Chapter 14.

Understanding and Controlling Nonnative Forest Pests in the South

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Abstract—*Invasive nonnative forest pests are multiplying and spreading in every forest type in the Southern United States. The costs of controlling these pests have become extremely high, and the damage they cause to ecosystem composition, structure, and function continues to increase. Plants imported for potential release for forage, crops, soil reclamation, and ornamental purposes are not evaluated for invasiveness. Insect pests and diseases arrive in infested nursery stock, wood products, pallets, and dunnage, in spite of our regulatory system, which has been overburdened by the rapid increase in international trade. The biological basis for the invasiveness of nonnative pests and possible means for dealing with them are discussed.*

INTRODUCTION

Nonnative insects, pathogens, and plants continue to flow into the United States, as they have for the past 500 years (Committee on the Scientific Basis for Predicting the Invasive Potential of Nonindigenous Plants and Plant Pests in the United States 2002). With global trade comes a mixing of once-separated organisms, often with harmful effects on their new natural systems and substantial costs for mitigation. Invasive nonnative pests pose major challenges. We are challenged to (1) detect and minimize entries, (2) detect critical outbreaks and mobilize rapid responses, (3) monitor existing invasive populations and apply integrated pest management (IPM) programs, and (4) disseminate information about the nature of the problem of invasive pests and possible means of its solution. Executive Order 13112, issued in 1999, established the National Invasive Species Council, comprised of the heads of eight Federal Agencies. This Executive order defined an invasive species as a species that is (1) nonnative (or alien) to the ecosystem under consideration, and (2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. The council finalized in 2001 a "National Management Plan: Meeting the Invasive Species Challenge," which is aimed at coordinating offensive and defensive efforts among the Government Agencies, nongovernmental organizations, and the public. New national initiatives in all elements of an IPM approach to invasive species are planned and specified, with actual regulatory and policy changes anticipated, as appropriations become available. This chapter addresses the biological and social bases for the current predicament, identifies the most damaging invasive pests, gives recommendations for their control, and formulates initiatives required for the defense of our native forests.

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Economic and Ecological Effects

Invasive nonnative pests cost the United States an estimated $137 billion per year (Pimentel and others 2000). This figure does not include the costs of species extinctions. Of the 958 listed threatened and endangered species, 57 percent are at risk primarily because of competition with and predation by invasive nonnatives (Reichard and White 2001). It is difficult or impossible to accurately and objectively determine the cost of species extinctions or of less severe damage to species and habitats. For this reason, natural resource losses are more difficult to estimate than agricultural losses. Forest product industries, although they represent only a small part of total forest value, are easier to evaluate economically. National losses in traditional forest products due to nonnative invasive insects and pathogens were estimated at $4.2 billion per year (Pimentel and others 2000). It has been estimated that 360 nonnative insects have become established in American forests (Liebhold and others 1995).

Data specific to southern forests are scarce, especially for invasive nonnative weeds. Although no comprehensive figures specific to forestry losses due to nonnative weeds are available, the State of Florida has compiled some impressive statistics for invasive nonnative weeds in wetlands. Their control costs for melaleuca (*Melaleuca* spp. L.) alone are $3 to $6 million per year and for purple loosestrife (*Lythrum salicaria* L.) $45 million per year. Florida spends $14.5 million per year to control *Hydrilla* spp. L.C. Rich., and still estimates losses in recreation values for just two lakes at $10 million per year (Pimentel and others 2000).

Since European settlement, nonnative forest pests have changed the composition and function of eastern forests in important ways. For example, as early as 1864, American chestnut [*Castanea dentata* (Marsh.) Borkh.] trees were being eliminated from the Southern Appalachian Mountains, although the cause was not discovered until 1932. Ink disease, caused by the nonnative pathogen *Phytophthora cinnamomi* Rands, virtually eliminated American chestnut in valleys and coves and gradually was extending upslope when chestnut blight [*Cryphonectria parasitica* (Murrill) Barr] arrived and removed the remaining trees, which occupied drier ridges (Crandall and others 1945, Hansen 1999). *P. cinnamomi* continues to impact southern forests, causing littleleaf disease of shortleaf pine (*Pinus echinata* Mill.), root rot on Fraser fir [*Abies fraseri* (Pursh) Poir.] Christmas trees, a decline syndrome in loblolly pine (*P. taeda* L.), and hundreds of other hosts. This same fungus killed 79 percent of the flora in the forests of Western Australia (Weste and Marks 1987) and was recently cited as causing an oak (*Quercus* spp. L.) mortality epicenter in Mexico (Tainter and others 1999).

