

## Appendix B: Case Histories of Previous Introductions of Forest Pests

Given the uncertainties involved in predicting what might happen if a potential pest were introduced to a new environment, the best descriptions of such events may be represented by past cases. The following eight case histories are examples of the consequences of introducing exotic forest insects and pathogens into a new environment. Seven of the eight insects and pathogens described were introduced and established in North America: the Asian longhorned beetle, chestnut blight fungus, Dutch elm disease fungus, Formosan subterranean termite, gypsy moth (European biotype), pine shoot beetle, and the smaller Japanese cedar longhorned beetle. The smaller Japanese cedar longhorned beetle and the pathogens that cause chestnut blight and Dutch elm disease were unknown as pests in their native habitats. The eighth case describes the pine wilt disease, which resulted from the introduction to Japan of a North American species, the pinewood nematode. Although tree pest species may (and have been) transported by a variety of means, each of the eight species described is an example of a kind of organism that could gain entry to new forest environments, urban settings, and other tree resources through movement with SWPM. Regardless of the actual mode of transportation, the consequences of introduction would remain similar based upon the biological characteristics of the pest organism and the environmental conditions present in the new locations.

### Asian Longhorned Beetle

**History of Introduction**—A pest native to the orient, the Asian longhorned beetle [*Anoplophora glabripennis* (Motschulsky)] was detected in the Greenpoint section of Brooklyn, NY, in August 1996 attacking healthy trees (Haack et al. 1997a). It is believed to have been brought in on solid-wood crating, the kind used for pipes and heavy machinery. Shortly thereafter it was also found in the Amityville area of Long Island, to which it likely had been transported from Brooklyn with firewood. Expansion of the Greenpoint infestation and spread into two additional locations in Queens and a park in Manhattan (found during 1999) likely has also been enhanced by movement of infested wood by people. On July 10, 1998, a separate population was discovered in an area north of Chicago known as Ravenswood (Poland et al. 1998) covering about 7.5 square miles. In August 1998, smaller pockets were located at Addison and Summit outside of Chicago. An additional infestation was found in the Kilbourn Park neighborhood in July 1999. On the basis of observed tree damage in the Chicago area, indications are that this beetle had been present for 5 to 7 years before detection. Because warehouses importing products from China were located near the infestations in the Chicago area, evidence again suggests that the beetle arrived from China. In 1998, Asian longhorned beetles were intercepted at warehouses in several States after passing through ports of entry; however, no established populations have yet been found around these sites. In December 1998, APHIS instituted treatment and certification requirements for SWPM arriving from China and Hong Kong and stepped up port inspections to ensure compliance.

**Range and Importance of Host**—Larvae of the Asian longhorned beetle feed on more than 24 species groups in the Orient and Palearctic, many of which are nonnative to North America. In this beetle's native China it prefers *Populus* spp., whereas in the United States maple species (*Acer* spp.) are most commonly attacked. Other hardwood species are also readily attacked within infested areas, and host-switching even in the presence of preferred hosts appears to be characteristic (V. Mastro 1999, personal communication).

The ability to switch from one host tree to another is of great concern because the current infestations lie in the heart of the susceptible mixed hardwoods forest type. Trees of all sizes (down to ½ inch in diameter) are attacked. Host plants of the Asian longhorned beetle are listed and discussed in appendix D.

**Life Cycle and Biology**—In its native habitat, the beetle has one generation per year. However, a small percentage of the population (less than 20 percent) may take 2 years to develop. Adult emergence begins in May and peaks in early July. Coincidentally, this is when (month of July) infestations in both New York and Illinois were first detected. In New York, adults emerged in August and September—especially during the heat of the day (Kucera 1996).

In their native range, adult beetles prefer shoots of poplar and willow for maturation feeding and oviposition. These attacks cause the shoots to wither and die. To lay eggs, the adult females make a groove on the branches where the new shoots arise (crotch). The first two larval instars feed primarily in the phloem, and the late third and early fourth instars move into the sapwood. Borings produced by the larvae are excelsior-like and typical of cerambycids.

Some beetle larvae also bore into the roots of trees (Kucera 1996). The basic biology of the Asian longhorned beetle is summarized in appendix D.

**Insect Spread**—Natural dispersal occurs when newly emerged adults fly up to 1,000 meters per each flight to locate new host material (Thier 1997). Population expansion by natural means is expected to be relatively slow. In contrast, spread by human activity can occur over long distances. Beetles have been intercepted numerous times on green or untreated SWPM imported with cargo; this is the suspected pathway for initial population introductions into New York and Illinois. Because the Asian longhorned beetle can complete its life cycle in freshly cut logs and firewood as well as woody debris, the potential for spread by tree-trimming companies and firewood collectors is great. The movement of firewood from Brooklyn, NY, has been implicated in the introduction of the Asian longhorned beetle into Amityville, NY. Beetles have also been found in nursery stock, thus posing a serious threat for introduction of new population centers via the movement of young trees. There is some concern that collection of beetles by curiosity seekers may contribute to further spread of beetles, although no such instances have yet been ascertained (Spencer and Campagna 1998).

**Economic and Ecological Impact**—The Asian longhorned beetle bores into the main trunk, branches, and roots of trees. It is the most important and destructive forest pest in its native China (Kucera 1996). Because a tree is repeatedly attacked, infested trees are killed within several years of initial attack. The beetle has the potential to destroy not only timber value, but maple syrup production potential, nursery stock, and fall coloration value of the major eastern hardwoods. It has already heavily impacted urban tree resources where it has become established in New York and Illinois.

As of 15 March 2000, more than 4,300 infested trees in New York and 1,260 infested trees in Illinois had been removed at a total cost of about \$25.1 million (M. Stefan, personal communication). Intensive surveys are continuing around the most recent detection points and in outlier areas to facilitate containment of this pest.

Loss of shade owing to removal of infested trees likely will produce “heat islands” until replacement trees mature. Urban plantings infested by the Asian longhorned beetle pose the additional threat of personal injury, property damage, and liability that can result from tree failures whenever beetles have weakened stems and branches.

**Management**—Quarantines have been established to prevent further spread of the Asian longhorned beetle from the known areas of infestation in New York and Illinois by restricting movement of potentially infested materials, including logs, green lumber, firewood, stumps, roots, branches, and debris of half an inch or more in diameter of susceptible tree species. Updated information on areas quarantined for the Asian longhorned beetle may be found on the Internet (Cooperative Agriculture Pest Survey 2000a). In the infested areas, intensive eradication programs are being conducted to locate, remove, and destroy infested trees. The only currently available and effective way to destroy infested woody material is to chip or burn the entire tree.

Because larvae bore deep into wood, they are difficult to kill with biological or chemical pesticides in field settings. Although some research is being conducted to develop better control techniques, methods involving mass trapping, use of pheromones, or pesticide application are not yet proven to be effective in limiting population spread. Field trials are currently being conducted in the United States to evaluate soil and trunk injections of Imidacloprid for preventing attack and controlling spread of the Asian longhorned beetle. In China, ashleaf maple or boxelder, *Acer negundo* L., is used as a trap tree in poplar plantations. A parasitic wasp, woodpeckers, and predatory Colydiidae beetles have also been reported to have some impact on the Asian longhorned beetle in China.

## Chestnut Blight

**History of Introduction**—Chestnut blight, one of the most infamous plant diseases in North America, illustrates the devastating impact of an introduced plant pathogen. The disease was first discovered killing trees in New York City's Bronx Zoological Park in 1904. Two years later, the fungus causing the disease was identified. Five years after the blight's discovery, infected chestnuts were found 30 miles from New York, and pockets of the disease appeared in Pennsylvania, Virginia, Maryland, Connecticut, and Rhode Island. Spread was exceedingly rapid. Within 50 years the disease had spread to the extremes of the natural range of the American chestnut [*Castanea dentata* (Marsh.) Borkh.], resulting in the loss of approximately 8 million trees.

