Exotic Pests: Major Threats to Forest Health

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Abstract.—Over 360 exotic forest insects and about 20 exotic diseases have become established in the U.S. Many of these organisms have become serious pests, causing great economic impacts and irreversible ecological harm. Despite efforts to exclude exotic species, forest insects and disease organisms continue to be introduced at a rather rapid rate. In the last few years, one disease organism and six forest insects have been introduced or discovered in the U.S. Some of these organisms have the potential to become serious pests. Preventing introductions of exotic organisms is a global problem that requires international cooperation. Rigorous quarantine protocols should be developed for all types of forest products, and monitoring progams are needed to detect new introductions. Lists of exotic species of quarantine significance should be developed to assist in assessing the risks of future introductions and in developing ways to prevent or eradicate exotic pests.

INTRODUCTION

Non-indigenous species seriously threaten the health of forest ecosystems. Many of the thousands of species of plants and animals introduced into the U.S. have become pests, and many are pests of forests. The threat of inadvertently introducing additional pests is increasing as the world's population increases and as world travel and commerce continue to expand. As more pests become established, their cumulative effects significantly degrade the health of our Nation's forests.

In this paper I will review the history of pest introductions and describe some of these organisms' impacts on forests. I will also discuss the potential of additional introductions and describe several forest pests that have been introduced in the past few years to illustrate the magnitude of the problem. Finally, I will suggest some ways to address the problem.

EXOTIC PEST INTRODUCTIONS

Over 4500 species of exotic organisms are established in the U.S. (U.S. Office of Technology Assessment 1993). By far the most numerous introduced species are plants and insects (Table 1). Over 2000 species of plants and arthropods have been introduced. This reflects, in part, the fact that more species of plants and insects have been described than species in other categories. These are probably conservative estimates, especially for insects, because only about 50% of insects have been identified (U.S. Office of Technology Assessment 1993). Undoubtedly some exotic insects have not yet been identified.

Non-indigenous species continue to be introduced into the U.S. A recently published study of non-indigenous species in the U.S. concluded that there was no evidence that the number of introductions has decreased in recent years (U.S. Office of Technology Assessment 1993). In fact, the threat of introductions is probably increasing as world commerce expands. Increased movement of people and their goods around the world increases the potential for additional introductions.

Because the majority of forest pests have been introduced on plants or plant materials (Campbell and Schlarbaum 1994), it is important to examine the pathways of introduction of logs or trees. In the past few years there has been increasing interest in importing logs from countries such as Russia, New Zealand, and Chile. This interest has prompted

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Table 1.—Estimated numbers of exotic species in the United States.[a]

Category	Number
Plant	>2000
Terrestrial vertebrates	142
Insects and arachnids	>2000
Fish	70
Mollusks (non-marine)	91
Plant pathogens	239
Total	>4,542

[a] *Data from U.S. Office of Technology Assessment (1993)*

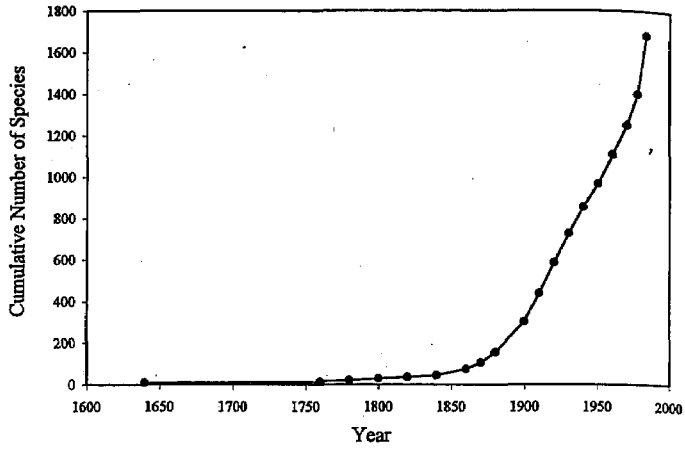

Figure 1.—Cumulative number of exotic insects introduced into the United States.

studies to assess the risk of pest introductions on imported logs. These assessments demonstrated that importing logs poses tremendous risks of introducing pest organisms (USDA 1991, USDA 1992, USDA 1993). For example, the Siberian log assessment identified over 170 pests on larch (USDA 1991). Many of these pests were considered to pose a high risk of being introduced and becoming established.

