# Live plant imports: the major pathway for forest insect and pathogen invasions of the US

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**Trade in live plants has been recognized worldwide as an important invasion pathway for non-native plant pests. Such pests can have severe economic and ecological consequences. Nearly 70% of damaging forest insects and pathogens established in the US between 1860 and 2006 most likely entered on imported live plants. The current regulation of plant imports is outdated and needs to balance the impacts of pest damage, the expense of mitigation efforts, and the benefits of live plant importation. To inform these discussions, we document large increases in the volume and value of plant imports over the past five decades and explain recent and proposed changes to plant import regulations. Two data sources were used to estimate the infestation rate of regulated pests in live plant shipments entering the US, thus allowing evaluation of the efficacy of the current port inspection process.**

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Invasions of non-native forest insects and pathogens continue despite ongoing countermeasures by federal and state agencies; on average, 2.5 previously unrecognized non-native insect species establish per year in the US (Aukema *et al.* 2010). Damages from these forest invaders cost US taxpayers several billions of dollars annually (Pimentel *et al.* 2005; Aukema *et al.* 2011). These costs are borne in part by federal, state, and local governments, which work to eradicate newly established pest populations, to slow the spread of established pests, and to remove hazardous dead trees on public lands. But major costs are also assumed by landowners who may lose valuable forest resources, as well as by homeowners who often must pay large sums for tree removal/replacement and suffer losses in property value resulting from associated tree mortality (Aukema *et al.* 2011). Less is known about the effects of invasive species on ecosystem services, although some pest invasions (eg chestnut blight in North America) have virtually extirpated their host tree species; thus, cascading environmental impacts may be substantial.

The importance of the plant trade as an invasion pathway for arthropod pests in Europe was recognized in several previous studies. By analyzing the non-native insect fauna in Switzerland and Austria and assessing the most likely introduction pathway for each species, Kenis *et al.* (2007) estimated that at least 43% of these introductions were the result of the plant trade, mainly that of ornamentals (including cut flowers). Expanding this analysis to all established non-native arthropods in Europe, Roques *et al.* (2009) attributed 38% of introductions to the horticultural and ornamental trade (including cut flowers and seed). Likewise, Smith *et al.* (2007) attributed nearly 90% of "human-assisted" invertebrate pest introductions in the UK between 1970 and 2004 to the plant trade. Live plants are also an important pathway for invasive plant pathogens, which are particularly difficult to detect in port inspections (Palm and Rossman 2003; Rossman 2009).

Here, we provide the first report quantifying the role of the live plant pathway for invasions of forest insect pests and diseases that have become established in the US. We also use historical trade data to characterize temporal trends in live plant imports, as well as historical pest interception data to illustrate the efficacy of plant import inspection stations. In this analysis, we include all live plants intended for retail and propagative use. In addition to including plants with roots, this commodity category – also referred to as "plants for planting" or "nursery stock" – encompasses bulbs, roots, and unrooted cuttings, but excludes cut flowers, ornamental foliage, and seed.

### In a nutshell:

- The importation of live plants is historically the most common pathway for the introduction of non-native forest insect pests and pathogens
- Plant imports in the US increased 33% per decade over the past 43 years; the customs value of current imports represents only 3.1% of the horticulture industry
- There are practical limitations to finding pests through inspections; we estimate that in fiscal year 2009, about 72% of infested plant shipments passed through US ports undetected

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## Forest pest invasion pathways

Of 455 species of non-indigenous forest insects and diseases documented in the US (Aukema *et al.* 2010), 82

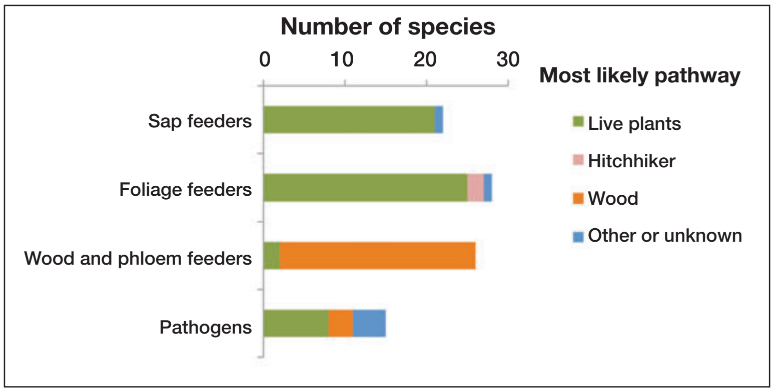


***Figure 1.*** *Most likely pathways for forest pathogens and different insect guilds. Pathway assignment for individual species was based on published information and biology, as detailed in WebTables 1–4.*

(representing 65 insects and 17 pathogens) were designated as having "high impact" (based on at least one published report of associated damage to forest tree species). For each of these 82 species, we identified the most likely pathway by which their invasion occurred, in most cases by relying on previous publications either reporting their invasion history or identifying that pathway given the species' biology. In instances where publications indicating a likely pathway were lacking, we designated the most likely pathway based upon species' biological characteristics and/or historical interceptions at ports-of-entry. Other possible pathways were also specified (WebTables 1–4).

The most common invasion pathway into the US for damaging forest insects and pathogens is via live plants (Figure 1), with approximately 69% of established, damaging non-native forest pests attributed to the live plant trade (Panel 1, a–d). This value is intermediate compared with previous estimates for Europe (Kenis *et al.* 2007; Smith *et al.* 2007; Roques *et al.* 2009). Although similar to methods used previously, our pathway analysis was limited to forest pests, and only to those that cause substantial impacts. Smith *et al.* (2007) attributed a much higher percentage of pests in the UK to the plant trade. Though it is tempting to suggest that this outcome is due to the historical predilection of the British people for collecting exotic plants, note that the analysis by Smith *et al.* (2007) examined all pest establishments in the UK in the recent past. In contrast, our analysis reported here did not limit the time of introduction. While the rate of accumulation of forest pests in general has been relatively constant since 1860 (Aukema *et al.* 2010), changes in trade and phytosanitary practices have likely altered the relative importance of particular pathways. For example, Aukema *et al.* (2010) found that establishment of wood-borers increased faster than any other insect guild since the 1980s, and attributed this to the increased volume of containerized freight and accompanying wood packaging material.

The most common pathway also varied considerably among insect guilds (Figure 1). A total of 95% of sap-feeding insects and 89% of foliage-feeding insects most likely entered the US on live plants (WebTables 1 and 2),

**Panel 1a. Examples of forest pests introduced via live plants**

**White pine blister rust (*Cronartium ribicola*)**

The earliest report of white pine blister rust (WPBR) in North America described the discovery on *Ribes* leaves at Geneva, New York, in 1906. In 1909, Spaulding (1911) found uniformly infested white pine (*Pinus* spp) seedlings in shipments sent from a German nursery to 226 localities in the US Midwest. In 1910, the pathogen was detected on infected eastern white pine (*Pinus strobus*) seedlings shipped from three nurseries in France, at least some of which were planted near Vancouver, British Columbia. This provided the pathogen entry to western North America, where this canker pathogen caused up to 90% mortality in once vigorous and majestic western white pine (*Pinus monticola*) forests (Mielke 1943).

Damage caused by WPBR provided some of the motivation for passage of the Plant Quarantine Act of 1912, and prohibition of imports of five-needle pines (*Pinus* subgenus *Strobus*) was the subject of Plant Quarantine Number 1 (Weber 1930). Over the next 50 years, more than $150 million was spent on control measures, such as aerial spraying of actidione and removal of the alternate WPBR host *Ribes* plants on >8 million hectares (Benedict 1981). Although these direct control efforts are no longer conducted, more than $2 million per year is spent searching for resistant trees and developing management strategies to control WPBR.

