, kills host trees; WPM (introduction)

Pathogens

Pathogens are cryptic organisms that can express symptoms that may be confused with symptoms of abiotic damage, or the pathogen can be present in the host but remain latent. These characteristics complicate detection in the field or at ports-of-entry. There are few port interception records of pathogens with wood or wood products due to the difficulty in visually detecting them as well as the time and expertise required for making accurate and timely identifications (Rogers, 2008; USDA, 2000). The taxonomy for many wood pathogens, particularly the deep wood fungi in the Ophiostomatoid group is very complex (Mireku and Simpson, 2002; Uzunovic et al., 1999; Wingfield et al., 1993).

While most publications focus on the threat and potential damage from exotic pathogen introductions, movement of native or long established pathogens within the United States is also important. This movement could bring the pathogen or pathogen vector to areas of the United States where they have not been reported. Over time, new opportunities for pathogens arise as strains develop, different mating types of the same species or strain become more virulent or susceptibilities change. Climate change is considered one of the reasons for expanding distributions and host ranges for pathogens (Dale et al., 2001; Woods et al., 2005); the timing and type of forest/nursery/landscape management practices is considered another (Castello et al., 1995; Harrington and Wingfield, 2000; MacDonald, 2003; Ostry and Juzwik, 2008; Ward and Mistretta, 2007).

Examples of fungi and associated diseases with potential to move on raw wood are outlined below (Table 9). Fact sheets for the majority of these pathogens are in Appendix C.

Table 9. Examples of forest pathogens and associated diseases with potential to move on raw wood/firewood.

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 sp. / thousand cankers disease	origin unknown (west)	Hardwoods: *Juglans*	Vectored by bark beetle (*P. juglandis*); likely to be moved in raw wood products; has been observed in walnut firewood for sale in CO
Neonectria faginata / beech bark disease	exotic (found in eastern U.S.)	Hardwoods: *Fagus*	Movement in MI associated with firewood and campgrounds
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; firewood is indicated in spread in southeastern U.S.
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
Class: Oomycetes **Order: Pythiales**			
Phytophthora ramorum / sudden oak death	exotic (in western U.S.)	Hardwoods & Conifers: Many known hosts, including *Acer, Aesculus, Camellia, Castanea, Fagus, Fraxinus, Magnolia, Quercus, Rhododendron, Rosa, Salix, Vaccinium; Pseudotsuga, Sequoia, Taxus, Abies*, and others	Firewood in *P. ramorum*-affected areas is federally regulated to prevent movement of this organism

Evolving forest pathosystems and the concerns they raise with domestic movement of unmitigated firewood

As pathogens are exposed to new variables such as new hosts, new vectors, different climates, or different forestry practices, the likelihood for new strains or associations increases (Dale et al., 2001). Domestic movement of unmitigated firewood could distribute pathogens, their vectors, or both, to environments where there are susceptible tree taxa and climatic conditions that could result in broader geographic distributions of the diseases or epidemics. There are costly historical examples of unexpected pathogen interactions as well as many new threats being reported.

Historical examples

Two well-known examples of unexpected interactions with introduced species are Dutch elm disease and pine wilt disease. In each of these forest pathosystems, a native species interacts with an introduced species and together the organisms cause damage far beyond what each organism could do on its own.

For Dutch elm disease, the association of an introduced *Ophiostoma* fungus with a native North American insect (*Hylurgopinus rufipes* (Eichhoff) [Coleoptera: Curculionidae: Scolytinae] and exotic European elm bark beetle (*Scolytus multistriatus* (Marsham) [Coleoptera: Curculionidae: Scolytinae] led to the downfall of elm as a major landscape and forest tree (Allen and Humble, 2002). Wood (1982) notes in his description of *H. rufipes* that prior to the association with the Dutch elm disease fungi, the native beetle was considered a species of limited economic importance (Allen and Humble, 2002; Wood, 1982).

Pine wilt disease is also a case where an introduced pathogen interacted with insect vectors already present to cause extensive tree mortality. This was the scenario in Japan with the introduced nematode (*Bursaphelenchus xylophilus* Stein) and the Japanese sawyer beetle (*Monochamus alternatus* Hope.) [Coleoptera: Cerambycidae] (CABI, 2007).

Hausner et al. (2005) conducted a study on the types of fungi associated with the pine shoot beetle (*Tomicus piniperda* (L.)) [Coleoptera: Curculionidae: Scolytinae] in Ontario, Canada. From their results, they suggested that *T. piniperda*, a relatively new forest pest issue for North America, may have also introduced more aggressive or virulent strains of fungi, and that the beetle could promote faster spread of pathogens to new hosts or to new vectors. Jacobs et al. (2004) reported that the forest pathogen *L. wingfieldii* was introduced to North America by *T. piniperda* and then was able to become associated with other native bark beetles [*Ips pini* (Say) and *Dendroctonus valens* LeConte] in its new location. Jacobs et al. (2004) contrasted this behavior to the behavior of *L. wingfieldii* in Europe where the fungus appears exclusive to *T. piniperda*.

Recently, a new disease was reported in the western United States called thousand cankers disease (Hoheisel, 2008; Murray, 2008); Tisserat et al., 2009). The pathogen is killing walnut trees, primarily black walnut (*Juglans nigra*), planted in the western United States (Murray, 2008); Tisserat et al., 2009). The causal organism is a newly described species of *Geosmithia* (proposed name *Geosmithia morbida*) [Ascomycetes: Eurotiales] and is vectored by the walnut twig beetle (*Pityophthorus juglandis*) [Coleoptera: Curculionidae: Scolytinae], an insect native to the southwestern United States (Campbell and Tisserat, 2008). *Geosmithia* species have been reported with bark beetles previously but this is the first association between the walnut twig beetle and walnut trees (Murray, 2008). Prior to this outbreak, the walnut twig beetle was reported as only a minor pest of the native Arizona walnut (*Juglans major*) in the southwestern United States (Campbell and Tisserat, 2008; CSU, 2008; Murray, 2008). Mortality of western populations of black walnut from this insect-pathogen complex is increasing and there is concern the disease could devastate the large native population of black walnut in the east or reduce commercial nut production of English walnut (*J. regia*) in California (Grainger et al., 2008).

The adaptability of these pathogens and vectors in different environments, combined with the United States' high volume of trade provides many opportunities for new pest interactions.

New Understanding and Risks

Nuances of these pathosystems are discovered as new molecular techniques are developed and applied, Some of the most important North American forest diseases and subsequently most heavily studied diseases are now being reported as complexes of species or subspecies with unique host ranges and distributions. This is the case with *Heterobasidion annosum*, where various intersterility groups and separate species are now reported that have unique host ranges and distributions (Linzer et al., 2008). *Ceratocystis fimbriata*, the causal agent of wilt and canker diseases around the world, was recently split into three geographic clades with multiple species emerging from those clades (Johnson et al., 2005). In some instances, such as in the North American clade, all previous reports of *C. fimbriata* on woody hosts in North America are no longer considered valid (Hodges, 2007). A similar scenario exits for the root-rotting fungi within the genus *Armillaria* (CABI, 2007), where prior to 1980 the species *A. mellea* was used for almost all reports of the disease in North America (Sinclair and Lyon, 2005). More recently the taxon has been separated into at least ten different species in North America and identification presents a challenge (Sinclair and Lyon, 2005).

Researchers who study beetle-vectored fungi frequently encounter new species of fungi. With these new discoveries, their distribution outside of the region of initial detection is not yet known and because pathogens are not always easily detected, once damage reaches a noticeable level the pathogen may have been present for a long time. When researchers began studying hickory decline and mortality in the eastern United States they found the beetle, *Scolytus quadrispoinosus* Say. [Coleoptera: Curculionidae: Scolytinae], and attributed the decline to a combination of stressed trees and the beetle activities (Juswik et al., 2008). However, additional research of this decline led to the discovery of a new fungus *Ceratocystis smalleyi* (Johnson et al., 2005). The fungus and beetle are believed to be part of a complex that is killing the hickory trees (Juzwik et al., 2008). The laurel wilt pathogen, *Raffaelea lauricola* Harr, Fraedrich and Aghayeva [Ascomycetes: Ophiostomatales] is another example. This is a newly described fungus that is killing native Lauraceae, particularly redbay (*Persea borbonia*) in the southeastern United States (Harrington et al., 2008). *Xyleborus glabratus* Eichhoff [Coleoptera: Curculionidae: Scolytinae] is believed to be the vector that arrived with the pathogen in wood packing materials from its native range in Asia (FDACS, 2008; Harrington et al., 2008).

Across the border, in Canada, *Leptographium fruticetum* Almouti, Kim & Breuil was identified in association with *Ips perturbatus* Wood & Bright (Alamouti et al., 2006). From this same collection study, *Ophiostoma manitobense* Reid & Hausner (Synonym: *Ceratocystiopsis manitobensis* (Reid and Hausner) Zipfel, de Beer & Wingf.) was also found and identified (Alamouti et al., 2007; Zipfel et al., 2006). This species had recently been reported and newly named from *Pinus resinosa* in Manitoba (Hausner et al., 2003; UBCF, 2004). In British Columbia, *Leptographium longiclavatum* Lee, Kim & Breuil was found in association with *Dendroctonus ponderosae* Hopkins (Lee et al., 2005). *Dendroctonus ponderosae* is native to North America and is present in the western United States (CABI, 2007). Studies by Lee et al. (2006) found that the fungus is pathogenic and may contribute to the mortality of pines infested by *D. ponderosae*.

There are also many examples of these types of detections beyond North America. Some examples from the last few years of published research include *Ophiostoma aurorae* Zhou & Wingf. associated with *Hylastes angustatus* (Herbst) in pine (Zhou et al., 2006); *O. ainoae* Solheim, *O. flexuosum* Solheim, and *O. cucullatum* Solheim associated with *Ips typographus* (L.) in spruce (Solheim, 2007); *Ceratocystis bhutanensis* van Wyk, Wingf. & Kirisits associated with *Ips schmutzenhoferi* Holzschuh in spruce (Van Wyk et al., 2004); *O. aoshimae* Ohtaka, Masuya & Yamaoka and *O. rectangulosporium* Ohtaka, Masuya & Yamaoka associated with scolytid beetles in fir trees (Ohtaka et al., 2006); *O. breviusculum* Chung, Yamaoka, Uzunovic & Kim associated with bark beetles in larch trees (Chung et al., 2006); *O. karelicum* Linnakoski, De Beer & Wingf. associated with *Scolytus ratzeburgi* Janson in birch trees (Linnakoski et al., 2008); *Leptographium koreanum* Kim & Kim associated with *Tomicus piniperda* (L.) in pine logs (Kim et al., 2004); and *Leptographium sinoprocerum* Lu, Decock & Maraite associated with *Dendroctonus valens* LeConte in pine trees (Lu et al., 2008). New associations are being found at a rapid rate. These findings, both past and present, raise the uncertainty of the current reported distribution of wood pathogens and their associations, and raise the level of concern regarding the movement of pathogen, vectors, or both in unmitigated firewood.

Summary

From our assessment we believe there are high risks associated with the movement and establishment of native and exotic forest pests in firewood. We based our risk determination on the following factors:

1. Firewood is a well-known pathway for the movement of wood pests. Firewood is a raw wood product. It is minimally processed: cut to usable length, bark in place, possibly split, and often freshly obtained from recently killed or stressed trees. Surveys of firewood have found that upwards of 20% may be infested with insect or pathogen forest pests.

2. The United States requires treatment of all imported firewood, with a few exceptions from Canada and Mexico. The United States imported nearly $8 million of firewood from 29 different countries annually from 2005-2009. The fact that firewood treatment is nearly universally required to allow entry indicates the recognized risk of the product.

3. Regulations prohibiting the domestic movement of firewood are already justified and in place for several states for five exotic forest pests. Currently, 16 states have regulations prohibiting the movement of firewood due to the presence of invasive species, but the regulations are often unclear or unknown to the public, they may vary from state to state and they are difficult to enforce.

4. Firewood readily moves throughout the United States. There are commercial firewood distributors in all 50 states. Interceptions of firewood from 48 states into California have been documented at border inspection stations. Firewood surveys support the fact that firewood moves readily through the United States, even out of quarantine zones. Additionally, numerous surveys conducted at stores and campsites illustrate firewood is being transported frequently and over substantial distances.

5. Urban area susceptibility. Urbanization of the United States is increasing with forested areas being urbanized at the greatest rate. Urban forests have a higher potential for invasion by forest pests due to human activity and trade and the urban trees can have increased susceptibility to attack due to various stresses. Urban areas are importers of firewood, which increases the likelihood of pests within the firewood moving short distances into the neighboring forest interface and establishing. The estimated cost of potential EAB damage in United States communities from 2009-2019 is $10.7 billion based on 25 state infestation and removal and replant or treatment of 17 million ash trees.. Estimates for ALB costs in urban areas ranges from $1.7 billion for nine selected cities to $669 billion for the entire United States. Additionally, the increased cost of fuel oil for home heating been related to increased use of alternate fuel sources such as firewood. The increased demand of firewood would also increase the distance that firewood could be economically moved into urban areas, further increasing the risk of long distance movement and urban area introduction.

6. Diversity and coverage of forests in the United States. Forests cover 33% of the United States with 22 main forest types. Although some tree species are preferred for use as firewood based on some characteristics like heat production and splitting, all species of trees can and are utilized as firewood. Fuel wood use is reported in varying amounts and type depending on region of the United States. Transportation routes allow for rapid and extensive movement of people and firewood, increasing the chance for forest pest introduction and establishment into new areas.

7. The value of the economic resources in the United States at risk if exotic or native forest pests are spread to additional areas is very high. The lumber and paper industries in the United States is a $262 billion a year industry, employing 1.3 million people (US DOE, 2000). However, it is difficult to estimate the economic impact to forest pest introductions as costs would vary based on the area of infestation, rate of spread and damage incurred.

8. Regulatory costs of forest pest management. The current average cost of USDA-APHIS-PPQ forest pest regulatory programs from 2004-2008 is $279 million (Lewis, 2008) and there are significant additional regulatory costs at the state level. The high cost of regulatory response combined with the difficulty of forest pest eradication and the high value of industry and resources at risk emphasizes the need to prevent the spread of non-native and native forest pests in the United States.

The movement of firewood is a high risk pathway for spreading non-native and native forest pests in the United States. In addition to known forest pests, new associations of insects and fungi (such as with Dutch elm disease) continue to occur, causing extensive damage.. We recommend that Federal and State regulatory agencies examine the current regulations for firewood movement and coordinate efforts to mitigate the potential risks, with primary focus on urban areas and long-distance movement. Urban areas are at greater risk of introduction due to many factors and costs of management are high. As discussed by Liebhold and Tobin (2008), long-distance spread events are typically less frequent than short distance, but have greater impact on rate of spread. Efforts to reduce long-distance movement may be the most effective in minimizing the risk of firewood.

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Acknowledgements

Portions of this document were extracted from the "Pest Risk Assessment for Importation of Solid Wood Packaging Material into the United States" (USDA, 2000). Contributors to this publication are hereby acknowledged.

Appendices

Appendix A. Overview of treatments for wood products entering the United States

The general requirement for any consignment of wood or lumber products is documentation accompanying each shipment that identifies the commodity, quantity, and its origin. All shipments are subject to inspection and may require other actions deemed necessary by Plant Protection and Quarantine as a result of inspection. Notice of arrival may be required at the discretion of the Officer in Charge at the port of first arrival. All pallets and other regulated wood packing materials used in the shipment are subject to inspection and must conform to 7 CFR 319.40-3(b).

The universal import option for logs or lumber includes either heat treatment or kiln drying and must be conducted prior to arrival. Treated or dried logs or lumber cannot be commingled with other regulated materials unless all regulated articles in the same hold or container have been heat treated or kiln dried. Lumber on the vessel's deck must be in a sealed container unless it has been kiln dried. Heat treated (HT) or kiln dried (KD) lumber must be marked by permanent marking on each piece of lumber or on the cover of bundles of lumber HT or KD, respectively. Alternatively, the importer document accompanying the shipment must state that the logs or lumber has been heat treated or kiln dried.

Tropical hardwood logs with no more than 2% of the total surface in a lot with bark and no single log with more than 5% bark on its surface are enterable. Lumber must be completely free of bark. Tropical hardwood logs and lumber (greater than 15 pieces, not debarked) must be fumigated prior to arrival. Tropical hardwood logs and lumber (less than 15 pieces, not debarked) cannot be imported into Hawaii, Puerto Rico, or the Virgin Islands of the United States.

Temperate hardwood logs, lumber (with or without bark), and untreated railroad ties are not authorized from areas in Asia that are east of 60 degrees east longitude and north of the Tropic of Cancer. Temperate hardwood logs and lumber must be fumigated prior to arrival.

Imported railroad ties must be completely free of bark and accompanied by an importer document stating that the cross-ties will be pressure treated with an approved preservative within 30 days following release from the first port of arrival.

Regarding movement of regulated articles of pine originating from areas in Canada non-infested with pine shoot beetle to or through U.S. non-infested areas, articles must be consigned to a designated U.S. facility that operates under a compliance agreement with the Animal and Plant Health Inspection Service (APHIS) for specified handling or processing of the articles. The name and address of the U.S. facility (including county and State) receiving the regulated articles must be plainly indicated on the articles or, if applicable, on the outer covering, packaging, or container. If the regulated articles are to be moved through an area of the United States quarantined for pine shoot beetle, en route to an area or areas in the United States not quarantined for pine shoot beetle during the period of January through September when the temperature is 10° C (50° F) or higher, then the regulated articles also must be shipped in an enclosed vehicle or completely covered (such as with plastic canvas, or other closely woven cloth) so as to prevent access by pine shoot beetle.

