# Gallery of Pests

The dangers of exotic forest pests were evident by the latter 1800s, as gypsy moth quickly became a problem after its release in 1869 (cf. Howard, 1898). Over the years, hundreds of insects and a number of fungi have been introduced to North America (Mattson *et al*., 1994; Liebhold *et al*., 1995), but only a portion of these exotic species cause dramatic damage to forests or threaten specific species. Most exotic forest pests have relatively low profiles but are nevertheless damaging our natural resources. Below are short summaries for: 1) some of the most serious established exotic pests in North American forests, 2) newly discovered pests in North America, and 3) pests that could potentially pose problems if introduced and established.

## Established Exotic Pests

### Chestnut Blight
### *Phytophthora cinnamomi*
### Chestnut Gall Wasp

Chestnut Blight - Chestnut blight on American chestnut sprouts. Photograph courtesy of Gene Johnston, Tennessee Agricultural Experiment Station, The University of Tennessee.

The American chestnut and related Allegheny and Ozark chinkapins were once important components of upland forests in eastern North America. American chestnut was the stalwart of eastern forests, with estimates accounting for one-quarter of all the standing timber (USDA Forest Service, 1991), and provided Native Americans and European colonists with wood, tannin, food, and mast for wildlife and domesticated animals. Though dwarfed by American chestnut, chinkapins provided large crops of nuts that were comparatively smaller than chestnuts but were preferred by wild turkeys (Minser *et al*., 1995). Chestnuts and chinkapins have had the misfortune of being attacked in succession by three different exotic pests. Decline of these species probably began approximately 200 years ago with the introduction of the soil-borne algal fungi, *Phytophthora cinnamomi*, which causes brown-black lesions with ink-black exudate girdling the roots and root collar. This pathogen thrives in wet, poorly drained soils. The first recorded observation of this disease was in 1825, when a Mr. Jones of Riceboro, Georgia, observed Allegheny chinkapins dying in great numbers with no apparent reason (*teste* Clinton, 1912). Mr. Jones suspected that extremely wet conditions in the preceding two years had created a disease responsible for the chinkapins' demise. By 1877, the disease had apparently become well established in North Carolina, as State Geologist William C. Kerr reported, "The chestnut was formerly abundant in the Piedmont region, down to the country between the Catawba and Yadkin Rivers, but within the last thirty years they have mostly perished" (Hough, 1877). Throughout the 1800s, the disease gradually decimated chestnut and chinkapin populations on relatively wet sites (Crandall *et al*., 1945). Currently, a troubling development with *P. cinnamomi* is a possible expansion of host range or the realization that the pathogen's host range includes oaks. Robin *et al*. (1994, 1998) reported on oak species in Europe, including the North American red oak, becoming infected with this pathogen. Considering the importance of oak species in eastern forests, the impact of *P. cinnamomi* may not yet have been fully realized.

American chestnuts dying from Phytophthora root rot. Photo Courtesy of Sunshine Brosi, Department of Forestry, University of Kentucky.

Chestnut blight (=chestnut bark disease) was the next exotic challenge to surviving chestnuts and chinkapins on upland or well drained sites. The disease was first reported in 1904, when cankers were observed in New York City (Merkel, 1905), although it was most assuredly widespread in the northeast at that time (Anagnostakis, 2001a). Chestnut blight is caused by an exotic fungus that attacks twigs, branches, and bole, causing cankers that eventually girdle the tree. Metcalf and Collins (1909) believed that the disease was imported on Japanese chestnut nursery stock, and distribution of successive importations was the major factor in the spread of the pathogen. Introduced to North America in the late 1800s on shipments of Asian chestnut nursery stock

(Anagnostakis, 2001a), chestnut blight rapidly decimated upland chestnut and chinkapin populations throughout eastern hardwood forests (National Academy of Sciences, 1975) over the next 60 years. By the 1950s, virtually all chestnut and chinkapins had been reduced to short-lived sprouts from old stumps and disease-ridden shrubs (cf. Burnham *et al.,* 1986).

A considerable amount of research has been conducted on countering the effects of chestnut blight pathogen. Introduction of strains of the fungus containing a fungal virus that causes debilitation of the blight fungus has been attempted (MacDonald and Fulbright, 1991; Anagnostakis, 2001b). Molecular manipulations of this virus (Choi and Nuss, 1992) has made transmission easier, and field experiments are in progress to evaluate effects and transmission (Anagnostakis, 2001a). Breeding resistance into American chestnut from Asian species began at the Connecticut Experiment Station in 1930 and progress continues today (Anagnostakis, 2001a). Breeding for resistance has been conducted by other research programs and private foundations. The American Chestnut Foundation has completed a backcross breeding program involving transferring resistance from Chinese chestnut into American chestnut (*sensu* Burnham *et al.*, 1986) and is planning on field testing progenies by 2006. The American Chestnut Cooperators Foundation is working within the American chestnut gene pool to develop resistance (Griffin, 2000). In breeding programs that utilize Asian germplasm, trees are being selected for both blight and *P. cinnamomi* resistance.

Galls on chestnut induced by the chestnut gall wasp. Photograph courtesy of William M. Ciesla, Forest Health Management International

(http://www.bugwood.org).

Unfortunately, these efforts to reintroduce American chestnut will be hampered by a new pest, the chestnut gall wasp, which was first reported in 1974 (Payne *et al.*, 1975). This pest was illegally imported into the country on smuggled budwood and became established in a chestnut orchard in southern Georgia. Chestnut gall wasps lay eggs in bud and flower tissue; feeding by the larvae results in the tree forming a characteristic gall. Branch die-back can occur, possibly from toxics produced by the larvae, and tree mortality can occur with severe infestations. Although there are biological controls for the chestnut gall wasp, none has been evaluated in North America (Murakami *et al*., 1995; Yara *et al*., 2000). Chinkapins appear to be resistant or immune to chestnut gall wasp and may be a source of resistance for breeding programs.

