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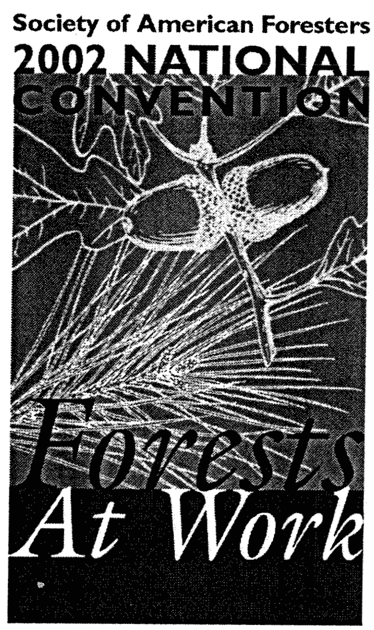

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EXOTIC FOREST INSECT PESTS AND THEIR IMPACT ON FOREST MANAGEMENT

Therese M. Poland and Robert A. Haack

ABSTRACT. More than 4500 exotic organisms are now established in the United States, of which over 400 are insects that feed on trees and shrubs. While most exotic insects cause little or no damage, a few have become serious pests and have greatly altered native forest ecosystems. Three of the most recently introduced exotic forest pests are the pine shoot beetle, the Asian longhorned beetle, and the emerald ash borer. The initial response to the detection of a new exotic forest insect pest involves verifying the identity and establishment of the insect, activating policy and response groups composed of regulatory and scientific professionals, initiating a scoping survey, and deciding if a quarantine should be established. Detailed survey and management options are then developed. Survey, eradication and management approaches depend on available knowledge of the biology of the particular insect pest. Surveys may be conducted with traps or by visual inspection. Management options may include tree removal, application of insecticides, and introduction or augmentation of natural enemies. The success of the management tactics employed is evaluated. If eradication or containment of the initial infestation is unsuccessful, long-term management strategies are implemented. Long-term forest management strategies include rogueing and burning infested trees, avoiding transportation of infested material, thinning of stands to improve tree vigor, replanting and encouraging tolerant tree species, increasing tree diversity, and selecting and breeding resistant trees. As world trade and the risk for new introductions of exotic insects continue to increase, forest managers must remain aware of potential new pests and quarantine regulations and continually monitor and improve the health, vigor, and diversity of forest stands.

KEY WORDS. Exotic insects, detection, quarantine, control, pine shoot beetle, Asian longhorned beetle, emerald ash borer

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INTRODUCTION

The introduction of exotic insects into forest ecosystems is an increasing consequence of international trade. Such introductions may seriously threaten the integrity of native forest ecosystems and biological diversity. At present, over 400 exotic insect species are known to attack woody plants in the United States (Haack and Cavey 1998, Mattson et al. 1994). While most of these established species cause little apparent damage, several have become important economic pests (Table 1). Exotic insects may become serious pests because they arrive without their normal suite of natural enemies, and their new plant hosts lack evolved natural defenses. Invasive forest insects may alter the diversity and function of native ecosystems by displacing native species and altering the dynamics of competitor and predator populations. Exotic insects may also alter the productivity of forest ecosystems through tree mortality and damage and through decreased growth, yield, and vigor of their hosts. Exotic species have tremendous economic and social impact due to their direct damage and the indirect costs of trade restrictions, regulations, inspections and treatment.

The invasion process may be broken down into three phases: 1) arrival, 2) establishment, and 3) spread. Most of the exotic tree-infesting insects that enter the US each year are associated with wood articles such as crating, pallets, and dunnage (i.e., the wood braces used to support cargo) (Haack and Cavey 1998). Forest insects may also be transported in other host material such as seeds, cones, nursery stock and cuttings or on ships, trucks, cargo, and equipment. There were 577,829 insect interceptions at US ports of entry reported in the USDA Animal and Plant Health Inspection Service (APHIS) Port Information Network (PIN) database from 1985 to August 2001 (Haack 2003). Relatively few of the exotic insects arriving at US ports actually become established. For an exotic insect to become established, it must enter undetected, the founding individuals must meet a minimum viable population size, and suitable hosts and favorable conditions must be available. Once established, an insect population can spread through human-assisted movement of infested materials and through natural dispersal where suitable hosts and favorable conditions are available.