The oak component in Kentucky, Virginia, and North Carolina is under attack from the advancing front of gypsy moth [*Lymantria dispar* (L.)]. The same forests may soon be threatened by a new species of *Phytophthora* now causing sudden oak death (*Phytophthora ramorum* Werres, de Cock & Man in't Veld) in parts of California. An outbreak of this disease in Oregon is being eradicated, but pathologists are conducting surveys to determine whether other, undetected outbreaks may exist. Beech bark disease (*Neonectria galligena*), dogwood anthracnose (*Discula destructiva* Redlin), and butternut canker (*Sirococcus clavigignenti-juglandacearum*) have reduced host populations as they spread through the understory. Adelgids [*Adelges piceae* (Ratzeburg)] attacking balsam fir [*Abies balsamea* (L.) Mill.] are causing losses of rare and threatened species dependent upon the special habitat associated with the fir (Alsop and Laughlin 1991). Similar losses are anticipated in hemlock forest types (*Tsuga* spp. Carr.) as the hemlock woolly adelgid [*Adelges tsugae* (Annand)] spreads south.

The threats posed by diseases and insect pests have long been recognized by the forestry community. In contrast, invasive nonnative forest plants are more insidious and have received far less attention from foresters. Although weeds cause losses roughly equivalent to those caused by insects and diseases in agricultural systems (Pimentel 1993), the frequent reliance of nonnative plants on disturbance as an entrée to invasion has led to the expectation that such invasions, therefore, are less significant in forests. However, this expectation has proven to be false for two reasons. First, a number of invasive weeds establish successfully without disturbance. Among them are garlic mustard [*Alliaria petiolata* (Bieb.) Cavara & Grande], oriental bittersweet (*Celastrus orbiculatus* Thunb.), and melaleuca. Second, forests are subject to frequent disturbances of various origins. Invasive nonnative plants often proliferate after harvests, fire, windthrow, or hurricanes, which create gaps of disturbed habitat. The increasing occupation of forests by nonnative plants has also been linked to increasing anthropogenic disturbance (Stapanian and others 1998). Such plants inhibit regeneration of native plants and reduce forest

growth and yield. Invasive nonnative weeds can alter ecosystems by changing nutrient cycling, geomorphology and physical structure of the site, drainage patterns and water flow, sedimentation rates, and disturbance regimes. They displace native flora by competition, and thus alter wildlife habitat (D'Antonio 2001, Reichard and White 2001).

Pathways

Many invasive forest plants were intentionally introduced as ornamentals or forage crops (table 14.1), often as a result of Government-sponsored plant introduction programs (Mack and Lonsdale 2001). Some of these plants are still being sold as nursery stock. Herbaceous weeds are more likely to have been introduced as seed contaminants or in soil used as ballast (Reichard and White 2001).

In contrast, most nonnative insects and pathogens were introduced unintentionally as contaminants on nursery stock (U.S. Congress Office of Technology Assessment 1993). The sudden oak death pathogen probably arrived on infected rhododendron (*Rhododendron* spp.) nursery stock. Its origin is unknown. The American strains of this pathogen cause only small leafspots and twig blight on rhododendron and many other hosts, but cause lethal cankers on oaks in coastal regions surrounding the San Francisco Bay (Rizzo and others 2002). Species killed by the pathogen include coast live oak (*Q. agrifolia* Nee), tanoak [*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.], and California black oak (*Q. kelloggii* Newb.). Nursery sanitation practices and fungicide applications can sometimes mask infection, particularly in the case of *Phytophthora* species, and may allow infected material to pass inspection. Sometimes an import host is only slightly susceptible to a disease but may harbor the nonnative pathogen, as infected Chinese chestnut (*Castanea mollissima* Blume) probably harbored chestnut blight. The associated pathogen is unnoticed on the resistant host, but under particularly favorable conditions may sporulate and spread to more susceptible native species. Nurseries with overhead irrigation systems often provide this ideal environment.