## European Gypsy Moth

The European gypsy moth has been one of the most destructive exotic forest pests introduced to North America. Gypsy moth larvae feed on the broadest host range of all established North American exotic pests in North America and prefer hardwood trees. Trees respond to defoliation from larval feeding by producing new leaves at the cost of draining energy reserves. Repeated defoliations will eventually cause decline and mortality in some cases. Oak species, particularly trees that are stressed or located on dry ridges, are preferred hosts. Other overstory and understory species important for timber, habitat, and/or mast production are also subject to attack (cf. Gottschalk, 1993). Gypsy moth damage affects timber and recreational industries and can have a significant impact on wildlife populations and the overall ecosystem (Allen and Bowersox, 1989; Corbett and Lynch, 1987; Swank *et al.*, 1981). Defoliation will cause declines in diameter and volume growth (Baker, 1941; Twery, 1987) and the quality of wood can be impacted (Twery, 1990). When populations reach epidemic levels, mortality can be as high as 90 percent (Herrick and Gansner, 1987).

Extensive defoliation in summer by European gypsy moth. Photograph courtesy of USDA Forest Service Archives (http://www.bugwood.org)

First instar (caterpillar) European gypsy moth larvae hatching from egg mass. Photograph courtesy of USDA Forest Service Achieves (http://www.bugwood.org)

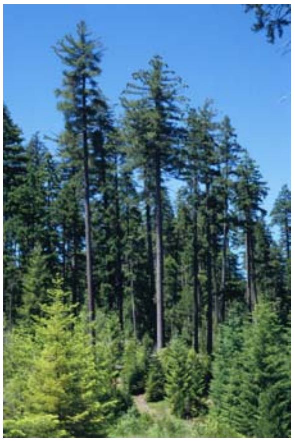
Gypsy moth was deliberately imported in 1869 to the U.S. by Etienne Leopold Trouvelot, an artist who was an amateur entomologist. Trouvelot was interested in identifying native silkworms that could be used for silk production, although his exact motive for importing gypsy moth egg masses is unknown (Liebhold *et al*., 1994). Trouvelot cultured the larvae on trees in his yard, but some larvae escaped. By 1898, gypsy moth (called "gipsy moth" in early publications) was considered to be a serious forest pest (Howard, 1898). Over time, the area of permanent infestation has spread west from the Northeast into Lake states and south into Virginia. Spot infestations are in many states and are treated with an eradication strategy. For a highly successful exotic pest, the spread has been relatively slow as the female gypsy moths do not fly. However, dispersal to uninfested locations has been greatly assisted by transportation of egg masses laid on vehicles, equipment, etc., at infested locations. During epidemic years, the number of acres defoliated can be staggering, e.g., 12.9 million acres nationwide in 1981.

European gypsy moth caterpillars feeding. Photograph courtesy of E. Bradford Walker, Vermont Department of Forests, Parks, and Recreation (http://www.bugwood.org).

Various strategies have been used to combat gypsy moth infestations. These strategies can employ insecticides, pathogens, e.g., *Bacillus thuringiensis* Beliner and *Entomophaga maimaiga* Humber, Shimazu and Soper, a naturally occurring virus, parasitoids, and silvicultural practices. The strategies selected to address a gypsy moth problem will vary with situation and can involve using several tools. States have county-level trapping programs for male moths using pheromone-baited traps to determine presence and population size. In 1991, the USDA Forest Service, in cooperation with APHIS and various states, initiated a pilot program, Slow the Spread, in 1991 that focused on slowing the spread of gypsy moth by using integrated pest management technology in areas that were in transition from uninfested to permanently infested. The pilot program was such a success that it was expanded in 1999 into a nationwide program. Through the efforts of this program and other similar efforts, the inevitable march of gypsy moth through North American forest can be slowed until a better solution is developed.

## White Pine Blister Rust

White pine blister rust is a disease that rivals chestnut blight for impact on North American ecosystems. The pathogen attacks five-needle pine species in both eastern and western forests, causing galls that eventually girdle branches and stems. Gooseberry and currant species serve as alternate hosts. The pathogen thrives in a cool, wet-weather environment, and climate is a major factor in determining rust hazard areas. The rust fungus was introduced in multiple shipments of nursery stock from Europe to Kansas (1892), eastern Canada and New York (1906), and western Canada (1910) (Mielke, 1938; cf. Tainter and Baker, 1996). After introduction, the pathogen quickly spread west and north to eastern white pine populations in the Great Lakes region and Northeast and subsequently southward, to high-elevation eastern white pine populations in North Carolina. In western forests, the disease rapidly spread through western white and sugar pines, as well as impacting whitebark and southwestern white pines (USDA Forest Service, 1991; Hoff and Hagel, 1989). Mortality in western white pine stands can approach 94 percent (Hirt, 1948). More recently, infection of limber pine has been observed (G. I. McDonald personal communication to S. E. Schlarbaum).



Healthy sugarpines, host for white pine blister rust. Photograph courtesy of Richard Sniezko, USDA Forest Service.

Screening for white pine blister rust resistance at the Dorena Tree Improvement Center, USDA Forest Service. Resistant seedlings within different genetic families are obvious. Photograph courtesy of Richard Sniezdo, USDA Forest Service.

Different approaches have been used to address white pine blister rust. In eastern forests, a massive gooseberry/currant eradication program reduced populations of the alternate host for the pathogen. This strategy was particularly effective for intermediate hazard areas (cf. Tainter and Baker, 1996). Exploiting natural resistance, long-term breeding programs were initiated by the USDA Forest Service (Bingham, 1983). Rust-resistant western white, sugar pine and eastern white pine seedlings were developed and are available for planting (Bingham,1983; Garrett, 1986).