Efforts to control the blight were begun soon after its discovery. In New York City, control measures included

pruning affected branches and applying Bordeaux mixture, but neither method was effective. In Washington, DC, all infected trees within disease centers were cut and burned, but also to little avail. In Pennsylvania, control efforts were abandoned after only 2 years. The quick proliferation of the blight and the enormous toll it took sparked prodigious research. Even by 1914, 399 articles had been published on various aspects of the epidemic (Anderson and Rankin 1914).

The legacy the blight fungus left was the near total decimation of the American chestnut from its natural range (Roane et al. 1986). Today, sprouts from the root systems of blighted trees are all that remain of this once important species.

**Range and Importance of Host**—The American chestnut was once the most abundant hardwood in the eastern deciduous forest. Its natural range encompassed more than 200 million acres. In the southern part of its range, the tree grew to 120 feet in height and 5 feet in diameter. The chestnut had a faster growth rate than its associated hardwood species, and normal growth was 500 board feet per acre per year with trees on good sites adding 1 inch in diameter per year.

The American chestnut had more uses than any other tree in the eastern forest: it was important as a timber, nut, and shade tree. The wood was extremely resistant to decay because of the tannins in the bark and wood. It was used for construction, furniture, tannins for leather, fences, boxes, barrel staves, railroad ties, telegraph poles, mine timbers, and musical instruments (Anderson and Rankin 1914, Boyce 1961, Roane et al. 1986, Sinclair et al. 1987). The delicious nuts were also an important source of food for wildlife, domestic livestock, and humans.

Although the blight rapidly killed chestnut trees and stump sprouts, oaks are more resistant to infection, but they do become infected and may live for years. Scarlet oak (*Quercus coccinea* Muenchh.) is most commonly infected and exhibits “swollen butts” composed of large irregular areas of curved bark, callus formation, and distorted wood. Other oak species affected include post oak (*Q. stellata* Wangenh.), white oak (*Q. alba* L.), and live oak (*Q. virginiana* Mill.) (Nash and O’Brien 1989). The fungus can also grow as a weak pathogen or saprophyte on other tree species (e.g., *Acer* spp., *Carya* spp., *Rhus* spp.) that serve as a reservoir when susceptible hosts are not available.

**Disease Organism**—The chestnut blight fungus [*Cryphonectria parasitica* (Murr.) Barr] is an Ascomycete (subclass Pyrenomycetes) belonging to the family Valsaceae. The fungus is now distributed throughout the Northern Hemisphere, but it is believed to be of Asian origin. The asexual, single-celled conidia are produced within pycnidial stromata on the bark of diseased trees. The sexual ascospores are two-celled, each with one to four nuclei, and are produced in perithecia within the same stromata as the pycnidia. Both spore types are produced in abundance on diseased trees, and both are capable of causing infection on healthy trees.

**Life Cycle and Biology**—Cankers can occur anywhere on the branches or trunk, but the fungus requires some type of wound to gain entrance. Once established, mycelial fans produced by the fungus rapidly colonize the bark tissue, encircling and girdling the branch or trunk and killing the cambium. After the sapwood at the site of a girdling lesion ceases to conduct water, the leaves and shoots above the canker wilt and die. Typical cankers on young, smooth-barked stems appear yellowish to reddish brown in contrast to the green–brown bark. On larger stems with thick corky bark, cankers are usually inconspicuous unless the bark begins to swell or crack.

Under moist conditions, orange–brown stromata of the fungus erupt through the surface of infected bark, releasing millions of conidia embedded in a water-soluble, gelatinous matrix (Anderson and Rankin 1914, Boyce 1961, Sinclair et al. 1987). These spores are adapted for spread by rain and perhaps by insects, birds, and small animals. Perithecia, producing ascospores, also form throughout the growing season in the same stromata that give rise to the conidia. These spores are released after rains and are adapted for spread by wind. New infections occur when ascospores or conidia germinate in fresh wounds that penetrate to living bark.

**Disease Spread**—The rate of spread of the main disease center south of New York has been estimated at 10 to 23 miles per year, and the blight had spread to southern Alabama by 1950 (Newhouse 1990). The discrepancy in estimates results from spot infections occurring up to 150 miles from the leading edge of the principal center. The most important insect carriers are probably the wound makers such as the chestnut bark borer [*Strophiona nitens* (Forster): Cerambycidae]. Conidia of the fungus may also be spread by birds (Boyce 1961, Sinclair et al. 1987) such as woodpeckers and the wound-inducing sapsucker. The north to south migration of birds in the fall may explain

the southwest spread of the blight against the prevailing winds.

The rapid spread of chestnut blight demonstrates the capability of spores to disperse from infected wood via wind currents (Sinclair et al. 1987). Infected wood, particularly when cankered bark is attached, could serve as a reservoir for chestnut blight and similar organisms and provide a pathway to new infestation centers when transported internationally, such as might occur with SWPM.

**Economic and Ecological Impact**—The American chestnut was once the most economically important hardwood species of the eastern forests. The time that has elapsed since the destruction caused by the blight makes it difficult to estimate the total impact of the disease. In 1912, the value of the standing chestnut timber in Pennsylvania, West Virginia, and North Carolina alone was estimated at \$82.5 million (. \$683.9 million in 1999 dollars). The value of the nut crop and shade trees in Pennsylvania was estimated at another \$15 million (. \$124.3 million in 1999 dollars). In Pennsylvania, \$275,000 was spent between 1912 and 1914 (. \$2.3 million in 1999 dollars) in a vain attempt to stop the disease (Hepting 1974).

Chestnut blight resulted in wholesale species conversions, primarily to oaks, on sites where chestnut was predominant. On the better sites it was replaced by red and white oaks (*Quercus rubra* L. and *Q. alba* L., respectively), whereas on the steeper hillsides these species gave way to pin oak (*Q. palustris* Muenchh.) and chestnut oak (*Q. prinus* L.). However, along many of the ridgetops in the Appalachian Mountains, the chestnut has not been replaced, leading to increased soil erosion. The increased abundance of oaks in many areas may, in turn, have exacerbated spread of other pests, such as the European gypsy moth and the pathogen that causes oak wilt.

**Management**—Over the past 50 years, experimental attempts have been made to restore the American chestnut using fungicides, biological controls, and breeding for blight resistance. Fungicides have shown some promise for controlling the blight on individual trees of high value, but annual applications are required. Biological control of virulent strains of the fungus by hypovirulent strains has been shown feasible in Europe (Newhouse 1990). In the United States, however, the greater spread and diversity of the virulent strains militates against the widespread introduction of hypovirulent strains. At this time, breeding for blight resistance is being done, but no clones of American chestnuts have sufficient blight resistance to be useful for outplanting. Some hybrids between the American chestnut and Asian species have been developed and are being sold, but they tend to have a less desirable form than the American chestnut.

## Dutch Elm Disease

**History of Introduction**—The cause of Dutch elm disease has historically been attributed to *Ophiostoma ulmi* (Buisman) Nannf. sensu lato, but debate continues about the origins of the various races and species of pathogens that produce the disease symptomatology. Recent taxonomic changes recognize a nonaggressive form, *Ophiostoma ulmi* (Buisman) Nannf. sensu stricto, and an aggressive form, *Ophiostoma novo-ulmi* Brasier. The fungus (or fungi) that causes Dutch elm disease was introduced to North America, together with one of the insects responsible for its spread, the smaller European elm bark beetle [*Scolytus multistriatus* (Marsh.)], on unpeeled veneer logs, and the earliest cases of the disease on this continent were reported in Ohio in 1930 (Sinclair and Campana 1978, Sinclair et al. 1987). In 1933, a Federal quarantine inspector at the port of Baltimore intercepted elm logs from France carrying the Dutch elm fungus together with the main bark beetle vector of the fungus in Europe. Subsequent inspections revealed the fungus in elm logs intercepted in New York, Norfolk, and New Orleans. The most serious disease centers arose around the cities of New York and Quebec in 1933. In the city of New York, spread of the disease was attributed to the presence of a breeding population of the introduced smaller European elm bark beetle and an abundance of the native (North American) elm bark beetle [*Hylurgopinus rufipes* (Eighh.)]. A second major disease center occurred in the late 1930's in Ohio and Indiana. Spread of the disease followed the movement of infected logs via railroads. Attempts at eradicating the pathogen, especially in the New York City area, were abandoned at the onset of the Second World War. By 1968, the disease was present throughout the eastern half of the continent and into Colorado and Idaho beyond the range of native elms. More aggressive forms of the Dutch elm disease fungus were reintroduced from North America, most probably between 1970 and 1990, into Europe, where they cause increased mortality.