All nine North American species in the white pine group are susceptible to the rust; in addition to impacts on high-value timber species, the pathogen is spreading to keystone high-elevation species like whitebark pine (*Pinus albicaulis*), bristlecone pines (*Pinus* subsection *Balfourianae*), and limber pine (*Pinus flexilis*), which are critical resources for birds, such as Clark's nutcracker (*Nucifraga columbiana*), and the grizzly bear (*Ursus arctos*). Ironically, European plant pathologists, with a knowledge of WPBR, had warned of impending disaster associated with importation of diseased pine nursery stock (Merrill 1988), but there were no quarantine laws in North America, and therefore no legal way to prevent shipments.

HJ Larsen, Bugwood.org

but most wood- and phloem-boring insects (borers) likely entered the country on wood packaging materials, as well as logs, lumber, or other wood sources (87.5%). Only 12.5% of borers (the most costly insect guild; Aukema *et al.* 2011) are believed to have entered via live plants (WebTable 3). For forest pathogens, 47% are attributed to the live plant pathway and 19% of invasions were associated with trade in wood (WebTable 4).

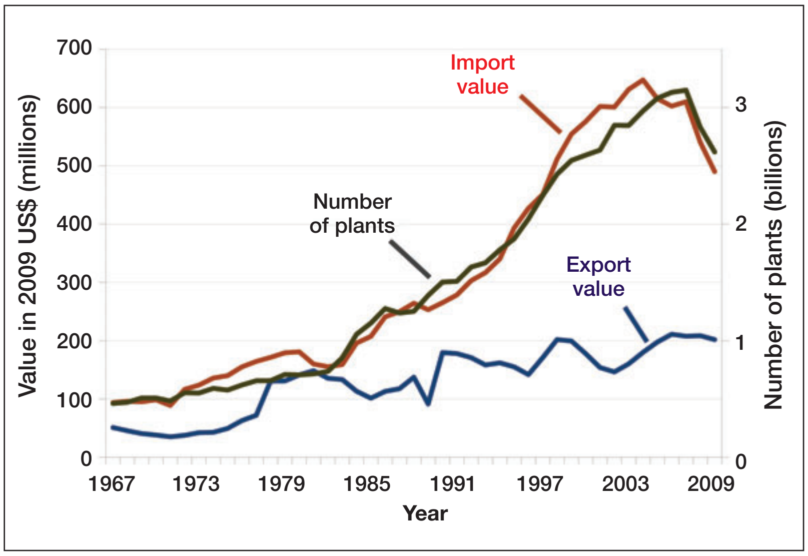


***Figure 2.*** *US imports and exports of live plants, 1967–2009. Values are adjusted to 2009 US$. Data obtained from the US Department of Commerce (2011).*

## ■ Characterizing the US international plant trade

The quantity of plant imports rose substantially during the past 43 years (US Department of Commerce 2011), increasing by more than 500% (an average increase of 51 million plants per year) to a maximum of 3.15 billion plants in 2007 (Figure 2). The recent economic downturn may account for the decline in plant imports during calendar years 2008 and 2009.

Since 1967, the value of all imported plants increased from nearly $94 million to a high of $647 million in 2004 (Figure 2; unless otherwise indicated, all monetary values reported in the text are in US$). Between 1989 and 2002, the value share of imported plants annually averaged only 3.1% of domestic consumption. The value of US nursery plant exports was substantially less, averaging $206.5 million annually (2005–2007). *Dracaena* was the genus most frequently imported between 2005 and 2009, followed by *Verbena*, *Calibrachoa*, *Codiaeum*, *Petunia*, *Phalaenopsis*, *Impatiens*, *Osteospermum*, *Lantana*, and *Lobelia*; imported plants belonging to these genera tended to be tropical in origin, meant for indoor use, or destined for ornamental bedding. After imported plants cleared the inspection process at their respective ports-of-entry (see section below), their destinations were California (27%), Florida (19%), Illinois (7%), Ohio (6%), New Jersey (6%), New York (6%), Michigan (4%), Colorado (3%), Pennsylvania (3%), and all other states combined (19%).

Woody ornamentals are more likely than herbaceous plants to harbor forest pests, and the probability of pest establishment may be elevated when the former are planted outdoors, in close proximity to other live hosts (Smith *et al.* 2007). During 1996–2009, an average of 105 million live trees and shrubs were imported to the US. The changing demographics of shipment origins for woody plants (WebTable 5) are revealed by contrasting the average volume of imported plants and market share between 1989 and 1993 with imports between 2005 and 2009. Canada is the listed source of 97% of woody plants, although Asia and Oceania are the fastest growing sources. Between 2005 and 2009, nearly 135 million plants on

**Panel 1b. Examples of forest pests introduced via live plants**

**Sudden oak death (*Phytophthora ramorum*)**

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*Phytophthora ramorum* emerged in the US as a forest pathogen causing mortality in oak (*Quercus* spp) and tanoak (*Notholithocarpus densiflorus*) in California in the mid-1990s, and appeared about the same time in Europe as a nursery pathogen. The pathogen produces spores on a wide variety of foliar hosts, including many popular landscape species. Population genetics studies indicate separate origins for the North American and European populations, and that the North American forest infestation likely originated in nurseries (Ivors *et al.* 2006; Mascheretti *et al.* 2008). Although nursery stock has been the major pathway for long-distance spread, the pathogen spreads locally in rain, as well as via surface water runoff from infested nurseries. The pathogen has spread to forests in 14 counties in coastal California and one county in southwest Oregon. In Europe, the pathogen has spread to woodlands in Ireland, the UK, Norway, the Netherlands, and Germany, and has been found in nurseries in sixteen other European countries and Canada.

Cost projections in Oregon alone for the current containment program and projected 20-year forest industry losses are estimated at $31 million, while the anticipated costs of impacts – if the current containment program is discontinued – have been estimated to be as much as $292 million (Hall 2009).


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***Figure 3.*** *Scenes from the live plant trade. (a) Japanese maples (*Acer palmatum*) newly imported to Germany. (b) Exit hole of citrus longhorned beetle (*Anoplophora chinensis*) in a young Japanese maple. (c and d) Inspectors at work in the Miami, Florida, Plant Inspection Station.*

average were imported annually with soil or potting media attached to roots, which increases the risk of transferring soil-borne insects and pathogens, with 94% of such plant shipments originating in Canada (WebTable 6).

## ■ Plant shipment inspections and the pests they find

The US Department of Agriculture's (USDA's) Animal and Plant Health Inspection Service (APHIS) inspects imports of plants, cuttings, and seeds, all of which must arrive at one of 17 Plant Inspection Stations located at ports-of-entry throughout the US. Activities at these stations include the physical inspection of plant material, identification of plants, seeds, and pests, and application of disinfection treatments. The Plant Inspection Stations also issue federal phytosanitary certificates (documents certifying the absence of regulated pests or confirming a treatment required by the importing country) for exports. In all, approximately 65 full-time personnel are employed to inspect incoming plant shipments (Figure 3), leading to an average workload in fiscal year (FY) 2010 of 43 million plants per inspector. Data on shipments inspected and pests detected are maintained by APHIS.

During FY 2003–2010, 22 267 shipments – representing 2.6% of the total number of incoming shipments – were found to be infested with at least one "reportable" pest species in normal port-of-entry inspections. Indeed, many of these shipments were found to contain more than one pest species. By examining records stored in the APHIS Pest Interception Database (PestID) (McCullough *et al.* 2006), we were able to characterize the types of detected pest species.

