Safeguarding Against Future Invasive Forest Insects

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Abstract

Many nonnative insect species have been introduced into North American forests, sometimes with a detrimental effect on wild and cultivated plants. Prevention of new invasive species depends on improved awareness of the pest and pathway risks, and finding methods to realistically mitigate those risks. Early detection and rapid response strategies aim to prevent new pest introductions. Within the timeline of each new pest introduction is a tenuous period where a population may or may not become established. After a new pest has become established in the landscape, the ability to detect that population before it spreads beyond controllable levels is critical. This article reviews the phases of a pest invasion, the safeguards needed to prevent or contain invasions, and some of the exotic insect pests, which may affect nursery production, forest outplantings, or mature woodlands in the future.

Introduction

Throughout the past century, foreign insect species have established in North America, some populations of which have greatly affected forested landscapes (Pimentel et al. 2005, Krcmer 2008, Aukema et al. 2011). Natural and urban forests are being attacked by exotic woodboring pests, such as emerald ash borer (*Agrilus planipennis* Fairmaire) (EAB) and Asian longhorned beetle (*Anoplophora glabripennis* [Motschulsky]) (ALB, figure 1), and by defoliating pests such as European gypsy moth (*Lymantria dispar dispar* [L.]) (EGM) and the hemlock wooly adelgid (*Adelges tsugae* Annand) (HWA). EAB, ALB, EGM, and HWA are widely considered invasive insect pests. "Invasive," for purposes of this article, refers to a nonnative organism whose introduction and establishment is likely to cause harm to economic and environmental plant resources.

The damage caused by invasive insect pests is considerable. The EAB alone has killed tens of millions of ash trees (*Fraxinus* spp.) since its detection in 2002, and predictive models estimate the cost of removing and replacing ash in urban and forest landscapes will exceed $12.5 billion (Herms and McCullough 2014). One report also indicates that this pest has an indirect effect on human health, with a measured increase in human illness in communities affected by the EAB (Donovan et al. 2013). Costly Federal and State quarantines have been established to attempt to contain EAB, ALB, and EGM and prevent their spread to other communities.

Figure 1. Asian longhorned beetle oviposition and exit hole damage in a maple tree in a southern Ohio quarantined area. (Photo by Helmuth Rogg, Oregon Department of Agriculture)

For example, efforts to contain EGM infestations include State and Federal quarantines, annual monitoring, an ambitious slow-the-spread program, and eradication of outlying satellite populations, have contributed to successfully preventing EGM from become a widespread pest across the Nation.

During the past few decades, an increase in global trade of agricultural products and live plants has increased the risk of new pest introductions (Mack et al. 2000). The initial North American introduction of invasive insect pests, such as HWA, EAB, and ALB, was likely caused by the importation of infested live plants and wood-packing material (Work et al. 2005, Liebhold et al. 2012).

By predicting the next invasive pest, regulatory agencies can focus inspection and survey resources on the highest risk pest pathways. A heightened awareness of new potential invasive pests can also help land managers implement phytosanitary conditions and increase monitoring and plant pest control programs.

Phases of an Invasion

When reviewing historical invasions of forest insect pests, such as EAB, ALB, and HWA, a generalized pattern can be seen, involving introduction, establishment, and integration. The term "introduction" refers to the arrival of a foreign pest and can also be considered adventive. The term "establishment" refers to a species ability to survive and complete at least one reproductive cycle at a given location. "Integration" refers to the success with which a newly established pest population assimilates into the local environment. For purposes of prioritizing safeguarding efforts, this generalized pest invasion timeline can also be described in the following phases (adapted from Krcmar 2008):

- Phase I: Not established; interceptions at ports of entry.
- Phase II: Detected beyond port setting, not known to be established.
- Phase III: Established, integration into the local environment, not causing damage.
- Phase IV: Established, widespread, causing noticeable damage.