Fraxinus spp. logs and wood from Canada originating in areas regulated for emerald ash borer (EAB) must be accompanied by a phytosanitary certificate (PC) and meet one of the following conditions: (i) Debarked with an additional declaration (AD) stating that, “The articles in the shipment were debarked and vascular cambium was removed to a depth of 1.27 cm during the debarking process,” or (ii) Heat treated at a temperature of at least 71.1° Celsius for a minimum of 75 minutes. The details of the treatment must be specified in the treatment section of the PC. Ash wood chips or bark chips larger than 1 inch in diameter from a county regulated for EAB are prohibited importation into the United States. Ash wood chips or bark chips 1 inch or less in diameter from a county regulated for EAB must be accompanied by a PC. *Fraxinus* spp. logs and wood from Canada originating in counties not regulated for emerald ash borer but located within a regulated province or territory must be accompanied by a phytosanitary certificate (PC) with an additional declaration (AD) stating that, “The articles in the shipment were produced/harvested in a county where the EAB does not occur, based on official surveys.” Ash wood chips or bark chips from Canadian counties not regulated for EAB, but located within a regulated Province or Territory, must be accompanied by a PC with an AD stating that, “The articles in the shipment were produced or harvested in a county where the EAB does not occur, based on official surveys.”

Raw lumber, including solid wood packing material imported as cargo, is not authorized from areas in Asia that are east of 60 degrees east longitude and north of the Tropic of Cancer.

Raw lumber must be completely debarked and cannot be commingled with other regulated materials unless the raw lumber and the other regulated articles are in separate holds or in separate sealed containers. Raw lumber on the vessel's deck must be in a sealed container. Raw lumber must be consigned to an approved facility operating under a valid compliance agreement with Plant Protection and Quarantine at the time the lumber is imported. The name of the approved facility will be submitted and re-approved before importation occurs. Lumber must be heat treated within 30 days from the time the lumber is released from the port of first arrival.

Wood & bark chips from tropical plantation grown trees must be accompanied by an importer document stating that the chips were derived from live, healthy, tropical species of plantation grown trees, grown in tropical areas. Chips must be free from rot at the time of importation, and chips cannot be co-mingled with other regulated materials (other than solid wood packing materials) unless the chips and the other regulated articles are in separate holds or in separate sealed containers. Chips may be shipped on deck if no other regulated articles are present on the vessel and the chips are completely covered by a tarpaulin during the entire journey. Shipments with covered chips must transit directly from the port of export to the United States. Chips must be consigned to an approved facility operating under a valid compliance agreement with Plant Protection and Quarantine at the time the chips are imported.

Pinus radiata chips from Chile must be accompanied by a certificate stating that the wood chips were treated with a surface pesticide treatment within 24 hours after the log was chipped and were retreated with a surface pesticide treatment if more than 30 days elapsed between the date of the first treatment and the date of export to the United States. Further, chips must be derived from live, healthy, plantation-grown trees grown trees that were apparently free of plant pests, plant pest damage, and decay organisms, and the logs used to make the wood chips were debarked before being chipped. No more than 45 days can have elapsed from the time the trees used to make the wood chips were felled to the time the wood chips were exported. During shipment to the United States, no other regulated articles (other than solid wood packing materials) are permitted in the holds or sealed containers carrying the wood chips. Wood chips on the vessel's deck must be in a sealed container. Wood chips must be processed within 45 days of arrival at a U.S. processing facility.

Wood to be used as wood mulch, compost, or litter must be fumigated, heat treated, or heat treated with moisture reduction prior to arrival. Wood, chips, cork, and bark to be used for food, for the manufacture of containers of fermented liquids, manufacture of medicine, flavoring additive to fermented beverages, or chemical extraction may be imported if free from rot at the time of importation and subject to the inspection and other requirements. Wood and back chips not from tropical plantation grown trees must be fumigated, heat treated, or heat treated with moisture reduction. Chips cannot be commingled with other regulated materials (other than solid wood packing materials) unless the chips and the other regulated articles are in separate holds or in separate sealed container.

Pinus radiata logs from New Zealand must be accompanied by a certificate stating that the logs are consigned to an approved facility. The logs must be from live healthy trees which are apparently free of plant pests, plant pest damage, and decay organisms, and logs must be debarked in accordance prior to fumigation. During shipment to the United States, no other regulated article is permitted on the means of conveyance with the logs, unless the logs and the other regulated articles are in separate holds or separate sealed containers, or, if the logs and other regulated articles are mixed in a hold or sealed container, the other regulated articles either have been heat treated with moisture reduction or have been fumigated in the hold or sealable container. Upon arrival of the logs in the United States, the logs must be kept segregated from other regulated articles from the time of discharge from the means of conveyance until the logs are completely processed at the approved facility operating under a valid compliance agreement with Plant Protection and Quarantine at the time the lumber is imported. The logs must be moved from the port of first arrival to the approved facility by as direct a route as reasonably possible.

Pinus radiata logs or lumber from Chile consigned to an approved facility may be imported if wood products originate from live, healthy trees which are apparently free of plant pests, plant pest damage, and decay organisms. Logs or lumber must be debarked prior to fumigation. Logs or lumber and solid wood packing materials to be used with the logs and/or lumber during shipment to the United States must be fumigated within 45 days following the date the trees are felled and prior to arrival of the logs in the United States, in the holds or in sealable containers. Fumigation must be conducted in the same sealable container or hold in which the logs and lumber and solid wood packing materials are exported to the United States. During shipment to the United States, no other regulated article is permitted on the means of conveyance, unless wood products and the other regulated articles are in separate holds or separate sealed containers, or, if wood products and other regulated articles are mixed in a hold or sealed container, the other regulated articles either have been heat treated with moisture reduction or have been fumigated in the hold or sealable container. Upon arrival of the logs or lumber in the United States, the logs must be kept segregated from other regulated articles from the time of discharge until the logs and/or lumber are completely processed. The logs or lumber must be moved from the port of first arrival to an approved facility operating under a valid compliance agreement with Plant Protection and Quarantine by as direct as a route as reasonably possible.

Bamboo timber consisting of whole culms or canes that are completely dry as evidenced by lack of moisture in node tissue may be imported into any port of the United States subject to inspection and other requirements. Bamboo timber consisting of whole culms or canes may be imported into Guam or the Northern Mariana Islands subject to inspection and other requirements.

In accordance with the Convention on International Trade in Endangered Species of Wild

Fauna and Flora (CITES) regulations, each shipment of regulated material must have CITES export permit or certificate from the exporting country and, if listed in Appendix I, a CITES import permit from the U.S. Fish and Wildlife Service will be required as well. Additional information should be obtained from the U.S. Fish and Wildlife Service, Office of Management Authority. A valid General Permit to Engage in the Business of Importing, Exporting, or Re-Exporting Terrestrial Plants (PPQ Form 622) issued by USDA-APHIS-PPQ is also required.

Shipments of logs, lumber, plywood, or veneers of *Swietenia macrophylla* CITES-regulated materials may enter only at an approved designated port. A shipment of *S. macrophylla* imported from a country in the Neotropics (Mexico, Central and South America, and the Caribbean), must be accompanied by an original, valid CITES export permit that was issued by the CITES Management Authority of the exporting country. A shipment that originated in the Neotropics but which is being imported into the United States from a country other than the country of origin must be accompanied by a CITES re-export certificate issued by the CITES Management Authority of the re-exporting country. Businesses in the United States which import, export or reexport logs, lumber, plywood or veneers of *S. macrophylla* must possess a valid General

Permit to Engage in the Business of Importing, Exporting, or Re-Exporting Terrestrial Plants issued by USDA-APHIS-PPQ. CITES import documents must be surrendered at the time of entry into the United States to the DHS [Customs and Border Protection (CBP) Agricultural Quarantine and Inspection (AQI)]. Importers of *S. macrophylla* should also supply additional copies of the CITES document to CBP-AQI. A copy of the CITES export document, validated by CBP-AQI, will be returned to the importer for his/her records provided the shipment and permits are in compliance with CITES.

Cedrela odorata imported from Colombia, Peru, or any other country that may list this plant in Appendix III of CITES, must be accompanied by an original CITES export permit issued by the CITES Management Authority of the exporting country. A shipment of *C. odorata* that originated in Colombia or Peru, but which is being imported into the United States from a country other than the country of origin, must be accompanied by a CITES re-export certificate issued by the CITES Management Authority of the re-exporting country. Each commercially traded shipment of CITES-regulated *C. odorata* must be accompanied by a valid General Permit to Engage in the Business of Importing, Exporting, or Re-Exporting Terrestrial Plants issued by the USDA-APHIS-PPQ. Regulated articles of *C. odorata*, the container in which it is shipped, or the documents accompanying shipments of *C. odorata*, must adequately describe the shipment. CITES documents must be surrendered to PPQ at the time of entry. CITES regulated materials may enter only at an approved designated port. Importers must receive a legible copy of the CITES export document validated by PPQ for their records. Therefore, importers should supply PPQ with additional copies of the CITES document for this purpose at the time of import.

Gonystylus spp. imported from Indonesia, or any other country that may list any species of *Gonystylus* in Appendix III of CITES, must be accompanied by an original CITES export permit issued by the CITES Management Authority of the exporting country. A shipment of *Gonystylus* spp. harvested from countries other than those described above must be accompanied by an original CITES certificate of origin issued by the CITES Management Authority of the exporting country. A shipment of *Gonystylus* spp. which is being imported into the United States from a country other than the country of origin must be accompanied by a CITES re-export certificate issued by the CITES Management Authority of the re-exporting country. Each commercially traded shipment of CITES-regulated *Gonystylus* spp. must be accompanied by a valid General Permit to Engage in the Business of Importing, Exporting, or Re-Exporting Terrestrial Plants (PPQ Form 622) issued by USDA-APHIS-PPQ. Regulated articles of *Gonystylus* spp., the container in which it is shipped, or the documents accompanying shipments of *Gonystylus* spp., must adequately describe the shipment. CITES documents must be surrendered to PPQ at the time of entry. CITES regulated materials may enter only at an approved designated port. Importers must receive a legible copy of the CITES export document validated by PPQ for their records. Therefore, importers should supply PPQ with additional copies of the CITES document for this purpose at the time of import.

Appendix B. Insects associated with firewood (fact sheets).

Agrilus coxalis Waterhouse

Taxonomy: Coleoptera: Buprestidae

Distribution: southeastern Arizona, Mexico, Guatemala; recently detected in southern California (Coleman and Seybold, 2008a).

Hosts: Oaks (*Quercus* spp.) (Coleman and Seybold, 2008b).

Environmental/Economic Importance: Coleman and Seybold (2008a) reported a 67% infestation rate in oaks in southern California, resulting in a significant degree of tree mortality. The species is said to pose a threat to the health of standing trees in the urban and peri-urban forests of the western United States (Seybold et al., 2009). Symptoms of injury include twig dieback, crown thinning, bark staining, and adult exit holes (Camilli, 2009).

Biology: Coleman and Seybold (2008a, b) outlined what little is known of the biology of *A. coxalis*. Eggs probably are deposited in bark crevices. Larvae construct galleries primarily on the sapwood surface along the main stem from the base of the trunk up to the larger branches. Pupation occurs in the outer bark. Evidence suggests that there is one generation per year.

Phytosanitary Significance: Oak firewood from Mexico is thought to have been a possible pathway for introduction of the beetle into California (Coleman and Seybold, 2008a).

Management: Possible management options include chemical and cultural controls (Coleman and Seybold, 2008b). For example, soil- or trunk-injected systemic insecticides may be effective in suppressing infestations of the beetle in hosts. Surface treatment of high-value trees with insecticide along the main stem, larger branches, and foliage may prevent attack. Removing dead and dying trees infested with the beetle and destruction of infested material may reduce localized populations.

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Agrilus planipennis Fairmaire, emerald ash borer (EAB)

Taxonomy: Coleoptera: Buprestidae

Distribution in North America: Canada (Ontario and Quebec), United States (Illinois, Indiana, Ohio, Maryland, Michigan, Missouri, Pennsylvania, Virginia, West Virginia, Wisconsin) (EPPO, 2005; Kimoto and Duthie-Holt, 2006; NAPPO, 2008). Figure 12 is a map of EAB detections and regulated areas in North America. The species is native to East Asia.

Hosts: *Fraxinus*, *Juglans*, *Pterocarya*, and *Ulmus* spp. (Kimoto and Duthie-Holt, 2006). *Fraxinus* spp. (ash) are the only known hosts in North America (Anulewicz et al., 2008).

Environmental/Economic Importance: The serpentine tunnels excavated by feeding larvae interrupt the transport of nutrients and water within the tree, causing foliage to wilt and branches to die; infested trees may lose 30-50% of their canopy after two years, and may die after three to four years (McCullough and Katovich, 2004). Heavy, tree-killing infestations may hasten succession in forests dominated by *Fraxinus* spp. (Eckardt and Kane, 2008). Continued spread of *A. planipennis* through North America threatens at least 16 endemic species of ash (MacFarlane and Meyer, 2005; Poland and McCullough, 2006). Since its introduction, the pest has killed 10-15 million ash trees in Michigan (Nzokou et al., 2006). Projected total economic losses to ash plantings in Ohio range from $1.8 billion to $7.6 billion should the pest destroy all native street, park, and private trees (Sydnor et al., 2007).

Biology: McCullough and Katovich (2004) outlined the reproductive biology of the species in North America. Adult beetles are 7.5 to 13.5 mm in length, the male being smaller than the female. Adult emergence, through characteristic D-shaped exit holes, begins in early June and continues through late July; adults live for about three weeks. Females may mate with several males. Eggs are deposited individually in bark crevices on the trunk or branches. Fecundity ranges from 60 to 90 eggs per female; one to two years may be required to complete development. After hatching, larvae tunnel through the bark and into the cambium, spending the next few weeks feeding on the phloem and outer sapwood tissues. Pupation occurs in late April or May in chambers excavated in the outer sapwood or in the bark on thick-barked trees.

Phytosanitary Significance: The species is thought to have been introduced into the United States in crating, dunnage, or pallets from Asia (Haack et al., 2002). Domestic spread has been traced to the movement of infested ash logs, firewood, and nursery stock (Herms et al., 2004). The natural flight range of females averages 1.7 km in 24 hours and rarely exceeds 4 km; for males, maximal flight range may exceed 5 km (Taylor et al., 2005).

Management: Biological Control: Microbial agents, such as the fungi *Beauveria bassiana* (Balsamo) Vuillemin and *Metarhizium anisopliae* (Metschnikoff) Sorokin, may prove useful in the containment and management of North American populations of *A. planipennis*, provided that application rates and delivery methods can be optimized (Liu and Bauer, 2006), (Liu and Bauer, 2008). Recent work suggests that the release of parasitoids in classical biological control programs also may prove effective in managing populations of the beetle (e.g., (Liu et al., 2007b; Wang et al., 2008).

Chemical Control: Application of insecticides, such as permethrin, bifenthrin, or imidacloprid, is effective in controlling *A. planipennis* infesting tree trunks if applied annually (Harrell, 2006; Petrice and Haack, 2006).

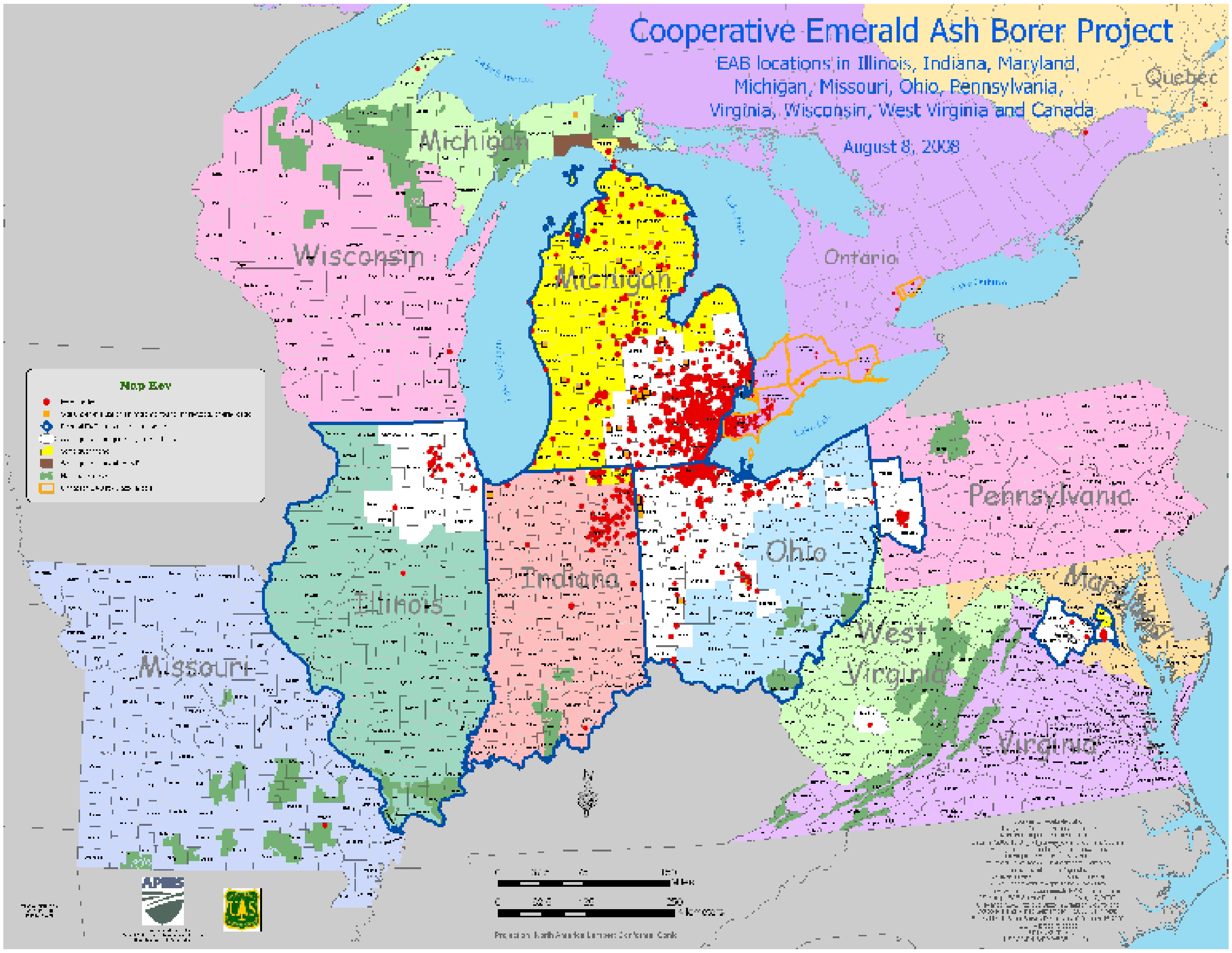

Figure 12. Emerald ash borer detections and regulated areas in North America. Source: http://www.emeraldashborer.info/files/MultiState_EABpos.pdf

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Agrilus sulcicollis Lacordaire

Taxonomy: Coleoptera: Buprestidae

Distribution in North America: Canada (southern Ontario); first detected in 2006 (Koehler, 2009). The species is palearctic (Eurasian) in origin (Kubán, 2004). It has been expanding its range across Europe in recent years (Anonymous, 2008).