Most intercepted pests (18 008) were insects (Figure 4a), predominated by the Order Homoptera – sucking insects, which include most insect vectors of plant viruses (Figure 4b). Among the non-insect pests, mites were detected in 6210 shipments, diseases in 2773 shipments, mollusks in 2187 shipments, nematodes in 81 shipments, and noxious weeds in 360 shipments (Figure 4a).

## ■ Inspection efficacy

In addition to conducting standard port inspections, APHIS implements the Agriculture Quarantine Inspection Monitoring (AQIM) program to monitor the effectiveness of these inspections and to provide a scientific basis for improving inspection procedures. Under AQIM, passenger baggage, vehicles, mail, and cargo are randomly sampled at seven of the 17 Plant Inspection Stations and undergo more thorough inspection processes to produce statistically based estimates of approach rates (percent of inspected shipments that are found to be infested) for potential pests (Work *et al.* 2005). Since 2008, live plant shipments have been included in the AQIM program; specifically, randomly selected shipments of live plants belonging to 24 commonly imported genera were subject to the more thorough AQIM inspection process. To determine inspection efficacy of the Plant Inspection Stations' normal operating procedures, we compared FY 2009 records of pest interceptions from AQIM sampling of plant propagative materials in cargo with the interception rate over the same period for shipments of the same 24 plant genera from PestID. Because the AQIM inspection methods are more thorough, it is reasonable to assume that the AQIM results provide a more accurate estimate of the actual infestation rate.

Under standard port inspections, infestations were detected in 810 out of 24 781 total recorded shipments (equivalent to 3.3%) of the 24 plant genera. In contrast, in a random subsample of inspections under the more thorough AQIM process conducted by the same inspectors, 118 out of 996 shipments (equivalent to 11.9%) were found to contain reportable pests. Conservatively

 

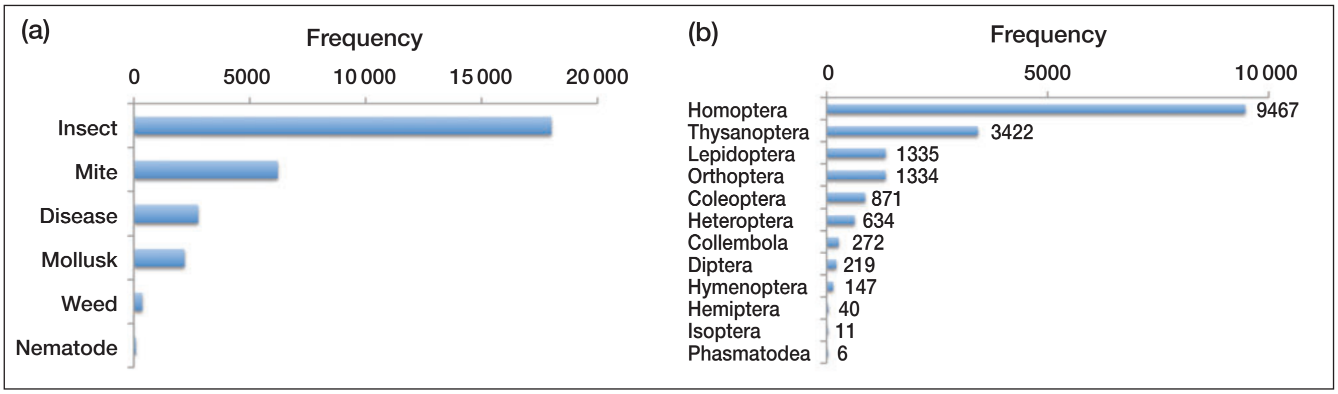


***Figure 4.*** *Frequency (number of shipments infested) and taxonomic characterization of pests detected in shipments of live plants, fiscal years 2003–2010. (a) Types of pests detected. (b) Breakdown among insect Orders.*

assuming that AQIM results reflect the actual infestation rate, then approximately 8.6% (ie the difference in infestations between AQIM inspections and standard inspections) of all incoming shipments were infested but escaped detection under standard inspection procedures. Expressed another way, only 28% of actual infestations were detected by standard inspections, whereas 72% escaped detection.

Even the most thorough port inspections are unlikely to detect all arriving pests, because some infestations will not display easily recognizable signs or symptoms of pests at the moment of passage. Therefore, if 11.9% of shipments were visibly infested, the actual infestation rate was probably higher. The total number of individuals of a species arriving per unit time – "arrival rate" (Brockerhoff *et al.* 2006) or "propagule pressure" (Lockwood *et al.* 2005; Von Holle and Simberloff 2005) – strongly influences the establishment success of non-native species, and thus it is important to reduce the arrival rate to mitigate future invasions.

## Regulation of live plant imports: outdated assumptions

Regulation of live plant imports by the USDA is codified in Title 7 of the Code of Federal Regulations, Part 319, Section 37 ("Nursery Stock, Plants, Roots, Bulbs, Seeds, and other Plant Products"). This regulation, also known as "Quarantine 37", was promulgated in 1918 "to reduce to the utmost the risk of introducing plant pests with plant importations" (Weber 1930). The regulatory design of the quarantine was based on existing conditions and particular assumptions. At the time, it was assumed that (1) typical shipments would be small (fewer than 100 individual plants) and infrequent; (2) imports would mainly be for the establishment of domestic propagation

### Panel 1c. Examples of forest pests introduced via live plants

**Citrus longhorned beetle (*Anoplophora chinensis*)**

Plant Protection Service, Bugwood.org

Citrus longhorned beetle (CLB) was first detected in the US at a nursery in Washington State in 2001 (USDA 2010). An eradication program was swiftly implemented to prevent the next generation of beetles from spreading; thousands of trees were removed, and a quarantine on the movement of wood was implemented over a one-half-mile radius around the introduction site. The program was effective in preventing further spread and the establishment of CLB, at a cost of $2.2 million between 2001 and 2007 (Haack *et al.* 2010). Although interceptions of the closely related Asian longhorned beetle (ALB; *Anoplophora glabripennis*) were strongly associated with wood packaging materials, almost all CLB interceptions at US borders were found on live plants, suggesting that live plants represent the main pathway for CLB invasion (Haack *et al.* 2010).

In Europe, accidental introductions of CLB associated with plants (Figure 3, a and b) caused several incursions and at least one successful establishment in northern Italy (Haack *et al.* 2010). CLB is a major pest in its native range in Southeast Asia, and is considered a high-risk quarantine pest in the US. CLB may potentially be a greater threat to trees than ALB, which has already caused hundreds of millions of dollars in damages and eradication expenditures (Haack *et al.* 2010), because CLB has higher fecundity and can tolerate a greater range of climates (WISC 2009). The beetle feeds on and can kill healthy trees, primarily hardwoods like maples (*Acer* spp), oaks, and poplars (*Populus* spp), as well as fruit trees and ornamentals.

stock and not for direct resale; (3) mandatory fumigation with methyl bromide would be applied to exterminate arthropod pests; (4) imports would enter only through ports with specialized staff and inspection facilities; and (5) taxa known to carry pests that are difficult to detect (eg pathogens) would be prohibited or have special requirements. These conditions prevailed until the 1970s (USDA-APHIS 2004).

Despite the recognized necessity for trade restrictions on certain plants to mitigate the introduction of harmful non-native pests, the counteracting need to import new plant species and varieties – to increase the germplasm available to US growers – was a powerful influence on subsequent changes to Quarantine 37. The horticulture industry favored a regulatory design that encouraged exploration of plant taxa for agriculture- and especially horticulture-based applications. At the time, however, there was limited understanding of the invasive potential of certain plants or of the risk magnitude posed by pests in the trade of propagative material. In addition, favorable growing conditions and inexpensive labor overseas led the industry to import large amounts of plants for domestic planting, or for immediate sale to consumers (USDA-APHIS 2004).