Susceptible and resistant sugar pines in a field test planted by the Dorena Tree Improvement Center, SUDA Forest Service. Photograph courtesy of Richard Sniezko, USDA Forest Service.

This a dramatic change from the late 1960s, when planting of western white pines was generally discontinued
(Ketcham *et al.*, 1968). Rust-resistance breeding programs continue today in the United States and Canada (Hunt, 2002; Neuenschwander *et al.*, 1999; Sniezko *et al.*, 2000).

Whitebark pine is not a commercially important species for timber and, therefore, has not received much attention in terms of resistance breeding. This is unfortunate, as Schmidt (1992) estimated that 80 to 90 percent of the whitebark pines in Glacier National Park and the Bob Marshall Wilderness area have blister rust. In British Columbia, a sampling of 54 stands revealed 21 percent of the trees were dead and as high as 44 percent of the remaining trees had blister rust (Campbell and Antos, 2000). Other whitebark pine populations have similar mortality and infection percentages. Whitebark pine occupies a critical niche in western ecosystems by producing large seeds that are extremely nutritious and important in food chains of 110 animals. Whitebark pine seeds are especially important components of grizzly bear, black bear, red squirrel, and Clark's nutcracker (Kendall and Arno, 1989; Schmidt, 1992; Reinhart *et al.*, 2001).

### Dutch Elm Disease

The American elm is a large, vase-shaped tree that was a minor timber species used for furniture, cooperage, and construction of boats. Many cities and towns across America once planted American elms along streets to provide shade (Karnosky, 1979). The species was ideal for urban settings in that it was able to withstand soil compaction and drought. In 1930, however, urban American elms began to die from a disease caused by an introduced fungus, *Ophiostoma* (=*Ceratocystis*) *ulmi*. The fungus was introduced on shipments of unpeeled raw veneer logs from Europe and rapidly spread from three infestation centers (cf. Stipes and Campana, 1981). The fungus is vectored by the native elm bark beetle and the exotic smaller European bark beetle. When trees are infected with the fungus, they react by producing tyloses and gums that will eventually block the vascular system and cause demise. It can be passed from tree to tree by root grafts, which are common in urban settings. American elm is the least resistant of North American elm species to Dutch elm disease. Other native elms, e.g., red or slippery elm, have more resistance.

Mortality in roadside planting due to Dutch elm disease. Photograph courtesy of Edward L. Barnard, Florida Department of Agriculture and Consumer Services (http://www.bugwood.org)

The disease has spread to most of the contiguous 48 states with the except of a few southwestern states. The demise of urban trees, however, has given a misleading impression that forest trees are also dead. In United States forests, the disease is still radiating south and westward. American elms over 30 inches in diameter are still common in Tennessee. The disease has evolved in North American conditions, producing a more aggressive strain, *Ophiostoma novo-ulmi*, which was reintroduced to Europe and caused a second epidemic (USDA Forest Service, 1991).

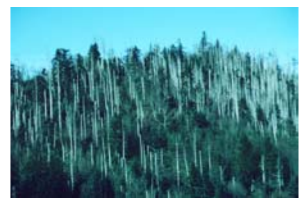
Insecticides and fungicides have been used to protect urban trees with varying success. Breeding resistance into American elm from other elm species has been complicated by the tetraploidy of American elm, in contrast with the diploid of all other elm species. Nevertheless, resistant hybrid triploids have been produced (Sherald *et al.*, 1994). Another approach that has met with good success is crossing among surviving individuals, followed by clonal propagation of resistant progenies (Smalley and Guries, 1993; Townsend, 2000). This work has been led by Adrian M. Townsend of the U. S. National Arboretum and the Elm Research Institute, a private, nonprofit organization, and a number of resistant elm clones have been released.

## Balsam Woolly Adelgid

The balsam woolly adelgid was introduced to New England in 1908 (Kotinsky, 1916) and western states in 1928 (Annand, 1928) on nursery stock from Europe. The pest attacks all North American true fir species, with the possible exception of the divergent bristlecone fir. Abnormal tissue development occurs due to salivary secretions during feeding, which change the balance of growth hormones and inhibitors (Balch *et al.*, 1964). It is believed that a combination of factors associated with salivary secretions kills the tissue (cf. Hay, 1978). The pest can damage and even kill western fir species and balsam firs in eastern forests (cf. Mitchell and Buffam, 2001). The greatest mortality, however, is in the southern Appalachian mountains where it kills mature specimens of Fraser fir. Fraser fir is restricted to mountaintop environments in the southern Appalachian mountains, where the species forms a unique forest type with red spruce.

Mortality in Fraser fir due to balsam woolly adelgid. Photograph courtesy of Rusty Rhea, USDA Forest Service.

The adelgid was first noticed on a northern population of Fraser fir in 1957, and it subsequently spread to all populations. Infested trees usually die within seven years (Johnson, 1980). A study on Mt. Guyot in the Great Smoky Mountains National Park revealed that Fraser fir declined from 80 percent to 2.5 percent of living crown trees in the time period of 1967-1985 (Alsop and Laughlin, 1991). This demise resulted in a dramatic change in forest composition and dynamics on former Fraser sites. With the forest canopy removed, the understory changed from primarily blueberry and fir saplings to dense blackberry, blueberry, and Viburnum populations. Increases occurred in the proportion of red spruce and yellow birch in the forest canopy. The spruce-fir moss spider that inhabits this unique habitat has now been listed as a federally endangered species. Changes in avian species and populations also have been observed in other studies (cf. Rabenold *et al.,* 1998).



Mortality of Fraser fir from balsam woolly adelgid in a red spruce - Fraser fir stand. Photograph courtesy of Rusty Rhea, USDA Forest Service.

Balsam woolly adelgid feeding on Fraser fir. Photograph courtesy of Rusty Rhea, USDA Forest Service.