Hosts: Oaks (*Quercus* spp.) appear to be the preferred hosts (Müller and Goßner, 2007). The pest is reported to attack *Fagus* spp., *Castanea* spp., and *Carpinus betulus* L. (Evans et al., 2004). The beetle also may be attracted to *Pinus sylvestris* L. (Eklund and Larsson, 2004), perhaps where its usual hosts are scarce or absent.

Environmental/Economic Importance: Larvae excavate galleries under the bark, eventually girdling the trunk, resulting in tree mortality (Moraal, 1999). *Agrilus sulcicollis* also may be a vector of fungal pathogens, causing tracheomycoses in host oaks (Čapek, 1986). The species has been implicated as a contributor to oak decline in Europe (König, 1996; Thomas et al., 2002). It is regarded as a threat to forests in Poland (Gutowski, 1988).

Biology: Little information is available on the biology of the species. Although *A. sulcicollis* appears primarily to infest dead wood (e.g., Ranius and Jansson, 2000; Wermelinger et al., 2002), it will attack living trees, particularly those in a weakened state (Moraal, 1999). Trees in exposed, sunny locations are preferred (Lindhe et al., 2005). The species tends to infest upper parts of stems and branches, and smaller-sized host trees (Evans et al., 2004). Development occurs mainly in the weaker branches (Mühle, 2007). Larvae develop in or under bark; completion of the life cycle requires 1-2 years (Bílý, 1982). Pupation occurs usually in the bark. The insect is reported to be generally uncommon over its range (Gellermann and Schreiber, 2007). In Finland, it has received the IUCN (International Union for Conservation of Nature) designation *vulnerable*, and is considered in danger of extinction (Rassi et al., 2001).

Phytosanitary Significance: The beetle is thought to have been introduced into Great Britain, where it was first detected in 1992, in imported timber (Alexander, 2003). Hedin et al. (2008) reported larvae to be common in cut wood piled in forests for later use as fuel, thus suggesting a significant potential for the species to be moved in firewood.

Management: Biogical Control: Parasitism of *A. sulcicollis* by the braconid *Polystenus rugosus* Förster has been reported (Čapek, 1986), although the degree of natural control achieved is unknown.

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Anoplophora glabripennis (Motschulsky), Asian longhorned beetle (ALB)

Taxonomy: Coleoptera: Cerambycidae

Distribution in North America: Canada (Ontario), United States [California (detected, but not established), Illinois (eradicated), New Jersey, New York] (APHIS, 2007); (EPPO, 2006). The species is indigenous to China (EPPO, 2007a).

Hosts: Major hosts are *Populus* and *Salix* spp. (EPPO, 2007a). Species of *Acer*, *Alnus*, *Malus*, *Morus*, *Platanus*, *Prunus*, *Pyrus*, *Robinia*, *Rosa*, *Sophora*, and *Ulmus* have been recorded as hosts in China. Lingafelter and Hoebeke (2002) report 18 species and 12 genera as hosts of ALB in North America, including *Betula* and *Fraxinus* spp., *Aesculus hippocastanum*, *Liriodendron tulipifera*, and *Hibiscus* spp. Controlled studies suggest that oaks (*Quercus* spp.) may also be suitable hosts (Morewood et al., 2003; Morewood et al., 2005).

Environmental/Economic Importance: In China, poplar wood damaged by *A. glabripennis* larvae has been downgraded, losing as much as 46% of its value (EPPO, 2007a). The potential annual economic losses due to infestations in Canada range from an estimated C$100 million in maple syrup production to C$9 billion in the wood products industry (Claudi, 2002). Infestations in Illinois, New Jersey, and New York have resulted in the removal of more than 30,000 trees at a cost exceeding $269 million (APHIS, 2007). In the absence of measures to prevent the beetle's spread, losses in the urban environment alone could total 1.2 billion trees worth $669 billion (Nowak et al., 2001).

Biology: Fecundity averages 32 eggs per female; depending on latitude, the life cycle is completed in one or two years (EPPO, 2007a). Eggs are laid singly within the bark, and hatch in about two weeks. Larvae feed initially in the cambium, later entering the woody tissues. Pupation occurs in chambers in the heartwood. Adult emergence peaks between late June and early July (EPPO, 2007a).

Phytosanitary Significance: *Anoplophora glabripennis* demonstrates a significant capacity for dispersal. For example, a flight range up to 2.6 km has been reported (Smith et al., 2004). Longer-distance spread is facilitated by the transport of wood products in trade. The pest is thought to have entered the United States in solid wood packaging material (APHIS, 2007; EPPO, 2007a). Based on results of simulation models, Peterson et al. (2004) concluded that much of eastern North America is vulnerable to invasion by *A. glabripennis*, whereas only limited areas in the western part of the continent are suitable for its establishment.

Management: Biological Control: Results reported by Dubois et al. (2004a), (2004b) suggested that microbial agents, such as the fungi *Beauveria brongniartii* (Sacc.) Petch, *Beauveria bassiana* (Balsamo) Vuillemin, and *Metarhizium anisopliae* (Metschnikoff) Sorokin, may hold promise for controlling *A. glabripennis*. The potential efficacy of entomopathogenic nematodes, such as *Steinernema feltiae* (Filipjev) Wouts et al. and *S. carpocapsae* (Weiser) Wouts et al., in controlling populations of the beetle also has been favorably assessed (Fallon et al., 2004).

Chemical Control: Trunk injection with systemic insecticides, such as imidacloprid, can be of value in controlling the pest, particularly as part of an integrated eradication or management program (Poland et al., 2006). Fumigants such as methyl bromide and sulfuryl fluoride are effective in disinfesting solid wood packaging material (Barak et al., 2005; Barak et al., 2006).

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Sirex noctilio **F. European woodwasp**

Taxonomy: Hymenoptera: Siricidae

Distribution In North America: Canada (Ontario), United States (Michigan, New York, Pennsylvania) (Anonymous, 2007; Dodds et al., 2007). The species probably is native to Eurasia, but has been introduced into South America, Africa, and Australasia, in addition to North America (CABI, 2007). A map of *S. noctilio* detections in North America can be found in Figure 13.

Hosts: *Pinus* spp. appear to be the favored hosts; the wasp also has been recorded on species of *Abies*, *Larix*, *Picea*, and *Pseudotsuga* (Hoebeke et al., 2005).

Environmental/Economic Importance: While depositing eggs, females inject a toxic mucus and symbiotic fungus into the sapwood (Haugen and Hoebeke, 2005). The mucus causes foliage to wilt and yellow, providing favorable conditions for the fungus to grow and spread throughout the tree. This, combined with larval tunneling through vascular tissue, disrupts water circulation, often resulting in death of the tree (ISSG, 2007). Between 1987 and 1989, an outbreak of *S. noctilio* in Australia destroyed more than 5 million maritime pines (*Pinus radiata* D. Don) worth A$10-12 million (Haugen et al., 1990). An estimated 250,000 ha of pine plantations in southern Brazil are infested with the pest, which is spreading rapidly (Ciesla, 2003). Tree mortality exceeding 80% has been reported in pine plantations in South America (Hopkins et al., 2008).

Biology: Hoebeke et al. (2005) summarized the biology of the species. Fecundity ranges from 20 to 500 eggs per female; the wasp usually completes one generation per year, but may require two years in colder regions. Females insert the ovipositor through the bark and into the sapwood, depositing one to three eggs at a time. During oviposition, the fungus *Amylostereum areolatum* (Fries) Boidin (Basidiomycetes) is introduced and provides food for the larvae as they tunnel through the wood. Adults range in size from 9 to 35 mm long and are strong fliers.

Phytosanitary Significance: *Sirex noctilio* is thought to have entered the United States in solid wood packaging material accompanying shipments from western Europe (Anonymous, 2005). A flight range of 48 km has been reported (Ismail et al., 2007), indicating that the wasp has significant spread potential.

Management: Biological Control: Both classical and augmentative techniques have proved effective in controlling the wasp in regions into which it has been introduced (e.g., (Fernández-Arhex and Corley, 2005). A key agent, effective in regulating populations of the wasp below economically significant levels, is the parasitic nematode *Deladenus siricidicola* Bedding (Neotylenchidae), which infects larvae, ultimately sterilizing the adult female (Haugen and Hoebeke, 2005).

Cultural Control: Damaged or stressed trees appear to be more susceptible to attack. Thus, a major preventative measure is to increase stand vigor by thinning (Haugen et al., 1990). Destruction of infested trees can be useful in maintaining low abundance of *S. noctilio* in newly infested areas (Hurley et al., 2007).

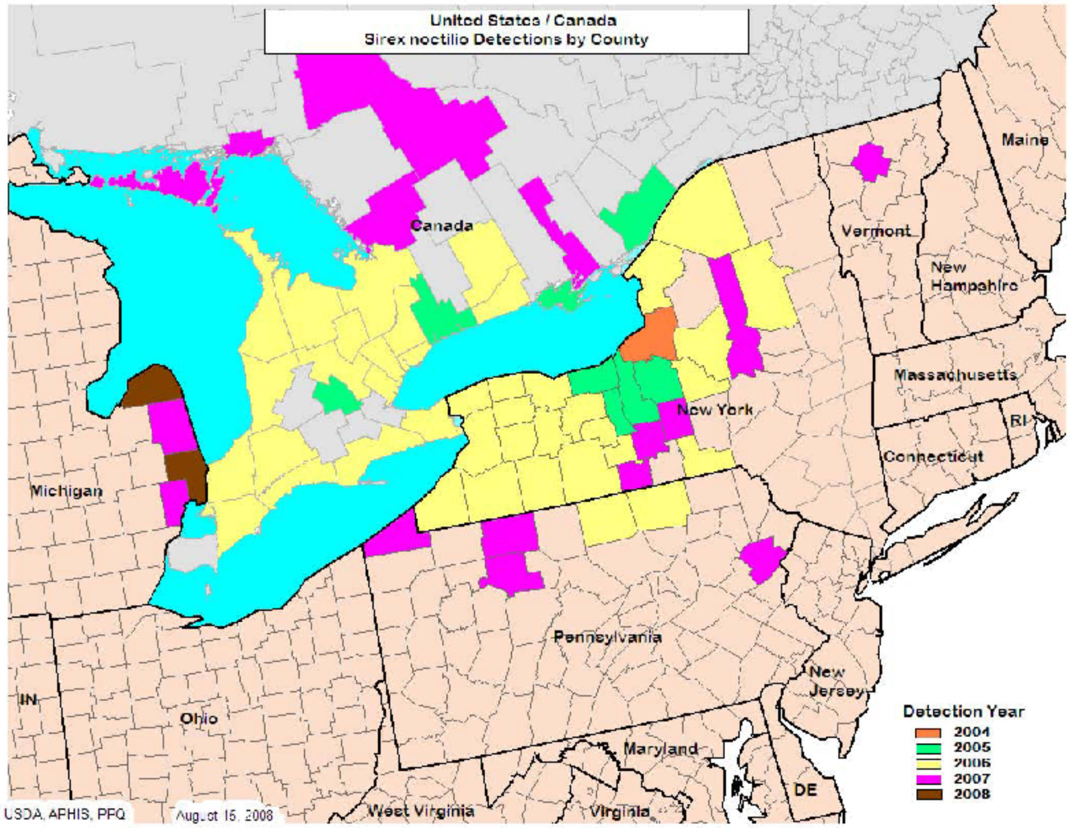

Figure 13. Counties and municipalities with *S. noctilio* detections (2004-2008)
Source; http://www.aphis.usda.gov/plant_health/plant_pest_info/sirex/downloads/postivecountiesbyyear.pdf

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Buprestis aurulenta L.

Taxonomy: Coleoptera: Buprestidae

Distribution: western Canada (British Columbia), western United States (Furniss and Carolin, 1977). There is one anomalous record from Florida (Capelouto, 1949).

Hosts: *Abies*, *Picea*, and *Pinus* spp., *Pseudotsuga menziesii* (Mirb.) Franco, *Thuja plicata* Donn ex D. Don (Furniss and Carolin, 1977; Garnett, 1918).

Environmental/Economic Importance: *Buprestis aurulenta* is said to be the most damaging western species in the genus (Furniss and Carolin, 1977). Larvae mine in and around fire scars and other wounds in trees. They damage structural wood in particular, such as boards and timbers used in buildings. Infestations may originate in the forest, in lumberyards, and in exposed parts of wooden structures (Furniss and Carolin, 1977). Larval tunneling also may facilitate the entry of wood-rotting fungi (Garcia and Morrell, 1999), thus compounding damage.

Biology: Little information is available on the reproductive biology of the species. Normally, larvae require from one to three years to complete development (Linsley, 1943). However, individuals may be extremely long-lived, the developmental period lasting as long as 51 years in one case (Smith, 1962). Females possess only one ovary (Rubio et al., 2008) which, in addition to long generation times, suggests that fecundity may be rather low. Eggs are deposited in flat masses on bark or in fire scars or cracks in the wood (Ebeling, 1975; Furniss and Carolin, 1977).

Phytosanitary Significance: The beetle can survive in large sections of fresh wood that are subsequently processed into other products (Garcia and Morrell, 1999). It has been intercepted at the California border in firewood (data from California Department of Food and Agriculture [CDFA]), indicating its tendency to be moved interstate in articles of wood.

Management: Mechanical Control: Infestations are unlikely to occur in wood from trees removed from the forest soon after they are felled (Ebeling, 1975). Larvae are unable to survive in kiln-dried lumber. Wood preservatives may discourage oviposition to some extent.

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Chrysobothris trinervia (Kirby)

Taxonomy: Coleoptera: Buprestidae

Distribution: western Canada, western United States (Furniss and Carolin, 1977). The beetle also has been reported from eastern North America: North Carolina (Hilchie, 2003) and Quebec Province (Vigneault, 2007).

Hosts: *Picea* and *Pinus* spp., *Larix laricina* (Du Roi) K. Koch, *Pseudotsuga menziesii* (Mirb.) Franco (Furniss and Carolin, 1977; Hilchie, 2003).

Environmental/Economic Importance: Most species of *Chrysobothris* bore through the bark and outer wood of limbs, trunks, and roots of weakened, dying, and dead trees and shrubs (Furniss and Carolin, 1977). Generally, they appear to be of little importance in the forest. However, *C. trinervia* is considered to be an important forestry pest in interior Alaska (Magoun and Dean, 2000).

Biology: No information is available on the biology of *C. trinervia*.

Phytosanitary Significance: The species has been found in Minnesota in barked logs of *Larix occidentalis* Nutt. imported from the western United States (Dodds et al., 2004), indicating the facility with which it may be moved intracontinentally in articles of wood.

Management: Cultural Control: As buprestids rarely injure healthy trees, maintenance of conditions promoting vigorous growth should reduce incidence of attack (Solomon, 1995).

Sanitation (removal of dead and dying trees) should be practiced to preclude the availability of breeding sites.

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Cucujus clavipes F.

Taxonomy: Coleoptera: Cucujidae

Distribution: broadly distributed in the United States from North Carolina to Alaska; (Bennett et al., 2005) and in Canada (Kukal and Duman, 1989).

Hosts: *Fraxinus* and *Populus* spp. (Baker, 1972).

Environmental/Economic Importance: No information is available concerning the environmental or economic importance of the species. Larvae and adults of Cucujidae generally are found under the bark of dead trees (Thomas et al., 2002).

Biology: Adults are 10-14 mm long (Furniss and Carolin, 1977). Larvae are commonly found under the bark of recently dead trees (Baker, 1972). Fungi as well as plant materials are consumed (Evans and Hogue, 2006). The species also is reported to be a predator (Hammond et al., 2001; Kennedy and McCullough, 2002).

Phytosanitary Significance: This species has been intercepted in California in oak firewood from Michigan and Oklahoma (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: No information is available on management of the species.

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Dendroctonus ponderosae Hopkins

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western Canada, western United States, Mexico (Baja California) (CABI/EPPO, 1997b).

Hosts: *Pinus* spp., *Picea engelmannii* Parry ex Engelm. Wood (1982) stated that all native pines and several exotic species within the species' range could be infested and killed.