MANAGING EXOTIC INSECTS

Management activities to reduce the threat of exotic insects may target any of the three phases of the invasion process. One of the most efficient means of preventing damage from invading pests is to prevent arrival by excluding them through inspections and quarantines. External quarantines prohibit the importation of specific pests or commodities from certain regions in the world, while internal quarantines regulate interstate movement of specific pests or commodities within certain portions of the US. Quarantines may permit importation of infested wood after performing mitigative procedures such as fumigation, heating in a kiln, or treating with preservatives. Prevention of widespread establishment may be achieved through eradication programs, which are designed to force populations to extinction during the establishment phase (Liebhold et al. 1995). Eradication programs have the greatest chance for success when populations are small and detected early. Other factors that favor successful eradication include: poor adaptation of the species to the new location; lack of genetic variability and no development of resistance or behavioral change; high host or habitat specificity; low reproductive rate and few generations per year; availability of efficient and inexpensive monitoring techniques; availability of powerful suppression methods; strong public support and effective education programs (Myers et al. 1998). Quarantine regulations and control tactics that reduce populations can reduce the spread of established pests. Pest detection and suppression along the expanding front of an infested area may help to slow the spread of established pests (Liebhold et al. 1992). Currently, US federal quarantines are enacted for four exotic forest insects: the Asian longhorned beetle, gypsy moth, Japanese beetle, and pine shoot beetle.

When a new exotic pest is discovered and its identity verified, USDA APHIS is notified; they organize a New Pest Advisory Group (NPAG) consisting of regulatory officials and specialists. The NPAG meets to discuss the known biology of the organism, its potential damage and range, mitigation strategies, and the possible need for a domestic quarantine. Based on these discussions, the NPAG may recommend to: 1) take no action; 2) gather additional information and conduct surveys; 3) take action (i.e, eradication, quarantine, implement treatments or controls); or 4) transfer authority to State or other Federal agencies (Haack and Poland 2001). A Science Advisory Panel (SAP) is also convened by APHIS to provide scientific guidance in developing quarantine regulations and eradication or control programs. Detailed survey and management options are then developed and implemented by APHIS and the infested states. Survey, eradication and management approaches depend on available knowledge of the biology and characteristics of the particular insect pest. Generally, information is first obtained from the scientific literature from those countries where the pest already occurs and then later modified as new research findings are produced locally. Surveys may be conducted using visual inspections and may include attractant-baited traps if available. Immediate management options generally include powerful suppression tactics such as tree removal or insecticides, while long-term management may include augmentation or introduction of natural enemies.

RECENT EXAMPLES: PINE SHOOT BEETLE, ASIAN LONGHORNED BEETLE AND EMERALD ASH BORER

Three of the most important forest insect pests introduced and established in the US in recent years are the pine shoot beetle, *Tomicus piniperda* (L.) (Coleoptera: Scolytidae), the Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae), and the emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) . The conditions surrounding the discovery of each of these three exotic pests were quite different, and as such, regulatory decisions and eradication and management programs were implemented according to the particular situations.

The Pine Shoot Beetle

The pine shoot beetle was initially discovered in a Scots pine, *Pinus sylvestris*, Christmas tree plantation in Ohio in July 1992. USDA APHIS established a New Pest Advisory Group and notified regulatory and extension agents throughout the US. Within one month, the pine shoot beetle was reported in five surrounding states in an area covering over 240,000 km^2. It is now believed that the beetle was introduced at least 8-10 years prior to its discovery.