**Range and Importance of Host**—The American elm (*Ulmus americana* L.) is native to all States east of the Great Plains and is generally highly susceptible (Haugen 1998). Winged elm (*U. alata* Michx.), September elm (*U. serotina* Sarg.), slippery elm (*U. rubra* Muhl.), rock elm (*U. thomasii* Sarg.), and cedar elm (*U. crassifolia* Nutt.)

range from susceptible to somewhat resistant. No native elms are immune to Dutch elm disease, but some individuals or cultivars have a higher tolerance of the disease. Elms usually grow in mixed stands with other hardwoods and in 1938 accounted for an estimated 16 billion board feet of merchantable timber. Elm wood has been used for veneer, furniture, shipbuilding, flooring, sporting goods, boxes, and crates.

The value of America's elms as ornamentals and shade trees surpasses that of all forest elms. Elms are especially adaptable to the urban environment. They are able to endure physical damage, such as repeated pruning for overhead utility lines, and are tolerant of soil compaction. The beauty of elms and their utility as shade trees have contributed to their popularity. As a result, they have been planted extensively on streets, roadsides, and homesites across the United States.

**Disease Organism**—The Dutch elm disease fungus is an Ascomycete belonging to the order Ophiostomatales. The most common form now recognized in the United States is *Ophiostoma novo-ulmi* Brasier. Its anamorph was named *Pesotum ulmi* (Schwarz) (Crane and Schoknecht 1973). The fungus has four commonly observed spore types: (1) sporothrix stage with conidia; (2) synnematal (*Pesotum*) stage, also with conidia; (3) "yeast-like" stage; and (4) perithecial (sexual) stage, producing ascospores. Spores produced by the two conidial stages and the perithecial stages are embedded in sticky mucilaginous drops. The yeastlike stage is thought to be involved in the spread of the fungus within a tree's vascular system.

**Life Cycle and Biology**—The fungus that causes Dutch elm disease is an example of a vector-borne plant disease and a highly specialized vascular-wilt organism. The fungus causes the disease, but insects are necessary to transmit the fungus to healthy elms at new locations. In North America, two insects (Scolytidae) are responsible for spread of the fungus: the smaller European elm bark beetle [*Scolytus multistriatus* (Marsh.)] and the native elm bark beetle [*Hylurgopinus rufipes* (Eichh.)].

The fungus is a primary colonizer of the inner bark of dying elms. Beetles breed in the inner bark of diseased or stressed trees. If the fungus is present in the tree, it produces mycelium and sticky *Pesotum*-type spores in the beetle tunnels and pupal chambers. When adult beetles emerge, they carry thousands of spores on and in their bodies. Dispersing beetles fly to healthy elms, where they feed, or to declining elms, where they breed (Sinclair and Campana 1978). On healthy elms, the beetles feed on, or burrow into, the bark of twig crotches, where the spores are deposited into the wounded tissues of the tree (Sinclair and Campana 1978). The fungus grows rapidly in the injured bark and wood. When it reaches the large xylem vessels of the springwood, it produces *Sporothrix*-type spores, which are carried in the sap stream. The extent of crown symptoms is directly related to the extent of vascular invasion. General invasion of the tissue begins at the dieback phase of the disease with considerable blockage of the sapwood by gums and tyloses produced by the tree to resist the fungal invasion. Infection induces browning of the water-conducting vessels. Infected twigs and branches soon wilt and die.

Spring infections result in the invasion of the long vessels of the springwood through which spores can be rapidly spread to all parts of the tree. If the vascular invasion becomes general, the tree may die within a few weeks. In summer infections, vascular invasion is limited to the short vessels of the summerwood, resulting in localized infections; tree death occurs the following year.

**Disease Spread**—Either the insect vector or human activities can cause long-distance spread of the fungus. The spread rate of the disease across Connecticut was 4.5 miles per year, which is equal to the flight of two generations of the smaller European bark beetle. Elm bark beetles commonly attack green elm logs cut for lumber or fuel. Cut elm logs colonized by contaminated beetles commonly serve as reservoirs of the fungus, including logs of the elm species that are not highly susceptible to the disease itself. Subsequent commercial transport of the logs has allowed both the Dutch elm disease fungus and bark beetles to spread over long distances—even across oceans.

The introduction of the Dutch elm disease fungus into the United States with logs demonstrates that the causal pathogen may be transported with its vector in infected wood. The beetle vector and pathogen could just as readily be transported in SWPM made from elm, provided pieces of bark remain attached to the wood that could harbor the beetle. In the absence of the exotic beetle vector, transmission of the fungus from imported wood materials to living trees would be dependent upon colonization and emergence of native bark beetle vectors. This could happen if fresh phloem were present under bark remaining on imported wood that was offloaded near existing infestations of the beetle vector.

Beetles that become contaminated by the fungus during development in logs or trees can introduce spores to healthy trees during adult feeding on twigs. As these trees begin to decline from Dutch elm disease, beetles are attracted to the trees as breeding sites. This secondary colonization ensures that most elm material in infested areas will produce contaminated beetles. Once the fungus has become established, spread to nearby healthy elms can occur without the insect vector by internal movement of the fungus through root grafts between living trees, which is a common occurrence in urban street tree plantings.

**Economic and Ecological Impact**—The primary impact of Dutch elm disease has been in the urban environment rather than in forests. Because of their esthetic appeal and their hardiness, by 1930 an estimated 77 million elms had been planted in densely populated areas across the United States. By 1977, an estimated 60 percent of urban elms in the United States had been lost to the disease.

More than \$11 million was spent over a 5-year period in the 1930's by Federal and State agencies to eradicate the pathogen. Costs of removal and replacement vary between about \$118 and \$501 per tree, with an average cost of about \$254 (1998 dollars). However, when esthetic and other values are factored in, the cost rises to about \$507 per tree (1998 dollars).

**Management**—Control programs enacted by urban governments in affected areas have ranged from complete neglect to an all-out assault. The primary control methods have been sanitation, which eliminates the breeding material of bark beetle vectors, and disruption of root grafts. Experience has shown that, despite costs, the control efforts are preferable to no action: communities that did nothing eventually incurred costs two to three times greater than those that implemented control programs. Preventive fungicide injection and eradication pruning plus fungicide injection and insecticide treatment are some options available for individual homeowners. Use of community ordinances to encourage prompt removal of diseased trees and the prevention of elm firewood storage with bark intact is important in reducing damage. Public education is also important in maintaining a sound prevention program. Historic and other highly valued trees may be saved if injected with a systemic fungicide. Effective treatment from 1981 to 1984 cost a minimum of \$40 to \$100 per tree (. \$57 to \$143 in 1998 dollars). Elm cultivars resistant to Dutch elm disease are now commercially available (Smalley and Guries 1993).

## Formosan Subterranean Termite

**History of Introduction**—The Formosan subterranean termite (*Coptotermes formosanus* Shiraki) is considered one of the most destructive and aggressive species of termites in the world (Oi 1997, Su and Scheffrahn 1998b). It is native to China and has been introduced to Japan, Sri Lanka, South Africa, Taiwan, Hawaii, and the continental United States. Introduction and initial spread throughout the world has probably been from ship transport. The Formosan subterranean termite very likely arrived in Hawaii as a result of trade activity and has been on Oahu for over 100 years. From Oahu, it gradually spread to all of the major islands: Hawaii 1925, Kauai 1929, Lanai 1932, Maui 1933, and Molokai 1975 (Yates and Tamashiro 1999). It is believed to have come to Honolulu in the soil of potted plants or in wood from China or Taiwan. It was first brought to the mainland United States on military ships returning supplies from the Pacific Theater after World War II. The Formosan subterranean termite was collected in Charleston, SC, in 1957, but was misidentified. The first confirmation of an established population in the continental United States was at a Houston, TX, shipyard in 1965. In 1966, well-established colonies were discovered in New Orleans and Lake Charles, LA, and Houston and Galveston, TX. In 1967, the termite was rediscovered in Charleston, SC. Well-established colonies were located in Florida in 1980, 1982, and 1984 (Oi 1997).