Environmental/Economic Importance: *Dendroctonus ponderosae* is said to rank first in destructiveness among the bark beetles of the West, where it is epidemic almost continually in one or more of its principal hosts (Furniss and Carolin, 1977). Attacks are generally heaviest along the main trunk of a tree, from within about a meter of the ground surface to the middle branches, but may extend from the root collar almost to the top and into the larger limbs. In lodgepole pine, *Pinus contorta* Douglas ex Loudon, losses ranging from 60% of the 30-cm DBH (diameter at breast height) class to about 90% of trees of 45-cm DBH and larger have been reported (CABI/EPPO, 1997b). Wood (1982) estimated that the average annual loss in timber attributed to the beetle may approach 1.5 billion board-feet.

Biology: Adults (CABI/EPPO, 1997b; Hall and Butler, 2007; Wood) and larvae are phloeophagous, or bark-feeding (CABI/EPPO, 1997b). Safranyik et al. (1999) outlined the reproductive biology of *D. ponderosae*. Emergence and adult flight occur in late July to mid-August. After finding a suitable host, the female initiates attack by boring through the bark and beginning excavation of a vertical egg gallery in the phloem parallel to the grain of the wood. Terpenes in the oleoresin are the primary source of attraction, guiding colonizing beetles to host trees (CABI/EPPO, 1997b). A male joins the female, and mating takes place in the lower end of the egg gallery. Average fecundity is 40-60 eggs per female. Eggs are deposited singly into niches excavated off the egg gallery, which may be as long as 2 m in length. Larvae hatch within about a week, and excavate tunnels in the phloem, at right angles to the egg gallery, as they feed. Overwintering occurs in the larval stage. One generation per year is the norm. In parts of California, two generations, and a partial third, may develop, and, in the coldest portions of the range, a generation may require two years (Furniss and Carolin, 1977).

Phytosanitary Significance: As is typical for scolytids, the most common mode of introduction into new areas for *D. ponderosae* would be via the movement of unseasoned wood with bark, including wooden crates and dunnage (CABI/EPPO, 1997b). The species has been intercepted in California in firewood from Oregon (data from CDFA), indicating its propensity for interstate transport.

Management: Cultural Control: Infestations may be reduced through management practices that maintain the health and vigor of forest stands, such as thinning stagnated young stands or removal of overmature trees in older stands (CABI/EPPO, 1997b).

Chemical Control: Infestations also may be contained and concentrated through the use of a combination of antiaggregation pheromones, such as verbenone, and aggregation pheromones (e.g., Lindgren and Borden, 1993).

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Dendroctonus pseudotsugae Hopkins

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western Canada (Alberta, British Columbia), western United States, northern Mexico (Chihuahua, Durango) (Cibrián et al., 1995; Wood, 1982).

Hosts: *Pseudotsuga menziesii* (Mirb.) Franco, *P. macrocarpa* (Vasey) Mayr, *Larix occidentalis* Nutt., *Tsuga heterophylla* (Raf.) Sarg. (Wood, 1982).

Environmental/Economic Importance: *Dendroctonus pseudotsugae* is the most important scolytid enemy of Douglas-fir (*P. menziesii*) throughout the range of the tree in western North America (Furniss and Carolin, 1977). Ordinarily, beetles are attracted to stumps, windthrows, or otherwise injured trees, but during population outbreaks or when stands are under stress, trees in a healthy and vigorous state may be attacked and large quantities of timber destroyed. Losses may be devastating. For example, during four outbreaks that occurred in western Oregon and Washington between 1950 and 1969, trees comprising more than 7 million board-feet of timber were killed (Schmitz and Gibson, 1996). Outbreaks typically last two to four years. The beetle also has been implicated in the transmission of pathogenic, wood-rotting fungi (e.g., Ross and Solheim, 1997; Solheim and Krokene, 1998).

Biology: Adult flight commences usually in mid- to late spring (Schmitz and Gibson, 1996). After mating, a female may deposit as many as 160 eggs in an egg gallery excavated in the inner bark in contact with the cambium (Wood, 1982). There is one complete, and possibly a partial second, generation per year. Both adults and larvae overwinter, with adults predominating (Furniss and Carolin, 1977).

Phytosanitary Significance: The species has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (LaBonte et al., 2005). LaBonte et al. (2005) suggested that the recent detection in the central and eastern United States of this western North American species was most likely the result of introduction of solid wood packing material or other raw wood products from the West. The beetle also has been intercepted in Great Britain in timber imports from Canada (Winter, 1991). It thus exhibits a significant capacity to be moved long distances in articles of wood.

Management: Cultural Control: The most practical management approach involves removal of infested or vulnerable timber and maintenance of stands in a vigorous condition (Schmitz and Gibson, 1996). Young stands should be thinned periodically to maintain vigorous growth, reduce moisture stress, and remove injured trees; in older stands, overmature trees, on which beetle attack is more successful, should be harvested.

Mechanical Control: Debarking logs significantly reduces infestations (Shore et al., 2005).

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Dendroctonus valens LeConte

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: Canada, Mexico, Guatemala, Honduras, United States (except for southern Atlantic and Gulf coast states) (Wood, 1982). Outside of the western hemisphere, the species occurs in China (CABI, 2005).

Hosts: *Pinus* and *Picea* spp., *Abies concolor* (Gordon & Glend.) Lindl. ex Hild., *Larix laricina* (Du Roi) Koch, *Pseudotsuga menziesii* (Mirb.) Franco (Baker, 1972; Wood, 1982).

Environmental/Economic Importance: *Dendroctonus valens* normally attacks injured, weakened, or dying trees, as well as freshly cut logs and stumps, but, on occasion, will attack and kill apparently healthy trees (Wood, 1982). Under ordinary circumstances, however, the species is not aggressive, and populations do not become irruptive (Furniss and Carolin, 1977). Trees are attacked near the ground as well as below ground on the large roots (Dreistadt et al., 2004). The beetle is implicated as a vector of fungi causing red pine decline disease (Klepzig et al., 1995). It contributes to tree mortality averaging almost 7% in *Pinus ponderosa* Douglas ex Lawson & C. Lawson (Schmid and Mata, 1991). Following its introduction about two decades ago, the beetle now infests over 500,000 ha of pine forest in China, causing extensive tree mortality resulting in the death of more than 10 million *Pinus tabuliformis* Carr. and other pines (Yan et al., 2005).

Biology: The adult beetle, averaging about 8 mm in length, is the largest in its genus (Furniss and Carolin, 1977). Individuals exploit volatile monoterpene compounds to locate host trees (Erbilgin et al., 2007). Peak flight and attack occur usually in the spring (Smith, 1971). The female chews through the bark to the surface of the sapwood where she is joined by a male, mates, and begins to excavate the egg gallery. Fecundity may exceed 100 eggs per female. There are 0.5 to 3 generations per year (Dreistadt et al., 2004).

Phytosanitary Significance: *Dendroctonus valens* exhibits a capacity for rapid, long-distance dispersal. Although known to fly as far as 35 km, transport by humans appears to be the primary means of spread of the beetle in areas, in which pine stands are widely separated (Yan et al., 2005). The beetle was introduced into China in unprocessed pine logs imported from the western United States; it has since spread rapidly in China, presently occupying four provinces. Domestically, it has been intercepted in California in firewood from Arizona (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: Cultural Control: Unthrifty, injured, or diseased trees should be removed to eliminate breeding sites for the beetle (Dreistadt et al., 2004; Smith, 1971).

Chemical Control: Application of insecticides, such as carbaryl and fenitrothion, may provide protection from *D. valens* attack (Hall, 1984).

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***Dryocoetes confusus* Swaine**

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western Canada, western United States (CABI/EPPO, 1997c).

Hosts: *Abies* spp., *Picea engelmannii* Parry ex Engelm., *Pinus contorta* Douglas ex Loudon (Furniss and Carolin, 1977).

Environmental/Economic Importance: *Dryocoetes confusus* has been described as "the most destructive species in the genus" (Furniss and Carolin, 1977). In British Columbia, the beetle killed trees of subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., amounting to more than 6.3 billion board-feet of timber between 1948 and 1975 (Stock et al., 1994). In 2001, over 1 million forested ha there sustained mortality caused by *D. confusus*; earlier, in 1996, attack by the beetle resulted in the death of an estimated 51,000 subalpine firs in one USDA Forest Service region (CABI, 2006). Attack is focused on the lower bole of standing trees; successive generations of beetles may girdle the tree (CABI/EPPO, 1997c). Pathogenic, blue-stain fungi (*Ceratocystis* spp., *Ophiostoma* spp.), introduced by the beetle (Bleiker and Uzunovic, 2004; Furniss and Carolin, 1977), contribute significantly to tree mortality (Garbutt, 1992).

Biology: Adults are 3.2-4.3 mm long and dark reddish brown in color (Wood, 1982) and larvae of *D. confusus* are phloeophagous, or bark-feeding (CABI/EPPO, 1997c). Mathers (1931) outlined the biology of the beetle in British Columbia. Young adults emerged from hibernation during the second half of June and throughout most of July, and attacked trees (*A. lasiocarpa*), in which they excavated the first brood chambers. Both sexes are attracted to plant chemicals, such as monoterpenes and other terpenoid compounds, emanating from uninfested hosts (CABI, 2006). Males attack first, thereupon emitting an aggregation pheromone that mediates simultaneous mass attack on the new host. Oviposition was completed in August, after which both sexes made feeding tunnels, in which they overwintered. Eggs, five to 14 per brood chamber, hatched during the second half of August. By the following June, the overwintered larvae had cut mines up to 25 mm in length. The first pupa of this brood was observed at the end of July, and, by mid-August, new adults had appeared. Females of the parental generation resumed oviposition in the spring. The species is polygamous, each male mating with two to five females (CABI/EPPO, 1997c). The life cycle may span three years (Hansen, 1996).

Phytosanitary Significance: *Dryocoetes confusus* presumably is moved to new areas in the same manner as other scolytid beetles, in unseasoned wood, including wood packaging material, retaining bark (CABI/EPPO, 1997c).

Management: Cultural Control: *Dryocoetes confusus* may be controlled by sanitation-salvage harvesting, which removes infested trees from a stand and kills the beetles during the manufacturing process in a saw mill or pulp mill (CABI, 2006).

Chemical Control: Infestations also may be contained and concentrated through the use of aggregation pheromones, such as (±)-*exo*-brevicomin (Stock et al., 1994).

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Hylesinus californicus (Swaine)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western United States historically (detected recently [1999] in Maryland), northern Mexico, Canada (Manitoba to British Columbia) (Langor, 1994; Rabaglia and Williams, 2002; Wood, 1982).

Hosts: *Fraxinus* spp., *Olea europaea* L. (Wood, 1982).

Environmental/Economic Importance: Larval tunneling may girdle and kill branches; on rare occasions, entire trees may be killed (Cranshaw et al., 1994). Under outbreak conditions, extensive branch death may occur, resulting in significant loss of aesthetic and commercial value in ash trees (Langor, 1994). McKnight and Aarhus (1973) reported severe dieback and some mortality in stands of green ash, *Fraxinus pennsylvanica* Marsh., a tree widely used in protective plantings for wind barriers, snow fences, wildlife habitat, noise abatement, and aesthetic purposes.

Biology: Adults are 2.0-3.1 mm in length (Wood, 1982). Adults, which hibernate within chambers in the trunk, become active in early to mid-spring, at which time females begin to construct egg galleries beneath the bark of host trees (Cranshaw et al., 1994). Larval tunneling may cause extensive scoring of the sapwood. The excavated galleries become stained by fungi of the genus *Ceratocystis* Ell. & Halst. (McKnight and Aarhus, 1973). Average fecundity appears to be about 21 eggs per female (Langor and Hergert, 1993). One generation per year is the norm; a partial second generation may occasionally occur (Cranshaw et al., 1994).

Phytosanitary Significance: LaBonte et al. (2005) suggested that the recent detection in the eastern United States of this western North American species was most likely the result of its introduction in solid wood packing material or other raw wood products from the western United States.

Management: Cultural Control: Good cultural practices, which maintain stand vigor and sanitation (i.e., removal of infested wood), are fundamental to *H. californicus* management (Cranshaw et al., 1994; Langor, 1994).

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Hylesinus criddlei (Swaine)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western and mid-western United States (Colorado to Iowa), Canada (Saskatchewan to Quebec) (Wood, 1982). The beetle recently was detected in Maine, Maryland, and Oregon (Donahue et al., 2007; ODA, 2007; Rabaglia and Williams, 2002).

Hosts: *Fraxinus* spp. (Wood, 1982).

Environmental/Economic Importance: Trees that are weakened, storm-damaged, or felled are most susceptible to attack, although the beetle occasionally may attack healthy trees, causing branch- and top-kill (Solomon et al., 1993). Injury results from larval tunneling in the inner bark and surface of the sapwood. McKnight and Aarhus (1973) reported severe dieback and some mortality in stands of green ash, *Fraxinus pennsylvanica* Marsh., a tree widely used in protective plantings for wind barriers, snow fences, wildlife habitat, noise abatement, and aesthetic purposes.

Biology: Adults are 1.9-2.4 mm in length (Wood, 1982). Overwintered adults emerge in the spring, fly to susceptible hosts, and begin to oviposit; egg galleries may be excavated in the bole, limbs, and larger branches (Solomon et al., 1993; Wood, 1982). There are one to two generations per year.

Phytosanitary Significance: LaBonte et al. (2005) suggested that the recent detection in the eastern United States of this western North American species was most likely the result of its introduction in solid wood packing material or other raw wood products from the western United States.

Management: Mechanical Control: Debarking of felled trees prevents brood development (Solomon et al., 1993).

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Ips mexicanus (Hopkins)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western Canada, western United States, Mexico, Guatemala (Wood, 1982).

Hosts: *Pinus* spp. (Wood, 1982).

Environmental/Economic Importance: This beetle attacks the bole of living, injured, dying, and recently felled pines (Furniss and Carolin, 1977). Attack may result in the death of trees, particularly those that are under stress (Cibrián et al., 1995). The species also has been implicated as a vector of *Fusarium circinatum* Nirenberg & O'Donnell, the fungus that causes pitch canker of pines and Douglas-fir (Erbilgin et al., 2008; Storer et al., 1996).

Biology: Fecundity in *I. mexicanus* (= *I. radiatae* Hopkins) averages 90 eggs per female (Trimble, 1924). The number of generations in a year ranges from three to seven (Cibrián et al., 1995). Males initiate attack on host trees through cracks in the bark, penetrating to the cambium where they construct a chamber. There, they mate with three to five females. Each female excavates a tunnel and deposits three to four eggs in chambers within it. Larvae extend galleries outward from the egg chambers (Cibrián et al., 1995).

Phytosanitary Significance: The species is considered to be of “medium” importance in Mexico, as it is a forest pest in various ways: as a tree killer, vector of tree pathogens, and competitor for other bark beetles (Cibrián et al., 1995). It has been intercepted in California in firewood from Arizona (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: Cultural Control: As outbreaks are likely to occur where weakened trees grow near accumulations of fresh slash, which are favored breeding sites for the beetle, infestations may be reduced by prompt disposal of slash larger than 80 mm in diameter (Furniss and Carolin, 1977).

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Lyctus cavicollis LeConte

Taxonomy: Coleoptera: Lyctidae

Distribution: United States (widespread) (Ebeling, 1975).

Hosts: *Eucalyptus*, *Carya*, *Fraxinus*, and *Quercus* spp., *Citrus* × *sinensis* (L.) Osbeck (Ebeling, 1975; Smith, 1968). In addition, in Germany, where it has been introduced, the species is reported to attack *Ulmus* spp., *Prunus* spp., *Platanus* spp., *Robinia pseudoacacia* L., and *Juglans regia* L. (Geis, 1997).

Environmental/Economic Importance: This pest often attacks lumber during air-drying, which may take as long as 18 months; the lumber is particularly susceptible after its moisture content falls below 30% (Smith, 1968). *Lyctus cavicollis* is considered to be a significant pest of finished wood or lumber in buildings (Jarratt, 2001). It may be found in hardwood flooring, paneling, and furniture (Ebeling, 1975). The beetle is considered an invasive species in Oregon (ODFW, 2005).

Biology: The size of adults varies from 2.5 to 5 mm, although usually not exceeding 3 mm in length (Ebeling, 1975). No information is available on the reproductive biology of the species.

Phytosanitary Significance: *Lyctus cavicollis* has been intercepted in California in oak firewood from Minnesota (data from CDFA). The major pathway via which it has been introduced into central Europe is thought to be consignments of sawn hardwood imported from the United States (Geis, 1996). The species thus exhibits a tendency to be moved frequently with the interstate and international transport of wood products.

Management: Chemical Control: Insecticidal dips (e.g., 0.06% lindane) may be used to protect lumber during the air-drying phase (Smith, 1968). Infestation of structures may require tent fumigation (Suomi, 2007).

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Megacyllene antennata (White)

Taxonomy: Coleoptera: Cerambycidae

Distribution: southwestern United States (Furniss and Carolin, 1977).

Hosts: *Prosopis* spp. (Furniss and Carolin, 1977).

Environmental/Economic Importance: Furniss and Carolin (1977) considered this species to be the most destructive borer in mesquite. Larvae typically mine the wood extensively, rendering it unfit for use in construction.

Biology: Craighead and Hofer (1921) provided an account of the biology of the species. Overwintering adults emerge and fly during March and April. Eggs are laid in crevices or under scales of the bark. Freshly cut wood is preferred. Larvae bore through the bark into the sapwood, in which they may feed for 40-60 days. They finally enter the heartwood, excavating long galleries. There are two generations per year.