Although foreign species may enter a country, a species may not always establish and become invasive. Random events, such as adverse climate conditions or lack of suitable host plants, or prescribed events, such as port inspections, treatments, or pesticide fumigations, reduce the chances that a species will establish. After a pest becomes established, regulatory agencies may have an opportunity to respond if the infestation is detected early. For instance, regulatory response to ALB has included State and Federal quarantines, and intensive surveillance and eradication programs within those quarantined areas. In other instances, a new pest, such as HWA, may remain undetected for years and spread rapidly, thereby allowing the population to establish and disperse to a size beyond which regulatory control is possible.

After an adventive population expands and integrates into a local environment, several factors influence whether it will become a pest on forest and agricultural crops. Presence of vulnerable hosts, absence of naturally occurring predators and parasites, and climatic condition all influence the chances a population may establish and build to outbreak levels (Eschtruth 2013). Some pest invasions go through a period of exponential growth, their populations appearing to suddenly increase in size and effect (figure 2). Loope and Howarth (2003) predicted that, in terms of invasive alien species during the subsequent 5 years, "because of the lag time in invasions, we will be dealing largely with alien species currently present but not yet recognized as problematic." In the time since Loope and Howarth's prediction, U.S. forests have experienced mortality attributed to the exponential rise of exotic pests, such as EAB and HWA.

If a newly introduced pest becomes established, landowners and producers may need to respond to the effects, adapting existing integrated pest management (IPM) programs to control a new pest. Recent economic studies have shown that a large burden from the introduction of invasive species falls on homeowners and municipal governments (Aukema et al. 2011). In addition, timber losses because of reduced tree growth, increased tree mortality, or reduction in viable seed, result in increased management and costs (Krcmer 2008).

Ideally, every step along the invasive timeline has a corresponding safeguarding measure to address the risk. The best way to avoid the effects is to prevent the introduction of new pests using prescribed phytosanitary management, certified inspections, and preventative treatments. If this approach fails, domestic surveillance can help detect a newly established pest population. Field surveys, such as those conducted using the U.S. Department of Agriculture's (USDA) Cooperative Agricultural Pest Surveys (CAPS), strive to detect new infestations of foreign invasive pests in the United States. Early detection of, and rapid response to, new nonindigenous pest introductions can increase our chances of control and eradication of pest populations before they can widely disperse and cause serious damage.

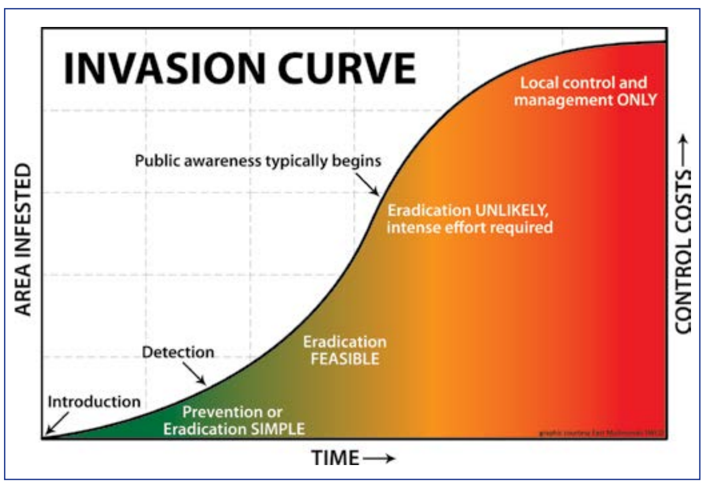

Figure 2. The invasion curve displays a generalized pest population response over time, after the introduction and establishment of a new invasive species into a new environment. As a pest population expands and integrates into the landscape, chances of detecting that pest become greater, yet that pest population also becomes more difficult to eradicate. (Image courtesy of East Multnomah Co. SWCD)

Potentially New Invasive Forest Insects in North America

By reviewing several examples of emerging invasive species, their biology and symptoms, their interception history, their known and preferred plant hosts, and by relaying some concerns about their possible effects, agencies and managers can develop a better understanding of these risks and how to prepare and protect forest nurseries and forested landscapes.