Mortality is variable among mountaintops, with some mountain populations almost entirely decimated of mature trees. On some mountaintops, less than ten mature trees survived, although many immature trees still persist. However, the reproductive potential of this species could be in jeopardy. Smith and Nicholas (2000) studied Fraser fir size and age class distributions and found lower densities of young firs in stands severely impacted by adelgids. They attributed the lower densities to low numbers of reproducing adults, competition, and other environmental factors.

Control of the adelgids with insecticides has not been successful or practical, particularly in Fraser fir populations residing in the Great Smoky Mountains National Park. Biological controls have been attempted (Schooley *et al.*, 1984; Humble, 1994), but none has demonstrated satisfactory levels of success to date. It is hoped that biological controls that are being studied for the hemlock woolly adelgid (see below) also will be successful with balsam woolly adelgid. A planting of genotypes from different mountaintops was established in the Great Smoky Mountains National Park during the early 1990s to conserve the genetic resources of this fir species.

## Butternut Canker

Butternut (= white walnut or oilnut) is a highly valued eastern hardwood species. The wood is prized for veneer, for lumber for cabinets, and especially for carving. Butternut also is an important mast species and can produce copious amount of nuts for a variety of wildlife species. The nut is very palatable for human consumption, and there are a number of cultivars that have been selected for nut production (Millikan and Stefan, 1989).

Presently, butternut populations are being decimated by an exotic fungal disease that causes multiple branch and bole cankers. The host tree is killed when multiple bole cankers join and girdle the tree. Although the disease was first discovered in 1967 in southwestern Wisconsin (Renlund, 1971), coring of infected trees in the southern portion of butternut's range suggest that the disease was introduced in the Southeast around 70 years ago (Anderson and LaMadeleine, 1978; Schlarbaum, unpublished). Over 80 percent of the butternut trees in the South are now dead.

Butternut canker has spread throughout much of the species' range, reaching Canada in 1990. Unlike American chestnuts and chinkapins, butternut will not sprout from the root crown when the top is killed by cankers. Seedlings and young sprouts are killed by the disease, in addition to mature trees (Prey and Kuntz, 1982). Therefore, when butternut canker disease destroys a population, that particular gene pool is lost forever, as there is no possibility for reproduction. The rapid demise of the species has caused the U. S. Fish and Wildlife Service to declare the butternut "a species of concern."

Butternut resistance test; insert shows cankers on saplings. Photograph Courtesy of Carol Young. Resistance Screening Center, USDA Forest Service

Despite the severe mortality from butternut canker disease, there is reasonable hope for returning butternut to eastern landscapes. Two groups of scientists and field experts from various organizations centered at the USDA Forest Service, North Central Experiment Station in St. Paul and at the University of Tennessee, have been working for a number of years on detection of resistance and genetic resource conservation (Ostry *et al.*, 1994, 1996; Schlarbaum *et al.*, 1997; van Manen *et al.,* 2002). Plantings to conserve the genetic diversity in surviving butternut populations have been established at various locations throughout the eastern states. Trees with putative resistance and immunity have been selected and are presently being evaluated for inclusion in breeding programs.

## Larch Casebearer

Larch casebearer is a moth species that feeds on larch species and was probably introduced in Massachusetts on nursery stock from Europe in 1886 (Tunnock and Ryan, 1983; Otvos and Quedau, 1984). The pest spread throughout the range of eastern larch (tamarack), reaching the Great Lakes region in the 1950s and southeastern Manitoba by 1970 (Otvos and Quednau, 1984). Almost 70 years later, the pest was introduced to western forests as an infestation was found on western larch in Idaho in 1957. In western forests, the insect spread rapidly and was soon considered to be the species' most serious pest (Denton, 1979). The insect feeds the internal tissue of needles, causing defoliation . Repeated defoliations can kill the host tree or stunt it by reducing potential growth by as much as 97 percent (Tunnock *et al.*, 1969). The casebearer favors younger trees growing in the open or along forest edges (Tunnock and Ryan, 1983).

Damage from larch casebearer larval feeding. Photograph courtesy of Jerald E. Dewey, USDA Forest Service (http://www.bugwood.org)

Larch casebearer adult. Photograph courtesy of Scott Tunnock, USDA Forest Service (http://www.bugwood.org)

Control of this pest has relied upon environmental factors and parasitoids, both natural and introduced. Prolonged cold, wet Springs with frosts will cause mortality. There is an abundance of natural predators/parasitoids, but they are not efficient enough to stop outbreaks. Fortunately, a combination of natural predators/parasitoids and introduced parasites has been successful in eastern and central Canada and the northwestern U.S. (Otvos and Quednau, 1984; Graham, 1949; Ryan *et al.,* 1987). Two introduced European parasites, *Agathis pumila* and *Chrysocharis laricinellae*, have been able to aid in keeping the pest under control in western forests where it causes the most serious damage (Tunnock and Ryan, 1995; Ryan, 1997).

## Dogwood Anthracnose Disease

Flowering and Pacific dogwoods are important components of the forest understory, as well as being valued by the American public for their natural beauty when flowering. Dogwood fruits are a valuable food source for migratory birds and mammals, and the twigs are browsed by a variety of animals (Mitchell *et al.*, 1988; Rossell *et al.*, 2001). In addition, the species provides habitat for nesting birds, and fallen leaves provide a significant amount of calcium to forest soils (Hepting, 1971).

Leaf blotch symptoms of dogwood anthracnose disease. Photograph courtesy of Robert L. Anderson, USDA Forest Service (http://www.bugwood.org)

Both dogwood species are in the process of being extirpated from North American forests by a relatively new exotic fungal disease. Dogwood anthracnose disease is migrating through eastern and western forests and killing entire dogwood populations (Britton, 1993; USDA Forest Service, 1999). The disease was discovered almost simultaneously in Washington (1976) and New York (1978) (cf. Daughtey and Hibben, 1994). The fungus is particularly virulent in cool, moist conditions, and dogwood populations proximal to water are at the greatest risk. Trees are killed by annual cankers that girdle the bole. Areas subjected to acid rain may predispose dogwoods to attack and increase the severity of the disease (Anderson *et al.*, 1993). In flowering dogwood, there are surviving trees in populations that have decimated, and natural resistance has been detected (Windham *et al.*, 1998). To date, there have been no reports of putative resistant Pacific dogwoods.