Phytosanitary Significance: *Megacyllene antennata* has been intercepted in California in firewood from Texas (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: Cultural Control: Wood should be cut later in the season (mid-October to the end of November) when adult beetles are absent (Craighead and Hofer, 1921).

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Melanophila drummondi (Kirby)

Taxonomy: Coleoptera: Buprestidae

Distribution: western Canada, western and eastern United States (Baker, 1972; Furniss and Carolin, 1977).

Hosts: *Abies*, *Larix*, *Picea*, and *Tsuga* spp., *Pseudotsuga menziesii* (Mirb.) Franco (Dodds et al., 2004; Furniss and Carolin, 1977). Scott (1974) reported an infestation in *Pinus ponderosa* Lawson, which may be an unusual host.

Environmental/Economic Importance: Although usually seen to infest injured, mistletoe-infected, dying, fire-killed, or recently felled trees, *M. drummondi* occasionally will attack and kill apparently healthy trees, particularly those under stress (Furniss and Carolin, 1977). It causes defects, such as gum spots or streaks, in timber, likely lowering its value (Snyder, 1927). The species is considered one of the most important pests of conifers in Oregon (Overhulser, 1986).

Biology: Adults emerge from overwintering in the spring, and fly to a suitable host tree (ODF, 2007). Eggs are laid in bark crevices, and, upon hatch, larvae bore into the inner bark to feed and develop in the phloem/cambium interface. There is one generation per year (Dodds et al., 2004).

Phytosanitary Significance: *Melanophila drummondi* has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (Dodds et al., 2004). It was introduced into China in unprocessed logs imported from western North America (Ciesla, 1992). These examples indicate the facility, with which the beetle may be moved both intracontinentally and intercontinentally in articles of wood.

Management: Cultural Control: Practices that maintain stand vigor, such as sanitation, removal of injured trees, and thinning, are thought to reduce susceptibility to attack by the beetle (ODF, 2007).

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***Micromalthus debilis* LeConte**

Taxonomy: Coleoptera: Micromalthidae

Distribution: native to the eastern United States (Massachusetts to Michigan, south to Virginia; (Scott, 1938), but found also in Florida, New Mexico, Texas, Oregon, Washington, and British Columbia (Durden, 1999; Mudge et al., 2001; Pollock and Normark, 2002). Outside of North America, the species has been reported from South Africa, Austria, Gibraltar, Hong Kong, Japan, Hawaii, Brazil, Cuba, and Belize (Beutel and Hörnschemeyer, 2002; Perkovsky, 2007; Philips and Young, 2001).

Hosts: *Pinus*, *Tsuga*, *Castanea*, and *Quercus* spp. (Scott, 1938). The species also is capable of infesting building materials of various woods, including species of *Pinus*, *Pseudotsuga*, *Acacia*, and *Eucalyptus*, when used in flooring, furniture, telephone poles, railroad ties, bridge abutments, and mine timbers (Lawrence, 1991).

Environmental/Economic Importance: Larval boring causes damage to buildings and other wooden structures (Craighead, 1950; Philips and Young, 2001). Larvae have been found infesting the wood panels comprising the walls and floors of bank vaults and safes (Mudge et al., 2001). The mass emergence of adults within buildings may create a nuisance (Anonymous, 1994).

Biology: The biology of the species is complex, with several reproductive types possible. For example, reproduction may be via thelytokous parthenogenesis and viviparity in paedogenetic females, in which case, fecundity averages 10 female larvae per female (Pollock and Normark, 2002). Alternatively, each female may produce a single male via arrhenotokous parthenogenesis or give birth to both male and female offspring (Scott, 1941). Sexual reproduction also has been reported in the species (Pollock and Normark, 2002). Larvae tunnel through the wood, producing long galleries that may extend deep into the heartwood (Scott, 1936; Scott, 1938). Development occurs apparently only in wood infected with decay fungi, particularly brown-rot fungi (Kuhne and Becker, 1976).

Phytosanitary Significance: It is generally thought that *M. debilis* has expanded its range in historical times through the transport of infested articles of wood (Lawrence, 1991). Dunnage and other solid wood packing material were implicated as probable pathways for the introduction of this eastern North American species into Oregon and Washington (Mudge et al., 2001). It was thought to have been introduced into South Africa in lumber from North America (Craighead, 1950).

Management: No information is available on control of the beetle.

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Monarthrum fasciatum (Say)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: eastern United States primarily, but found as far west as Texas (Wood, 1982).

Hosts: *Betula*, *Quercus*, *Carya*, *Malus*, *Mimosa*, *Nyssa*, *Populus*, *Prunus*, *Pinus*, and *Tsuga* spp., *Acer rubrum* L., *Castanea dentata* (Marsh.) Borkh., and *Liquidambar styraciflua* L. (Baker, 1972; Frank and Iii, 2006; Wood, 1982).

Environmental/Economic Importance: *Monarthrum fasciatum* attacks only dying, injured, or recently felled trees, and its burrows in logs left unsawed too long reduce the value of the final product (Craighead, 1950; Dorsey and Leach, 1956). Attacks from ground level to over 13 m up the bole and occasionally in the larger branches have been recorded (Roling and Kearby, 1974). The beetle is highly destructive of green lumber (Baker, 1972). It is considered one of the most serious scolytid pests of hardwoods in the midwestern United States (Deyrup, 1978).

Biology: Roling and Kearby (1974) recorded aspects of the life history of the species. Adult flight commences in March. The male initiates an entrance hole in a susceptible tree, which leads into a nuptial chamber. Eggs are deposited in niches off galleries branching from the nuptial chamber. A sex ratio of 2:1 (females:males) was reported. There are at least two generations per year (Batra, 1963).

Phytosanitary Significance: LaBonte et al. (2005) suggested that this eastern North American species likely was introduced into Oregon in solid wood packing material or other raw wood products. The beetle is thought to have been introduced into Germany in sawtimber or other wood imported from North America (Schneider, 1963).

Management: No information is available concerning management of *M. fasciatum*. Roling and Kearby (1974) suggested that the insect was beneficial in that it hastened decomposition of deadwood in forest ecosystems.

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Monochamus obtusus Casey

Taxonomy: Coleoptera: Cerambycidae

Distribution: western Canada, western United States (Furniss and Carolin, 1977).

Hosts: *Abies* and *Pinus* spp., *Pseudotsuga menziesii* (Mirb.) Franco (Furniss and Carolin, 1977).

Environmental/Economic Importance: Larval galleries that are bored deeply into the wood may result in a reduced value of the final product (e.g., veneer logs downgraded to saw logs) (CABI, 2005). The presence of one larval gallery in a structural pole log may compromise its integrity, resulting in its rejection for use as, for example, a utility pole. The beetle also is a vector of the nematode, *Bursaphelenchus xylophilus* (Steiner & Buhrer) Nickle, a parasite of pines, which causes losses in excess of 847 million board-feet annually in Japan (CABI/EPPO, 1997a).

Biology: *Monochamus* beetles generally attack only trees under stress or those recently felled (CABI/EPPO, 1997a). Fecundity ranges from 40 to over 200 eggs per female. Eggs are laid in the bark. After hatch, larvae feed on phloem and cambial tissues, later boring into the sapwood. Pupation occurs in a chamber excavated in the sapwood.

Phytosanitary Significance: *Monochamus obtusus* has been intercepted in California in firewood from Washington and Michigan (data from CDFA), indicating its tendency to be moved interstate in articles of wood. Because it easily may be transported outside its natural range in untreated wood (CABI, 2005), it has been proposed as an A1 quarantine pest for the European and Mediterranean Plant Protection Organization (EPPO, 2007b).

Management: Mechanical Control: Mass-trapping shows promise as an efficient means for suppressing population densities of the beetle over the flight season (McIntosh et al., 2001). Wood may be disinfested by heating it to 56°C for at least 30 minutes (CABI/EPPO, 1997a).

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Neoclytus muricatulus Kirby

Taxonomy: Coleoptera: Cerambycidae

Distribution: western Canada, western United States, eastern United States (Maine to Ohio, North Carolina) (Baker, 1972; Furniss and Carolin, 1977).

Hosts: *Abies*, *Larix*, *Picea*, and *Pinus* spp., *Quercus stellata* Wangenh., *Pseudotsuga menziesii* (Mirb.) Franco (Baker, 1972; Furniss and Carolin, 1977).

Environmental/Economic Importance: No information is available on the impact of the species. The related species, *N. acuminatus* (F.), produces numerous galleries throughout the wood; lumber cut from infested logs is riddled with tunnels, rendering it unmarketable (Solomon, 1995).

Biology: Larvae bore through dead, dry branches and larger woody material (Furniss and Carolin, 1977).

Phytosanitary Significance: The beetle has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (Dodds et al., 2004), indicating the facility, with which it may be moved intracontinentally in articles of wood.

Management: No information is available on management options.

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***Phymatodes decussatus* (LeConte)**

Taxonomy: Coleoptera: Cerambycidae

Distribution: western North America (British Columbia to California) (Furniss and Carolin, 1977).

Hosts: *Quercus* spp. (Furniss and Carolin, 1977).

Environmental/Economic Importance: No information is available on the impact of the species.

Biology: Larvae feed in the dead or dying branches, or thin-barked parts of the bole (Furniss and Carolin, 1977; Swift, 2008).

Phytosanitary Significance: *Phymatodes decussatus* has been intercepted at the California border in oak firewood (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: No information is available on management of the species.

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Phymatodes dimidiatus (Kirby)

Taxonomy: Coleoptera: Cerambycidae

Distribution: western Canada, western and northern United States (Baker, 1972; Furniss and Carolin, 1977).

Hosts: *Abies*, *Larix*, *Picea*, *Pseudotsuga*, and *Tsuga* spp. (Baker, 1972; Furniss and Carolin, 1977).

Environmental/Economic Importance: Adults have been observed emerging from structural timbers of cedar (*Thuja plicata* Don) and fir (Leech, 1944) used in houses.

Biology: No information is available on the biology of the species.

Phytosanitary Significance: The beetle has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (Dodds et al., 2004), indicating the facility, with which it may be moved intracontinentally in articles of wood.

Management: No information is available on management of the species.

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Phymatodes lecontei Linsley

Taxonomy: Coleoptera: Cerambycidae

Distribution: western North America (British Columbia to California) (Furniss and Carolin, 1977).

Hosts: *Quercus* spp. (Furniss and Carolin, 1977).

Environmental/Economic Importance: No information is available on the impact of the species.

Biology: No information is available on the biology of the species.

Phytosanitary Significance: The species has been intercepted in California in firewood with an origin listed as Tennessee (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: No information is available on management of the species.

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***Pityophthorus juglandis* Blackman**

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: The insect occurs in eight western states (Arizona, California, Colorado, Idaho, New Mexico, Oregon, Utah, and Washington) and northern Mexico (Chihuahua) (Cranshaw and Tisserat, 2008).

Hosts: Walnut (*Juglans* spp.) (Cranshaw and Tisserat, 2008).

Environmental/Economic Importance: Although *P. juglandis* historically was not considered a pest of walnut trees (Graves et al., 2009), it is a vector of thousand cankers disease of walnuts, caused by a newly recognized *Geosmithia* fungus (Tisserat et al., 2009). Brood galleries on branches (1.5 cm and greater) are frequently associated with staining and initiation of *Geosmithia* canker formation (Seybold et al. 2009). A great number of cankers tend to be formed, which coalesce to girdle twigs and branches (Clark, 2010). The disease progresses from a thinning and yellowing of the upper crown to dieback of larger branches and eventual collapse. Trees often die within three years of initial symptoms (Hasey, 2009).

Biology: Adults, which are minute in size (1.5-1.9 mm), overwinter in cavities excavated in the bark of the trunk (Cranshaw and Tisserat, 2008). In spring, they emerge and fly to branches to mate and initiate new tunnels for egg galleries. The *Geosmithia* fungus is introduced during tunneling. Larvae feed for four to six weeks under the bark in tunnels running perpendicular to the egg galleries. Pupation occurs in the tunnels. Adults emerge to produce a second generation.

Phytosanitary Significance: *Pityophthorus juglandis* is a phloem feeder, and not a wood borer, which reduces the probability that it will be successfully moved in processed wood products (Anonymous, 2009). Long-distance movement with unfinished wood is possible. The beetle has been intercepted in New Zealand on walnut from the United States (Brockerhoff et al., 2003). The possibility of interstate movement in firewood has been suggested, and the beetle and the fungus, *Geosmithia* sp., have been observed on firewood for sale in Colorado (Jacobi et al., 2010a).

Management: Controls for thousand cankers disease have not yet been developed (Rose, 2008). At present, no state quarantines exist for the disease (Clark, 2010). Prompt detection and removal of affected trees currently is the primary means of managing infestations, but insecticides applied to the trunk in late summer may be effective in killing adults as they seek overwintering sites (Cranshaw and Tisserat, 2008).

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Polygraphus rufipennis (Kirby)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: Canada (all provinces), United States (broadly distributed) (Baker, 1972).

Hosts: *Pinus*, *Larix*, *Abies*, and *Picea* spp. (Baker, 1972; Wood, 1982).

Environmental/Economic Importance: Although *P*. *rufipennis* infestations usually occur in slash and in dead and dying trees, during periods, in which high population densities develop, healthy trees may be subject to attack (Baker, 1972). Under such conditions, trees may be killed, particularly if they have been weakened by other pests (Bowers et al., 1996a). Mining by the larvae may be so extensive as to destroy almost completely the inner bark (Simpson, 1929). The beetle is a vector of at least four species of wood-infecting fungi: *Leptographium abietinum* (Peck) Wingf., *Ophiostoma bicolor* Davidson & Wells, *O*. *piceaperdum* (Rumbold) Arx, and *O*. *ips* (Rumbold) Nannf. (Haberkern et al., 2002).

Biology: Hibernation takes place in the larval, pupal, or adult stages, in the bark of stumps, logs, and the tops of trees cut during the previous spring or summer (Simpson, 1929). Adults emerge in May and June, and attack the bark of unthrifty trees or those recently felled. Females cut a tunnel through to the inner bark where a chamber is excavated and mating takes place. Eggs are laid in tunnels radiating from the nuptial chamber. One female may produce up to four distinct broods, extending over one or more seasons. In Newfoundland, there is one generation per year (Bowers et al., 1996b).

Phytosanitary Significance: *Polygraphus rufipennis* has been intercepted at the U.S. border in dunnage and firewood, among other wooden items (data from the USDA-APHIS, PPQ Port Information Network [PIN 309] database), and in Great Britain in timber imports (Winter, 1991), from Canada. It has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (Dodds et al., 2004). These examples illustrate the facility with which the species may be moved both intracontinentally and intercontinentally in articles of wood.

Management: Biological Control: Entomopathogenic nematodes have been suggested as possible agents for the biological control of *P*. *rufipennis* (Tomalak et al., 1989).

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Pseudopityophthorus pubipennis (LeConte)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western United States (Arizona, California, Oregon, Washington), western Canada (British Columbia) (LU, 2006; Solomon, 1995).

Hosts: *Quercus*, *Lithocarpus*, and *Castanea* spp., *Aesculus californica* (Spach) Nutt. (Swiecki and Bernhardt, 2006).

Environmental/Economic Importance: The beetles typically infest the bole and branches of injured, diseased, felled, or recently dead trees, or the dead branches of healthy trees (Furniss and Carolin, 1977; Rizzo et al., 2002), and may cause occasional tree mortality. Penetration of xylem tissues by the beetle impedes water transport in trees (Švihra et al., 2004). With the emergence and spread of the pathogen causing sudden oak death, *Phytophthora ramorum* Werres *et al*., *P. pubipennis* populations have reached outbreak densities, and are thought to be a factor in the decline of oaks in coastal forests of California (Švihra et al., 2004). It has been suggested that mass attacks by beetles are more likely the proximate cause of sudden death in trees, rather than the comparatively slow-developing infection produced by the pathogen (Swain, 2002).

Biology: Adults bore through the bark to the sapwood where two tunnels are excavated perpendicular to the wood grain (Swiecki and Bernhardt, 2006). Eggs are laid in niches along the tunnels. Upon hatch, larvae begin tunneling and feeding in the phloem. Pupation occurs just below the bark surface. Both larvae and adults overwinter. Depending on latitude, there may be two or more generations per year (Swiecki and Bernhardt, 2006).

Phytosanitary Significance: *Pseudopityophthorus pubipennis* has been intercepted in California in firewood with an origin listed as Texas (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: Chemical Control: Application of insecticides, such as permethrin, may be effective in suppressing beetle populations on a local scale (Švihra et al., 2004).

Cultural Control: Judicious pruning, watering, and fertilizing of valuable trees can reduce their susceptibility to attack (Solomon, 1995).

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Scobicia declivis (LeConte)

Taxonomy: Coleoptera: Bostrichidae

Distribution: western United States (e.g., California, Oregon, Utah) (Furniss and Carolin, 1977; Pitts and Alston, 2004). The species was detected in Florida in 2000 (Halbert, 2000).

Hosts: *Quercus*, *Acer*, *Acacia*, and *Eucalyptus* spp., *Umbellularia californica* (Hook. & Arn.) Nutt. (Furniss and Carolin, 1977).

Environmental/Economic Importance: The species usually feeds in seasoned hardwood, but will also attack living trees (Swiecki and Bernhardt, 2006). Larvae may tunnel through grape vines, weakening them (Bentley et al., 2006). The beetle has been known to infest hardwood paneling and floors in dwellings (Ebeling, 1975), and to damage wine casks (Furniss and Carolin, 1977) and asphalt roofing material (Linsley, 1942).