**Range and Importance of Host**—Like nearly all other termites, the Formosan subterranean termite feeds on plant-derived cellulose. It is known to damage wood in buildings, living trees, utility poles, and railroad ties. This species has been reported to attack over 50 species of living plants, including citrus (*Citrus*), sugarcane (*Saccharum officinarum* L.), avocado (*Persea americana* Mill.), wild cherry (*Prunus*), cherry-laurel [*Prunus caroliniana* (Mill.) Ait.], privet (*Ligustrum*), hackberry (*Celtis*), cedar (*Juniperus*), willow (*Salix*), Chinese tallowtree [*Sapium sebiferum* (L.) Roxb.], waxmyrtle (*Myrica cerifera* L.), sweetgum (*Liquidambar styraciflua* L.), mimosa (*Albizia julibrissin* Durazzini), cypress (*Cupressus*), redbud (*Cercis*), Chinese elm (*Ulmus parvifolia* Jacq.), and various species of oak (*Quercus*) (Oi 1997, Su and Scheffrahn 1988). It will attack nearly any wood in contact with the soil and has been known to construct galleries to the upper stories of buildings to feed on wood.

**Life Cycle and Biology**—All termites are social insects and live in colonies (Thorne 1998). A mature Formosan

subterranean termite colony averages between 2 to 8.5 million individuals, and its foraging territory may range up to 90 m (300 ft) from the nest (King and Spink 1969, Lai 1977). Nests can be constructed in the ground or above ground. Any wood in contact with the ground where this species occurs, is susceptible to the Formosan subterranean termite. They generally invade structures from the ground by entering through expansion joints, cracks, utility conduits in slabs, and holes for tub drains. A Formosan subterranean termite colony can construct a gallery system covering 0.5 ha of land, thus it can easily find untreated areas to enter a building. The primary nest is usually constructed near a food source in or on the soil (King and Spink 1969). Foraging galleries lined with carton (made of chewed wood, saliva, and excrement) are then constructed to the food source. Auxiliary nests are often constructed in the walls of buildings or in the food source. Galleries may be extended from the soil to the upper stories of buildings to permit feeding on wood.

The Formosan subterranean termite, like all subterranean termites, uses the soil for a source of moisture. However, termite colonies can obtain moisture from plumbing or roofing leaks. Although they can survive on small amounts of moisture, the need for some moisture is critical, which is one reason the Formosan subterranean termite swarms only when the air is windless and humid (Oi 1997).

Three forms or castes are common in these colonies: workers, soldiers, and reproductives (Thorne 1998, Yates and Tamashiro 1999). The great majority of individuals in a colony are workers that forage for food and maintain the colony. Workers are very susceptible to desiccation, and thus they always work within tunnels and galleries. They are the ones that do the damage caused by termite colonies.

Most subterranean termites feed along the grain of wood, eating the springwood and leaving the summerwood. Formosan subterranean termites feed on both and form a hollow. If the hollow is large (tree or timber), then it is filled with carton material to form a nest (Oi 1997).

The soldier caste is the second to appear in a new colony and has the function of defending it. The third caste produced is the reproductive caste. Primary reproductives, also called alates or swarmers, leave the nest to start new colonies. They have wings and functional eyes. Thousands of primary reproductives are produced each year by mature colonies. After swarming, landing, and shedding their wings, the adults pair off and move about in tandem, with the male following the female, searching for a place to live. If they successfully find a small crevice containing moist wood, the pair forms a chamber in which the eggs are laid. The Formosan subterranean termite does not always require ground connection. If a pair of alates successfully finds adequate food and moisture sources in a building, it can initiate a colony with no ground connection. Very few of these pairs survive to start new colonies. Most are eaten by predators.

About 5 days after mating, the female (queen) lays a batch of 15 to 25 eggs. These hatch in 21 to 30 days (Yates and Tamashiro 1999). The young remain in the nursery until they go through two molts. They then become functional workers in the colony and can leave the nursery to forage. Subsequent offspring are first fed by the workers in the colony rather than the parents. It will take at least 7 years to produce a major colony made up of two million or more termites. The "royal pair" may live 20 years or more, but they are seldom seen unless the colony is disturbed. A mature Formosan subterranean termite queen lays from 1,000 to 2,000 eggs per day (Yates and Tamashiro 1999). Formosan subterranean termite colonies are much larger than native termite colonies.

**Insect Spread**—The Formosan subterranean termite is a widespread, significant pest in Hawaii, Louisiana, and Florida, but also now infests locations in California, Texas, Mississippi, Alabama, Georgia, South Carolina, North Carolina, and Tennessee (Su and Scheffrahn 2000). It has taken the termite 50 years to spread to its current locations, but unfortunately, infestations appear to be increasing as colonies multiply, grow, and expand across the United States. Furthermore, introductions of this termite are often missed because it usually takes 3 to 5 years to develop a mature colony (Oi 1997); young or incipient colonies are cryptic and difficult to detect.

Once introduced, this termite's natural method of spread is swarming, but it is a weak flier and does not spread rapidly by itself. The movement of infested soil or material such as lumber, wooden crates, or other wood products that have been in contact with soil is another important method of spread (Yates and Tamashiro 1999). Intra- and interstate movement of railroad ties used for landscaping is a common mechanism for spreading the Formosan subterranean termite in the continental United States (Oi 1997).

In the United States, the Formosan subterranean termite is generally confined to areas south of about 32.5°N.

latitude (Oi 1997). This latitude coincides with the warmer temperatures usually associated with the Formosan subterranean termite. The Formosan subterranean termite's distribution in the United States will probably be limited by severe winter temperatures, and it will probably not disperse to the northern United States. However, the belief that low winter temperatures limit the spread of the Formosan subterranean termite may not hold true owing to the widespread use of central heating that provides a warm environment conducive to the survival of termites during winter.

**Economic and Ecological Impact**—Termites are among the most economically important insects in the world. Although ecologically important in nutrient cycling, they are best known as structural and plant pests that compete with people for shelter and food. The Formosan subterranean termite is extremely destructive where it has become established and each year costs consumers about one billion dollars nationally, including repair expenses (Su and Scheffrahn 1998b). This termite is one of the top pests in New Orleans, LA, and the State of Hawaii; prevention and repair of damage to wooden structures is estimated to cost over \$400 million per year (Yates and Tamashiro 1999, Su and Scheffrahn 2000). This termite species is known to damage buildings, living trees, utility poles, and railroad ties but also penetrates noncellulose material (such as thin sheets of soft metal, asphalt, plaster, mortar, creosote, rubber, and plastic) in search of food and moisture (Su and Scheffrahn 2000). In Hawaii, this termite has caused short circuits by damaging electrical cables.

A single Formosan subterranean termite does not consume more wood than do the native subterranean termites (Thorne 1998). The rapidity of damage is related to the termite's high reproductive capacity and large colony size. In Hawaii, where unprotected homes were built over large colonies, records show that this species caused major structural damage in 6 months and almost complete destruction in 2 years (Tamashiro 1984).

**Management**—To control Formosan subterranean termites, the goal is to make it hard for the termite to find conditions necessary for its survival in the structure. Once termites become established, the goal is to interfere with their necessities of life. Because subterranean termites must have a source of moisture, buildings should be thoroughly inspected to discover and eliminate all sources of moisture (Forschler 1998).

The standard method for management of subterranean termites in buildings is to treat the soil under and adjacent to the structure so that termites are repelled if they attempt to enter the structure or die as they move between the colony and wood (Forschler 1998). If a continuous termite-proof chemical barrier between the soil and the wood is maintained, termites in the house cannot gain access to the soil to get moisture nor can termites in the soil gain access to the house. A ban in 1988 on the last organochlorine soil termiticides because of human health and safety concerns escalated the Formosan termite problem. The chemical replacements now used as soil treatments are not as effective (Su and Scheffrahn 1998b).