Table 14.1—Examples of intentionally introduced invasive nonnative weeds

Common name	Scientific name
Melaleuca	*Melaleuca*
Australian pine	*Pinus nigra* Arnold
Japanese climbing fern	*Lygodium japonicum* (Thunb. Ex Murr.) Sw.
Old World climbing fern	*L. microphyllum* (Car.) R. Br.
Kudzu	*Pueraria montana* (Lour.) Merr.
Mile-a-minute weed	*Ipomoea cairica* (L.) Sweet
Tree-of-heaven	*Ailanthus altissima* (P. Mill.) Swingle
Oriental bittersweet	*Celastrus orbiculata* Thunb.
Silktree or mimosa	*Albizia julibrissin* Durazz.
Chinaberrytree	*Melia azedarach* L.
Winged burning bush	*Euonymus alata* (Thunb.) Sieb.
Bush honeysuckle	*Lonicera* spp. L.
Cogongrass	*Imperata cylindrica* (L.) Beauv.
Chinese silvergrass	*Miscanthus sinensis* Anderss.
Chinese privet	*Ligustrum sinense* Lour.
Tallowtree	*Triadica sebifera* (L.) Small
Chinese wisteria	*Wisteria sinensis* (Sims) DC.
Japanese honeysuckle	*Lonicera japonica* Thunb.

Another common source of nonnative insects and pathogens has been the trade in wood and wood products (U.S. Congress Office of Technology Assessment 1993). In the United States, 35 percent of all softwood consumed is imported, and up to 70 percent of all international cargo arrives supported by solid wood packing material. The recent arrival of the Asian longhorned beetle [*Anoplophora glabripennis* (Motschulsky)] in solid wood packing material has focused attention on this previously loosely regulated pathway. In addition to established populations in New York and Chicago, the beetles have been intercepted in 26 warehouse locations in 12 other States. Solid wood packing material is usually constructed of poor-quality wood, often from trees damaged or killed by pests. Bark remnants increase the likelihood of pest association, and boards with bark attached can be hidden in middle layers of products such as wooden spools. One study found 2,500 live insects in 29 short log bolts used to brace granite blocks in metal containers (Allen 2001).

The particularly invasive nature of many nonnative forest pests first became apparent near the close of the 19th century. Over the past 100 years, plant pathologists, entomologists, and weed scientists have developed a broadly applicable concept of IPM. In this chapter, we will describe a few important nonnative forest pathogens, insect pests, and invasive plants, and will discuss their entry pathways, control strategies, and ecological and environmental impacts. We will apply the lessons learned from these examples to develop recommendations for a more proactive IPM approach to preventing future invasions.

INVASIVE NONNATIVE FOREST PATHOGENS

Nonnative pathogens are presumably more disruptive than native pathogens because they have not coevolved with their new host. Therefore, the host lacks resistance genes, unless some generalized response to attack provides adequate protection against the new pest. Chestnut blight, dogwood anthracnose, and Dutch elm disease [*Ophiostoma ulmi* (Buisman) Nannf.] will be used here to provide examples of such "unnatural" interactions.

Chestnut Blight

In 1904, H.W. Merkel, Chief Forester of the New York Zoological Society, noticed that chestnut trees in the Bronx were dying. At first, recent droughts were suspected as the cause, but later a fungus, now called *Cryphonectria parasitica* (Murrill) Barr, was discovered killing the bark and cambial layers of American chestnut. Oriental chestnuts (*Castanea* spp.) were unaffected, and asymptomatic nursery stock is believed to have provided the initial inoculum for this epidemic. Despite every effort to quarantine, remove, and burn infected trees and to protect the uninfected trees with fungicidal sprays, the fungus spread within 40 years throughout the range of American chestnut. Because this is a nonsystemic bark disease, the roots of chestnut survive and produce coppice, but the sprouts eventually become diseased. The fungus is a weaker pathogen but can survive on oak; e.g., live (*Q. virginiana* Mill.), post (*Q. stellata* Wangenh.), scarlet (*Q. coccinea* Munchh.), and white (*Q. alba* L.), as well as oriental chestnut. Thus there is no hope of the disease ever dying out for lack of host material (Anagnostakis 1987, Liebhold and others 1995).