The following sections describe some of the pests that are at varying phases of introduction, establishment, and integration. These species are a representative sample of forest insect pests that are not established in the United States, but have a high likelihood of arrival, establishment, and spread, or have been introduced into the United States and are at varying phases of establishment. None of the following pests are currently regulated under Federal domestic quarantine.

Defoliating Insects

Asian Gypsy Moth, Status: Phase II

European gypsy moth populations are found within quarantined areas of North America, their larvae causing defoliation on forest and agricultural crops in several States. Their rate of natural dispersal is limited by the flightless condition of female EGM, who typically deposit egg masses near or on the same tree on which she developed. Unlike EGM, Asian gypsy moths (AGM, including *Lymantria dispar asiatica* Vnukovskij, *L. dispar japonica* [Motschulsky], *L. albescens* Hori and Umeno, *L. umbrosa* [Butler], and *L. postalba* Inoue) are not so limited in mobility (figure 3). Female AGM typically fly several hundred meters in a night, sometimes traveling up to 12 mi (20 km) to deposit their eggs (Iwaizumi et al. 2010, Molet 2014). Those egg masses, and the emerging larvae, could form the basis of a new infestation. If the AGM were ever to establish in the United States, this female dispersal behavior would be a significant challenge for containment and control of this species. In forested areas of Japan and Russia, AGM populations periodically build to high numbers, at times producing great "swarms" of moths near port areas. This intersection between AGM mating flights and international marine conveyance poses a risk of pest introduction to the United States.

AGM are drawn to bright lights, where they deposit eggs on many substrates, including cargo and marine vessels. Vessels departing Asian ports bound for America are inspected, cleaned, and certified to be free from AGM eggs. Despite such efforts, AGM eggmasses are found during inspections every year at North American ports of entry. When an approaching vessel

Figure 3. Female Asian gypsy moths are capable of long flight, thereby increasing the geographic dispersal of eggs and rapidly spreading a population. (Photo by John H. Ghent, USDA Forest Service)

is found with significant AGM risk, the ship is frequently ordered back out to sea to undergo a cleaning treatment. Additional risks related to AGM eggmasses on imported cargo increase the possibility for the introduction, and establishment of a new population of AGM, not only at the port but also far inland, where the imported cargo may travel. Pheromone trapping surveys are conducted annually to detect new AGM populations that may have established in the United States. The AGM is not known to be established in the United States; the risks, however, are evidenced by interceptions of AGM in inland survey traps in Idaho and Oklahoma (USDA-APHIS 2014b). Response to a new AGM detection includes increased surveillance and, if warranted, control treatments to eradicate the pest population. These response measures have been crucial in keeping this invasive species from establishing in North America.

Pine Sawfly, Status: Phase I

The pine sawfly (*Diprion pini* [L.]) attacks several species of pine (*Pinus* spp.) in areas where it occurs (Albrecht 2014). The larvae are gregarious feeders, feeding in groups and consuming needles and shoots, and then pupating on the twigs, or on understory objects beneath the tree. In Russia, Ukraine, and Belarus, sawfly populations build and decline in natural cycles, occasionally reaching outbreak levels, contributing to tree stress, secondary infection, and mortality. In Finland, these outbreaks have become more frequent, contributing to timber loss (De Somviele et al. 2007).

The pine sawfly is not known to occur in the United States, and queries of U.S. port interception records reveal no significant reports for pine sawfly life stages on imported commodities during the past 20 years (AQAS 1994–2014). Other exotic sawfly species, such as *Diprion similis* (Hartig) and *Gilpinia hercyniae* (Hartig), have been found on imported plant material, and are now established and spreading throughout much of North America (Wilson 2005, LaGasa et al. 2012). The risk of introduction of pine sawfly has likely been minimized using tight phytosanitary measures such as import requirements for pine Christmas trees and increased restrictions on logs with bark; the permissibility of pine boughs, cut branches, and Christmas trees, however, will continue to serve as a potential pathway for pine sawfly introduction (USDA 2014).