The Formosan subterranean termite can build auxiliary nests in the walls of buildings and survive for months without soil contact. Therefore, nests should be located and a chemical treatment applied to destroy them (Yates and Tamashiro 1999). Generally, fumigation is not recommended. It may be necessary, however, to apply a fumigant gas to kill auxiliary nests in special cases (Oi 1997). If a house is fumigated and the soil is not treated, there is nothing to prevent reentry of the termites from the soil.

Alternatives to soil treatments are needed because the soil termiticides currently used do not always work, or conditions exist that do not allow use of soil treatments. Alternative techniques include particle barriers, wire-mesh barriers, inground and aboveground baiting systems, and construction materials that are resistant to termite damage (Forschler 1998, Su and Scheffrahn 1998b, Yates et al. 1999). Resistant building materials, such as steel framing and naturally resistant and preservative-treated wood, can provide protection to many of the components of a building but will not prevent Formosan subterranean termites from attacking cellulose-containing materials in the structure.

## **Gypsy Moth (European biotype)**

**History of Introduction**—Of European origin, the gypsy moth [*Lymantria dispar* (L.)] was introduced into Eastern North America in the 1870's by a French astronomer seeking a silk moth that could survive in North America. Several of the moths escaped, and though local authorities were notified, nothing was done. Free from its natural enemies, the gypsy moth dispersed rapidly, and by 1910 it had spread to three New England States. The European gypsy moth now infests all of Connecticut, Delaware, the District of Columbia, Maryland, Massachusetts, New

Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and portions of Indiana, Maine, Michigan, North Carolina, Ohio, Virginia, West Virginia, and Wisconsin (Cooperative Agriculture Pest Survey 2000b). Spot infestations have arisen in Arkansas, California, Colorado, Idaho, Illinois, Kentucky, Minnesota, New Mexico, Oregon, Tennessee, Utah, and Washington; these populations have been eradicated or have current eradication programs. The Asian biotype of gypsy moth, although taxonomically similar to that of European origin, has behavioral and physiological traits that make it potentially more dangerous. (See appendix D for an assessment of pest risk for the Asian gypsy moth biotype).

**Range and Importance of Host**—Larvae of the gypsy moth can feed on more than 500 species of trees, shrubs, and vines found in the Eastern United States (Barbosa and Greenblatt 1979). The insect prefers oak species (*Quercus* spp.), but additional hosts include apple, aspen (*Populus* spp.), basswood (*Tilia* spp.), beech (*Fagus grandifolia* Ehrh.), gray and river birch (*Betula populifolia* Marsh. and *B. nigra* L., respectively), hawthorn (*Crataegus* spp.), sweetgum (*Liquidambar styraciflua* L.), and willow (*Salix* spp.). Other species are less preferred, but during outbreaks gypsy moths feed on almost all vegetation, including conifers (Baranchikov 1989).

Although the gypsy moth feeds on a several economically important hardwood species, it is the breadth of species fed upon that is of greatest concern. During outbreaks, gypsy moth larvae will defoliate all hardwood and shrub species in their path, and at the advancing front, gypsy moth irruptions are severe.

**Life Cycle and Biology**—The life history of the European gypsy moth is essentially the same as that of the Asian gypsy moth described in appendix D.

**Insect Spread**—Natural dispersal occurs when newly hatched larvae climb to the tops of trees or other tall objects and suspend themselves from silken threads, allowing the wind to move them to potential hosts. In nonmountainous terrain, the larvae may be deposited within 1/2 mile of their source; however, in mountainous terrain the larvae may be dispersed up to 3 miles (Taylor and Reling 1986).

The gypsy moth is often spread artificially when egg masses or pupae are transported to new areas on vehicles or outdoor articles. Egg masses may be deposited on SWPM when cargo originates near areas infested by gypsy moths. Crates carrying household goods are a common substrate for hitchhiking gypsy moth egg masses.

**Economic and Ecological Impact**—The gypsy moth is a serious pest of hardwood forests and shade trees in the United States. Even otherwise healthy trees defoliated by gypsy moths are seriously weakened, and defoliation over 2 consecutive years can kill a tree. Urban trees have a much greater value than those grown for timber, and the loss of an urban tree results not only in removal and replacement costs but also a reduction in esthetic and property values. In 1973, the value of trees lost to the gypsy moth was estimated at \$375 (. \$1,134 in 1998 dollars) per tree. An owner's willingness to pay to prevent damage has been estimated at \$27 to \$494 (. \$32 to \$585 in 1998 dollars) per household in various studies (Leuschner et al. 1996). Loss of property value given 15 percent tree mortality due to gypsy moth defoliation has been estimated at about \$1,175 (. \$3,553 in 1998 dollars) per acre (Payne et al. 1973).

In urban areas, gypsy moth larvae, their droppings, and egg masses present additional nuisance factors. In humans, allergic reactions to body hairs of the caterpillars are common and well documented. Defoliation by the gypsy moth can also severely affect parks and recreational areas. With heavy infestations, larvae crawl over picnic tables, cabins, roads, and trees, leaving their droppings and creating a nuisance and possible health hazard to humans. Defoliated trees are unattractive, and in the Northeast, tourism has suffered sharp declines in areas where outbreaks have occurred. Reductions in recreation visitor days averaged 161 person-days per year for commercial campgrounds, 240 for concessionaire-leased public campgrounds, and 36,660 for public recreation areas (Moeller et al. 1977).

Because forests are used for many types of activities, the value loss caused by the gypsy moth is more difficult to predict than for urban areas. Value loss to Northeastern forests, assessed in 1978, ranged from \$0 to \$468 (. \$0 to \$987 in 1998 dollars) per acre, depending on use, and averaged \$14 (. \$30 in 1998 dollars). Since 1924, gypsy moth defoliation has fluctuated widely from a low of 125 acres in 1958 to a high of 12,886,535 acres in 1981 (USDA Forest Service, n.d.). Annual costs to control the gypsy moth since 1980 exceeded \$35 million (Wallner 1996a), and the USDA Forest Service has spent about \$11 million (. \$12 million in 1998 dollars) annually (Campbell and Schlarbaum 1994).

**Management**—Because gypsy moth outbreaks are long (often lasting from 5 to 7 years) and attack a large number of tree species, public pressure for control measures is often intense. Possible control measures for the gypsy moth include the chemical insecticide dimilin, the release of sterile life stages, mass trapping using a pheromone sex attractant, mating disruption using pheromone, and biological controls such as the release of parasites or predators or the use of the biological insecticide *Bacillus thuringiensis* var. *kurstaki* Berliner (Btk). Since 1980, 1.7 million ha have been treated with Btk in the Eastern United States under the Federal, State, and County Gypsy Moth Cooperative Suppression Program (Reardon et al. 1999). The release of sterile life stages, such as sterile male release, has been used successfully to eliminate isolated low-level infestations, but this approach has had little effect on larger populations (Mastro et al. 1989). Mass trappings using pheromones and the use of parasites and predators are likewise effective only when gypsy moth populations are very low. The use of biological insecticides, such as Btk, is favored to protect recreational areas and high-value timber species. In recent years, the fungal pathogen, *Entomophaga maimaiga* Humber, Shimazu and Soper, has drastically reduced population levels over widespread areas in the northeastern United States, but the long-term effect of this natural control agent is unknown (Elkinton et al. 1991, Reardon and Hajek 1993).

## Pine Shoot Beetle

**History of Introduction**—In 1992, the pine shoot beetle [*Tomicus piniperda* (L.)] was discovered in a Christmas tree farm in Ohio, and was probably introduced into the United States with SWPM associated with maritime cargo from Europe (Haack 1997, Haack and Kucera 1993, Haack et al. 1997b). The pine shoot beetle was the seventh most commonly intercepted bark beetle found on wood articles at U.S. ports of entry between 1985 and 1996 (Haack and Cavey 1997). Within a month of the initial discovery, surveys indicated that populations were present in at least six States. Moreover, in New York State, tree ring analysis suggests that the pine shoot beetle likely arrived sometime during the 1980's (Czokajlo et al. 1997). By the summer of 2000, pine shoot beetle had been detected in portions of 11 States and two Canadian Provinces. In November 1992, APHIS quarantined counties known to be infested to prevent human-assisted spread of the pine shoot beetle; the quarantined area has repeatedly been expanded since then as additional counties were found to harbor pine shoot beetle populations (Cooperative Agriculture Pest Survey 2000c). However, pine materials such as logs and Christmas trees may be transported out of the quarantined area if certain management or treatment requirements are met (7 CFR 301.50).