Two separate avenues of research have been taken to reduce the impact of chestnut blight: (1) hypovirulence and (2) resistance breeding. Hypovirulence is a debilitating disease of the fungus, caused by infection by hypoviruses. In the 1950s, researchers in Italy noted that cankers appeared to be callusing over and healing due to hypoviruses. Italian chestnut (*C. sativa* Miller) recovered and remains a viable crop today. In the United States, unfortunately, greater diversity exists in vegetative compatibility (v-c) groups of the fungus than is found in Europe. *Cryphonectria parasitica* strains in the United States are less likely than European strains to fuse mycelium and exchange the virus. Much effort has been directed at getting the virus into the recalcitrant strains. Recently researchers succeeded in getting synthetic DNA coding for viruslike ribonucleic acid particles into the DNA of uninfected strains. It is hoped that the synthetic genes will eventually spread through sexual reproduction into all v-c groups, thus promoting the spread of the hypovirulence.

Early attempts to incorporate Asian resistance genes into American chestnut by crossbreeding gave disappointing results. The hybrids often resembled the Asian species rather than the majestic American parent, because of backcrossing to the Asian parent. The American Chestnut Foundation (ACF's) has selected third-generation backcrosses, containing 94 percent American chestnut genes and possessing varying levels of resistance. Their results indicate that some individuals have resistance genes acquired from the American parents as well. The time and cost required to identify resistant progeny could be reduced greatly by the use of marker-assisted selection for the resistance trait. The ACF hybrids were developed mainly from three Chinese cultivars. The ACF intention now is to broaden their breeding program by incorporating more Chinese sources of resistance and outcrossing to locally adapted American parents (Hebard and others 2000).

Dogwood Anthracnose

The cause of dogwood anthracnose is a fungus named *Discula destructiva* Redlin. The details of introduction and origin are not precisely known, but the lack of genetic diversity in the pathogen points to a recent introduction (Daughtrey and others 1996). The relative resistance of Chinese dogwood (*Cornus kousa* Hatch) suggests that the fungus has Asian origins. In addition, the disease was first detected in North America almost simultaneously near two port cities, on opposite coasts, shortly after trade with China was reopened in 1975. Features of pathogen biology, forest history, and the silvical characteristics of the tree all help explain the severe damage caused by this disease.

The fungus produces only asexual spores, but these grow in great numbers in pustules with a slimy matrix, mostly on the underside of the leaf. They are well adapted to spread in splashing rain. The wet period necessary for infections is unusually long (24 to 48 hours), which partially explains why the disease is more severe in the mountains, at higher elevations, on north-facing slopes, and near streams and waterfalls where moist conditions are common. Wet periods within 2 weeks of each other were needed to maintain epidemic development, whereas dry periods of a

month or more greatly reduced the infection rate (Britton 1993). These requirements greatly slowed the spread of the fungus as it reached the southern edge of the Appalachians.

Eastern flowering dogwood (*C. florida* L.), the main host in southern forests, is a rapid colonizer of gaps, and its population probably expanded greatly after the demise of chestnut and as a consequence of logging activity in the early 20th century. This shade-tolerant species persisted after gap closure, surviving under as little as 2 percent ambient light in the photosynthetically active range (Chellemi and Britton 1992). Trees growing in these conditions had few carbohydrate reserves and could not withstand the stress of repeated defoliation when a susceptible population and environmental conditions favorable for epidemic disease development coincided.

Since it was first reported in the southern region in 1986, anthracnose has spread into 277 counties (Anderson and others 1994; U.S. Department of Agriculture, Forest Service 1999). The epidemic is now spreading West more than South or East and is generating much concern in Michigan, Indiana, Ohio, and Missouri. Flowering dogwood impact plots in western North Carolina, where the climate is very favorable for the disease, have incurred 56 percent mortality since 1991 (http://fhpr8.srs.fs.fed.us/2001Conditions/index.html). Disease severity today is much greater at the epidemic front than behind it, for several reasons: (1) the dry weather experienced recently in the South has probably reduced the number of secondary disease cycles occurring each year, (2) the loss of so many dogwoods growing in microsites optimal for fungal development reduced the inoculum load for the surviving trees, (3) survivors are growing on sites less favorable for fungal development, and (4) survivors may possess some genetic resistance.

No economically feasible control measures have been found to protect dogwood in forest environments. A 10-point program for reducing disease severity was developed for landscape trees. The main goal of the program is to improve tree vigor and thus reduce disease impact (Bailey and Brown 1991). The 10 points are:

1. Select healthy trees to plant.
2. Purchase trees from a reputable nursery; do not transplant trees from the wild.
3. Select good planting sites to promote rapid foliage drying.
4. Use proper planting techniques.
5. Prune and destroy deadwood and leaves yearly, and prune trunk sprouts in the fall.
6. Water weekly in the morning during drought; do not wet foliage.
7. Maintain a 4- to 6-inch deep mulch around trees; do not use dogwood chips as mulch.
8. Fertilize according to soil analysis.
9. Use proper insecticides and fungicides where appropriate.
10. Avoid mechanical and chemical injury to trees.