Today, US plant import regulations categorize imported plants as either prohibited (not allowed) or restricted (allowed under certain conditions). Specifying prohibited plants and allowing entry to the unspecified remaining genera is referred to as a "black list" approach. Most plant genera are permitted entry if accompanied by a phytosanitary certificate from the country of origin and inspected upon arrival at a Plant Inspection Station.

Some plant genera are required to be held in post-entry quarantine for specific time periods. There are no longer mandatory fumigation requirements for all plants, and no limits on shipment size; some shipments now consist of hundreds of thousands of plants.

To address concerns about the influx of pests via live plants, APHIS recently established a new "gray list" category of live plants – those "Not Approved Pending a Pest Risk Analysis" (NAPPRA; USDA-APHIS 2011a). Instituted in 2011, NAPPRA includes two lists: (1) potential quarantine pest plants (ie weeds) and (2) potential hosts of quarantine pests. Initially, the gray list will focus on plants that have not been imported in large quantities in the past; for example, several forest tree genera have been proposed for inclusion in the NAPPRA category. This new category allows APHIS to respond more quickly to scientific evidence demonstrating that a plant taxon is itself a pest, or may carry a pest of concern, without first engaging in a lengthy pest risk analysis. APHIS accepts public input for plant taxa that should be listed in this category (www.aphis.usda.gov/import_export/plants/plant_imports/Q37/nappra/suggestions.shtml), and contributions from the scientific community could greatly enhance the protection of natural resources through this important tool.

Although there are no data to empirically evaluate the role of plant smuggling in the introduction of insect pests and diseases, there are several instances where pests have arrived despite regulations prohibiting host entry; plant smuggling may be the most likely explanation for these cases. For example, the chestnut gall wasp (*Dryocosmus kuriphilus*), a harmless insect in its native range in China, was found in 1940 in Japan and in 1974 in the US, where it was illegally imported on smuggled budwood (Rieske 2007). It has become the most severe insect pest of American chestnut (*Castanea dentata*) and

**Panel 1d. Examples of forest pests introduced via live plants**

**Light brown apple moth (*Epiphyas postvittana*)**

The Australian light brown apple moth (LBAM; *Epiphyas postvittana*) is a highly polyphagous pest, affecting many trees (horticultural and otherwise) and other plants (Suckling and Brockerhoff 2010). LBAM was accidentally introduced to New Zealand, Hawaii, and the UK, and it has been intercepted numerous times at US and New Zealand borders and in several other countries on fruit and live plants (eg Venette *et al*. 2003; New Zealand Ministry of Agriculture and Forestry 2011). In 2006, two LBAM were found in Berkeley, California. Subsequent delimitation trapping and trace-backs of finds on nursery plants revealed the presence of the largest populations around Santa Cruz, California, where the California Department of Food and Agriculture detected heavy infestations in several wholesale nurseries. Some of these nurseries had imported nursery stock from Australia and New Zealand, suggesting that the initial introduction may have occurred there. Though importation of cut flowers and fresh produce represent alternative pathways by which the species could have possibly gained entrance, various evidence supports live plant importation as the most likely entry pathway.

California Department of Food and Agriculture

An economic risk analysis suggested that damages to California's four main fruit crops, as well as quarantine and other costs, could reach $105 million annually (Fowler *et al*. 2007). Although the moth's California distribution in 2007 spanned approximately 150-km north–south and 40-km inland, eradication efforts were undertaken because of the potential damage and impacts on trade (Suckling and Brockerhoff 2010). In 2008, the USDA's budget for the eradication was $74.5 million. However, further spread of LBAM occurred, probably aided by long-distance movements of nursery plants and infested crops; the program goal was eventually changed from moth eradication to containment.

is expected to complicate the introduction of blight-resistant hybrids.

## New horizons in regulating the plant trade

In further efforts to address the live plant invasion pathway, the North American Plant Protection Organization adopted Regional Standard for Phytosanitary Measures number 24 in 2005 (NAPPO 2005), signaling the intention of the three member countries (Canada, the US, and Mexico) to develop and implement regulations that rely on an integrated measures approach to pest risk management in live plants. This approach has the advantage of reducing unknown as well as known pest problems through the use of best management practices at plant nurseries, although required measures must be based on specific pest risks. The process of developing and implementing regulations for integrated measures is complicated by the myriad of host plants and potential pests for which appropriate pest risk management measures must be determined and negotiated between trading partners.

Both APHIS and the Canadian Food Inspection Agency are testing a pilot nursery certification program that uses an integrated measures approach to address particular pests on specific plants from specific geographical locations. A participating facility must maintain records that verify the origin of all plant material and document the required monitoring and production practices. The facility must also ensure that only eligible plant material is exported under the program. After participating in the program for 1 year, the facility then becomes eligible to issue its own phytosanitary certificate, thus expediting shipping and passage through ports and reducing the chances of shipment rejection.

Similar "pre-clearance" programs exist for bulbs from the Netherlands. Pre-clearance programs expedite trade because entry requirements are met in the country of origin. Such programs may be more effective at pest detection than port inspections because the former often require growing-season inspections that facilitate detection (if pests are present), whereas plant material is often shipped and thus inspected in a dormant state (in which pests may be more difficult to detect). Industry benefits from faster access to markets, which results in fresher products, as well as reduced rejection rates and arrival delays. Rejections are also less costly when imposed prior to shipping.

The International Plant Protection Convention (IPPC) is working to standardize an integrated measures approach to reduce pest presence in the live plant trade (IPPC 2006). Our findings support the need for more robust methods to maintain and verify plant health. Clearly, given the volume of current trade in live plants and the difficulties of detecting pests in ports, we should seek methods that complement inspection and provide more comprehensive approaches to manage pest-related risks. Combined improvements will minimize the likelihood of introducing non-native pests via live plants.

## Conclusions

Live plants represent the most common pathway by which non-native forest insects and pathogens have likely arrived in the US. Furthermore, international movement of plants is increasing worldwide, as demonstrated by the data presented here on live plant imports to, and exports from, the US. While live plants were previously introduced to the US mainly for plant breeding purposes and as propagation stock, there is a rapidly increasing trend in large volumes of plants being grown overseas for domestic planting or US retail sales. Given this trend, non-native forest insect and pathogen invasions may likely increase in the future under the current system; thus, it is important to address this anticipated and developing invasion pathway. Bradley *et al.* (2012) recently discussed trends of increasing plant imports relative to the risks of novel plant invasions, but here we identify perhaps an even more insidious problem of plant pests associated with plant imports.

One mitigation approach would be to intensify inspection efforts at Plant Inspection Stations. Although not all actionable pests found by inspectors at any level of inspection pose the same risk to US plant resources, there are nevertheless practical limitations to our ability to detect pests as they pass through ports. To avoid prohibitively expensive increases in personnel and facilities, APHIS recently announced the implementation of a risk-based inspection process that will target shipments of high-risk plants for more intense inspections, recognizing that it is impractical to completely inspect every item (USDA-APHIS 2011b). Molecular technology should be explored to improve detection – especially for plant pathogens, which are particularly difficult to detect visually.

Another alternative would be to adopt a "white list" system, such as that used in Australia. Australian regulations prohibit plants from entry until a pest risk assessment demonstrates that they pose very little risk. Most of the species for which entry is approved also require post-entry quarantine. The Australian system has been shown to produce net bioeconomic benefits (Keller *et al.* 2007).

Other countries, such as New Zealand, require post-entry quarantine of all imported whole plants and cuttings. In the US, post-entry quarantine is required for certain genera of plants; for example, grapevines and fruit trees are imported into a post-entry quarantine program called the National Clean Plant Network (NCPN), under which incoming germplasm is screened for pathogens and maintained as a source of pathogen-free propagative material for industry. Expanding NCPN to include ornamental plants would be an expensive, but probably effective, option.