Mortality in understory dogwoods from dogwood anthracnose disease. Photograph courtesy of Robert L. Anderson, USDA Forest Service (http://www.bugwood.org)

## Port-Orford-Cedar Root Disease

Port-Orford-cedar is a valuable forest tree that has a limited distribution along the Pacific coast from southern Oregon to northern California. The species has a highly aromatic wood and is widely used as a landscape plant. Unfortunately, Port-Orford-cedar populations have been decimated by a root disease caused by the exotic algal fungus *Phytophthora lateralis*. The disease was first reported in 1923 near a Seattle nursery (Hunt in Zobel *et al.*, 1985), which is outside Port-Orford-cedar's natural range. In 1938, the disease was again discovered in Oregon's Willamette Valley, where it virtually halted nursery production of ornamental *Chamaecyparis*. The disease was discovered in the naturally occurring Port-Orford-cedars in 1952 and has since spread throughout the host's range. How *Phytophthora lateralis* entered the country or even the exact country of origin are uncertain. Partial resistance in Asian *Chamaecyparis* species suggests an eastern Asian origin (Roth *et al.*, 1987).

The fungus invades fine roots and subsequently colonizes the entire root system. Multiple root infections will spread to the root collar, and the tree will die from girdling. Aerial infections of branches that come into contact with infected litter or soil can occur during wet weather. The infection will eventually migrate to the bole, and girdling will occur. Pathogen spores are spread by surface water or rain splash, usually in the wet Spring. It can be transferred in spore-contaminated soil by machinery and animals but does not occur independently in soil (Ostrofsky *et al.*, 1977). The pathogen will attack seedlings as well as mature trees. Seedling mortality can occur within a few days, while mature trees may take two to four years to die. The disease also can be spread by movement of infected Port-Orford-cedar nursery stock, including other *Chamaecyparis* species. Zobel *et al.* (1985) believe that the disease "probably never would have emerged in epidemic form without the widespread planting of ornamental Chamaecyparis in northwestern Oregon and Washington."

Resistant tree to Port-Orford-Cedar root disease next to dead, susceptible trees. Photograph courtesy of Chuck Frank, USDA Forest Service.

The USDA Forest Service at the Dorena Tree Improvement Center, in conjunction with the USDI Bureau of Land Management and Oregon State University, have been working many years on detection of resistance to this disease. Over 9,000 trees has been screened for resistance, and controlled pollinations are now being made to develop resistant genotypes and to understand the mechanisms of resistance. Meanwhile, surviving trees and stands are being protected by management practices, including restriction of movement of people and machinery during wet periods where spores are abundant.

## Hemlock Woolly Adelgid

The Asian hemlock woolly adelgid was first reported in the 1920s, where it was attacking western hemlock in the Pacific Northwest (Annand, 1924). A separate introduction established the pest in Virginia, from where it spread to attack eastern and Carolina hemlocks (USDI NPS EIS, 2000). The insect feeds on the contents of parenchyma cells that comprise the xylem rays, and a toxin may be involved in causing the needles to prematurely drop (Young *et al*., 1995).

Eastern and Carolina hemlock populations can die from severe infestations. Extensive decline and mortality has occurred in Virginia, Pennsylvania, New Jersey, and Connecticut within ten years of the first detection (Orwig and Foster, 1998). At Shenandoah National Park in Virginia, where HWA has been present since 1988, only 8.4 percent of hemlocks sampled still have 90 to 100 percent of foliage intact; very few stands are entirely free of adelgid. Hemlock populations in Connecticut were infested in 1985, and mortality ranged up to 95 percent in the sample stands studied (Orwig and Foster, 1998).

Hemlocks play an important ecological role in riparian communities by creating distinctive microclimates, which are important habitats for a variety of wildlife. In northern New Jersey, 96 bird and 47 mammal species are associated with hemlock forests (USDI NPS EIS, 2000). Amphibians, particularly salamanders, also depend on the unique habitat under a hemlock canopy (Brooks, 2001). Hemlock glades and the streams in them are especially important habitats for smaller organisms. These forests shelter more than 14 species of amphibians, more than 12 species of small mammals, at least 152 species of terrestrial invertebrates. Hemlock-lined streams also keep water temperatures cool enough for brook trout.

Mortality in eastern hemlock due to hemlock woolly adelgid. Photograph courtesy of Rusty Rhea, USDA Forest Service.

According to the National Park Service (USDI NPS EIS, 2000) decline of hemlock in the Delaware Water Gap NRA is likely to have “massive adverse effects on the ecological, aesthetic, and recreational values of the park.” Affected streams would be warmer, have lower water flows, and be more likely to dry up during summer droughts. Overall species diversity in hemlock-dominated habitats would probably decline by 35 percent or more. Decaying and downed trees would increased debris flow, interfere with water flow, and cause channel scouring that would raise the chance of extreme flood damage. Nurtient cycling would also be disturbed (Jenkins *et al.*, 1999).

Infestation of hemlock woolly adelgid. Photograph courtesy of Robert L. Anderson, USDA Forest Service.