Wood Borers

Bamboo Longhorned Beetle, Status: Phase I

The bamboo longhorned beetle (*Chlorophorus annularis* [Fabricius]), or tiger longicorn as it is known in its native Asian territory, is a pest of cut bamboo products but has also been reported in live citrus (*Citrus* spp.), English gurjuntree (*Dipterocarpus tuberculatus* Roxb.), sugarcane (*Saccharum officinarum* L.), grape (*Vitis* spp.), apple (*Malus* spp.), and sweetgum (*Liquidambar* spp.) (Duffy 1968, USDA-APHIS 2014c). In bamboo, the bamboo longhorned beetle larvae feed and pupate internally in the sapwood tissue. The hidden larval lifestages within the wood make this pest difficult to detect. The species is not known to be established in the continental United States; however, live specimens have been intercepted several times in imported bamboo material (AQAS 2014; USDA-APHIS 2014c). In plant nursery settings, bamboo stakes are sometimes used as stays or vertical supports for young trees. The coincidental integration of infected bamboo stakes with exposed host material could allow the bamboo longhorned beetle to damage nursery stock or spread through nursery trade to other regions of the United States where the beetle could establish in the landscape. Imported dried bamboo is required to undergo treatment before entry; ineffective treatment, or mismanifested imports of dried bamboo stakes, furniture products, and possibly bamboo nursery stock could serve to transport the bamboo longhorned beetle to new regions.

Pine Cone Cerambycid, Status: Phase II

The pine cone cerambycid (*Chlorophorus strobilicola* [Champion]) is another woodboring beetle not known to be established in the United States. The species is native to India, where the larvae infest pine cones and cause as much as 80 percent seed loss (Singh 2007) (figure 4). In late 2003 and early 2004, U.S. regulatory agencies issued a recall notice after finding imported shipments of scented pine cones and potpourri from India infested with pine cone cerambycid (Albrecht et al. 2014). Detection surveys conducted immediately following this incident did not detect any established populations of this pest. Although the pine cone cerambycid is a priority for surveys under the CAPS program, only five States have surveyed for it during the past few years (USDA-APHIS 2014b). Pine cone cerambycid has no known attractants, and, therefore, surveys involve visual inspection of host trees and cones for evidence of this pest. Pine cone damage is described as dust-filled, with oval-shaped emergence holes (USDA-APHIS 2014c).

Figure 4. The adult *Chlorophorus strobilicola* (A) and pine cone with larval damage caused by this pest (B). (Photos courtesy of Pennsylvania Department of Conservation and Natural Resources—Forestry Archive [A] and Steven Valley, Oregon Department of Agriculture [B])

Japanese Pine Sawyer, Status: Phase I

Japanese pine sawyer beetles (*Monochamus saltuarius* [Hope] and *M. alternatus* [Hope]) typically attack dead or downed timber in their native habitat. Introduction of Japanese pine sawyer beetles along with associated foreign wood nematodes (*Bursaphelenchus* spp.), however, may have invasive impacts on North American pine forests. The beetles use strong mandibles to chew into the bark, where they deposit eggs. Pine sawyer larvae bore extensive tunnels throughout the tree, while the associated pine wood nematodes feed on epithelial cells and disrupt water transport within the tree, causing wilt within a few weeks of infestation. Wood nematodes cannot travel independently and rely on beetles, such as the Japanese pine sawyer, to transport them to a new tree host in the beetle's trachea. Although neither species of Japanese pine sawyer is currently established in the United States, Japanese pine sawyer beetle larvae have been frequently intercepted in imported wood pallets and dunnage.

Velvet Longhorned Beetle, Status: Phase III

The velvet longhorned beetle (*Trichoferus campestris* [Faldermann]) is an exotic insect native to Asia. The species feeds mainly on dry, dead wood; however, occasional reports record the species feeding on living hosts, such as birch (*Betula* spp.), mulberry (*Morus* spp.), spruce (*Picea* spp.), and pine (Smith 2009). The velvet longhorned beetle has been intercepted several times at U.S. ports of entry between 1997 and 2014, mostly as live larvae in wood packing material (dunnage, crates) from Asia (USDA-APHIS 2014c). This risky pathway is likely the vector that introduced velvet longhorned beetle populations to limited areas of Utah and Illinois. In Salt Lake City, UT, these beetles have been trapped since 2010, and intensive surveys have discovered specimens in local hardwood trees. Widespread damage has not been confirmed; however, early indications suggest larva of the species may be surviving in living tree tissue, raising concerns that the velvet longhorned beetle may become a plant pest. Woodborer surveys continue to monitor for this pest in several States.