Smuggling of plant germplasm may increase with trade restrictions. Rigorous enforcement of regulations will need to be coupled with aggressive consumer/importer education programs that highlight the importance of compliance to protect natural resources.

There is, moreover, an intrinsic weakness in any system that relies on knowing what pests exist on ornamental crops in the country of origin, because such background knowledge is not robust (Simberloff 2000, 2001; Reaser *et al.* 2008). This difficulty plagues both "black list" and "white list" countries. One widely respected and outspoken critic points out that pests that coevolved with hosts in the country of origin are unlikely to be damaging enough there to allow experts to predict their risk in novel ecosystems and hosts (Brasier 2008).

Although reducing the lag time to limit introductions once pest threats are recognized, the new NAPPRA category still depends on advance knowledge of existing pest threats. Yet most microorganisms are as yet unknown to science. In 2009 alone, 6129 unique combinations of "country of origin" and "plant genus" were imported into the US. Such a diversity of plant imports increases the introduction likelihood of potential pests and diseases that these plants might harbor. Expansion of offshore information gathering, through systems such as APHIS Offshore Pest Information Program and the Sentinel Plant Network, which could collect data on pests of plants native to the US that are growing abroad, would help inform list-based systems.

The integrated systems approach called for by the North American Plant Protection Organization standard, and being explored by the IPPC, offers the potential to address this unknown diversity of pests. However, expanded partnerships between the research community and the nursery industry are needed to develop best management practices that provide affordable and broadly effective pest management systems.

Further research is necessary to evaluate the costs and benefits of various approaches to reducing pest risk in live plant imports. However, it is unrealistic to expect any single approach to solve the problem of pest imports via the plant trade pathway. A holistic system, relying on improvements in offshore production practices, plant-tracking systems, risk-based inspection procedures, and more effective phytosanitary practices in receiving nurseries, would be more likely to reduce risks to an acceptable level.

As global trade expands, our knowledge of pest pathways must be improved to ensure trade is accomplished with minimal environmental degradation. Agricultural quarantine inspection monitoring surveys, such as AQIM, can provide very useful information on the efficacy of current practices, as demonstrated here. Such robust sampling of other high-risk commodities can inform prevention activities to address other critical pest pathways, such as wood packaging materials.

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**WebTable 1. List of economically important sap-feeding insect species presently established in the US (Aukema *et al.* 2010) and most likely invasion pathways by which they arrived**

| *Species* | *Common name* | *Order: Family* | *Most likely pathway* | *Other possible pathways* | *Details/notes* |
|---|---|---|---|---|---|
| *Adelges abietis* | Eastern spruce gall aphid | Hemiptera: Adelgidae | plants | | Inferred from biology (females and nymphs feed on spruce either inside of gall or free-living at base of needle or on twig; both stages are soft-bodied; eggs laid on twigs in frothy mass) |
| *Adelges piceae* | Balsam woolly adelgid | Hemiptera: Adelgidae | plants | | Apparently introduced into Maine and Nova Scotia in early 20th century on imported nursery stock of European silver fir (*Abies alba* Mill) (Kotinski 1916; Balch 1952; Witter and Amman 1969) |
| *Adelges tsugae* | Hemlock woolly adelgid | Hemiptera: Adelgidae | plants | | Wealthy person near Richmond, Virginia, planted infested hemlock from Japan in his garden (Stoetzel 2002; Havill *et al.* 2006) |
| *Aonidiella aurantii* | California red scale | Hemiptera: Diaspididae | plants | | Introduced into California between 1868 and 1875, apparently on citrus seedlings from Australia (Luck and Hoddle 2010) |
| *Asterolecanium variolosum* | Golden oak scale | Hemiptera: Asterolecaniidae | plants | | Inferred from biology (scale insect that feeds on oak twigs) |
| *Blastopsylla occidentalis* | Eucalyptus psyllid | Hemiptera: Psyllidae | plants | | Inferred from biology (soft-bodied insects; adults and nymphs feed on leaves) |
| *Carulaspis juniperi* | Juniper scale | Hemiptera: Diaspididae | plants | | Inferred from biology (scale insects feeding on foliage) |
| *Cryptococcus fagisuga* | Beech scale | Hemiptera: Eriococcidae | plants | | Accidentally introduced on ornamental European beech brought to Halifax, Nova Scotia, public gardens in late 1800s (Newton and Hain 2005; Ehrlich 1934) |
| *Diaspidiotus perniciosus* | San Jose scale | Hemiptera: Diaspididae | plants | | Introduced to California from Australia on a shipment of trees to a collector in San Francisco, California (Luck 2007; Stouthammer and Luck 1993) |
| *Elatobium abietinum* | Green spruce aphid | Hemiptera: Aphididae | plants | | Introduced to Iceland on Norway spruce Christmas trees imported from Denmark annually from 1959 up to 1990 (Carter and Halldórsson |

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| | | | | | 1998) |
| *Eulecanium cerasorum* | Callico scale | Hemiptera: Coccidae | plants | | Inferred from biology (scale insect that feeds on twigs and leaves; wind-borne crawlers) |
| *Fiorinia externa* | Elongate hemlock scale | Hemiptera: Diaspididae | plants | | Introduced into the US in 1910 on Japanese hemlock shipped to New Jersey from Japan (Weis 1914) |
| *Glycaspis brimblecombei* | Redgum lerp psyllid | Hemiptera: Psyllidae | plants | | The Florida infestation likely came from California via movement of infested plants (Halbert 2002) |
| *Icerya purchasi* | Cottony cushion scale | Hemiptera: Margarodidae | plants | | Apparently transported from Australia to California on acacia plants around 1868 or 1869 (Ebeling 1959; Hamon and Fasulo 1998) |
| *Lepidosaphes ulmi* | Oystershell scale | Hemiptera: Diaspididae | plants | | Inferred from biology (scale insect feeds on branches and twigs) |
| *Maconellicoccus hirsutus* | Pink hibiscus mealybug | Hemiptera: Psuedococcidae | plants | cut flowers, fruit | Inferred from biology (EPPO 2005) |
| *Matsucoccus matsumurae* | Red pine scale | Hemiptera: Margarodidae | plants | | Probably introduced from Japan on exotic pines planted at the New York World's Fair in 1939 (McClure 1983) |
| *Nuculaspis tsugae* | Circular hemlock scale | Hemiptera: Diaspididae | plants | | Introduced into the US on hemlock shipped to New Jersey from Japan (Weiss 1914; McClure 2002) |
| *Paratachardina pseudolobata* | Lobate lac scale | Hemiptera: Kerriidae | plants | | Most likely introduced with plants (Campbell and Lowenstein 2008) |
| *Physokermes picea* | Spruce bud scale | Hemiptera: Coccidae | plants | | Inferred from biology (this scale insect overwinters as a first instar nymph on needles, but later instars and adults feed on twigs) |
| *Taeniothrips inconsequens* | Pear thrips | Thysanoptera: Thripidae | plants | soil | Inferred from biology (these soft-bodied insects feed as adults and larvae on buds and leaves; they overwinter as pupae underground) |
| *Thrips calcaratus* | Introduced basswood thrips | Thysanoptera: Thripidae | soil | plants | Inferred from biology (soft-bodied larvae and adults feed on buds and leaves; pupation takes place in soil; they overwinter as adults in soil) |