Although damage levels have generally remained relatively low in the United States, moderate to severe shoot feeding was first observed at numerous sites in 10 counties scattered across southwestern Ontario during 1998 (E. Czerwinski, unpublished report). Three of those counties were previously unknown to be infested. Shoot loss was estimated to range from 20 to 90 percent, and 100 percent of the trees were infested at the worst site. Many of the affected sites were abandoned Scotch pine Christmas tree farms where management was not occurring or where rogued trees likely provided ample breeding material for pine shoot beetles (T. Scarr, personal observation). Affected Scotch pines showed evidence of decline, based on tree ring analysis, beginning in 1988 or earlier likely due to a combination of shoot feeding by pine shoot beetle, tip blight, drought, and overstocking stressors (T. Poland and T. Petrice, unpublished 1998 Site Visit Report). Tree mortality was observed in some affected stands, although the specific cause has not been verified. Native white, red, and jack pines were affected as well as the Eurasian Scotch pine but were generally adjacent to, or mixed with, the preferred Scotch pine host.

**Range and Importance of Host**—The primary native host of pine shoot beetle in Europe is the Scotch pine, *Pinus sylvestris* L., which has been introduced and widely planted in the United States. The pine shoot beetle has been tested on 15 species of native pines, all of which proved acceptable, and can serve as hosts (Berisford and Eager 1997, Långström et al. 1995, Lawrence and Haack 1995; Eager and Berisford, unpublished data). It is likely that the pine shoot beetle will be able to colonize most, if not all, species of pine present in the United States, although levels of susceptibility and suitability will vary. This beetle has occasionally attacked other conifers in the genera *Abies*, *Larix*, *Picea*, and *Pseudotsuga*. Some scientists believe that the pine shoot beetle feeds on the aforementioned hosts in transit (i.e., while it is looking for more suitable pine hosts). Conifers other than pine are unlikely to serve as significant hosts in the United States, although they may opportunistically be utilized when close to established beetle populations.

**Life Cycle and Biology**—The pine shoot beetle causes most of its damage during maturation feeding (Långström 1983). This occurs when adult beetles fly to the crowns of living healthy trees of all ages—especially taller trees. Adults feed primarily in current-year lateral shoots, mostly in the upper half of the crown from April through October in the Great Lake States (Haack and Lawrence 1997, Långström 1980; Haack et al. in press). During this

period of maturation feeding, each adult may destroy one to six shoots (Långström 1979, 1980, 1983; Ye 1991). Scotch pine is preferred, but in the Great Lake States, red, eastern white, and jack pine have also been attacked (Sadof et al. 1994).

One generation per year is the norm for the pine shoot beetle (Långström 1983). Overwintering adults initiate flight on the first warm (50–54 °F) days of spring, which probably occurs in February or March in the Great Lake States and in the Northeastern United States (Haack and Lawrence 1995, Haack et al. 1998). Adults quickly colonize either recently cut pine stumps and logs, or, at times, infest the trunks of weakened trees. Some adults will disperse at least several hundred meters after emerging from brood material even when breeding material suitable for colonization is abundant nearby (Poland et al. in press), and marked adults have been recaptured as far as 2 km from a release point (Barak et al. in press).

Male and female pairs construct individual longitudinal egg galleries within the inner bark and outer sapwood (USDA 1972). After eggs hatch, larvae construct irregular feeding galleries of 1.5 to 3.5 inches (4–9 cm) in length that radiate from the egg gallery. Most larvae complete development, pupate, and transform into adults in May and June.

**Insect Spread**—Beetles spread naturally by flying to suitable host material. Populations may accumulate in log yards and then move on to healthy trees nearby. Infestation spread from a concentrated source of breeding material to adjoining pine stands may generally be limited to about 2 km per year (Långström and Hellqvist 1990). Although the pine shoot beetle may fly up to a kilometer or more, it may spread farther on wind currents, perhaps tens of kilometers downwind (Pine Shoot Beetle Science Panel 1993).

Pine shoot beetles may be transported as brood in infested logs or wood articles containing bark or as adult beetles in pine shoots or in overwintering sites at the base of tree trunks. The primary means of new introductions to the United States is likely to be through infested wood articles containing bark, such as in SWPM made of pine. Redistribution from established populations in the United States to other regions of North America may occur on recently dug or cut plant stock, logs, rough lumber with bark intact, or nursery stock.

**Economic and Ecological Impact**—Most often *Tomicus piniperda* (L.) breeds in dead, dying, and downed pine material, and feeding by larvae seldom results in economic loss. Exceptions have been observed in Yunnan, China, where extensive tree mortality occurred because of trunk attacks in Yunnan pine stands stressed by winter drought and in areas affected by fires during the 1970's (Haack et al. 1999; H. Ye, personal communication). In Russia, beetle populations have built up after fires and in some cases have caused serious damage.

Generally, the greatest impact from infestation by the pine shoot beetle (except in instances of trunk attack when outbreak levels are reached) results from shoot feeding of the adults in stressed and apparently healthy trees. Shoot feeding can cause a loss of growth and disfigurement of the tree. With severe shoot feeding, some trees may be killed. Shoot attack can be increased by recent fires, the presence of log decks or slash, or downed material resulting from storm damage that provides breeding sites for population buildup.

Large accumulations of breeding material are most likely to occur in natural pine stands where removal of such material is not feasible. Breeding material is commonly generated by thinning and harvest activities, storm damage, windthrow, or fire. Unknowing landowners may cut and pile infested trees near healthy stands or nurseries, thereby increasing damage.

The pine shoot beetle is a vector of several blue stain fungi in the genera *Ophiostoma*, *Leptographium*, *Graphium*, *Hormonema*, and *Aureobasidium* in Europe (Gibbs and Inman 1991, Solheim and Långström 1991). Further, the pine shoot beetle, by means of its shoot-feeding and overwintering behaviors, may be able to transmit pathogenic fungi such as *Fusarium circinatum* Nirenberg and O'Donnell [= *Fusarium subglutinans* (Wollenw. and Reinking) Nelson et al. f. sp. *pini* Correll et al.] found in the United States.

**Management**—The amount of breeding material present can more easily be reduced at locations of intensive pine production or management, such as nurseries, Christmas tree farms, and urban plantings. Additional tools available to the land manager in these situations include trap logs, insecticide applications, or shearing of infested shoots. Abandoned or unmanaged Christmas tree plantations on sandy soils seem to be more susceptible to shoot feeding than well-groomed, managed stands (0–4 percent of trees infested in managed stands compared with 28–67 percent

in unmanaged stands) (McCullough and Sadof 1998).

When harvesting timber in infested natural pine stands, it is advisable to process or destroy slash and debris. Large accumulations of slash should be removed or destroyed (e.g., chipped or burned) as a part of the management plan. Alternatively, tree harvesting should occur during periods when slash material is unsuitable for rapid colonization.

## Pine Wilt Disease (Pinewood Nematode)

**History of Introduction**—Like Dutch elm disease, pine wilt disease is a highly specialized vector-borne plant disease. It is caused by the pinewood nematode [*Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle] and transmitted by cerambycid beetles.

The pinewood nematode was first recognized as a pathogen in Japan (Kiyohara and Tokushige 1971), where it is a devastating pest of native pine forests. Although first identified in Japan in 1971, it may have been introduced there from North America as early as the turn of the century (Mamiya 1987). It is currently the most serious disease of native pines in Japan, causing extensive mortality in Japanese red pine (*Pinus densiflora* Sieb. et Zucc.) and Japanese black pine (*P. thunbergii* Parl.) (Mamiya 1984). In addition, the nematode has recently been discovered causing disease and mortality in pines in Korea (Choi et al. 1992), Taiwan (Chang and Lu 1996), and Portugal (Mota et al. 1999).