Exotic Insects

Because the rate of introductions is not declining, the cumulative number of exotic pests continue to grow as illustrated by the introduction of insects into the U.S. (fig. 1). During the late 1800's and early 1900's, introductions increased almost exponentially. After 1920 the rate of introduction leveled off due in part to the passage of the Plant Quarantine Act in 1912 (Sailer 1983). Since the 1920's, approximately equal numbers were introduced each decade. The rate is not decreasing, and the cumulative number of introductions continues to rise extremely
rapidly.

Many of the species of insects that have become established in the U.S. are forest dwelling. Mattson and others (1994) list 368 species of phytophagous insects on woody plants in the U.S. and Canada. About half of these insects are pests, some of which seriously threaten forest ecosystems and cause economical or ecological harm. Pimentel (1986) estimated that 19 of 70 major insects pests of U.S. forests were exotic species. Patterns of species introductions have paralleled intercontinental commerce patterns. Most came from Europe (73%) or Asia (18%) (Mattson and others 1994).

Exotic Diseases

Although only about 20 diseases have been introduced into the U.S. (Table 2), some of these pests have been devastating to native forests. Most are from Europe and were probably introduced by humans, often on infected plants. A characteristic of plant pathogen introductions has been their association with humans and the transport of nursery material or timber. The most serious forest pests arrived this way before strict implementation of quarantines (von Broembsen 1989).

Chestnut Blight

Perhaps the most striking example of an exotic forest disease is chestnut blight. The impact of chestnut blight impact has been called the largest single change in any natural plant population in history (Harper 1977). The fungus was discovered in the early 1900's in New York City (Liebhold and others 1995), but was probably introduced from Asia on ornamental nursery material in the late 1890's (von Broembsen 1989). The disease spread rapidly throughout the eastern U.S. and in less than 50 years had spread throughout the range of chestnuts, virtually eliminating chestnut, which was the dominant tree species in the hardwood forests of the East.

Table 2.—Exotic diseases of woody plants established in the United States.[a]

Disease organism	Common Name	Origin	Reference
Ascocalyx abietina	Scleroderris canker	Europe	Manion 1984
Cercospora nandinae	Heavenly bamboo blight	Japan	Sinclair et al. 1987
Coleosporium sonchi	Scotch pine needle rust	Europe	Boyce 1961
Cronartium ribicola	White pine blister rust	Europe	Walker 1950
Crypphonectria parasitica	Chestnut blight	Asia	Walker 1950
Discosporium populeum	Dothichiza canker	Europe	Hubbes 1967
Discula destructive	Dogwood anthracnose	Japan	Redlin 1991
Elsinoe euonymi-japonica	Euonymus scab	Japan	Sinclair et al. 1987
Fusarium oxysporium f.sp. perniciosum	Mimosa wilt	Asia	Boyce 1961
Fusicladium saliciperdum	Willow scab	Europe	Boyce 1961
Gymnosporangium confusum	Medlar rust	Eurasia	Sinclair 1987
Lachnellula willkommii	Larch canker	Europe	Boyce 1961
Melampsora larici-populina	Poplar leaf rust	Asia	Newcombe & Chastagner 1993
Nectria coccinea var. faginata	Beech bark disease	Europe	Houston & O'Brien 1983
Ophiostoma ulmi	Dutch elm disease	Europe	Walker 1950
Phomopsis arnoldiae	Phomopsis canker	Europe	Sinclair et al. 1987
Physalospora miyabeana	Black canker of willow	Europe	Boyce 1961
Phytophthora cinnamomi	Phytophthora root rot	Asia	Sinclair et al. 1987
Phytophthora lateralis	Phytophthora root rot	Asia	Roth et al. 1972
Sirococcus clavigignenti-juglandacerarum	Butternut Canker	?	Ostry et al. 1994
Viscum album	Mistletoe	Europe	Sharpf & Hawksworth 1974

[a]*List compiled by Imants Millers, USDA Forest Service*

White Pine Blister Rust

White pine blister rust (WPBR) is the most important disease of five-needle pines. The disease is native to Asia but was introduced to Europe in the 1800's where it was then exported to the U.S. on diseased nursery stock in the late 1900's (Liebhold and others 1995). WPBR has spread throughout the range of the white pines (Schmidt 1992) and was recently discovered as far south as New Mexico, where it infects southwestern white pine *Pinus storbiformis*. WPBR has had a major impact on the timber industry (Ketcham and others 1968) and has caused ecological impacts by killing whitebark pines throughout their distribution. Seeds from this tree are an extremely important food source for the endangered grizzly bear and associated birds and mammals (Schmidt 1992).