Bark Beetles and Ambrosia Beetles

Although small in size, bark and ambrosia beetles can build to such high population densities that their attacks overwhelm a tree and introduce pathogens. In outbreak conditions, these pests can cause widespread mortality. For instance, the native mountain pine beetle (*Dendroctonus ponderosae* Hopkins) has been a major cause of pine mortality in North America in recent years. Although outbreaks of native beetles occur, the episodes are usually part of a natural cycle in the ecosystem of a forest. Nonnative species, however, may establish and integrate into the environment in unpredictable ways and can threaten coniferous and hardwood forests.

Mediterranean Pine Engraver, Status: Phase III

Native to Europe, northern Africa, and Asia, the Mediterranean pine engraver (*Orthotomicus erosus* [Wollaston]) is a bark beetle that attacks several species of conifer host trees (USDA-APHIS 2014c). The beetle and larvae feed internally, tunneling through cambium and phloem layers, creating a reddish-brown dust, and on occasion, if a healthy tree is attacked, pitch tubes may extend from the bark. Blue staining may also be present on the sapwood. As an internal feeding insect, this bark beetle species can be spread through the movement of untreated pallets, crates, and firewood containing bark. In 2004, Mediterranean pine engraver was first detected in Fresno, CA, when 50 beetles were intercepted in funnel traps at a municipal zoo. Beetles were detected again in 2006, indicating a population had established (USDA-APHIS 2014c). Delimitation survey is being conducted using the USDA Forest Service's Early Detection Rapid Response program (EDRR). In 2011, an additional detection of a single Mediterranean pine engraver was reported from a trap near Raleigh, NC. It is still unclear whether this single detection was an interception of a new accidental introduction from wooden pallets, or if a new population has indeed established in the landscape (NAPIS 2014). Continued monitoring and research will define its presence, the distribution of the pest population, and its integration into the environment.

Woodboring Ambrosia Beetle, Status: Phase I

The woodboring ambrosia beetle (*Megaplatypus mutates* [Chapuis]) is a species whose larvae bore internally into the trunk of walnut (*Juglans* spp.), apple, poplar (*Populus* spp.) and several other species of hardwood trees. Most ambrosia beetles, as the name suggests, carry a fungus, which inoculates the tunnels and galleries created by the larvae (Figure 5). The larvae feed on the fungus, and under native conditions, this group of insects is not considered a major pest. In Argentina and Italy, however, the woodboring ambrosia beetle is known to attack live and vigorous trees. In Argentina, this beetle has infested commercial poplar plantations, weakening the trees, impeding growth, and introducing a fungus, which decays and downgrades the wood quality (Gimenez 2003). The species is not known to occur in North America, although it has been found as a hitchhiker on infested wood packing material (Alfaro et al. 2007).

Figure 5. Tunneling "galleries" made by the exotic ambrosia beetle *Megaplatypus* mutates. (Photo by Gianni Allegro, CRA-PLF Unita di Ricerca per le Produzioni Legnose Fuori Foresta, Casale Monferrato, Italy)

Figure 6. Weeping sap is one symptom that may indicate a pine tree is infested with the exotic woodwasp *Sirex noctilio*. (Photo by Dennis Haugen, Bugwood.org)

Woodwasps

Also known as horntails, so named for the sturdy spike on their posterior, woodwasps (Hymenoptera: Siricidae) are exclusively plant feeders. They reproduce by injecting eggs with a long ovipositor into the sapwood of trees. The emerging larvae bore tunnels and holes as they develop inside the tree. Many native species of woodwasps occur in North America, attacking dead and declining trees, and sometimes becoming secondary pests. These native populations are usually kept in check by natural predators and parasites that have coevolved. Exotic introductions of woodwasp species, however, may find an arena void of ecological checks. Populations may establish and pose a potential threat to urban and rural forests.