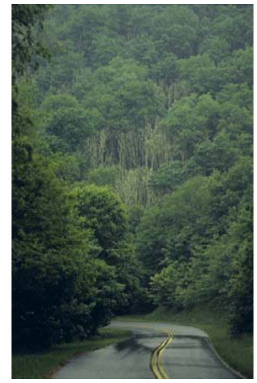
Spraying of insecticides to control hemlock woolly adelgid will not be effective in many cases, possibly because of the riparian habitat. In the last decade there has been a significant amount of research conducted on biological control of the adelgid through introductions of predators from Asia and natural predators (McClure, 1995; Wallace and Hain, 2000; Lu and Montgomery, 2001; Zilahi-Balogh *et al*., 2002). However, the greatest challenge may be to reintroduce hemlock into former sites. Little is known about hemlock genetics and diversity, and there are no seed orchards of eastern or Carolina hemlocks to provide seed, unlike many other forest species that are utilized for timber. Reintroduction efforts will be forced to use non-local seed with no information on the effects of seed movement on growth and survival. In addition, virtually nothing is known about post-planting requirements of hemlock seedlings. While the present work is encouraging, a complete solution to this exotic pest problem appears to still be distant.

## Beech Bark Disease

American beech is a common component of eastern North America. The species is utilized for lumber and pulp, and it periodically produces hard mast (beech nuts) for wildlife. Beech was not commercially utilized until the 1950s when drying problems were solved (cf. Tainter and Baker, 1996). By that time, an exotic insect-disease complex had become established in northeastern beech populations that was causing extensive mortality. Beech bark disease is due to the activities of the exotic beech scale and an associated exotic fungus, *Nectria coccinea* var. *faginata* (cf. Mahony *et al.*, 1999). Beech scale was imported in the late 1800s into Halifax, Nova Scotia, probably on nursery stock of European beech (Hawbolt, 1944). However, it

Beech Bark disease in Great Smokey Mountains National Park. Photograph courtesy of Glenn Taylor, Nation Park Service.

was not until around 1920 that an outbreak of beech bark disease was recorded. The disease spread rapidly and was commonplace in Nova Scotia by 1930. In the United States, the first report of beech bark disease was in Massachusetts in 1929. By the early 1970s, the disease had spread throughout New England and into eastern Pennsylvania. The scale and associated fungus are easily transported over long distances by animals and humans, which has resulted in isolated outbreaks and establishments in West Virginia (1981), Virginia (1983), and more recently, in the Great Smoky Mountains National Park (Tennessee) far ahead of the advancing front in Pennsylvania. The scale penetrates the bark during feeding, letting the associated fungi enter the tree. The tree is girdled from the resulting multiple cankers (Houston and Valentine, 1988).


Beech Bark disease in Great Smokey Mountains National Park. Photograph courtesy of Glenn Taylor, Nation Park Service.

There is no practical chemical control of the beech scale in natural forests. The scale has several natural predators, but none has been sufficiently effective to stop the spread of beech bark disease. Resistance to beech scale attacks has been discovered in some beech trees (Shigo, 1964; Cammermeyer, 1993; Houston and Houston, 2000) and can be integrated into breeding programs to produce beech bark disease-resistant trees for restoration of the species.

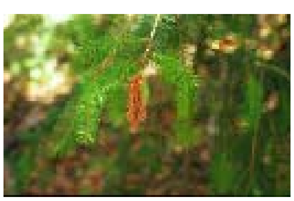
## New Exotic Forest Pests in North America

Established populations of new exotic forest pests are now being discovered all too frequently. In the Introduction, we describe various pests that have become established in recent years, around the last 15 years. While each of these pests poses serious challenges to North America's natural resources, widespread publicity in the popular press did not occur until Asian longhorned beetle was discovered in two of the largest cities in the country, New York and Chicago. As a result, we feel that the general public and natural resource professionals became more cognizant of the increased possibilities of additional exotic pests emerging as problems. We have already mentioned the Asian longhorned beetle and Sudden Oak Death pathogen. However, the announcement of Sudden Oak Death disease attacking redwood and Douglas-fir prompted us to include details about this serious exotic pest.

Below are four additional examples of pests that have been recently discovered. Two pests, the brown longhorned spruce beetle and the red-haired pine bark beetle, are estimated to have been in North America for over ten years, while the newly discovered emerald ash borer has been resident for approximately five years. We feel the detection of the citrus longhorned beetle and rapid response to eradicate the pest before it becomes established represent a good example of how an exotic pest should be addressed.

**Sudden Oak Death disease**

After the printed version of Fading Forests II went to press, in September 2002, Drs. Dave Rizzo and Mateo Garebelotto of the University of California announced that redwood and Douglas-fir are susceptible to the pathogen that causes Sudden Oak Death, *Phytophthora ramorum*. Infected redwood saplings have been found at several sites, while infected Douglas-fir saplings have been found at only one site to date. Both field studies and laboratory tests indicate that Douglas-fir might be more susceptible (California Oak Mortality Task Force News Release, September 4, 2002. UC RESEARCHERS CONFIRM COAST REDWOOD AND DOUGLAS FIR AS HOSTS FOR SUDDEN OAK DEATH PATHOGEN).


Sudden Oak Death on Douglas fir foliage. Photograph Courtesy of Faith Thompson Campbell, American Lands Alliance.


Sudden Oak Death on redwood foliage. Photograph Courtesy of Faith Thompson Campbell, Ph.D., American Lands Alliance.

Movement of living and harvested redwood and Douglas-fir trees from counties with Sudden Oak Death will now be subject to state and federal quarantine rules. The quarantine rules require that infected logs be debarked in the same county where they are felled. Together, redwoods and Douglas-fir account for more than half of the $3 billion generated by

California's timber industry. According to an expert from the California Department of Forestry and Fire Protection, 95 percent of the redwood and 45 percent of the Douglas-fir harvested in California come from counties where Sudden Oak Death disease is present (Peter Fimrite, "California rushes to protect redwoods; Davis seeks Bush aid as tests confirm sudden oak death," San Francisco Chronicle, September 5, 2002). Timber spokespeople
disagree over whether these rules will disrupt commercial lumber production in California. The California Department of Food and Agriculture and USDA APHIS are reported to be reviewing the restrictions on movement of wood (Peter Fimrite, San Francisco Chronicle, September 5, 2002). The impact could be even greater if SOD spreads farther north in Oregon and Washington, where Douglas-fir is even more important as a timber resource.