Dutch Elm Disease

Dutch elm disease is the most important pest of shade trees in the U.S. It is caused by the fungus *Ophiostoma ulmi,* which is vectored by bark beetles. The primary vector is the European elm bark beetle, *Scolytus multistriatus*. Both the fungus and its vector were introduced from Europe on diseased timber in the early 1900's. By 1977 the disease had spread to most of the contiguous 48 states and by 1979 had killed three quarters of the elms in the Northeast (Campbell and Schlarbaum 1994).

Butternut Canker

Butternut canker is caused by the fungus, *Sirococcus clavigignenti-juglandacerarum,* of unknown origin. It was discovered in the U.S. in 1967 in Wisconsin but is thought to have been introduced several years before (Ostry and others 1994). The fungus was described as a new species in 1979, and butternut is the only known natural host. The disease is thought to be exotic, although there are no records of its occurrence anywhere else in the world (Ostry, personal communication). Since its discovery, the disease has spread very quickly throughout much of the range of butternut (Campbell and Schlarbaum 1994). It is very destructive with only a few "resistant" trees surviving. The loss of butternut from this disease has been so rapid and extensive that butternut is a Category 2 candidate for listing under the Endangered Species Act. (Ostry and others 1994).

RECENT INTRODUCTIONS

Animal and Plant Health Inspection Service (APHIS) port inspectors often find insects on cargo entering the U.S. APHIS maintains a database of these interceptions. Most of the intercepted forest insects are associated with wood (mostly crating, pallets, dunnage). Some of the most frequently intercepted pests on wood include several bark beetles that have the potential to be serious pests. Table 3 shows a list of the most frequently intercepted species during 1985–1994. In addition to these insects, unidentified species in the family Scolytidae (bark beetles) were intercepted over 1000 times during the same period. Most interceptions are bark beetles in the family Scolytidae, mainly from Europe (Table 3). *Pisodes* and *Hylobius* are weevils. Three species on this list, *Hylurgus ligniperda, Ips typographus,* and *Tomicus piniperda,* have been introduced or discovered in the last few years.

Within the last few years, at least one disease organism and six insects have been introduced or discovered in the U.S. Most species are established here and some were probably here for some time before being discovered. Of the insects, most are bark beetles that have been intercepted at ports many times through the years.

Table 3.—Most frequently intercepted insects found on wood at U.S. ports (1985–1994).[a]

Species	Most common countries of origin	Number
Pityogenes chalcographus	West Germany, Italy, Belgium	318
Ips erosus	Spain, Italy	305
Pissodes sp.	United Kingdom, Italy	215
Hylurgops palliatus	West Germany, Belgium, United Kingdom	187
Hylurgus ligniperda	Italy, Spain, Portugal	135
Ips typographus	Italy, West Germany	133
Hylobius sp.	West Germany, United Kingdom, Belgium	127
Ips sexdentatus	Italy, Spain	111
Hypothenemus sp.	India, Brazil	96
Tomicus piniperda	France, United Kingdom, Italy	94

[a]*Data from USDA, Animal and Plant Health Inspection Service, Room 312E, Administration Building, Washington, DC 20250–3401.*

Asian Gypsy Moth, *Lymantria dispar*

In the past few years the Asian strain of the gypsy moth has been introduced several times in the U.S. and Canada, both on the east and west coasts. Although it is similar to the gypsy moth that has been in the North America for over 100 years, the Asian strain has certain characteristics that could increase its potential to be a serious pest. Unlike the North American strain, females of the Asian strain are capable of sustained flight. The Asian strain is also thought to have a wider host range, which includes larch as a preferred host.