**WebTable 2. List of economically important foliage-feeding insect species presently established in the US (Aukema *et al.* 2010) and most likely invasion pathways by which they arrived**

| *Species* | *Common name* | *Order: Family* | *Most likely pathway* | *Other possible pathways* | *Details/notes* |
|---|---|---|---|---|---|
| *Profenusa thomsoni* | Ambermarked birch leafminer | Hymenoptera: Tenthredinidae | plants | hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Cyrtepistomus castaneus* | Asiatic oak weevil | Coleoptera: Curculionidae | hitchhiker | plants, soil | Inferred from biology (larvae feed on roots, adults feed on foliage; adults commonly found inside of buildings, where they seek out overwintering locations) |
| *Fenusa pusilla* | Birch leafminer | Hymenoptera: Tenthredinidae | plants | hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Euproctis chrysorrhoea* | Browntail moth | Lepidoptera: Lymantriidae | plants | hitchhiker | Likely introduced accidentally on roses or shrubs (Fernald and Kirkland 1903) |
| *Otiorhynchus sulcatus* | Black vine weevil | Coleoptera: Curculionidae | plants | soil, hitchhiker | Inferred from biology (larvae feed on roots, adults feed on foliage; overwinter as larvae in soil; pupate just below soil surface) |
| *Enarmonia formosana* | Cherry bark tortrix | Lepidoptera: Tortricidae | plants | hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Orchestes alni* | Elm flea weevil | Coleoptera: Curculioidae | plants | soil, hitchhiker | Inferred here from biology (larvae and adults feed on leaves; larvae are leaf-miners; eggs laid on leaves; overwinter as adults in bark or leaf litter) |
| *Xanthogaleruca luteola* | Elm leafbeetle | Coleoptera: Chrysomelidae | plants | hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Fenusa ulmi* | Elm leafminer | Hymenoptera: Tenthredinidae | plants | hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Contarinia baeri* | European pine needle midge | Diptera: Cecidomyiidae | plants | soil, hitchhiker | Inferred from biology (eggs laid on needle sheaths; larvae are needle miners; infested needles fall to forest floor, where larvae pupate and overwinter still inside of needle in litter layer) |
| *Neodiprion sertifer* | European pine sawfly | Hymenoptera: Diprionidae | plants | soil, hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Rhyacionia buoliana* | European pine shoot moth | Lepidoptera: Tortricidae | plants | hitchhiker | Most likely introduced on nursery seedlings (Thorpe 1930) |
| *Gonipterus scutellatus* | Eucalyptus snout beetle | Coleoptera: Curculionidae | plants | soil, hitchhiker | Inferred from biology (adults overwinter under bark; larvae feed on leaves; young larvae are leaf miners, large larvae are free feeders; pupae are found in the soil) |

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| *Epinotia nanana* | European spruce needleminer | Lepidoptera: Tortricidae | plants | hitchhiker | Inferred from biology (larvae are needle-miners; adults are short lived) |
| *Cephalcia lariciphila* | European web-spinning larch sawfly | Hymenoptera: Pamphiliidae | plants | soil | Eggs and larvae could be transported on plants of *Larix* for propagation, and nymphs and pupae could be transported in soil (EPPO 1990) |
| *Lymantria dispar* | Gypsy moth | Lepidoptera: Lymantriidae | accident | hitchhiker | Escaped from culture in Medford, Massachusetts (Forbush and Fernald 1896) |
| *Diprion similis* | Introduced pine sawfly | Hymenoptera: Diprionidae | plants | hitchhiker, packing material | Most likely introduced as pupae on nursery stock from Holland (Wilson 1966) |
| *Plagiodera versicolora* | Imported willow leaf beetle | Coleoptera: Chrysomelidae | plants | soil, hitchhiker | Inferred from biology (overwinter as adults under loose bark or in leaf-litter; larvae free feeding on foliage) |
| *Popillia japonica* | Japanese beetle | Coleoptera: Scarabaeidae | plants | soil, hitchhiker | Introduced at a New Jersey nursery as larvae on iris roots (Dickerson and Weiss 1918) |
| *Coleophora laricella* | Larch casebearer | Lepidoptera: Coleophoridae | plants | hitchhiker | Probably entered on planting stock (Tunnock and Ryan 1985) |
| *Pristiphora erichsonii* | Larch sawfly | Hymenoptera: Tenthredinidae | plants | soil | Inferred from biology (overwinter as prepupae in soil; pupate in soil in spring; eggs laid on twigs; larvae free-feeding on needles) |
| *Pristiphora geniculata* | Mountain ash sawfly | Hymenoptera: Tenthredinidae | plants | hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Caulocampus acericaulis* | Maple petiole borer | Hymenoptera: Tenthredinidae | plants | soil | Inferred from biology (overwinter as pupae in soil; eggs laid on petioles; larvae mine petioles) |
| *Homadaula anisocentra* | Mimosa webworm | Lepidoptera: Galacticidae | hitchhiker | plants | Inferred from biology (overwinter as pupae in bark crevices or in litter; larvae feed in aggregations with copious silk) |
| *Acantholyda erythrocephala* | Pine false webworm | Hymenoptera: Pamphiliidae | plants | soil | Inferred from biology (larvae feed in silken tubes; overwinter as pupae in the soil; eggs laid on needles; Humble and Allen 2004) |
| *Trichiocampus viminalis* | Poplar sawfly | Hymenoptera: Tenthredinidae | plants | hitchhiker | Inferred from biology (Humble and Allen 2004) |
| *Leucoma salicis* | Satin moth | Lepidoptera: Lymantriidae | plants | hitchhiker | Most likely entered during the dormant season in crevices of bark on live or dead trees or bits of infested bark mixed in packing material (Burgess 1921) |
| *Operophtera brumata* | Winter moth | Lepidoptera: Geometridae | plants | hitchhiker, soil | Most likely introduced on ornamental plants (Embree 1965) |

**WebTable 3. List of economically important wood-boring or bark-boring insect species presently established in the US (Aukema *et al.* 2010) and most likely invasion pathways by which they arrived**

| *Species* | *Common name* | *Order: Family* | *Most likely pathway* | *Other possible pathways* | *Details/notes* |
|---|---|---|---|---|---|
| *Agrilus planipennis* Fairmaire | Emerald ash borer | Coleoptera: Buprestidae | Solid wood packing material (SWPM) | plants | Primarily associated with SWPM, but also occasionally found in live plant imports (Humble and Allen 2004; Poland and McCullough 2006) |
| *Agrilus prionurus* Chevrolat | Soapberry borer | Coleoptera: Buprestidae | firewood | SWPM, natural dispersal (flight) | First reported in the US in urban areas of Austin, Texas, in 2003, attacking western soapberry (*Sapindus drummondii*) trees (Haack 2003); is thought to have been transported to Texas with firewood from Mexico where it is native (Haack 2006) |
| *Anarsia lineatella* Zeller | Peach twig borer | Lepidoptera: Gelechiidae | plants | fresh produce (fruit) | Inferred from biology; larvae bore into twigs and fruit (peach, apricot, plum, almond; Alston and Murray 2007) and were probably introduced with nursery stock or possibly with imported fruit |
| *Anoplophora glabripennis* (Motchulsky) | Asian longhorned beetle | Coleoptera: Cerambycidae | SWPM | plants | Often intercepted with SWPM, and most interceptions of *Anoplophora* on wood packing material were *A glabripennis* (96%), whereas most interceptions of *Anoplophora* on live plants were *A chinensis* (99%) (Haack *et al.* 2010) |
| *Callidellum rufipenne* Motschulsky | Japanese cedar longhorned beetle | Coleoptera: Cerambycidae | SWPM | plants | Very often intercepted in SWPM, although, theoretically, it could also be transported in live plants (see Haack 2006; Hoebeke 1999) |
| *Cryptorhynchus lapathi* (Linnaeus) | Poplar and willow borer | Coleoptera: Curculionidae | SWPM | plants | Attacks and develops under the bark in the wood of poplar and willow stems (Drooz 1985); can be transported both with infested wood (eg SWPM) and infested live plants |
| *Hylastes opacus* Erichson | European bark beetle | Coleoptera: Curculionidae – Scolytinae | SWPM | logs or timber | Already widespread at the time of detection (R Rabaglia pers comm), making it difficult to retrace its introduction; occasionally intercepted in SWPM (Haack 2001); based on its biology (secondary bark beetle), it is most likely to have arrived with wood packing material or logs/timber (Rabaglia and Cavey 1994) |