Tanoak dying of Sudden Oak Death. Photograph Courtesy of Faith Thompson Campbell, American Lands Alliance.

Nursery and Christmas tree growers and those who have sold bark for garden mulch are much more likely to be affected in the immediate future. The regulations require annual inspections of nurseries in the quarantine counties that wish to ship plants belonging to host species. Furthermore, each shipment containing host plant species must also be inspected immediately prior to shipment. If either inspection detects the SOD pathogen, the nursery is barred from shipping host species. The huge trade in cut greens is also regulated. Wreaths, garlands, and greenery may be shipped out of the quarantine area only after being dipped for hour in water that is held at a temperature of at least 160℉.

If contamination were to spread to Christmas tree-producing regions of Oregon or Washington, sales of infected trees could be limited to local clientele. Oregon produces more Christmas trees than any other state; sales were $131 million last year. Oregon also ranks among the largest producers of nursery stock in the nation. Oregon's $696 million nursery industry was reported to be "on high alert" (Michael Rose, "Fir, redwood may house fungus; Sudden Oak Death is linked to Douglas firs, Salem (OR) Statesman Journal, September 5, 2002). Washington State is the fourth-largest producer of Christmas trees nationally (Lisa Stiffler, "New disease infects Doug firs; Spread of 'sudden oak death' along coast alarms researchers", Seattle Post-Intelligencer September 5, 2002). Such restriction would seriously impact these industries.

### Brown Longhorned Spruce Beetle

An infestation of the brown longhorned spruce beetle has been found in and around a Halifax, Nova Scotia park, where it was causing mortality to red and white spruce (Smith and Hurley, 2000). The pest is thought to have been imported around 12 years ago on SWPM through the port of Halifax. The beetle is native to Europe and Asia, ranging from Lapland to Japan. In its native habitat, the pest primarily feeds on dead, felled, or stressed spruce species but will also attack pines, fir, larch, and some hardwood species. Trees are girdled by larvae tunneling under the bark in the cambial layer. Living, non-stressed trees have been successfully attacked in Nova Scotia, suggesting that there may be less resistance in the North American red spruce than European species (Ontario's Forests, 2000). Canadian authorities are presently attempting to eradicate the insect by cutting and chipping up infested trees and proximal trees that could provide habitat. Chemical insecticide applications have not proven to be a successful strategy to combat this pest. North American spruce forests and perhaps other conifer-dominated forests are at risk from this serious pest.

### Red-haired (=Golden-haired) Pine Bark Beetle

Red-haired pine bark beetle adult. Photograph courtesy of Steve Passoa, USDA APHIS PPQ (http://www.bugwood.org)

The red-haired pine bark beetle has been trying to gain a foothold in this country since the early 1990s. The species is native to Mediterranean areas and Africa but has been introduced to South America, Japan, Sri Lanka, Australia, and New Zealand. The species can be imported on SWPM made of pine, *e.g.*, cargo crates (Ciesla, 1993), and infested logs (Sato, 1975) and is occasionally intercepted by APHIS at United States ports. More recently, an infestation of the species was discovered in November 2000 at a Christmas tree plantation in Rochester, New York. Subsequent surveys in 2001 detected two additional infestations in the same county, as well as small infestations in two adjacent counties. Adult beetles can be vectors for pathogenic fungi (Ciesla, 1988; Zhou *et al.*, 2001). Silvicultural controls include removal of tree stumps and slash to limit breeding habitat and delay in planting of seedlings for six to nine months after harvest.

### Emerald Ash Borer

Dead ash tree from girdling by emerald ash borer larval galleries. Photograph courtesy of James W. Smith, USDA APHIS PPQ (http://www.bugwood.org)

Widespread damage by the emerald ash borer has been recently recognized in Michigan and neighboring Ontario. The species was probably introduced in SWPM, as APHIS has intercepted the insect 36 times, primarily on dunnage. Larvae feed in the phloem and outer sapwood, producing galleries that damage and can eventually kill the host. Adults have been observed to feed on host foliage. In North America the borer has been found only on ash species, but the pest feeds on elm and *Juglandaceae* species (walnuts and hickories) in its native, east Asian range (McCullough and Roberts, 2002a and 2002b). The pest is thought to have been established in Michigan for at least five years. Although the infestation is now thought to be confined to Michigan/Ontario, the insect has been intercepted in ten other eastern states. This is particularly ominous, as a phenomenon known as ash decline has been observed in at least 14 eastern states. Ash decline has been ascribed to several or a complex of causes but now warrants careful examination to determine if emerald ash borers are involved. An interagency task force has been formed and is in the process of characterizing tree damage, determining the distribution in the United States, and gathering information on the insect (Millsap, 2002).

Emerald ash borer adult and larval galleries. Photograph courtesy of Dave Roberts, Michigan State University (www.msue.msu.edu/reg_se/roberts).

### Citrus Longhorned Beetle

Although the name of this Asian pest implies attacks on fruit trees, the citrus longhorned beetle attacks and kills a wide range of hardwood species, including maple, oak, willow, and poplar in addition to apple and citrus trees. The species is closely related to the Asian longhorned beetle and attacks living trees. The larvae are very large, around 2 inches in length, and bore numerous tunnels in the bole that sever internal transport and can eventually kill the tree, in addition to making it susceptible to wind breakage. The insect was intercepted in Chinese shipments of bonzai plants to Georgia in 1999. An infestation of citrus longhorned beetles was first discovered in 2001 on quarantined, imported maple trees in a plant nursery in Tukwila, Washington. Examination of the damage raised suspicions that up to five beetles had escaped. Correspondingly, the Washington State Department of Agriculture imposed a quarantine of properties within one-half mile of the point of introduction. As of summer 2002, APHIS and the Washington State Department of Agriculture were cutting and chipping up to 1,000 trees in hopes eradicating this dangerous pest (USDA APHIS, 2002; Washington State Department of Agriculture News Release, June 26, 2992). The risk rating for this beetle is very high, and professionals consider that the impact of this insect could be greater than the more widely known Asian longhorned beetle, if it becomes established.