In 1991 a large number of egg masses were found on Russian grain ships docked at Vancouver, BC and Portland, OR. That summer male moths were caught in pheromone traps in areas around Portland, Vancouver, and Tacoma, WA. The source of these moths were thought to be larvae blown ashore from the Russian ships. A large eradication program using sprays of Bt was initiated in 1992 in Washington, Oregon, and British Columbia. The eradication program was apparently successful because no Asian gypsy moths were trapped in the sprayed areas in subsequent years.

The Asian gypsy moth (AGM) was introduced into North Carolina in July, 1993 by a military cargo ship from Nordenham, Germany, docked at Sunny Point Military Ocean Terminal near Wilmington, NC (Hofacker and others 1993). When inspectors examined the ship, they found that it was contaminated with gypsy moth pupae, larvae, and egg masses. Thousands of moths, including females, were seen flying from the ship. DNA testing of samples of moths from the ship demonstrated that the Asian strain, the European strain, and Asian × European hybrids were present. Apparently, the Asian strain had been introduced into western Europe and had hybridized with the native European strain. During an outbreak in Germany individuals of both strains and hybrids were accidentally transported on cargo containers (Hofacker and others 1993).

Areas around Wilmington, NC were sprayed in 1994 in an attempt to eradicate AGM populations. In 1995 additional areas were sprayed in nearby South Carolina. In 1994, a gypsy moth specimen trapped near Puyallup, WA was determined by

DNA testing to be an AGM strain from central Siberia. An area of one-half mile radius around the trap was sprayed with Bt to eradicate AGM populations. Results of ongoing trapping surveys will determine whether these eradication efforts were successful.

In addition to these introductions, moths with AGM characteristics as determined by DNA testing have been trapped in several states. Although there is no definitive evidence that AGM has become firmly established in the U.S., the risk that it will become established in the U.S. remains high.

Larger Pine Shoot Beetle, *Tomicus piniperda*

Tomicus piniperda was first detected in the U.S. in July 1992 in a Christmas tree plantation near Cleveland, Ohio. Since that time it has been found in nine states in the U.S. and in Ontario, Canada. The current distribution indicates that it was probably introduced in the 1980's, but it was not detected until 1992 (Haack and Lawrence 1994). Recent genetic analyses suggest that populations in the U.S. may have arisen from two introductions—one in Illinois near Lake Michigan, and one in Ohio near Lake Erie (Carter and others 1995).

Most *T. piniperda* infestations in the U.S. have occurred in Scotch pine, primarily in Christmas tree plantations. However, adults have been recovered from shoots of native jack pine, red pine, and white pine (Haack and others 1993). Studies in this country have shown that *T. piniperda* shoot-feed and reproduce in many North American pines, including southern pines (Lawrence and Haack 1995). The extent to which this beetle will become a serious pest has not been determined, but it is likely to be very successful in North America. *T. piniperda* is the first beetle to fly in the spring, which may give it a competitive advantage over native bark beetles (Haack and Lawrence 1995). Many, if not all, native pines will be suitable hosts, and *T. piniperda* will probably spread through the pine-growing regions of North America (Lawrence and Haack 1995).

T. piniperda is a significant pest in its native range of Europe, Asia, and North Africa (Haack and Lawrence 1994). It breeds in downed pines and stumps. Newly developed adults fly to crowns of living pines and feed inside the shoots during the summer, killing the attacked shoots and causing growth loss. It is this shoot-feeding behavior that, causes this insect to be a major pest of pines.

Following the discovery of *T. piniperda* in 1992, APHIS and cooperating states in the Northeast initiated a trapping program in 1993 to survey for exotic bark beetles. The program consisted of deployment of pheromone-baited traps in areas around ports, near importer warehouses, and in areas near logging operations, lumberyards, etc. The targeted species were ones determined to have the highest potential for introduction. Most of the targeted species are on the list of most frequently intercepted insects on wood (Table 3). *Ips typographus* and *Hulurgus ligniperda* were considered to have the highest risk of introduction (Knodel 1995). Both were found in the first year of the trapping program. Other targeted species were *Pityogenes chalcographus, Ips sexdentatus, Ips erosus, Hylurgus palliatus,* and *T. piniperda.* In 1994, for example, 4 exotic species of bark beetles were found in New York (Knodel 1995).