Sirex Woodwasp, Status: Phase IV

The exotic Sirex woodwasp (*Sirex noctilio* Fabricius) larvae feed internally in the sapwood of the trunk and limbs of several pine species. Damage symptoms include resin beads, weeping sap, and discolored, wilting foliage (figure 6). Adult female Sirex woodwasps carry a symbiotic fungus (*Amylostereum* spp.) and mucoid substance which, when injected into the tree during oviposition, hastens wood decomposition and softens the tree tissue for the young woodwasp larvae to develop (Fundazioa 2012). The fungus is typically a weak pathogen, but in high titer, can reduce sap flow, and hasten a tree's decline. In its native habitat in Europe, Asia, and North Africa, Sirex woodwasp populations are usually kept in check by native predators and parasites, although they can sometimes become secondary pests. Sirex woodwasps have established in Australia, New Zealand, and South America, sometimes with significant effects. Historic outbreaks in southeastern Australia have killed more than 1.8 million pines in a single year, and in South America, the woodwasps, and their fungal associate, have caused up to 80 percent tree mortality in pine stands (Rawlings 1954, Coutts 1968, Carnegie 2007).

Sirex woodwasp has been found in New York, Connecticut, Michigan, New Jersey, Ohio, Pennsylvania, Vermont, and Ontario, Canada (USDA-APHIS 2014b). Recent research has shown that both native and exotic woodwasp species can coexist in the same tree (Hajek et al. 2013), and that each species may carry the exotic fungal symbiont. This "fungal swapping" may be a concern, where both exotic and native woodwasp outbreaks may be accompanied by an exotic fungal symbiont. Although no Federal quarantine regulates Sirex woodwasp in the United States, several States maintain exclusionary quarantines to prevent artificial spread in wood materials, such as logs and firewood. Detection surveys continue to monitor for the pest in areas of high pine production, and ongoing research aims to manage the pest in pine plantations.

Tremex Woodwasp, Status: Phase II

The Tremex woodwasp (*Tremex fuscicornis* [Fabricius]) is native to Europe and Asia where it typically attacks mainly dead and declining trees (figure 7). The species has moved to other regions, likely from imported wooden crates, where it has affected hardwood tree plantations and agricultural windbreaks. In Chile, infestations have been observed on healthy maple (*Acer* spp.), willow (*Salix* spp.), and poplar trees. In these cases, the Tremex woodwasp begins its attack by ovipositing in the branches of the tree. The emerging larvae bore through the wood and develop inside the tree for 1 to 3 years, consequently weakening the tree (Ciesla 2003, Parra et al. 2005). Adult emergence holes are round and 5 to 6 mm (about 0.2 in) in diameter. Other symptoms of an infested tree include branch and crown dieback, yellowing and wilted leaves, leaf and trunk necroses, bubble-like tyloses formation in the cells, loosened bark, sapwood discoloration, and general structural weakening. As with Sirex woodwasps, Tremex woodwasps also carry fungal symbionts, which soften and degrade the wood (Ciesla 2003, Parra et al. 2005, CABI 2011). Tremex infestations in Chile have also affected agricultural crops through destruction of forested windbreaks that shelter agricultural fields (Palma et al. 2005). Despite increased safeguarding measures for imported wood packing material, live larvae, pupae, and adults of Tremex woodwasps are still intercepted with imported commodities, including reports of adult Tremex woodwasps flying from a shipping container when opened. Given the difficulty in inspecting for internal-feeding woodwasps, the detection of an emerging adult in a shipping container can be considered a chance find. Unfortunately, the high number of adult wasp interceptions suggests that insufficient safeguards are in place to adequately reduce the risk of Tremex woodwasp introduction.