Biology: Ebeling (1975) summarized the life cycle of the species. The female bores an egg gallery to a depth of about 8 mm. She then turns perpendicularly, across the wood grain, and continues to excavate the gallery, where mating and oviposition occur. Eggs are deposited one each in pores in the wood. After hatch, larvae tunnel and feed, excavating long galleries (50-60 cm),and maturing in about nine months. Pupation occurs in the wood. Peak emergence of adults is in July and August. There is one generation per year.

Phytosanitary Significance: *Scobicia declivis* has been intercepted in California in firewood from Missouri and Colorado (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: Cultural Control: Maintaining proper sanitation, such as removal and destruction of prunings and dead wood before adults emerge in the spring, is perhaps the most effective means of control (Bentley et al., 2006).

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Scolytus laricis Blackman

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: western Canada (British Columbia), western United States (Idaho, Montana, Oregon, Washington) (Wood, 1982).

Hosts: *Larix occidentalis* Nutt. and *L. lyallii* Parl. (Wood, 1982).

Environmental/Economic Importance: The species attacks distressed trees of pole size, suppressed limbs on larger trees, and slash (Furniss and Carolin, 1977).

Biology: According to Wood (1982), the biology is similar to that of *S. unispinosus* LeConte. Adults of the latter species form uniramous and biramous parental galleries in the wood, from which larval mines radiate. Pupation occurs in the phloem. Adult flight periods are in May and July and there are up to two generations per year.

Phytosanitary Significance: The beetle has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (Dodds et al., 2004). It also has been intercepted in Great Britain in timber imports from Canada (Winter, 1991). These examples illustrate the facility with which the species may be moved both intracontinentally and intercontinentally in articles of wood.

Management: No information is available on control of this species.

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Tetropium velutinum LeConte

Taxonomy: Coleoptera: Cerambycidae

Distribution: western Canada (British Columbia), western United States (Alaska, California, Montana, New Mexico, Utah) (Furniss and Carolin, 1977; Holsten et al., 1980; Snow, 1906).

Hosts: *Abies*, *Picea*, and *Pinus* spp., *Larix occidentalis* Nutt., *Pseudotsuga menziesii* (Mirb.) Franco, *Tsuga heterophylla* (Raf.) Sarg. (Furniss and Carolin, 1977).

Environmental/Economic Importance: Drought-stressed, defoliated, and fire-scorched trees are susceptible to attack by the beetle and may be killed; the beetle caused widespread deterioration in larch stands in northern Washington during the 1930s (Furniss and Carolin, 1977). Mortality in apparently healthy trees also has been reported (Dodds et al., 2004).

Biology: Oviposition extends from May to August; eggs are laid under loose bark or between bark scales (Dodds et al., 2004). Larvae feed within the phloem and cambial tissues, and pupate in the sapwood. In Canada, one generation per year has been reported (Furniss and Carolin, 1977).

Phytosanitary Significance: The beetle has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (Dodds et al., 2004), indicating the facility with which it may be moved intracontinentally in articles of wood.

Management: Chemical Control: A 1% emulsion of lindane (γ-hexachlorocyclohexane) was reported to protect freshly felled trees from *T. velutinum* attack and reduce damage to already infested wood (Ross and Geistlinger, 1968).

Cultural Control: Prompt salvage logging after distubance that causes mortality or reduces tree vigor can reduce the impact of *T. velutinum* in forest stands (Dodds et al., 2004).

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Tomicus piniperda (L.)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: Native to Europe, the species has been introduced into north Africa, East Asia, Turkey, Canada, and north central and northeastern United States (Thomas et al., 2006).

Hosts: Primarily pines (*Pinus* spp.); the beetle also has been reported to attack *Picea* spp., *Abies pectinata*, and *Larix europea* (Anonymous, 1972; Jankowiak and Bilański, 2007). In North America, red pine (*P. resinosa*) is a particularly favored host (Ryall and Smith, 2000).

Environmental/Economic Importance: *Tomicus piniperda* is generally regarded as a secondary pest, successfully colonizing only recently dead pine trees or trees suffering from stress (Chen et al., 2004; Lånström et al., 1999; Morgan et al., 2004). However, populations can quickly build up to outbreak densities lasting many years, promoted by an abundance of breeding material; during such periods, healthy trees may be attacked (Anonymous, 1972). The beetle is considered to be the most serious scolytid pest of pines in Europe (Thomas et al., 2006). Damage is caused by adult and larval feeding on phloem tissue under thick bark at the base of the tree and by feeding on pith in young shoots in the tree crown, which causes them to wither and brown. Trees with severe damage to crowns show significant loss of growth increment (as high as 50%) compared to trees with less damage (Czokajlo et al., 1997). The beetle is a vector of blue-staining fungi of the genera *Hormonema*, *Leptographium*, *Ophiostoma*, *Diplodia*, *Aureobasidium*, and *Graphium* (Gibbs and Inman, 1991; Jankowiak and Bilański, 2007; Masuya et al., 1999; Punithalingam and Waterston, 1970; Solheim and Långström, 1991), some of which are highly virulent and capable of killing entire trees (Jankowiak, 2006).

Biology: The life history was discussed by Anonymous (1972) and Thomas et al. (2006). The beetle overwinters as a fully grown larva, pupa, or adult. Adults emerge in late winter or early spring, mate, and begin excavating egg galleries under the thick bark of a living tree, fresh stump, or recently cut material. Fecundity ranges from 60 to 160 eggs per female. Development from egg to adult requires about three months, adults of the first generation beginning to emerge in June. These individuals fly to the crown to feed on the new growth throughout the summer. There are one or two generations per year, depending on climate.

Phytosanitary Significance: Logs containing overwintering adults pose a significant risk of spreading infestations (Poland et al., 2000). The species has often been intercepted at U.S. ports in wood packaging material, particularly dunnage (Anonymous, 1972).

Management: According to Thomas et al. (2006), there appear to be no practical chemical controls for the pest, although methyl bromide is indicated as the treatment of choice for infested trees requiring a phytosanitary certificate (Humphreys and Allen, 1998). Proper silvicultural practices, such as thinning and removal of recently dead trees, could help keep *T. piniperda* populations at low levels (Morgan et al., 2004). The beetle is under a Federal quarantine in the United States (7 CFR §301.50), which restricts the movement of host material.

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Xyleborus glabratus Eichhoff

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: Native to Asia; the original distribution included India, Bangladesh, Burma, Taiwan, and Japan (Cognato, 2004). First detected in North America in 2002, *X. glabratus* presently is established in Florida, Georgia, and South Carolina (Rabaglia et al., 2006). Recently, the beetle was detected in Mississippi (Mayfield and Thomas, 2009b).

Hosts: Primarily Lauraceae, including *Lindera latifolia*, *Litsaea elongata*, *Phoebe lanceolata*, *Persea borbonia*, and *Sassafras albidum*; also recorded on *Shorea robusta* (Dipterocarpaceae) and *Leucaena glauca* (Fabaceae) (Rabaglia et al., 2006).

Environmental/Economic Importance: *Xyleborus glabratus* serves as a vector for *Raffaelea lauricola* Harrington, Fraedrich, & Aghayeva (Ascomycetes: Ophiostomatales), which causes a vascular wilt disease in lauraceous hosts (Fraedrich et al., 2008; Harrington et al., 2008). The disease has spread rapidly since it was first reported in Georgia in 2003, and has caused extensive mortality (estimated at 75-80% (Fraedrich et al., 2007) in redbay (*P. borbonia*) an ecologically dominant tree in coastal hammock vegetation in the southeastern United States (Goldberg and Heine, 2009), the fruit and foliage of which are important sources of food for wildlife (Hall and Butler, 2007). The fungus also has been reported to infect *Lindera melissifolia* (Koch and Smith, 2008), a Federally listed endangered species (50 CFR §17.12). Recently, *X. glabratus* and its fungal symbiont were found to attack avocado, *Persea americana* (Mayfield et al., 2008a), an important revenue-generating crop in the Florida economy (Evans, 2005). The beetle and its associated fungus are now considered potential threats to avocado production in Florida (Hanula et al., 2008).

Biology: Little information is available on the life history or ecology of *X. glabratus*. Hanula et al. (2008) reported a developmental period (from egg to adult) of 50-60 days and probable multiple, overlapping generations per year. The beetle, which is apparently attracted to aromatic compounds in the wood, attacks healthy as well as injured trees. The wilt fungus is introduced as the female beetle tunnels through the wood in preparation for oviposition, and provides food for the larvae (Fraedrich et al., 2008).

Phytosanitary Significance: The pest most likely was introduced into the United States in wood packaging material (Fraedrich et al., 2007). Firewood also is indicated as a pathway for spread of infestations (Mayfield and Thomas, 2009a).

Management: Systemic fungicides, such as propiconazole, have shown some promise in inhibiting infection of individual *P. borbonia* trees by the wilt fungus, and could be useful in protecting large, high-value trees in parks, residential areas, and historic sites that are currently succumbing to the disease and for which no other preventive management options currently exist

(Mayfield et al., 2008b). Hanula and Sullivan (2008) have evaluated attractants that may be useful in traps to detect and monitor populations of the beetle in areas, such as ports-of-entry.

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***Xyleborus xylographus* (Say)**

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: Primarily the eastern half of the United States, but also reported from Texas, New Mexico, Oregon, and California; Canada (Quebec, Ontario, British Columbia); and Cuba (Mudge et al., 2001; Snow, 1906; Wood, 1982). Outside of North America, the species occurs in Turkey, Romania, the former Czechoslovakia, Austria, the former USSR, France, Great Britain, South Africa, and the Canary Islands (Ak et al., 2005; Cal, 2008; Cognato, 2004; Fischer, 1954; GusEv, 1941; Hobson and Bright, 1994; IAPSC, 1999; Majernik, 1959; Michel, 1937; Munro, 1926; Negru and Pîrvescu, 1966).

Hosts: *Quercus* spp. appear to be the primary hosts (Wood, 1982). Other recorded hosts include *Corylus*, *Prunus*, *Malus*, *Alnus*, *Acer*, *Abies*, and *Juglans* spp.; *Acer pseudoplatanus* L.; and *Corylus avellana* L. (Ak et al., 2005; Fischer, 1954; GusEv, 1941; Michel, 1937; Pyatnitzkii, 1932; Snare, 2006).

Environmental/Economic Importance: Diseased or injured trees appear to be most susceptible to attack, although infestation of apparently healthy trees has been reported (Fischer, 1954). The beetle has been reported to be a pest of pear in California (Weldon, 1918), of hazelnut in Europe and Turkey (Ak et al., 2005; Snare, 2006), and of avocado in the Canary Islands (Cal, 2008).

Biology: Fischer (1954) discussed the reproductive biology of the species. During April and May, females emerging from hibernation select thick branches or trunks and bore down to the heartwood, then tunnel laterally, following one of the annual rings. Eggs are deposited in clusters of 8-12 in galleries. Observed fecundity ranged from 21-100 eggs per female. Larvae feed on a fungus introduced by the ovipositing female. The pupal stage lasts about one week, and adults mate soon after eclosion. A sex ratio of 20:1 (females:males) was observed. There is one generation per year.

Phytosanitary Significance: Dunnage and other solid wood packing material were implicated as probable pathways for the introduction of this eastern North American species into Oregon (Mudge et al. 2001).

Management: Chemical Control: Application of insecticides, such as BHC and parathion, has been reported to provide some measure of control (Fischer, 1954).

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Xyloterinus politus (Say)

Taxonomy: Coleoptera: Curculionidae: Scolytinae

Distribution: primarily the eastern half of the United States, but also occurring in Washington and Alaska; Canada (Yukon to Nova Scotia) (Majka et al., 2007; Mudge et al., 2001; Wood, 1982).

Hosts: *Acer*, *Alnus*, *Betula*, *Carya*, *Castanea*, *Fagus*, *Fraxinus*, *Magnolia*, *Populus*, *Prunus*, *Quercus*, *Picea*, *Pinus*, *Tsuga*, and *Ulmus* spp. (Baker, 1972; Saint-Germain et al., 2007; Wood, 1982).

Environmental/Economic Importance: *Xyloterinus politus* breeds in injured, dying, and newly felled trees and limbs; lumber cut from infested wood may be severely degraded, and its value reduced, by adult entrance holes and associated stains (Baker, 1972). Wounds inflicted by the beetle may expose host trees to secondary infection by organisms of decay (Shigo, 1966). The beetle is considered a potential vector of the fungus causing Dutch elm disease (Finnegan and Gagnon, 1964).

Biology: Oviposition occurs between May and August (Robinson, 2005). After tunneling through the bark, the female excavates a gallery 2-45 mm into the sapwood of a host tree. Eggs are deposited in secondary tunnels at right angles to the main gallery. Eggs are present during two periods: mid-May to mid-June and early to late August (MacLean and Giese, 1967), suggesting two generations per year. Larvae feed on fungi growing within the tunnels, and the beetle completes its development after about 29 days. Adults overwinter in the galleries and larval cradles.

Phytosanitary Significance: Dunnage and other solid wood packing material were implicated as probable pathways for the introduction of this eastern North American species into Washington (Mudge et al., 2001). Under experimental conditions, the beetle was able to infest wood treated according to ISPM No. 15 guidelines (Anonymous, 2006).

Management: No information is available on control of the beetle.

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Xylotrechus longitarsus Casey

Taxonomy: Coleoptera: Cerambycidae

Distribution: western Canada (British Columbia), western United States (California, Colorado) (Furniss and Carolin, 1977).

Hosts: *Pseudotsuga menziesii* (Mirb.) Franco (Furniss and Carolin, 1977).

Environmental/Economic Importance: Trees that are injured, dying, or dead tend to be most susceptible to attack by the beetle (Jackson and Bulaon, 2005). Cerambycidae reduce the value of logs by producing large holes in the wood (McIntosh et al., 2001).

Biology: No information is available on the biology of the species.

Phytosanitary Significance: The beetle has been found in Minnesota in barked logs of *Larix occidentalis* imported from the western United States (Dodds et al., 2004), indicating the facility with which it may be moved intracontinentally in articles of wood.

Management: Mechanical Control: Attack by wood borers (such as *X. longitarsus*) may be prevented by rapid utilization of wood, peeling, water sprinkling, or storage of logs in water or in compact decks with maximal shading (Morewood et al., 2002). Mass-trapping has been proposed as a feasible means of suppressing populations of wood borers, such as *X. longitarsus* (McIntosh et al., 2001).

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Xylotrechus nauticus (Mannerheim)

Taxonomy: Coleoptera: Cerambycidae

Distribution: predominantly western North America (British Columbia to California) (Furniss and Carolin, 1977), but the species also has been reported from Iowa (PSU, 2002).

Hosts: *Quercus*, *Arbutus*, *Eucalyptus*, *Prunus*, *Salix*, and *Juglans* spp. (Ebeling, 1975; Solomon, 1995).

Environmental/Economic Importance: Unhealthy trees seem preferentially to be attacked by *X. nauticus* (Linsley and Macleod, 1942). Attack may result in extensive dieback in branches (Solomon, 1995). The beetle is a common pest of Pacific madrone, *Arbutus menziesii* Pursh (Bennett and Shaw, 2008), and of oaks (Hagen, 1993), causing extensive riddling of the wood. Eucalyptus logs cut for lumber have been destroyed (Solomon, 1995). It commonly infests firewood (Furniss and Carolin, 1977).

Biology: Adults emerge and fly from May to July (Solomon, 1995). Larvae bore into the inner bark, producing an engraved pattern in the sapwood, and tunnel within the heartwood (Swiecki and Bernhardt, 2006). There is one generation per year (Hagen, 1993).

Phytosanitary Significance: The species has been intercepted in California in firewood with an origin listed as Pennsylvania (data from CDFA), indicating its tendency to be moved interstate in articles of wood.

Management: Cultural Control: Alleviating stressful conditions in stands is recommended to maintain tree health and reduce incidence of attack by *X. nauticus* (Hagen, 1993).

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***Xylotrechus sagittatus* (Germar)**

Taxonomy: Coleoptera: Cerambycidae

Distribution: eastern Canada, northern and eastern United States, but also reported from Arizona and New Mexico (Baker, 1972; Furniss and Carolin, 1977).

Hosts: *Abies*, *Picea*, and *Pinus* spp. (Hanula, 1996).

Environmental/Economic Importance: *Xylotrechus sagittatus* generally breeds in dead conifers, and is particularly attracted to logs, slash, or standing trees killed by fire or bark beetles (Baker, 1972). However, the beetle also will attack living trees under stress (Heikkenen et al., 1986).

Biology: Little information on biology is available. After hatch, larvae feed first beneath the bark, then tunnel deeply into the heartwood (Baker, 1972).

Phytosanitary Significance: LaBonte et al. (2005) suggested that this eastern North American species was likely introduced into Oregon in solid wood packing material or other raw wood products.

Management: No information is available on management of the species.

Appendix C. Pathogens Associated with Firewood (fact sheets)

The following pathogens are native to or long-established in the United States and yet new records of damage or new geographic distributions are being reported. Based on their biology and host range, each species has the potential to be moved with unmitigated firewood.

Pathogen: *Fusarium circinatum* Nirenberg & O'Donnell
Disease: Pitch Canker

Taxonomy: Ascomycetes: Hypocreales; Synonym: *Fusarium subglutinans* f.sp. *pini* Correll; Teleomorph: *Gibberella circinata* Nirenberg & O'Donnell; previously referred to as *Fusarium moniliforme* var. *subglutinans* Wollenw. & Reinking. (Farr et al. 2010).