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| *Hylurgus ligniperda* (Fabricius) | Red-haired pine bark beetle | Coleoptera: Curculionidae – Scolytinae | SWPM | logs or timber | Often intercepted, most commonly in crating and dunnage, less in pallets (Haack 2001); occasionally intercepted with other imports of wood such as logs; based on its biology (secondary bark beetle), it is most likely to have arrived with SWPM or logs/timber (see also Ciesla 1993; see also Hoebeke 2001) |
| *Orthotomicus erosus* (Wollaston) | Mediterranean pine engraver beetle | Coleoptera: Curculionidae – Scolytinae | SWPM | logs or timber | This is one of the most commonly intercepted bark beetles in the US, primarily on wood packing material (Haack 2001, 2006); based on its biology (secondary bark beetle), it is most likely to have arrived with wood packing material or logs/timber |
| *Phoracantha recurva* Newman | Eucalyptus borer | Coleoptera: Cerambycidae | SWPM | logs or timber | There are only two interception records for *P recurva* in the US (both for SWPM with shipments from Brazil; Pest ID Database, USDA APHIS); interception data from New Zealand show eight records, mostly with wood packing material from Australia, and one record with timber from Australia (Brockerhoff *et al.* 2006); based on its biology (a borer typically attacking dying or dead eucalypts), it is most likely to have arrived with wood packing or logs/timber |
| *Scolytus multistriatus* (Marsham) | Smaller European elm bark beetle | Coleoptera: Curculionidae – Scolytinae | logs or timber | SWPM | Probably introduced with elm logs or timber imported from Europe (see May 1934); Humble and Allen (2004) also consider "timber" as the most likely pathway for its introduction into Canada |
| *Scolytus schevyrewi* Semenov | Banded elm bark beetle | Coleoptera: Curculionidae – Scolytinae | SWPM | timber or plants | At the time of its discovery in the US, *S schevyrewi* was already present across the country (Haack 2006), and the circumstances of its introduction are not known; interceptions of this species had not been recorded in the US, but one specimen had been intercepted in New Zealand in 1995; based on its biology and because two of the locations in Colorado where this insect was first found are near solid wood packing recyclers, it was probably introduced under bark on wood packing (Liu and Haack 2003); other wood with bark as well as live plants could also have been responsible (EPPO 2006) |
| *Sirex noctilio* Fabricius | Old world wood wasp | Hymenoptera: Siricidae | SWPM | logs or timber | Prior to its discovery in the US, *S noctilio* and other siricids were often intercepted at US borders, mostly on SWPM (particularly crating and dunnage) (Hoebeke *et al.* 2005; see also Burnip *et al.* 2010); |

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| | | | | | based on this, and considering its biology, wood packing was probably responsible for its introduction in the US |
| *Tomicus piniperda* (Linnaeus) | European pine bark beetle | Coleoptera: Curculionidae – Scolytinae | SWPM | logs or timber or plants | First detected inside pine shoots at a Christmas tree plantation in Ohio, and later at nurseries in Ohio (Haack and Poland 2001); it has often been intercepted with SWPM (Haack 2006); based on its biology, it could have been transported under bark with wood packing, pine logs or timber, or, less likely, with potted pine trees (while feeding inside shoots); Humble and Allen (2004) also consider wood packing as the most likely pathway for its introduction into Canada |
| *Xyleborus glabratus* Eichoff | Ambrosia beetle | Coleoptera: Curculionidae – Scolytinae | SWPM | logs or timber | Rabaglia (2003; revised 2008) considers the international transport of wood products responsible for the introduction and establishment of *X glabratus* into Georgia; based on its biology (an ambrosia beetle), and the probable role of SWPM in other recent introductions, this is probably the most likely pathway |

**WebTable 4. List of economically important pathogen species presently established in the US (Aukema *et al*. 2010) and most likely invasion pathways by which they arrived**

| *Species* | *Common name* | *Order: Family* | *Most likely pathway* | *Other possible pathways* | *Details/notes* |
|---|---|---|---|---|---|
| *Ceratocystis fagacearum* (Bretz) Hunt | Oak wilt | Ophiostomatales: Ceratocystidae | unknown | insects, birds | Disease symptoms first observed in late 1800s in the upper Mississippi Valley; now widespread in the middle to eastern US; the pathogen could be endemic or exotic, but genetic evidence is consistent with the theory that *C fagacearum* was introduced, possibly by spore-laden sap-feeding insects or birds (Juzwik *et al.* 2008) |
| *Cronartium ribicola* JC Fisch | White pine blister rust | Uredinales: Cronartiaceae | plants | none | Infested white pine seedlings in shipments from a German nursery were sent to 226 localities in the Midwest (Spaulding 1911); no other pathway is likely for this obligate parasite |
| *Cryphonectria parasitica* (Murrill) Barr, (formerly *Endothia parasitica* [Murrill] Anderson and Anderson) | Chestnut blight | Diaporthales: Cryphonectriaceae | plants | logs or timber | Disease was first discovered on American chestnut trees at what is now the Bronx Zoo in 1904 (Metcalf and Collins 1909 per Anagnostakis 2000); the causal organism was likely introduced on nursery stock of Japanese chestnut widely sold by mail-order nurseries beginning in the 1890s; the fungus was detected in China and Japan in 1913 and 1915, respectively; by 1926 the disease had spread throughout eastern forests, eliminating mature American chestnut throughout its native range (Freinkel 2007) |
| *Cryptodiaporthe populea* (Sacc) Butin | Cryptodiaporthe canker | Diaporthales: Gnomoniaceae | unknown | plants | Widespread in Europe where it is very destructive in poplar nurseries and plantations; first observed in North America in 1915 (Waterman 1957; Sinclair and Lyon 2005) |
| *Discula destructiva* Redlin | Dogwood anthracnose | Diaporthales : Gnomoniaceae | plants | | First observed on western flowering dogwood (*Cornus nuttallii*) in Washington state in 1976; in 1983, the disease was observed in northeastern US on flowering dogwood (*C* |

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| | | | | | *florida*) and Japanese dogwood (*C kousa*); the source of the fungus has never been found but nursery stock or specimen trees for botanic gardens are suspected pathways of introduction (Daughtery and Hibben 1994) |
| *Gremmeniella abietina* (Lagerberg) Morelet var *abietina* | Scleroderris canker – Euro race | Helotiales: Helotiaceae | plants | cut Christmas trees | Strong circumstantial evidence suggests that the European race of the pathogen, capable of killing mature trees, was likely introduced into eastern North America on infected, asymptomatic pine seedlings or on cut Christmas trees (Hamelin *et al.* 1998, 2000) |
| *Lachnellula willkommii* (Hartig) Dennis | European larch canker | Helotiales: Hyaloscyphaceae | plants | logs or timber | The disease appeared in 1927 in two forest plantations in Massachusetts that had received larch nursery stock from Great Britain in 1904 and 1907 (Hahn and Ayers 1936); there was an attempt to survey and eradicate the disease but it reappeared in the 1980s and 1990s in the Canadian maritime provinces and in Maine where it continues to cause serious disease losses (Sinclair and Lyon 2005) |
| *Melampsora larici-populina* Kleb | Eurasian poplar leaf rust | Uredinales: Melampsoraceae | plants | wind | A native of Eurasia, the pathogen was first discovered in North America in 1991 on clonally propagated hybrid poplars grown along the Columbia River in Oregon and Washington. The disease has since spread to California and to eastern North America; although airborne urediniospores may be carried long distances and are believed to be responsible for spread from Australia to New Zealand, it is unlikely that airborne spores could have carried the pathogen from Asia to North America; it is more likely that this obligate parasite was introduced on live hybrid popular tissue or by one of the conifer alternate hosts (*Larix* spp and *Pinus* spp) (Newcombe and Chastagner 1993; Newcombe 1996) |