Hybrids of *C. florida* x *C. kousa* resistant to anthracnose were developed at Rutgers University. Selections from resistant *C. florida* survivors at Mt. Catoctin National Park were propagated and tested by the University of Tennessee and entered the market in 2002.

Dutch Elm Disease

The story of Dutch elm disease [*Ophiostoma ulmi* (Buisman) Nannf.] clearly illustrates a weak link in the defensive cordon of our quarantine regulations. Current U.S. regulations prevent entry only of pests that are (1) not present in the United States; or (2) present, but of limited distribution, and subject to an active eradication/control program.

To be effective, inspectors must be able to find and identify new invaders before they enter and become established. Unfortunately, the necessary taxonomic information did not exist in the case of Dutch elm disease. A new invader arrived and was mistakenly assumed to be the original Dutch elm disease fungus, which had become widespread and consequently not subject to regulation.

The new invader was much more aggressive than the first Dutch elm disease species. Thus there have been two separate epidemics of this vascular wilt in North America, Europe, and Asia. The original causal fungus, *Ophiostoma ulmi* (Buisman) Nannf., was probably of Himalayan origin and reached the Netherlands by way of the Dutch East Indies (Brasier 1990). It was introduced from there into North America in the 1930s.

The second, visually similar species, *O. novo-ulmi* Brasier, was not discovered in the American Midwest until after it began killing elms in Britain that had survived the original epidemic. The second epidemic was traced to elm logs shipped from North America in the 1960s.

In Britain alone, *O. novo-ulmi* killed 30 million elm trees. Hundreds of millions of elms (*Ulmus* spp. L.) in the United States were lost to the new fungus (Brasier 2001). Gene flow between the two species has been demonstrated using molecular techniques, and this gene flow brings advantageous *O. ulmi* genes for heterogeneity of v-c groups (and subsequent protection from debilitating viruses) into the more pathogenic *O. novo-ulmi* (Brasier 2001).

All North American elm species, and particularly the historically significant street tree *U. americana* L., are susceptible to Dutch elm disease. The spores are carried from tree to tree by *Hylurgopinus rufipes* (Eichhoff), a native elm bark beetle, in the northern tier of the United States and Canada. In the South, *Scolytus multistriatus* (Marsham), the smaller European elm bark beetle, is the more common vector. The beetles become infested with spores as they feed on dying elms, and when they emerge as adults they spread the spores to healthy trees while feeding in twig crotches. The fungus spreads within the tree by spores transported in the xylem, and by mycelial growth through other tissues. Leaves on infected branches wilt, curl, turn yellow, and die. Sometimes the tree dies within a few weeks, its vascular tissue plugged with fungal mycelium, tyloses, and gums. This is particularly true in cases where the fungus has spread through root grafts. In other cases, the tree may die one limb at a time over a period of a year or more (Haugen 2001). The cost of removal of dead elms is estimated at $100 million per year (Pimentel and others 2000). Although *U. americana* was not planted as widely in the South as in the Northern United States, it is gradually losing its place in southern landscapes, as well as in native forests.

Control measures for Dutch elm disease are most successful when adopted communitywide. Rapid sanitation of dead branches and dying trees greatly reduces populations of the beetle vectors. Prunings must be destroyed prior to beetle emergence. Insecticides can also be used to reduce vector populations. Root grafts between diseased and healthy trees should be broken with a vibratory plow or a trenching machine. Trenching should be done prior to the removal of diseased trees to prevent the drawing of inoculum across root grafts from diseased roots to the transpiring healthy tree (Haugen 2001). Santamour and Bentz (1995) list five varieties of Dutch elm disease-resistant *U. americana*: (1) Princeton elm, (2) American Liberty, (3) Independence, (4) Valley Forge, and (5) New Harmony. Other nonnative *Ulmus* species and some hybrids are also resistant to Dutch elm disease.