The pine shoot beetle is a pest of pines in Europe where it occasionally causes reduced growth and yield or tree mortality in poorly managed areas where populations were allowed to build up in abundant slash or windthrow (Långström and Hellqvist 1991, Långström 1984). The pine shoot beetle typically breeds in stumps, slash or windthrown pines. When progeny adults emerge, they complete maturation feeding in the shoots of living pines (Bakke 1968). At the time pine shoot beetle was discovered in the U.S., considerable information was available on its biology and management in Europe (Bakke 1968, Långström 1983). Also, semiochemical baits and traps were available for survey and detection of this insect.

Given the widespread distribution of the initial infestation, eradication of the pine shoot beetle was not attempted. Infestations in the six infested states were found primarily in Scots pine stands with most damage being aesthetic as a result of shoot-feeding. Nevertheless, it was believed that the pine shoot beetle could be a highly destructive pest that might reach outbreak levels and devastate pine forests throughout the US (USDA 1972). Studies in Europe show that pine shoot beetle is capable of attacking and reproducing in species of North American pines (Långström and Hellqvist 1985). Therefore quarantines were soon imposed to prevent artificial movement of infested material. Initially, seven US states imposed state-level quarantines on various pine articles from the six infested states. Requirements of the state quarantines varied from state to state (Haack and Poland 2001). In November 1992, APHIS imposed a federal quarantine on the movement of host material from infested to uninfested areas within the US with a standard set of regulations for the entire country (USDA APHIS 1992).

Over the next several years, numerous research studies were conducted in North America on pine shoot beetle biology, management and control. Many of the research results led to the development of the "Pine Shoot Beetle Compliance Management Program" for both Christmas tree and nursery stock producers (USDA APHIS 1996). This program provided a series of management protocols for controlling the pine shoot beetle including 1) destruction of brood material, 2) trapping of parent adults, 3) foliar and trunk insecticide applications, 4) monitoring for shoot damage, and 5) record keeping. Under the compliance management program, pine shoot beetle populations would theoretically be reduced to very low or undetectable levels, allowing the movement of trees with extremely little or no risk of moving the pine shoot beetle (McCullough and Sadof 1996, 1998). The components of the compliance program also provide long-term management tactics to reduce populations and to minimize damage from this exotic pest.

To date, the pine shoot beetle has caused very little damage to pine Christmas trees growing in well-managed fields (McCullough and Sadof 1998), or to native pine trees growing in natural or planted forest stands in North America. Nevertheless severe damage and tree mortality were reported in an unmanaged Scots pine stand in New York state (Czokajlo et al. 1997) and in several similar stands in southwestern Ontario (Scarr et al. 1999).

Despite the quarantine, the pine shoot beetle continues to spread throughout North America and as of December 2002 was established or regulated in 384 counties in 12 US states and 51 counties in Ontario and Quebec, Canada (NAPIS, 2002, CFIA 2002). On average, the pine shoot beetle is found in approximately 30 new counties per year. This spread is primarily due to natural dispersal. In March 2001, APHIS reevaluated the federal quarantine given the high costs of detection and monitoring, the low levels of damage associated with the pine shoot beetle, and the continued natural spread of the insect. However, the decision was made to maintain the federal quarantine because of continued concerns by the uninfested southern and western states, and the likelihood of numerous individual state-level quarantines being imposed if the federal quarantine were dropped (Haack and Poland 2001).

The Asian Longhorned Beetle

The Asian longhorned beetle was discovered in the Brooklyn and Amityville areas of New York in 1996 (Haack et al. 1997) and in Chicago in 1998 (Poland et al. 1998). The initial infestations were relatively small (several hundred trees) and localized. Nevertheless, a few trees had already been killed, indicating the beetle had been present for at least 5-10 years prior to detection in either state. This insect is native to China and

Korea where it is known to attack and kill several species of maple (*Acer*), birch (*Betula*), poplar (*Populus*), willow (*Salix*), and elm (*Ulmus*) (Haack et al. 1997). Asian longhorned beetles infest both stressed and apparently healthy trees, attacking the upper branches first and, in subsequent years, progressing down to the lower bole. Successive generations tunnel into the inner bark and wood, eventually killing the tree.