In addition to the pheromone trapping efforts, APHIS and cooperating states in the Northeast implemented a trapping program to monitor for the pine shoot beetle, *T. piniperda* (Hoebeke 1994). This program consisted of deployment of pine logs baited with ethanol. In addition to trapping *T. piniperda* and several species of native bark beetles, exotic species were also discovered (see below).

European Spruce Beetle, *Ips typographus*

Thirteen specimens of *Ips typographus* were trapped at the port of Erie, PA in May 1993 in pheromone-baited traps deployed as part of the exotic bark beetle monitoring program described above. The captures were in the vicinity of a waste dunnage pile, which could have been the source of the beetles. In June 1993, several hundred additional pheromone-baited traps were placed in and around the port area. Trapping results for 1993 and 1994 have been negative for *Ips typographus.* In 1995 another European spruce beetle specimen was captured in a pheromone trap near Porter, IN. An intensive trapping program has been initiated in

the area of the capture to determine whether an infestation exists.

Ips typographus is native to Eurasia where it is a serious pest of spruce (USDA 1991). It occasionally attacks other species such as pines and larches. The beetle is associated with several species of fungi, some of which are extremely pathogenic. Spruce beetles most often attack downed trees but can attack and kill healthy trees during outbreaks. The beetle has 1–3 generations per year in Europe depending on temperature. Spruce beetles are strong fliers and if established in North America would be expected to spread rapidly; it could become a serious pest of spruce forests. The pathogenic fungus, *Ophiostoma polonica,* would probably also be introduced with *I. typographus* and might then be transmitted by native bark beetles (USDA 1991).

European Black Pine Beetle, *Hylastes opacus*

Hylastes opacus was first collected in North America in Suffolk Country, NY in 1989 (Wood, 1992). In 1993 and 1994 it was collected several times as part of the exotic bark beetle monitoring program in Maine, Vermont, New Hampshire, and West Virginia (Rabaglia and Cavey 1994). In 1993, 117 specimens of *H. opacus* were collected from 32 sites in 22 counties across New York (Hoebeke 1994). These collections were made during the trap-log survey program for *T. piniperda.*

H. opacus is widely distributed in the Palearctic region (Hoebeke 1994). Its hosts are *Pinus* spp., but it will occasionally infest other conifers. Its primary host is Scotch pine, *P. sylvestris.* It breeds in stumps or at the base of weakened trees. Adults feed on the tender bark near the root collar or seedlings, often girdling them. This species is frequently a pest in nurseries and pine plantations where it kills young trees and wounds older trees exposing them to infection by disease organisms (Hoebeke 1994).

Two-Toothed Bark Beetle, *Pityogenes bidentates*

The two-toothed bark beetle, *Pityogenes bidentates,* was first reported in nursery stock in Lima, NY in 1988 (Hoebeke 1989). This initial detection was thought to be only an interception, because the infested stock was destroyed and infestations were not found in subsequent years. It was collected again in 1993 from two sites in Monroe County, NY during a survey for *T. piniperda* using trap logs (Hoebeke 1994). In 1994 a single specimen was captured in a pheromone-baited trap near Rensselaer, NY as part of the exotic bark beetle survey (Knodel 1995). These collections suggest that this bark beetle is established and breeding in New York.

Pityogenes bidentates is widely distributed in Europe and attacks several species of conifers, including fir, larch, spruce, and pine (Brown and Laurie 1968). It usually breeds in slash and is considered to be a secondary pest. It has been reported occasionally as a pest in young plantations, especially following frost damage.

Red-Haired Bark Beetle, *Hylurgus ligniperda*

The red-haired bark beetle, *Hylurgus ligniperda,* was found for the first time in North America in May, 1994 during the exotic bark beetle survey (Knodel 1995). A single female beetle was collected in a pheromone trap near Rochester, NY in the vicinity of a stand of mixed conifers that had been damaged during a winter storm in 1991. Follow-up trapping and surveys are planned for this year.

Hylurgus ligniperda is distributed throughout Europe, into the Caucasus Mountains and Western Siberia (USDA 1991). It has also been introduced into several other countries, including Japan, Chile, and New Zealand. This insect feeds and breeds in phloem of logging slash, stumps, stump roots, and at the root crown of pine seedlings. Damage occurs when newly emerged adults feed on roots of young pine seedlings until beetles reach sexual maturity (USDA 1991). It has the potential to vector diseases associated with intensive management, such as that caused by the fungus, *Leptographium wageneri.* Its potential to be a significant pest is related to its potential to vector black stain root disease. *Leptographium* species have been isolated from more than 70% of beetles examined in New Zealand (USDA 1995).