Distribution in the United States: In the United States, pitch canker is found in parts of California (3 distinct outbreaks) (Gordon et al., 2001; Wikler et al., 2003b) and parts of the southeastern United States, where it is considered endemic (Barnard and Blakeslee, 1980; Enebak and Carey, 2003; Gordon et al., 2001; Storer et al., 1995). The U.S. Forest Service recently reported that pitch canker continues to spread and cause significant damage in southeast states such Georgia and Tennessee (USFS, 2006). Outside of the United States it is reported in Italy (Carlucci et al., 2007), Spain (Landeras et al., 2005), Chile (Gordon et al., 2001), South Africa (Gordon et al., 2001), Haiti, Japan, and Mexico (Starkey et al., 2007).

Hosts: At least 51 species of pine (Gordon, 2006) as well as *Pseudotsuga menziesii* (Douglas-fir) (Gordon, 2006) are hosts. In the southeastern United States, *Pinus elliottii* (slash pine) is very susceptible (Enebak and Carey, 2003). In California, most native pines are susceptible but infections on Monterey pine (*Pinus radiata*) are the most common (Wikler et al., 2003a) and at epidemic levels (Wikler et al., 2003b).

Environmental/Economic Importance: The pathogen can affect all life stages of susceptible pines (Barnard and Blakeslee, 1980; Barnard and Blakeslee, 2006; Starkey et al., 2007) but infections are most common in trees 10 years or older (FDACS, 1983). The pathogen causes losses due to tree mortality, reduction in lumber value from stem deformation, reduced growth, and seed contamination in seed orchards (Storer et al., 1995).

All commercially important native pine species in California are susceptible (Storer et al., 1995). Monterey pine is used internationally as a plantation tree (Starkey et al., 2007) and is widely planted in New Zealand, Australia, and Chile (Storer et al., 1995). Native populations of the Monterey pine are only found in five locations worldwide—two on islands off the coast of Baja California and three in mainland central California (Wikler et al., 2003b). The Monterey pine is considered one of the most important amenity trees in California (Storer et al., 1995) and the loss of the native population would be the loss of an invaluable genetic resource (Worrall, 2007). The Christmas tree industry in California is affected because Monterey pine comprises 70% of that market (CFPC, 1994).

Douglas-fir is another significant commercial species in the western United States and nationally (Tompkins, 2005). It remains one of the most popular Christmas tree species (Tompkins, 2005). For a softwood species, the wood of Douglas-fir is one of the stronger woods and is widely used for structural purposes, including flooring, cabinetry, ladders, pallets, and boxes (Tompkins, 2005).

Currently, in the western United States, pitch canker is limited to the coastal areas of California; however, there are extensive native pine forests in Oregon, inland California, and Washington that include species susceptible to this disease (Aegerter et al., 2003).

Biology/Behavior: The pathogen can be spread by wind and water to wounded hosts (Gordon et al., 2001), by infested or infected seed (Storer et al., 1995), or by infested soil (Wikler et al., 2003a). It can also be vectored by insects associated with the wood (FDACS, 1983). In California, the disease is vectored by four species of *Pityophthorus* [Coleoptera: Scoyltidae], *Conophthorus radiatae* [Coleoptera: Scolytidae], *Ernobius punctulatus* [Coleoptera: Anobiidae], (Gordon et al., 2001) and at least two species of *Ips* [Coleoptera: Scolytidae] (Gordon et al., 2001;Wikler et al., 2003a). In Florida, the deodar weevil (*Pissodes nemorensis*) [Coleoptera: Curculionidae] is reported as a vector (FDACS, 1983).

The pathogen uses wounds caused by insect feeding, weather-related damage, or silvicultural practices to infect the host (Gordon, 2006). Cankers girdle trunks, exposed roots, or branches (Gordon et al., 2001; Wikler et al., 2003a). Girdled branches will typically wilt and turn yellow and then red (Wikler et al., 2003a). Multiple branch infections can lead to crown dieback and tree mortality (Gordon et al., 2001; Wikler et al., 2003a). Infected trees are also more susceptible to further attack and damage by insects such as engraver beetles (Wikler et al., 2003a).

Phytosanitary Significance: The first description of pitch canker in the United States was in 1946 by Hepting and Roth (Gordon, 2006). Until 1986, the reports of pitch canker were limited to the southeastern United States. In 1986, it was reported for the first time in California by McCain, Koehler, and Tjosvold (Gordon, 2006). Studies on the populations of the pathogen in California found them to be largely clonal and in three geographically separate areas of the state, suggesting a recent introduction with human-facilitated transport (Gordon, 2006). Molecular studies found two multilocus haplotypes shared between the populations in Florida and California, suggesting that Florida, or at least some part of the southeastern United States, was the source of the disease in California (Gordon, 2006).

Asexual reproduction is the primary mode of reproduction for the fungus; however, some strains in California were found to have the ability to sexually reproduce (Wikler et al., 2003a). Sexual reproduction can result in the development of new strains that can overcome plant disease resistance. Researchers have already found that strains of the fungus in Mexico and Florida were able to infect a Monterey pine that is resistant to the eight most predominant strains of the fungus in California (Wikler et al., 2003a). The domestic movement of these strains could result in increased damage to known hosts or new hosts.

Gordon et al. (2001) reported that untreated logs from infected trees could disseminate the pathogen. The pathogen is estimated to be able to survive in cut wood for a year or more (CFPC, 1994). Debarking may help reduce pathogen presence; however, the California Pitch Canker Task Force recommends a fungicidal treatment to eliminate the pathogen from the surface of the logs (Gordon et al., n.d.).

Other phytosanitary considerations include the pathogen's ability to survive in and on pine seed (Storer et al., 1995), within soil, and the ability to incite cryptic infections on seedlings (Wikler et al., 2003a).

Management: There are limited realistic options for managing this disease once older trees are infected, especially in the forest vs. urban landscape environment (Gordon et al., 2001). Proven, cost-effective fungicidal controls are not available (Barnard and Blakeslee, 2006). Strategies to limit the movement and handle infected materials properly as well as to replace diseased trees with those displaying some level of disease resistance are promoted (Gordon et al., 2001). Researchers have identified some pitch canker resistant germplasm but due to sexual reproduction of the fungus, the longevity of this resistance could be short-lived (Wikler et al., 2003a).

Unpublished research by McNee, Wood, Storer, and Gordon (n.d) suggests chipping branches of infected trees can greatly reduce insect populations but is not as effective on pathogens (Gordon et al., 2001). The pathogen is recoverable in chipped wood for over one year after the tree is cut (Gordon et al., n.d.). Additional treatment of chipped wood or logs by either heat treatment or fumigation is recommended (Gordon et al., 2001). Research from the California Pitch Canker Task Force found that continuous exposure at or above 50º C (122º F) for ten days was an effective measure to treat infected chipped wood (Gordon et al., n.d.).

California is currently attempting to limit the spread of the disease by restricting the transport of host material into and out-of infested areas with education and restrictions on the movement of Christmas trees, wood chips, and firewood (Gordon, 2003; Owen, 2001).

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Pathogen: *Ceratocystis fagacearum* (T. W. Bretz) J. Hunt
Disease: Oak Wilt

Taxonomy: Ascomycetes, Microascales; Synonym: *Endoconidiophora fagacearum* T.W. Bretz 1952; Anamorph: *Thielaviopsis quercina* (B.W. Henry) A.E. Paulin, T.C. Harr. & McNew; Synanamorph: *Chalara quercina* Henry (Farr et al., 2010)

Distribution in the United States: Whether *C. fagacearum* is native to the United States is debatable (Hudler, 2008; Juswik et al., 2008; McDonald et al., 1998); however, it is a long-established pathogen in the United States that continues to spread and move into new areas. Currently it is reported in the eastern United States (CABI, 2007). There are no reports of the disease west of the Rocky Mountains (Hudler, 2008). New reports in 2007 and 2008 include New York State (Hudler, 2008), and new areas of Michigan (Kidd, 2008; DFMFM, 2007), and Texas (TFS, 2007). In the north central region of the United States the pathogen recently emerged as a serious threat to oaks and is expanding its distribution and impact (Haugen et al., 2007).

Hosts: All *Quercus* spp. are to some degree susceptible (Appel et al., 2005; Farr et al., 2010; Gleason and Mueller, 2005). Red oaks such as *Q. buckleyi*, *Q. shumardii*, and *Q. marilandica* are very susceptible and may play a role in the establishment of new oak wilt infections (Appel et al., 2005). White oaks such as *Q. stellata*, *Q. macrocarpa*, and *Q. muehlenbergii* are considered more resistant than red oaks and may recover from infection with little crown loss (Appel, 2001; Appel et al., 2005). Live oaks are considered intermediate in their susceptibility to the oak wilt pathogen; however, due to their growth habit, the movement of the pathogen between adjacent trees is enhanced and the fungus is able to cause considerable damage (Appel et al., 2005). In central Texas, *C. fagacearum* occurs at epidemic levels on live oak trees (Appel et al., 2005).

Environmental/Economic Importance: Oak wilt is one of the most destructive tree diseases in the eastern United States (Appel et al., 2005; O'Brien et al., 2000). On a susceptible red oak, tree death may occur in as little as three weeks (Hudler, 2008). Oaks are among the most economically important trees, providing high-quality timber, tannins for leather, firewood, dye, and food products (Nixon, 2007). In Texas, live oak is a premier shade tree that is valued for its aesthetics and wildlife benefits (USFS, 2006). Up to 20% of the property value in cities like Austin or San Antonio may be attributed to the presence of live oak trees (Billings, 2007).

An economic assessment was conducted on the impact of oak wilt on just one county in Minnesota (Mehta et al., 2008). The preliminary model developed by Mehta et al. estimated that if oak wilt is not managed "21,000 to 29,000 trees would die each year and approximately 20% of all oaks would be killed over the next 20 years" (Mehta et al., 2008). The removal of dead oaks from this area could incur damages of at least $88.8 million in five years, $111.1 million in 10 years, and $143 million in 20 years. These damage estimates do not quantify losses such as the carbon sequestration, energy conservation, and wildlife resource that trees provide (Mehta et al., 2008).

Biology/Behavior: The fungus infects through fresh wounds or by root grafts connecting diseased trees to healthy trees (Juswik et al., 2008; Pecknold, 2001). The fungus invades the xylem, leading to obstruction of water movement (Gleason and Mueller, 2005). This causes the foliage to wilt and die (Gleason and Mueller, 2005). Under appropriate environmental conditionals, dense fungal mats are produced under the bark of recently killed trees. These mats create pressure and break through the bark where they sporulate and emit a rotten melon-scented odor (Gleason and Mueller, 2005). This odor is attractive to nitidulids that visit the fungal mats as feeding and breeding sites (Appel, 2001). The sticky spores of the fungus adhere to the beetle, internally and externally, and can then be moved to the next host the insect visits (Gleason and Mueller, 2005). Recently made pruning wounds on oak are also attractive feeding sites for the beetle by serving as an entry point for the fungus (Gleason and Mueller, 2005). Oak bark beetles (*Pseudopityophihorus* spp.) [Coleoptera: Scolytidae] can also transmit the fungus (Rexrode and Brown, 1983) but do not play an important role in all parts of the United States (French and Juzwik, 1999).

Phytosanitary Significance: Fungal mats produced on the unmitigated dWPM could be visited by vectors at the destination or vectors associated at the original site could move with the wood to the new location (Appel, 1994). The jump of the oak wilt pathogen from central Texas to west Texas has been attributed to insect transmission via mat-laden firewood moved from oak wilt areas to the east (Juzwick et al., 2008; TFS, 2007). Infested firewood is also implicated in the movement of *C. fagacearum* from Wisconsin to the south-central portion of Michigan's Upper Peninsula (Juzwick et al., 2008). Dunnage or other packing material with bark intact could act in the same transport manner.

Ceratocystis fagacearum is considered adaptable enough to be a threat to oak forests in the western United States (Appel, 2001). As the fungus adapts to oaks in Texas there is concern it will spread throughout the southern range of oak (Ward and Mistretta, 2007). Inoculation studies have shown that several western red oak species are susceptible (Appel, 1994). The oak forests in California comprised of live and red oak are considered at risk from this pathogen (Appel, 2001).

Tainter et al. (1984) found that *C. fagacearum* survived in air-dried lumber for 20 weeks and that lumber should be dried to a moisture content of 20% or less to devitalize *C. fagacearum.*

Management: Root trenching, pruning when vectors are inactive, removal of diseased trees, and management of firewood piles are all considered effective means to reduce the spread of the oak wilt pathogen (O'Brien et al., 2000). Fungicides are available as a preventative and possibly therapeutic measure but to due to high costs and risk associated with application their use is generally limited to high-value, specimen oaks (Appel et al., 2005; O'Brien et al., 2000).

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Pathogen: *Heterobasidion annosum* (Fr.) Bref. (North American Strains)
Disease: Annosum Root Rot/Butt Rot

Taxonomy: Basidiomycetes: Russulales; Synonym: *Fomitopsis annosa* (Fr.: Fr.) P. Karst. 1881; *Fomes annosus* (Fr.: Fr.) Cooke 1885; Anamorph: *Spiniger meineckellus* (A. Olson) Stalpers (Farr et al., 2010)

The species concept for *H. annosum* has recently changed. Intersterility groups and separate species are now reported that have unique host ranges and distributions (Linzer et al., 2008). In North America there are two reported intersterile strains of *H. annosum*, the P-type and S-type (Ostry and Juzwik, 2008).

Distribution in the United States: The P-type strain is found in the eastern states, Texas (Ostry and Juzwik, 2008) and west coast (Asiegbu et al., 2005). The S-type strain is only found on the west coast (Schmitt et al., 2000; Worrall, 2007).

Hosts: Conifers are considered the primary hosts. P-type strains damage *Pinus taeda* (loblolly pine), *P. resinosa* (red pine), and *P. elliottii* (slash pine); S-type strains are commonly reported on *Abies* (fir), *Picea* (spruce), *Pseudotsuga menziesii* (Douglas-fir), and *Tsuga* (hemlock) (Ostry and Juzwik, 2008).

Environmental/Economic Importance: Plantation conifers are at a high level of risk from *H. annosum* due to susceptibilities from poor management practices or poor site selection (Ward and Mistretta, 2007). Although *H. annosum sensu lato* has been reported from North America for at least a century, reports of significant damage are more recent and in some areas have reached epidemic proportions (Ostry and Juzwik, 2008; Schmitt et al., 2000). As forest management practices change, the range and intensity of the disease is anticipated to increase due to prescribed burning and partial cutting (Ostry and Juzwik, 2008).

Damage caused by *Heterobasidion annosum* includes root rot, butt rot, reduced growth and mortality (Schmitt et al., 2000). The disease is regarded as one of the most economically important forest pathogens in temperate, northern hemisphere forests (Asiegbu et al., 2005).

In the southern United States, the occurrence of the disease is often correlated to recent thinnings in tree plantations (Cram, 2003; USFS, 2006). In 2006, *H. annosum* caused the greatest amount of disease-related mortality of pines in Georgia, and in South Carolina the pathogen caused financial losses close to $2 million (USFW, 2006). Damage to conifers in recreational sites creates hazardous situations with trees that become susceptible to wind fall (Cram, 2003).

Biology/Behavior: The fungus infects hosts via basidiospores, mycelia, or conidia (Sinclair and Lyon, 2005). Damage is often in the heartwood of species however for some hosts the fungus can attack living cells of the cambium and phloem (Schmitt et al., 2000). In fir trees, the fungus commonly moves from the inner sapwood to outer sapwood (Schmitt et al., 2000). Basidiospores can be wind blown to new hosts or moved through course soils with rainwater (Sinclair and Lyon, 2005). Airborne basidiospores colonize stumps of recently cut trees or wounds on hosts at the exposed roots, butt, or upper bole (Schmitt et al., 2000). Conidia may be moved via insects or other small animals; however conidia of *H. annosum* were shown to survive passage through the alimentary canal of the large pine weevil (*Hylobius abietis* (L.) [Coleoptera: Curculionidae] (Kadlec et al., 1992). Larva of these types of insects tunnel into wood to feed (CABI, 2007). The fungus can also form mycelial mats between the wood and bark of the infected host (Lucas et al., 1992).

Pathogen activity in stands is favored after second and subsequent thinnings due to production of spores and stump infections (Sinclair and Lyon, 2005). *Heterobasidion annosum* can spread via root to root contact and therefore infected stumps left after thinning can serve as inoculum for newly planted trees of the next stand (Otrosina and Cobb, 1989; Greig and Pratt, 1976; Schmitt et al., 2000; Sinclair and Lyon, 2005). The pathogen can survive in stumps for decades (Greig and Pratt, 1976; Piri, 1996). The pathogen is adapted to sandy soils with neutral to alkaline pH (Demers et al., 2001; Sinclair and Lyon, 2005). The pine plantations on sandy soils in north Florida are considered at high risk from this pathogen (Demers et al., 2001), however Eastern white pine is considered very susceptible to infection regardless of soil type (Cram, 2003).

Phytosanitary Significance: Because the fungus can live as a saprobe in host material for long periods, it is likely it would be able to survive in unmitigated wood and be able to sporulate under moist conditions. Spores of the fungus may move on the exterior of certain insects associated with unmitigated wood or be spread after passage through their bodies (Kadlec et al., 1992). Long-distance transport was documented by Australian researchers when *H. annosum* was found in green lumber shipments from northwestern North America (Mireku and Simpson, 2002). The presence of *H. annosum* in an isolated region of Italy is attributed to the movement of unprocessed wood into the area for military purposes (Gonthier et al., 2004; Linzer et al., 2008). This particular region was sealed off from the public for centuries and contains only native plants, removing the possibility of introduction from exotic plantings (Gonthier et al., 2004; Linzer et al., 2008). Comparative molecular work suggests there was a significant lag time from the period of introduction to noticeable mortality of stone pines (*Pinus pinea*) (Gonthier et al., 2004).