Because the Asian longhorned beetle is an aggressive tree killer with a wide host range, and since the initial infestations were small, APHIS quickly decided to enact a federal quarantine and implement an eradication program. The prospect of successful eradication was considered high since populations were small and localized; the rate of population growth and spread had apparently been very low during the 5-10 years of establishment; powerful suppression methods (i.e., tree removal and chipping) were available; and public support for the program was strong. The benefits of eradication were also considered extremely high since the Asian longhorned beetle is such a destructive pest with the potential to cause great economic damage throughout much of North America's hardwood forests (Nowak 2001).

The most limiting factor to successful eradication of the Asian longhorned beetle is the ability to accurately detect every infested tree. Currently, the only means for locating attacked trees is through visual inspections by ground crews, bucket trucks or tree climbers. Infested trees may be difficult to detect during the early stages of attack when the only visual signs include small circular pits in the bark made by adult female beetles when chewing egg-laying sites, sap leakage from the opening of the larval gallery, accumulation of boring dust (frass) from the larvae feeding within the tree, and 1-cm-wide circular exit holes through which adult beetles emerge. Acoustic detection devices that pick up the sounds made by larvae feeding in the sapwood are currently being tested operationally by APHIS.

In 2000, APHIS began to treat uninfested host trees in Chicago with the systemic insecticide, Imidacloprid, in an effort to protect them from becoming attacked by the Asian longhorned beetle. In 2001 and 2002, soil and trunk injections were continued in Chicago and implemented in New York.

Overall, the Asian longhorned beetle eradication is fairly successful. The number of infested trees detected and cut each year in Chicago has steadily declined, with 911 trees cut in 1998 and only 4 in 2002 (Table 2). In New York, the decline is more gradual, with notable exceptions when additional infestations were detected in the Bayside and Queens area. Nevertheless, the number of infested trees has decreased from 1220 cut in 1996 to 125 cut in 2002 (Table 2). In addition, in 2002, a small infestation was found in Jersey City, NJ and is thought to have spread from the New York infestation.

The Emerald Ash Borer

The emerald ash borer is the latest exotic forest insect pest discovered in North America. In June 2002, the emerald ash borer was identified as the causative agent of widespread ash (*Fraxinus* sp.) mortality in southeastern Michigan. As of September 2002, emerald ash borer was found in 6 counties in southeastern Michigan and in nearby Essex County, Ontario, Canada (Haack et al. 2002). Based on aerial and ground surveys, it is estimated that approximately 5 million dead or dying ash trees are infested with emerald ash borer in a 2500 km^2 area in the 6 infested Michigan counties. It is believed that emerald ash borer has been established in the area for at least 5-10 years.

Emerald ash borer is a native of Asia (Yu 1986) and was likely introduced inadvertently in solid wood packing material. Little information on emerald ash borer is available in the scientific literature, and there are no known recommendations for trapping adults or to control this pest in urban or forest trees. The emerald ash borer appears to be an aggressive beetle and is killing apparently healthy trees, including trees under regular irrigation and fertilization regimes. First-year infestations of emerald ash borer are difficult to detect without stripping bark off the tree to look for larval galleries. D-shaped exit holes, canopy dieback, and epicormic shoots first appear in the second year of attack. Trees often die within 2-4 years of initial attack.