For many years in Japan after the disease was first recognized, abnormally high populations of pine bark beetles were believed to cause the pine wilt syndrome. But it was eventually established that the pinewood nematode in association with an insect vector, the Japanese pine sawyer [*Monochamus alternatus* (Hope)], is the real cause of the disease (Kiyohara and Tokushige 1971). Although the Japanese pine sawyer is native to Japan, it has been suggested that the nematode found in Japan originated in North America, probably from the United States (Wingfield et al. 1984), which is a scenario that has been supported by studies of the genetic relationships of the nematode populations (Abad et al. 1991, Beckenbach et al. 1992, de Guiran and Bruguier 1989, Harmey and Harmey 1993, Iwahori et al. 1998, Riga et al. 1992). Thus, pine wilt disease is an example of an introduced pathogen adapting to, and being transported by, a native vector.

The first reported occurrence of the nematode that causes pine wilt disease in North America was in 1979, when the nematode was recovered from a dead Austrian pine (*P. nigra* L.) growing in Missouri (Dropkin and Foudin 1979). Virtually all subsequent reports of the disease in the United States have been on exotic pine species. The pinewood nematode is inconspicuous as a pathogen on pines endemic to North America.

**Range and Importance of Hosts**—The pinewood nematode is found throughout North America and in portions of Japan, the People's Republic of China, Taiwan, and Korea (Chang and Lu 1996, Rutherford et al. 1990, Yang and Wang 1989, Yi et al. 1989). It has recently been identified in Portugal, which is the first report of *B. xylophilus* in Europe (Mota et al. 1999).

The nematode is probably indigenous to North America, where it causes significant disease only in introduced pines, especially Scotch pine (*Pinus sylvestris* L.) and Austrian pine (*P. nigra* Arnold). Even in these species, disease occurs only where the mean temperature exceeds 20 °C in July (Rutherford and Webster 1987). The nematode has been reported in 40 States in the United States, 7 Canadian Provinces (Tainter and Baker 1996), and in northeastern Mexico (Dwinell 1993).

The two pine species that predominate throughout the islands of Japan are both extremely susceptible to the wilt caused by the pinewood nematode. Japanese red pine is Japan's most important timber species, and Japanese black pine is important throughout the region as an ornamental and shade tree. Luchu pine (*P. luchuensis* Mayr) on Okinawa and Masson pine (*P. massoniana* Lamb.) in China are also susceptible.

Although the nematode is widespread in North America, development of pine wilt disease has been demonstrated only in exotic or stressed trees. Survival and establishment of nematodes in feeding wounds on native conifers is apparently limited. However, the nematodes are almost ubiquitous in dying or recently dead pines and other conifers.

**Disease Organism**—The pinewood nematode is a member of the family Aphelenchoididae. The microscopic

nematode is about 800 : m long and 22 : m in diameter. Each female lays about 80 eggs, which, after hatching, pass through four stages of larval development before reaching adulthood. Depending on temperature, the pinewood nematode can develop rapidly, completing its life cycle in 12 days at 60 °F or in just 4 days at 80 °F (Mamiya 1975).

A closely related nematode, *Bursaphelenchus mucronatus*, is generally considered to be a potentially pathogenic organism with low virulence. Under experimental conditions, some symptoms in pine can be obtained (Riga et al. 1991), but they are rarely observed in nature. *B. mucronatus* has been reported from Europe, the former Soviet Union, Japan, Korea and China (Choi et al. 1992, Rutherford et al. 1990).

**Life Cycle and Biology**—The nematode has two distinct means of dispersal, known either as “primary” and “secondary,” or “transmission by feeding” and “transmission by oviposition” (Fielding and Evans 1996). In either case, the nematode larvae survive and reproduce within dead or dying trees, molting through four larval stages. In the late stages of infection, after tree death, nematode development switches to a dispersive stage. Third-stage larvae migrate to the pupal chambers of insect vectors, if they are present in the dead or dying trees, and molt to become fourth-stage larvae. These fourth-stage larvae, also called JIV or dauerlarvae, are especially adapted to survive in the respiratory systems of certain cerambycid beetles.

They enter the bodies of new adult beetles just before the beetles emerge from the bark and are introduced into feeding wounds created by the beetles as they feed on the branches of healthy pines (transmission by feeding) or are introduced into dead or dying trees by the cerambycids during egg laying (transmission by oviposition). Once inside the tree, the dauerlarvae undergo a final molt to adult nematodes, which can then reproduce. In the plant, the nematodes migrate to the resin canals, feeding on and killing the epithelial cells. Once the tree dies, the nematodes thrive on the blue stain and other fungi that typically develop in beetle-infested pines.

In Japanese forests, the native beetle *Monochamus alternatus* transmits the nematodes to healthy hosts during host feeding (Mamiya and Enda 1972). Within 10 days of inoculation of pines with the nematodes, the destruction of resin cells leads to a cessation of resin flow (Kiyohara and Tokushige 1971). After 30 days, foliage transpiration ceases and is followed by the sudden wilting and loss of foliage color. As trees die, they become attractive to adult beetle females searching for stressed and dying hosts in which to lay their eggs. Nematodes are apparently transmitted very efficiently during oviposition and fully colonize trees or logs. Beetle eggs hatch in late summer, and the first two instars of the insect feed under the bark before the third penetrates to the wood. Larvae molt into a fourth instar that overwinters. The following spring, the beetle larvae excavate small chambers in which they pupate. The emerging beetles carry an average of 15,000 to 20,000 dauerlarvae. The next spring another brood of beetles emerges carrying thousands of nematodes, and the cycle is repeated.

**Disease Spread**—*Monochamus alternatus* is the principal vector of the nematode in Japan. Spread of the disease has been estimated at about 20 miles per year solely because of beetle movement. However, the movement of infected logs by man has apparently increased the extent of the epidemic. In North America, at least four species of cerambycid beetles are capable of acting as vectors for the nematode, but the number of nematodes reported per beetle is lower than in Japan (Linit 1987).

**Economic and Ecological Impact**—In Japan, the first record of symptoms similar to those induced by the pinewood nematode probably dates from 1905 in Nagasaki, Kyushu (Yano 1913). Although the cause of death could not be determined, the affected trees were cut and burned. The disease spread throughout the pine-growing areas of Japan, causing annual losses approaching 200,000 m<sup>3</sup> by the 1940's (Mamiya 1983). Efforts to control the epidemic by cutting and burning were begun in many areas but were abandoned during the Second World War. In 1948 alone, 1,230,000 m<sup>3</sup> of pine were lost to the disease. Periodic attempts at control by felling and burning resulted in subsequent annual losses varying from about 500,000 m<sup>3</sup> to a high of 2.4 million m<sup>3</sup> in 1979 (Mamiya 1983). Intensive efforts to manage pine wilt disease in Japan by sanitation and quarantine have helped to reduce the extent of the losses, but pine wilt disease continues to be one of the most important forest tree diseases in Japan.

*Bursaphelenchus xylophilus* was implicated in the death of 600,000 pines in China between 1983 and 1988 (Yang and Wang 1989). Originally found in the Nanjing province, *B. xylophilus* is currently causing mortality in pines in at least five provinces in China (Baojun and Qouli 1989) and is considered to be one of the most important tree diseases in that country (X.F. Zhu 1999, personal communication).

China has initiated measures to control the spread of the pinewood nematode, including strict quarantines, cutting and burning trees, and extensive use of insecticides, in an effort to eradicate the organism from all affected areas (Yang and Wang 1989). Although spread of the disease in China has been limited, long-term prospects for eradicating pine wilt in China appear to be low.

The recent discovery of *Bursaphelenchus xylophilus* in Europe (Mota et al. 1999) suggests that increased costs for surveys will be incurred throughout Europe, and control costs will quickly escalate in Portugal, where the organism has already been identified.

The ecological impact of pine wilt disease can only be surmised here. The loss of one-quarter of the Japanese pine forests is comparable in scale to the loss in the United States of the American chestnut as the result of chestnut blight. Loss of tree cover can lead to soil erosion and possibly flooding—particularly on steeper slopes.