| | | | | | |
|---|---|---|---|---|---|
| *Ophiostoma novo-ulmi* Brasier | Dutch elm disease | Ophiostomatales: Ophiostomataceae | logs | timber | A second epidemic of Dutch elm disease in the 1940s–1980s is attributed to *O novo-ulmi*, a more aggressive pathogen than *O ulmi*; hundreds of millions of elms are killed across North America (Brasier and Buck 2001) |
| *Ophiostoma ulmi* (Buisman) Nannf | Dutch elm disease | Ophiostomatales: Ophiostomataceae | logs | timber | The first epidemic began after furniture makers in the 1920s used imported elm logs from Europe to make veneers; some of the elm bark beetle vectors (*Scolytus*) had been introduced previously (May 1934 per Gibbs 1978) |
| *Phytophthora cinnamomi* Rands | Phytophthora root rot | Peronosporales: Pythiaceae | unknown | plants, soil | *P cinnamomi* is believed to have originated in Sumatra and may have been transported on food plants or in soil used as ballast by 17th century explorers to South America, Australia, and South Africa; some speculate that the pathogen was introduced to California on avocado plants brought by Spanish missionaries; it is now distributed widely on nearly 1000 hosts; it causes damaging forest diseases on oak, chestnut, and conifers (Zentmyer 1988) |
| *Phytophthora lateralis* Tucker and Milbrath | Port Orford cedar root disease | Peronosporales: Pythiaceae | plants | soil | First observed in ornamental Port Orford cedar nursery stock near Seattle, Washington, in 1923; not found in native forests until 1952, disease is now widespread within the native range of *Chamaecyparis lawsoniana* in southwestern Oregon and northern California (Hansen *et al.* 2000); Taiwan may be the geographic origin of this pathogen (Brasier *et al.* 2010) |
| *Phytophthora ramorum* S Werres, AWAM de Cock | Sudden oak death | Peronosporales: Pythiaceae | plants | | Microsatellite analysis of isolates indicates that the pathogen was originally introduced into North America via nurseries in Marin County and Santa Cruz, California, where it then spread to adjacent tanoak–bay forests; introductions of two other clonal lineages of the pathogen were also associated with the nursery trade (Mascheretti *et al.* 2008) |

| | | | | | |
|---|---|---|---|---|---|
| *Raffaelea lauricola* T.C. Harr. Fraedrich and Aghayeva | Laurel wilt | Ophiostomatales: Ophiostomataceae | beetles via SWPM | logs or timber | Three adult specimens of ambrosia beetles (*Xyleborus glabratus*) previously known only from southeast Asia, were discovered at Port Wentworth, Savannah, Georgia in 2002; widespread mortality of redbay (*Persea borbonia*), associated with presence of the beetles and a new species of the fungus *Raffaelea*, was observed in the Savannah area in 2003; the disease is causing extensive mortality in coastal Georgia, South Carolina, and Florida; other members of the Lauraceae are also susceptible to the disease (Fraedrich *et al.* 2008) |
| *Sirococcus clavigignenti-juglandacearum* Nair, Kostichka, and Kuntz | Butternut canker | Diaporthales: Gnomoniaceae | unknown | | Believed to be an exotic pathogen of unknown origin, butternut canker appeared in Wisconsin in 1967 and has caused extensive mortality throughout the native range of butternut (Anderson and LaMadeleine 1978; Ostry and Juzwik 2008) |
| *Venturia saliciperda* and *Glomerella miyabeana* (Fukushi) Arx 1957 | Willow blight | Venturiales : Venturiaceae Hypocreomycetidae incertae sedis Glomerellaceae | unknown | | The disease results from simultaneous infection by both pathogens; disease was first described in Japan, then reported in Europe, and later North America and New Zealand; appeared in maritime provinces of Canada in 1920s, becoming widespread in eastern Canada and northeast US (Sinclair and Lyon 2005) |

**WebTable 5. Sources of annual US imports of live trees and shrubs, including fruit trees, rhododendrons, and azaleas**

| | *Average annual imports (in 1000s of plant units)* | | |
|---|---|---|---|
| ***Import source*** | *1989–1993* | *2005–2009* | *Percent change* |
| *Total world* | 74 838 | 117 795 | 57% |
| *North America* | 72 949 | 114 390 | 57% |
| Canada | 72 943 | 114 383 | |
| Mexico | 6 | 7 | |
| *Central America and Caribbean* | 0 | 142 | |
| Costa Rica | 0 | 138 | |
| Guatemala | 0 | 4 | |
| *Asia* | 12 | 806 | 6 617% |
| Taiwan | 0 | 55 | |
| China | 5 | 667 | |
| Republic of Korea | 0 | 2 | |
| Japan | 3 | 28 | |
| Thailand | 0 | 6 | |
| India | 0 | 1 | |
| all other | 4 | 47 | |
| *Europe* | 1 863 | 2 042 | 10% |
| Netherlands | 1 607 | 837 | |
| France | 119 | 133 | |
| Italy | 9 | 0 | |
| Germany | 3 | 180 | |
| Belgium and Luxembourg | 90 | 236 | |
| United Kingdom | 35 | 3 | |
| Spain | 0 | 653 | |
| *South America* | 11 | 2 | –82% |
| Venezuela | 9 | 0 | |
| Ecuador | 3 | 0 | |
| Chile | 0 | 1 | |
| Colombia | 0 | 1 | |
| *Middle East* | 2 | 0 | –100% |
| Israel | 1 | 0 | |
| Turkey | 1 | 0 | |
| *Oceania* | 1 | 412 | 41 100% |
| New Zealand | 1 | 233 | |
| Australia | 0 | 179 | |

**Notes:** Data from US Department of Commerce (2011).

**WebTable 6. Characterization of average annual US trade in live plants (2005–2009)**

| *Plant type* | *Import quantity (in thousand unit items* or metric tons**)* | *Export quantity (in thousand unit items* or metric tons**)* | *Re-export quantity (in thousand unit items* or metric tons**)* |
|---|---|---|---|
| Unrooted cuttings* | 914 946 | 4836 | 441 |
| Fruit trees, shrubs, and bushes that will bear edible fruit* | 107 987 | 2132 | 19 |
| Rhododendrons and azaleas* | 616 | 1506 | 0 |
| Roses* | 6286 | 1537 | 922 |
| Orchid plants** | 3177 | 188 | 18 |
| Chrysanthemums with soil attached to roots* | 6479 | 3 | 0 |
| Other herbaceous perennials with soil attached to roots* | 7660 | 29 | 1 |
| Trees and shrubs with soil attached to roots** | 26 683 | 121 | 4 |
| Poinsettias with soil attached to roots* | 2221 | 3 | 0 |
| Other live plants with soil attached to roots* | 91 911 | 1468 | 13 |
| Herbaceous perennials bare-root (no soil)** | 6334 | 859 | 522 |
| Trees and shrubs bare-root (no soil)* | 9192 | 8140 | 5 |
| Other bare-root plants* | 308 866 | 28 084 | 522 |

**Notes:** Data from US Department of Commerce (2011).

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