Citrus longhorned beetle adult. Photograph courtesy of Washington State Department of Agriculture (http://www.wa.gov/agr/CitrusLHBeetle.htm)

### Newly Discovered Beetles in Mississippi and Texas

In summer 2002, exotic forest pests were also discovered to be established in Mississippi and Texas. In Mississippi, an ambrosia beetle *Xylosandrus mutilatus* first detected in 1999 was identified after becoming more numerous in 2002. The beetle appears to be well established in at least 10 counties in eastern Mississippi, although it has not yet been found in Alabama. The economic and ecological damage that this species may cause is still unknown. In its native Asia, it has a broad host range on hardwood trees and shrubs, including some ornamentals. In addition, many ambrosia beetles indirectly impact host trees by vectoring fungal pathogens.

Another exotic tree-feeding insect, *Xyleborus similis*, has been found in Memorial Park, Houston. These traps were placed as part of the joint APHIS-Forest Service Rapid Detection of Exotic Scolytidae project. This beetle is widely distributed in Africa, Asia, Australia, and several Pacific Islands. It has an exceptionally broad host range in these tropical countries.

## Potential Exotic Pest Threats to North American Forests

Two of the most serious pests, Asian gypsy moth and woodwasps with the associated *Amylostereum* pathogen, that are potential threats to North American forests were mentioned in the introduction. Entry by either pest through the different importation pathways could be directly from their respective natural ranges or indirectly from established populations in countries/continents/hemispheres that have been previously invaded (Tribe, 1995; Garner and Slavicek, 1996; Zlotina *et al*., 1999). Asian gypsy moth infestations have been found on a number of occasions on both western and eastern seaboards, but eradications have been successful. To date, woodwasp infestations have not been found. Below are examples of additional pests that have a high potential to become established in North America.

Larvel galleries of the Mediterranean pine engraver beetle. Photograph courtesy of William M. Ciesla, Forest Health Management International (http://www.bugwood.org)

### Mediterranean Pine Engraver Beetle

Mediterranean pine engraver beetles primarily attack pine species but also can occur on Douglas-fir, spruce, fir, and cedar species. Reproduction, however, is limited to infestations in pine species (Mendel and Halperin, 1982). The species infests recently fallen trees, slash, and stressed living trees. As with other bark beetles, one of the major dangers from these engraver beetles is the transmission of pathogenic fungi, including blue stain fungi. This pest is native to Europe, the Middle East, northern Africa, and possibly China and has been introduced with certainty to United Kingdom, Fiji, and Chile. The entry potential to the United States is considered high, as it is the second most commonly intercepted bark beetle. The species is usually intercepted on logs. Biological controls are being used in South Africa to address this pest (Tribe and Kfir, 2001).

### European Oak Bark Beetle

Introduction of European oak bark beetle into North America would probably have the greatest impact on eastern hardwood-dominated forests. In Europe, this bark beetle feeds on branches and secondary shoots of various hardwood species, including oaks, chestnuts, beech, birch, poplars, willows, and elms. The insect targets recently dead, felled, and stressed trees. The beetle has been found to vector a wide variety of fungi, including pathogenic species. Dunnage is the primary vector for the European oak bark beetle, and establishment potential is considered high if introduced (USDA APHIS and Forest Service 2000).

### Nun Moth

The Eurasian nun moth is in the same genus (*Lymantria*) as European and Asian gypsy moth and is similar in host utilization and behavior. The host range is wide, consisting of conifer and hardwood species. Nun moth causes more damage in continental Europe than any other forest defoliator, including gypsy moth. The Siberian risk assessment (USDA Forest Service, 1991) stated that if nun moth would become established, 172 million acres could be affected in the United States. Entry potential is considered to be high, as nun moth females can lay egg masses in crevasses ranging from pallets to ship structures. Extensive research has been conducted on detection and biological control of this potential pest if it is introduced into North America (Morewood *et al.*, 2000; Gries *et al*., 2001; Fuester *et al.,* 2001).


Newly hatch larvae of nun moth on pine bark. Photograph courtesy of William M. Ciesla, Forest Health Management International (http://www.bugwood.org)

## Pine Flat Bug

Pine flat bug is a Palearctic Region pest of coniferous and hardwood trees. The pest is distributed from the United Kingdom to Siberia and feeds on the tissue of seedlings and young trees and can cause serious damage in nurseries, Christmas tree plantations, and seedlings/sprouts naturally regenerated or artificially regenerated (planted seedlings). The likelihood of introduction and subsequent establishment in the United States is high, as the species is easily overlooked, transportable in low temperatures, and unlikely to be dislodged during transport. Infestations of pine flat bug in North America have not been observed to date (USDA APHIS and Forest Service 2000).

## Chilean carpenter worm

The Chilean carpenter worm is endemic to South America and occurs naturally in central to southern Chile and Argentina. The species feeds on various hardwood timber species and fruit trees. In 1992 the pest was observed to attack eucalyptus plantations in Chile. Larvae feed in living trees and bore relatively large holes in the bole, making them susceptible to wind breakage. Adults can fly over considerable distances, and the pest could quickly spread if established. The insect has a long life-cycle, with the larvae taking two or more years to complete development. Transportation of late instar larvae, pupae, and adults to North America in bole galleries within imported logs is considered to be a moderate risk (USDA Forest Service 2001).