Management: Proper site selection, as well as consistent and properly timed management practices is recommended (Cram, 2003; Demers et al., 2001). In some situations, chemical treatment of stumps from recently felled trees is recommended to prevent infection and further spread of the disease (Schmitt et al., 2000).

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Pathogen: *Neonectria faginata* (Lohman, Watson & Ayers) Castl. & Rossman
Disease: Beech Bark Disease

Taxonomy: Ascomycetes: Hypocreales; also caused by *Neonectria ditissima* (Tul. & C. Tul.) Samuels & Rossman (syn. *N. galligena*) (Castlebury et al., 2006; Houston and O'Brien, 1983) and potentially a third species (*Nectria ochroleuca* (Schwein) Berk.) (McCullough et al., 2001)

Fungal species associated beech bark disease were transferred from the genus *Nectria* to *Neonectria* Wollenw. (Rossman et al., 1999). Castlebury et al. (2006) re-described *Neonectria coccinea* (Pers.: Fr.) Rossman & Samuels var. *faginata* (Lohman et al.) as *Neonectria faginata* (Lohman et al.) Castl. & Rossman *comb. nov.* and *stat. nov* that only occurs on beech in North America, while the European species, *Neonectria coccinea* (Pers.: Fr.) Samuels & Rossman, only occurs on beech in Europe. Castlebury et al. (2006) also synonymized *Neonectria galligena* (Bres.) Rossman & Samuels, a species generally accepted as native to North America (Houston, 1994; MacKenzie and Iskra, 2005; Mahoney et al., 1999; O'Brien et al., 2001; Plante et al., 2002), with *Neonectria ditissima* (Tul. & C. Tul.) Samuels & Rossman. *Neonectria ditissima* appears to have North American and European populations (Castlebury et al., 2006).

Distribution in the United States: The disease was reported in the United States in the early 1900s and new reports of its movement in the United States are still surfacing (MacKenzie and Iskra, 2005; O'Brien et al., 2001). The disease is reported in Michigan, Virginia, West Virginia, Pennsylvania, New York, Massachusetts, Connecticut, Vermont, New Hampshire, Maine, New Jersey, North Carolina, Tennessee, and Ohio (USDAFS, 2005).

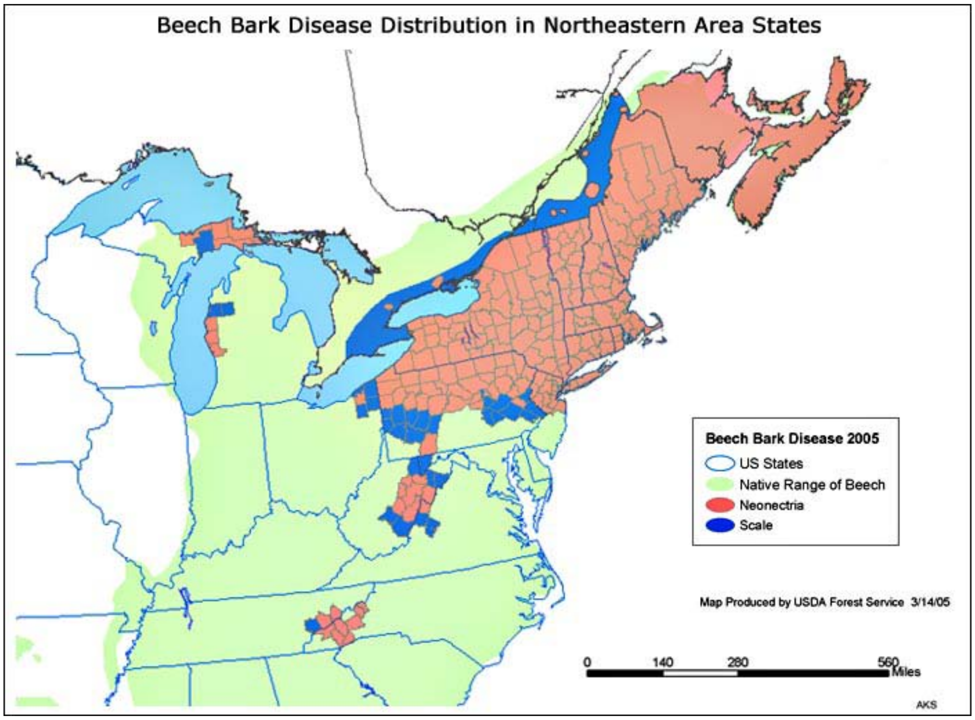

Figure 14. U.S. distribution of beech bark disease constituents in 2005 (USDA Forest Service, 2005).

Hosts: *Fagus grandifolia* (Houston and O'Brien, 1983)

Environmental/Economic Importance: Beech bark disease is a significant and ongoing threat to U.S. American beech trees, and its damage will have lasting effects on the forest composition of affected areas (Griffin et al., 2003). Beech trees play an important role in forest ecosystems as the beech nuts are staple source of nutrition for many animals (Depolo, 2008). Beech trees are an important source of "mast" because they provide food and habitat for more than 40 species of birds and mammals (McCullough et al., 2001). Beech wood is also used for timber and the trees have ornamental value in parks and landscape plantings (WDNR, 2007).

In Michigan alone, 75 million beech trees larger than 10 inches diameter are considered at risk from beech bark disease (Depolo, 2008). In the initial phases of infection in Pennsylvania, 50 percent of the trees larger than 10 inches in diameter were killed. The other trees were severely compromised or somewhat resistant (McCullough et al., 2001). Other insects and pathogens may invade the weakened trees and the trees are easily broken by high winds (McCullough et al., 2001). In Maine, most of the older beech trees have been killed and those that survive are compromised and of low timber value (McCullough et al., 2001). Trees that survive or regenerate after the initial wave of disease may be colonized by a second scale insect, *Xylococculus betulae* (Perg.) Morrison whose feeding can cause bark swelling and fissures easily colonized by another generation of scales (McCullough et al., 2001; Sinclair and Lyon, 2005). Regenerated stands can also cause a shift in forest species composition. Excessive root sprouting from trees killed by the pathogen can lead to dense thickets of deformed beech trees that exclude other species and lead to long-term beech bark susceptibility of the stand (Houston, 1994; McCullough et al., 2001).

Biology/Behavior: The pathogen is associated with the introduced beech scale (*Cryptococcus fagisuga* Lind.) [Hemiptera: Eriococcidae], a minute scale easily moved by wind or on animals (Depolo, 2008; Houston and O'Brien, 1983). Scales are protected by a white wooly waxy layer that is noticeable when scales are in mass (Depolo, 2008; Houston and O'Brien, 1983). All scales are female and reproduction is parthenogenic (Houston and O'Brien, 1983). Feeding by the scales makes the tree susceptible to infection by the *Nectria* fungus (Depolo, 2008). The fungus infects the inner bark of the host into the sapwood and can eventually girdle the tree (Depolo, 2008; Houston and O'Brien, 1983). Sexual reproductive structures mature in the fall and continue to produce viable spores into the next year (Houston and O'Brien, 1983). Asexual spores can be found mid-summer until fall and are easily moved by wind (Houston and O'Brien, 1983).

There are two distinct phases of the disease. The first involves the epidemic build up of the scale and fungus called the killing front, and the second phase involves the effects of the complex on successionary trees emerging after the killing front (Houston, 1997).

Two North American species are associated with the disease in the United States, *Neonectria faginata* and *N. ditissima* (syn. *N. galligena*) (Farr et al., 2010; Houston and O'Brien, 1983). *Neonectria ditissima* is generally accepted as a native species and is typically associated with the killing front of the disease rather than the introduced species *N. faginata* (MacKenzie and Iskra, 2005; O'Brien et al., 2001). However, recently *N. galligena* (*N. faginata*) was found associated with a killing front of American beech in Ohio (MacKenzie and Iskra, 2005).

Phytosanitary Significance: The native range of beech extends along the eastern seaboard to the southern border of the United States including parts of Louisiana and Mississippi (USDAFS, 2005). The majority of this large range is not yet affected but it is anticipated that the impacts of the disease will increase in the future (Liebhold et al., 2002).

Management: Approximately 1% of American beech trees in the northeastern United States are considered resistant to this disease (Depolo, 2008; Houston, 1994; McCullough et al., 2001). Retaining resistant trees and removing susceptible species is encouraged (McCullough et al., 2001). For small infestations on high value trees, scrubbing the exterior of the trees to rid them of the scales or application of insecticides is recommended (Depolo, 2008; Houston and O'Brien, 1983). Management of the scale is critical as heavy scale infestations will allow a rapid spread of the pathogen (Houston, 1994).

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Pathogen: *Leptographium wageneri* (Kendr.) Wingf.
Disease: Black Stain Root Disease

Taxonomy: Ascomycetes: Ophiostomatales. There are three fungal taxa associated with black stain disease:

- *L. wageneri* var. *ponderosum* (Harr. & Cobb) Harr and Cobb
- *L. wageneri* var. *pseudotsugae* Harr. & Cobb
- *L. wageneri* var. *wageneri* (Kendr.) Wingf.

Distribution in the United States: All three fungal taxa are in the United States west of Rocky Mountains (Hessburg and Hansen, 2000; Jacobs and Wingfield, 2001; Sinclair and Lyon, 2005).

Hosts:

- *L. wageneri* var. *ponderosum* infects *Pinus ponderosa* Dougl. ex P.& C. Laws., *P. jeffreyi* Grev. & Balf., and *P. contorta* Dougl. ex Loud.
- *L. wageneri* var. *pseudotsugae* infects *Pseudotsuga menziesii* (Mirbel) Franco
- *L. wageneri* var. *wageneri* mainly infects *Pinus monophylla* Torr. & Frem., *P. edulis* Engelm., as well as other coniferous hosts (Jacobs and Wingfield, 2001; Schweigkofler et al., 2005)

Other host records compiled by Jacobs and Wingfield (2001) for *L. wageneri* (encompassing all varieties) included: *Abies grandis*, *Larix occidentalis*, *Picea engelmannii*, *P. glauca*, *Pinus aristata*, *P. attenuata*, *P. lambertiana*, *P. monticola*, *P. strobus*, *P. sylvestris*, *Tsuga heterophylla*, and *T. mertensiana*.

Environmental/Economic Importance: Black stain is a debilitating and usually lethal disease of important conifer species in the United States (Sinclair and Lyon, 2005). Metabolites of *L. wageneri* cause water inhibition in pine seedlings (Ayer et al., 1989). It is found in a wide range of elevations and habitats (Sinclair and Lyon, 2005).

Biology/Behavior: There are differences in the epidemiology and biology of the three host specific varieties, and not all are well understood (Schweigkofler et al., 2005). Black stain is a vascular wilt growing mainly in the root and 3-4 m above the crown. The disease is vectored by root feeding beetles, although the exact identity of the major species involved in disease spread are unknown on the West Coast (Schweigkofler et al., 2005). Jacobs and Wingfield (2001) compiled a list of insects reported with *L. wageneri*; species included were *Dendroctonus brevicomis, D. ponderosae, D. valens, Hylastes macer, H. nigrinus, Hylurgops porosus*

[Coleoptera: Scolytidae], *Ips latidens, I. mexicanus, Pissodes fasciatus,* and *Steremnius carinatus* [Coleoptera: Curculionidae].

Causal fungi are restricted to the tracheids of the host and do not colonize ray parenchyma like other fungi that cause stain in conifer sapwood. This results in a longitudinal "streaking" pattern on infected logs and not the typical pie-shaped stain seen with other species (Jacobs and Wingfield, 2001). Fungi sporulate in beetle galleries or other wounded tissue of the host (Sinclair and Lyon, 2005). Conidia are 4-8 x1-3 µm, sticky, and produced in minute droplets (Sinclair and Lyon, 2005). Sticky conidia adhere to the beetle's exterior and are transferred to new hosts visited by the beetle (Sinclair and Lyon, 2005). The vectors initiate new disease foci (Sinclair and Lyon, 2005). Conidia may also be moved via rain splash (Sinclair and Lyon, 2005).

Phytosanitary Significance: Because the pathogen is found in a wide range of elevations and habitats (Sinclair and Lyon, 2005) it has the potential to establish in other parts of the United States. The host range includes species present on the East coast (NRCS, 2009). The association of this fungus with diverse taxa of bark beetles and weevils increases the likelihood of movement in wood.

The introduced bark beetle, *Hylurgus ligniperda* Fabricius [Coleoptera: Scolytidae], is considered a potential vector of *L. wageneri* (Eglitis, 2001; Liu et al., 2007). It was first detected in the United States in New York in 2000 (Cavey et al., 2002). In 2003, it was detected in California (Liu et al., 2007). In other countries, this beetle is an efficient vector of other *Leptographium* species and therefore there is concern it will associate with *L. wageneri* and become a more efficient vector than the native vectors (USDA, 2000). The beetle could spread the pathogen to new areas, or cause greater levels of disease where the pathogen is known to occur. The global spread of this beetle is attributed to trade involving wood products (Cavey et al., 2002). Between 1985 and 2009, the beetle was intercepted approximately 300 times at U.S. ports of entry (PestID, 2009). *Hylurgus ligniperda* is considered readily transported on cut logs and wood packing material (Eglitis, 2001).

Management: Few control options are available for black stain. Management is limited to cultural practices and sanitation (EPPO, 2004).

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Pathogen: *Gremmeniella abietina* var. *abietina* (Lagerb.) M. Morelet

Disease: Scleroderris Canker

Taxonomy: Ascomycetes: Helotiales; Anamorph: *Brunchorstia pinea* (P. Karst.) Höhn. (Farr et al., 2010)

This species is indigenous to Europe but is long established in North America (EPPO, 2004; Skilling et al., 1986). There are three races of *G. abietina* var. *abietina:* the North American race, the European race, and the Asian race (Sinclair and Lyon, 2005). Evidence indicates the North American race has been in the United States since at least 1950 (Skilling et al., 1986). The European race was first reported in the United States in 1975 (Hamelin et al., 1998).

Distribution in the United States: Both races are only found in the northeastern United States; however, the European race is not as widely distributed as the North American race (Hamelin et al., 2000). The European race is limited to New York, Vermont, New Hampshire, and Maine (Skilling et al., 2004). The North American race can be found in the lakes states and New England (Skilling et al., 2004).

Hosts: The North American race occurs on *P. banksiana* Lamb. (jack pine), *P. contorta* Douglas & Loud. (lodgepole pine) (Hamelin and Rail, 1997) and *P. sylvestris* (Scots pine) (Skilling et al., 2004). Jack pine is considered a threatened or endangered species in some northeastern states (NRCS, 2009). In Canada, *P. monticola* (Western white pine), *Picea glauca* (white spruce) and *Picea mariana* (black spruce) are also infected (Skilling et al., 2004).

The European race occurs on several *Pinus* and *Larix* species (Hamelin and Rail, 1997), in particular *P. strobus* (Eastern white pine), *P. banksiana* (jack pine), and *P. resinosa* (red pine) (NRC, 2009). It also infects *Pseudotsuga menziesii* (Douglas fir) and most species of *Abies* (fir), *Picea* (spruce), and *Tsuga* (hemlock) (Skilling et al., 2004).

Environmental/Economic Importance: The North American race causes cankers in areas with heavy snowfall (Hamelin and Rail, 1997) and generally only affects seedlings and trees up to 2 m tall (Sinclair and Lyon, 2005). If the young trees do survive, they are stunted or deformed thereby reducing log quality (CABI, 2005; Sinclair and Lyon, 2005). The European race differs from the North American race in that it causes dieback and canker on trees of all sizes (Sinclair and Lyon, 2005). The European race is capable of infecting the entire crown of the tree and killing mature trees over a few years (Hamelin and Rail, 1997; Hamelin et al., 2000; NRC, 2009). When first discovered in New York, the mortality in 30-40 year red pine stands was more than 90% (Skilling et al., 1986). *Gremmeniella abietina* is considered a threat to *Picea* and *Pinus* forests in North America particularly if they are planted at high density and a low diversity of other species (CABI, 2005).

Biology/Behavior: Infection begins at the needles and moves to the shoots (NRC, 2009). Infected shoots and buds turn a greenish-yellow color and die off (NRC, 2009; Skilling et al., 2004). Cankers may form when the infection reaches the trunk (NRC, 2009).

The causal fungus is spread by airborne or rain-splashed spores and infected trees may not show symptoms until the following year (Skilling et al., 2004). Scleroderris canker is very cold tolerant and is promoted with snowy winters (Sinclair and Lyon, 2005). Continued cool, wet conditions in spring and summer favor large-scale outbreaks of the disease (CABI, 2005; Sinclair and Lyon, 2005).

Phytosanitary Significance: *Gremmeniella abietina* is primarily a concern with the movement of nursery stock however the European race is also able to infect mature trees. Trunk cankers can form on the bark (NRC, 2009) and therefore could be associated with dWPM where bark remains. This pathogen is also known to be able to infect and remain latent in host tissues and therefore would be difficult to detect (Yakota, 1975).

In the United States, the European race is more aggressive than the North American race and has a wider host range (Sinclair and Lyon, 2005); however, damage from the European race is no longer causing epidemics documented in the early 1970s (Ostry and Juzwik, 2008). This is believed to be from certain climatic factors at the time and cultural practices now in place (Ostry and Juzwik, 2008). Movement of the fungus via dWPM could distribute the pathogen to high hazard areas.

The European race and North American race of *G. abietina* are not distinguishable morphologically and the fungus can remain latent in host tissues (Hamelin et al., 2000; Skilling et al., 2004). Polymerase chain reaction (PCR) can be used to differentiate the races and detect latent infections (Hamelin et al., 2000).

Management: Planting resistant species (Sinclair and Lyon, 2005) and preventative fungicide applications in nursery situations are recommended (Skilling et al., 2004).

Appendix D. Literature Cited

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