Popular-Larch Leaf Rust, *Melampsora larici-populina*

Popular-larch leaf rust caused by *Melampsora larici-populina* was first found in North America in 1991 in hybrid poplar plantations along the Columbia river in Washington and Oregon (Newcombe and Chastagner 1993). Although the fungus is native to Eurasia, little is know of its distribution in North America (Haack 1993), but it has been reported from California (Liebhold and others 1995). It is not known how it was introduced or when it arrived (Haack 1993).

Melampsora larici-populina alternates between species of larch and poplar. Spores of the fungus are disseminated by wind and can be spread over great distances (Liebhold and others 1995). The rust is thought to have great potential for spreading given the widespread distribution of larch and poplar and could potentially be a serious pest in plantations. Little is known about its pathogenic variability or host resistance (Liebhold and others 1995).

IMPACTS OF EXOTIC PESTS

Exotic pests have had huge, irreversible impacts on forest resources. Timber losses alone have exceeded $2 billion (Pimentel 1986). Species such as chestnut, butternut, American elm, and Port-Orford-cedar are no longer used for timber due to the impacts of exotic pests (Campbell, 1994). White pine in the West is not being planted as it once was for fear of loss to WPBR (Ketchum and other 1968). Pest control activities, tree improvement breeding, silvicultural controls and other programs are expensive but necessary to mitigate the effects of exotic pests (Campbell 1994). For example, the amount of money spent annually for research, eradication, and control of the gypsy moth averaged more than $20 million during the last decade.

Ecological impacts are immeasurable. According to Campbell (1994) the impacts of exotic pests have been greater than that of other, more widely recognized, human-caused factors, such forest fragmentation, pollution, and altered habitat. Liebhold and others (1995) consider the impacts of exotic pests to be comparable to that caused by global warming. Ledig (1992) considers exotic species to be the most serious threat to biological diversity of forest ecosystems. There are many examples, especially in the East, where forest ecosystems have been or are being changed by exotic pests. Chestnut has been virtually eliminated by chestnut blight; butternut is threatened by butternut canker; oak-hickory forests of the East have been changed by the gypsy moth; wildlife has no doubt been negatively affected by the loss of mast production by these species. The hemlock woolly adelgid (*Adelges tsugae*) threatens unique stands of eastern hemlock, and the balsam woolly adelgid (*Adelges picea*) threatens to eliminate high elevation stands of Fraser fir.

WHAT CAN BE DONE?

First we must recognize that exotic pests are a global problem. As the movement of people and their materials increases around the world, the risk of introducing foreign organisms increases. As more species are introduced around the world, the chances of further introductions also increase. We need to cooperate with foreign colleagues to assess the risk of introductions and develop ways to prevent introductions. We need to conduct studies in foreign countries on pest organisms before they are introduced. A starting point would be to prepare a list of insects and pathogens by host and country of origin, especially for areas of high risk, such as that complied several years ago for diseases of commercial tree species (Anonymous 1963). Compilations of information on exotic species of quarantine significance would be invaluable for developing prevention and eradication programs.

The most efficient way to address the problem of exotic pests is to prevent their entry. Quarantine procedures should be developed for all types of forest products. The reports by the three assessment teams (USDA 1991; USDA 1992; USDA 1993) provide a model of interdisciplinary approach to analyzing the risks of exotic introductions from which prevention protocols can be developed. In addition to aggressive prevention programs, we also need monitoring efforts to detect new introductions. This would increase our ability to eradicate incipient populations before they have a chance to expand or spread.

Liebhold and others (1995) recommended against widespread planting of exotic tree species, which can be at higher risk of being hosts for exotic pests. Some exotic trees have the potential to become pests. They also recommend not planting a limited number of species over large areas.

Finally, we need to continue to develop ways to reduce the damaging effects of exotic forest pests already present. Research needs to respond quickly to introductions and threats of introductions with information about the pest to support eradication and control.

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