**Management**—Current control measures in Japan consist of restricting movement of infected material, aerial and ground sprays of insecticide to control the beetle vectors, felling and burning diseased trees to eliminate breeding habitat of the nematode and insect vector, the use of injectable nematicides, and breeding pines resistant to the disease (Ichinohe 1988). Although destroying infested trees is preferable from an environmental viewpoint, a wider area can be treated by insecticides. However, these techniques are only moderately effective and are practical only in relatively limited areas. Costs of sanitation felling and burning are unavailable. In 1981 alone, \$30 million (. \$49 million in 1998 dollars) was spent on insecticide aerial applications.

### Smaller Japanese Cedar Longhorned Beetle

**History of Introduction**—The smaller Japanese cedar longhorned beetle [*Callidiellum rufipenne* (Motschulsky)] was first reported in cargo shipments at Vancouver, BC, in Canada in 1927 and then in Seattle, WA, in 1954 (Hoebeker 1999). It was frequently intercepted with cargo entering ports in the United States from 1973 to 1983, often in *Cryptomeria* dunnage and casewood (USDA APHIS, unpublished report, 3 March 1998). In 1982, a risk assessment indicated that this insect was secondary (feeding only on dead or dying material), and it was dropped from the list of quarantine-significant pest species subject to regulatory action by APHIS (Wallenmaier 1982) until its status was reevaluated in 1998.

In May 1997, a homeowner in Manteo, NC, found two beetles in a dead tree on her property; however, no more beetles were found during followup inspection of nearby eastern red-cedar trees (E. Suggs 1998, unpublished information). Then, a startling discovery occurred in October 1998. A landscape worker at Precision Metal Products Co. in Milford, CT, brought a branch containing beetles from a live arborvitae (*Thuja occidentalis* L.) to the Connecticut Agricultural Experiment Station in New Haven and requested identification of the beetles. Specimens passed on to APHIS on September 29 were identified as *Callidiellum* on October 4 and confirmed as *C. rufipenne* on October 15 (USDA APHIS, unpublished reports, 7 Oct. 1998; 18 Nov. 1998). Investigations revealed that this tree may have been part of an earlier shipment of 275 plants imported from a nursery in British Columbia. Of the 275 plants imported into Connecticut, 184 have been accounted for, and 47 of those were found to be infested (USDA APHIS, unpublished report, 7 Oct. 1998). Extensive examination of suppliers' remaining stock and *Thuja* in several nurseries in British Columbia turned up no beetles (Bell and Gill, unpublished report). All infested live arborvitae thus far have been found only in Connecticut (USDA APHIS, unpublished report, 18 Nov. 1998). Trees likely became infested after arrival in Connecticut, perhaps from populations of *Callidiellum rufipenne* established through introduction of beetles traveling with SWPM.

APHIS responded within days to the new development in Connecticut by declaring *Callidiellum rufipenne* a quarantine-significant pest (Cavey 1998, unpublished information). Infested trees were destroyed, and measures were initiated to prevent further spread. *Callidiellum rufipenne* is likely to encounter many suitable hosts in Connecticut because arborvitae are abundant in New England, and eastern red-cedar is a common tree in forests and roadside plantings.

In 1999, *Callidiellum rufipenne* was determined to be established in at least 10 towns in 3 counties in Connecticut based primarily upon trap-log surveys (C. Maier 1999, unpublished data). The distribution of *Callidiellum rufipenne* in the United States has not been fully determined yet, but survey efforts are continuing. *Callidiellum rufipenne* was also detected in 1999 infesting cedar plant stakes at two locations in New York. Field surveys were initiated in additional locations in 2000 to assess the distribution of this insect further. By spring 2000, the known

distribution of *C. rufipenne* included four counties in Connecticut, one county in Massachusetts, five counties in New Jersey, four counties in New York, one county in North Carolina, and one county in Rhode Island (C. Maier, M. Negrón, 2000, personal communications).

**Range and Importance of Host**—This longhorned beetle (after the findings in Connecticut in 1998) is now known to feed on species in at least nine genera of conifers. Native hosts in the Orient include species of *Chamaecyparis*, *Cryptomeria*, and *Thujopsis*. Hosts attacked in Asia, Europe (where it was introduced in Italy in 1988 [Campadelli and Sama 1989]), and the United States include *Abies*, *Taxodium*, *Cupressus*, *Juniperus*, *Pinus*, and most recently *Thuja*. By January 1999, *C. rufipenne* had been detected in five Connecticut nurseries affecting *Thuja occidentalis* L. varieties Emerald Green, Brandon, and Nigra; *Juniperus virginiana* L. variety Skyrocket; and *Chamaecyparis nootkatensis* (D. Don) Spach variety Pendula (Bell and Gill, unpublished report). Trap logs of *Juniperus virginiana* were found to be twice as attractive to *C. rufipenne* as was *Thuja occidentalis* (C. Maier 1999, unpublished data). A pest not listed as important from its native lands in the Orient surprisingly will feed on live, healthy trees in the United States. Because this find in North America is so recent and because we have so many tree species that the beetle has not as yet been exposed to, we know little of the potential damage and new tree species that may become infested. Four of the five genera of cypress and cedar in the family Cupressaceae present in the United States have already been identified as hosts for *C. rufipenne*. Although we do not have *Cryptomeria* spp. in our native forests, we do have other redwoods in the family Taxodiaceae, such as *Sequoia*, *Sequoiadendron*, and *Taxodium*, which are limited in distribution. Although *C. rufipenne* has not been considered a major colonizer of pines, the great number of pine species present in the United States (40) (Harlow 1978) may present more opportunity for utilization of pine hosts.

**Life Cycle and Biology**—The smaller Japanese cedar longhorned beetle, typical of cerambycids, causes its damage in the larval stage of its development by feeding first in the phloem and in later instars entering the xylem or wood (USDA APHIS, unpublished report, 3 March 1998). Larvae show resistance to injury, drowning, and frost. Beetles overwinter as adults. In the spring (early April in Japan) adults emerge from dead trees and mate on the surface of the trunk of weakened or dead trees; then, the female lays eggs in bark crevices. Adults were captured in trap logs between April 6 and June 2 in 1999 in Connecticut (C. Maier 1999, unpublished data). Unlike the Asian longhorned beetle, they do not require maturation feeding prior to egg laying (Shibata 1998, unpublished information).

**Insect Spread**—Although interception records on this insect were not kept between 1982 and 1998 in the United States when it was dropped from quarantine-significant and reportable status, this beetle has been one of the most frequently intercepted species entering with SWPM. Its ability to move with commerce is demonstrated by its introduction into Italy and Spain. On the basis of the recent find of *C. rufipenne* in arborvitae nursery stock in Milford, CT, it has become apparent that this species might also be transported via balled and burlapped trees. Other means of local spread of the beetle may be with movement of infested material such as freshly felled trees, green logs, green firewood, or pruned branches.

**Economic and Ecological Impact**—Because this insect has not previously been considered a pest of live healthy trees, little is known of its potential for damage. In the Northeastern United States, the demand for nursery planting stock is great, and the nursery industry is heavily dependent on conifers as a sale item. Arborvitae has become a significant replacement tree species for eastern hemlock, which has declined owing to introduction of the exotic hemlock woolly adelgid (*Adelges tsugae* Annand). Juniper is common in Connecticut fields as well as highway plantings.

**Management**—Increased surveys and vigilance are needed to keep this beetle from becoming a widespread invasive species in the United States. Strategies for managing the pest need to be developed. Because host condition may influence host selection, and the beetle is known to reproduce well in dead and dying trees, prompt removal of such material will aid in control. Recognizing this preference is an important factor in preventing attack. Trap logs may be useful if put out in March–April because this beetle is an early flier, much like the pine shoot beetle. Several insecticides may be effective against adult beetles; however, effectiveness against larvae may be limited owing to difficulty in reaching established larvae deep within wood or logs.

Natural enemies exist, and at least two wasp species reduce damage of this pest in Japan, that is, a braconid and an ichneumonid (Shibata 1994). It is unknown whether any natural control organisms occurring in the United States would attack *C. rufipenne*.