Figure 7. Tremex woodwasp deposits eggs, a fungus, and a mucoid substance into the wood of hardwood trees. (Photo by Jiří Berkovec, Plzni, Czech Republic)

Preventing the Next Invasion

Over the past few decades, as global trade has increased, so has the need to better understand pest risks and safeguards against invasive species (Work et al 2005, Krcmar 2008, Liebhold et al. 2012). Through governmental regulations, such as the Plant Protection Act of 2000 (Library of Congress 2000), or global treaties such as the International Plant Protection Convention (IPPC), agencies regulate the movement of commodities to protect native plants and the production of agricultural and silvicultural resources. Preventative safeguarding measures have been adopted by many countries, in the form of sanitary treatments and certification, improved inspection at ports, and an improved ability to detect nonnative species beyond ports of entry.

Sometimes referred to as the "safeguarding continuum," this network of pest exclusion efforts includes components aimed at reducing the overall risk of pest introduction and establishment. This safeguarding network involves several components including overseas preinspection of commodities, import inspections at U.S. ports of entry, domestic surveys, and pest eradication and management programs. These safeguarding programs are typically conducted by Federal, State, and municipal government agencies, universities, and private industry. In the United States, the USDA Animal and Plant Health Inspection Service (APHIS) and State agricultural agencies provide guidance and certification for the import and export permitting of plant products. Likewise, when U.S. commodities are destined for international trade, importing countries have certain phytosanitary requirements. A phytosanitary certificate may be required by the importing country to certify that the product has been inspected and found free of regulated pests (FAO 2011). Field and greenhouse propagative plants are subject to import requirements depending on the country of origin. Propagative plant material that originates in Canada is also subject to inspection (USDA 2014). For help reviewing plans for international movement of plants, contact the USDA's permit unit (http://www.aphis.usda.gov/permits).

The USDA's Cooperative Agriculture Pest Survey program conducts annual detection surveys targeting specific insect and disease species that pose a significant threat to agriculture. Using this program, States select from a list of target pests that are considered high-risk for their region. Although some pests are considered to be the highest risk for introductions, the frequency with which a pest is monitored depends on several challenges. For example, States frequently survey for AGM and the Mediterranean pine engraver beetle, whereas the velvet longhorned beetle and Tremex woodwasp are not as frequently selected as target pests for surveys (USDA-APHIS 2014b). This avoidance may be partly because of challenges in the development and deployment of effective lures and traps for some target pests. Research continues to make scientific advances in developing new survey tools to strengthen our pest monitoring programs.

Regulatory agencies and port inspections are unable to completely mitigate all risk. Safeguarding also relies greatly on the vigilance of businesses and citizens, especially when considering international commerce and movement of plant material. Horticultural professionals, especially those with import and export businesses, are also a critical part of biosecurity. It is important to be aware of phytosanitary issues and safeguard nursery sites, ensuring only healthy stock is brought into an active productive area (Landis et al. 2010). Nursery owners who desire to import new tree varieties may be required to obtain an import permit and may qualify for post-entry quarantine arrangements to minimize risks for introduction of new plant pests. For instance, routine inspections of imported nursery stock, and staging new plant materials separately from the main growing area for a period of observation, help prevent any new insect or disease pests from establishing in the nursery or the surrounding environment.

Another critical component of the safeguarding net is the inclusion of education and recruitment of citizens. Private citizens, or citizens engaged in nonsurvey activities, are reporting new nonnative species and playing an important role in the detection of new invasive species populations. Between 1991 and 2001, Washington State logged 57 new records for invasive pests never before found in the State. Nearly one-third of those new detections were made during random encounters by private citizens or off-duty biologists (Looney et al. 2011). The importance of public education has been critical in detecting new populations of ALB in the United States and has led to an extensive outreach program (http://www.beetlebusters.info/). Beyond outreach, new initiatives to train and include citizen scientists in surveys can further improve chances of finding new infestations of exotic plant pests.

Many pests discussed in this article are representative of nonnative insects that have the potential to be introduced into North America and become new invasive forest pests. Other pests not discussed here, such as nonnative pathogens, nematodes, mollusks, and weeds, also represent important plant health risks. Although governmental regulations, monitoring, and control programs greatly reduce the risk of establishment of new foreign pests, these steps are not solely effective at prevention. The pest safeguarding system also relies heavily on a vigilant citizenry and an attentive marketplace.

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