When emerald ash borer was discovered, the Michigan Department of Agriculture quickly imposed a state-level (internal) quarantine prohibiting movement of host material out of the infested 6-county area. APHIS convened a New Pest Advisory Group and a Science Advisory Panel to provide guidance in developing a federal quarantine and management plan. Although emerald ash borer is already found in 6 Michigan counties, APHIS determined eradication must be considered due to the highly destructive nature of this pest. Because the infestation is localized and centered around Detroit, MI, a proposal for containment and eventual eradication has been proposed. The strategy recommended by the Science Advisory Panel will require establishment of Suppression and "Fire Break" zones around the known infested Core area. The Fire Break zone will link areas of low ash density. Any new emerald ash borer infestations detected in the Fire Break zone will be treated aggressively and eradicated. The Suppression zone will be established inside the Fire Break zone and 1-3 miles beyond the perimeter of the infested Core area. Ash trees in the Suppression zone will function as a sink for emerald ash borers dispersing from the Core infestation, and infested trees will be removed or treated annually to decrease beetle density and protect the Fire Break zone from infestation. Within the Core infested area, some tree removal will take place; however, the population is expected to decline and eventually collapse when the host resource becomes depleted. It is thought that within the infested Core, the number of infested trees is simply too large to economically treat in an aggressive eradication and tree removal program such as that used for the Asian longhorned beetle.

CONCLUSIONS

Invasions by exotic forest pests present major environmental problems that will likely increase in the future with expanding global trade unless new regulations are imposed and compliance by exporting countries is good. A greater emphasis on survey and detection of new introductions would greatly decrease the probability of new pest establishments. Forest management that emphasizes a diversity of native tree species will help minimize the damage caused by invading exotic insects. Forest managers must remain aware of potential new threats and quarantine regulations and continually monitor and improve the health, vigor, and diversity of their forest stands.

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Table 1. Examples of economically important exotic forest insect pests established in North America, arranged by year of initial discovery.

Common name	Scientific name (Insect family)	Origin	Year
Elm leaf beetle	*Xanthogaleruca luteola* (Chrysomelidae)	Europe	1834
European gypsy moth	*Lymantria dispar* (Lymantriidae)	Europe	1869
Larch sawfly	*Pristiphora erichsonii* (Tenthredinidae)	Eurasia	1880
San Jose scale	*Quadraspidiotus perniciosus*: (Diaspididae)	Asia	1880
Larch casebearer	*Coleophora laricella* (Coleophoridae)	Europe	1886
Beech scale	*Cryptococcus fagisuga* (Coccidae)	Europe	1890
Introduced basswood thrips	*Thrips calcaratus* (Thripidae)	Europe	1904
Balsam woolly adelgid	*Adelges piceae* (Adelgidae)	Europe	1908
Smaller European elm bark beetle	*Scolytus multistriatus* (Scolytidae)	Europe	1909
European pine shoot moth	*Rhyacionia buoliana* (Tortricidae)	Europe	1914
Japanese beetle	*Popillia japonica* (Scarabaeidae)	Japan	1916
Birch leaf miner	*Fenusa pusilla* (Tenthredinidae)	Europe	1923
Pear thrips	*Taeniothrips inconsequens* (Thripidae)	Europe	1925
Pine false webworm	*Acantholyda erythrocephala* (Pamphiliidae)	Eurasia	1925
Hemlock woolly adelgid	*Adelges tsugae* (Adelgidae)	Europe	1927
European pine sawfly	*Neodiprion sertifer* (Dipronidae)	Europe	1932
Asiatic oak weevil	*Cyrtepistomus castaneus*(Curculionidae)	Asia	1933
Pine shoot beetle	*Tomicus piniperda* (Scolytidae)	Europe	1992
Asian longhorned beetle	*Anoplophora glabripennis* (Cerambycidae)	Asia	1996
Japanese cedar longhorned beetle	*Callidiellum rufipenne* (Cerambycidae)	Japan	1997
Brown spruce longhorned beetle	*Tetropium fuscum* (Cerambycidae)	Eruope	1999
Emerald ash borer	*Agrillus planipennis* (Buprestidae)	Asia	2002

Table 2. Number of trees detected and cut per year as part of the Asian longhorned beetle eradication programs in New York and Chicago.

	Number of infested trees cut down							
State	1996	1997	1998	1999	2000	2001	2002	TOTAL
New York	1220	754	954	1640	610	571	125	5904
Illinois	-	-	911	508	128	19	4	1570
New Jersey	-	-	-	-	-	-	102	102

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