Injection or infusion of fungicides is used as a preventive measure only for high-value trees. Since the treatment must be repeated every 1 to 3 years, depending on the fungicide used, damage to the tree in creating injection ports is also a significant factor in overall tree health. Stipes and Fraedrich (2001) suggest that injections rise in priority relative to other control options when other factors, such as poor sanitation practices and community objections to insecticidal sprays, contribute to the development of plentiful inoculum. Fungicide injection improves the success of sanitation pruning and has the advantage of localizing control chemicals within the tree, as opposed to insecticidal sprays, which are subject to drift and possible nontarget effects. Again there are no economically feasible control measures suitable for use in the forest environment.

INVASIVE NONNATIVE FOREST INSECTS

Nonnative insects have had a profound effect on southern forests. Over 70 species of nonnative forest insects are currently established throughout the Southeastern United States. Because these pests have rapid dispersal rates and high reproductive capacities, it is necessary to detect new ones quickly and then apply effective eradication programs based on IPM before they become established and cause further damage. This portion of the present chapter will focus on several of the more destructive nonnative insects which have past, present, or potential future impacts on Southern U.S. forests.

Gypsy Moth

The gypsy moth [*Lymantria dispar* (L.)] is one of the most serious pests of hardwood trees in the Eastern United States. In most years, millions of acres are defoliated by the gypsy moth (fig. 14.1), and the costs of damage and control run into tens of millions of dollars annually. Useful general information about the gypsy moth can be found in the "Forest Insect & Disease Leaflet 162" for gypsy moth (McManus and others 1989) and in the book "Insects of Eastern Forests" (U.S. Department of Agriculture, Forest Service 1985).

The gypsy moth is native to Europe and was introduced into the United States in 1869 by a French scientist living in Boston. The first outbreak occurred in 1889. The gypsy moth has spread to all or parts of 17 States, mostly in the Northeast and the Great Lakes region, as well

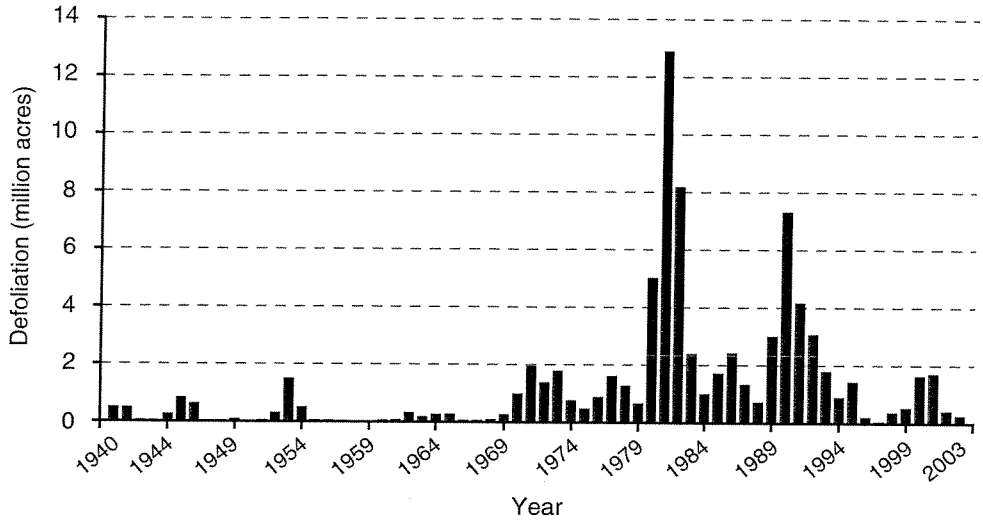

Figure 14.1—Amount of defoliation by the European gypsy moth 1940–2003.

as to the District of Columbia. In the Southeast, the current advancing front runs eastwest across northern North Carolina then slants northwest through southwestern Virginia and eastern Kentucky.

The gypsy moth life cycle has four stages: (1) egg, (2) larva, (3) pupa, and (4) adult (moth stage). Only the larvae damage trees and shrubs. Gypsy moth egg masses are most often laid on branches and trunks of trees, but egg masses may be found in any sheltered location. Egg masses are buff-colored when first laid, but may bleach out during the winter months. The hatching of gypsy moth eggs coincides with the budding of most hardwood trees, from early spring through mid-May. Larvae are dispersed naturally by the wind and artificially on cars and recreational vehicles, firewood, household goods, and other personal possessions. The larvae feed until early July before pupating. Adult females do not fly.

Gypsy moth larvae prefer hardwoods, but may feed on several hundred different species of trees and shrubs (for a list of host plants, see http://www.gypsymoth.ento.vt.edu/vagm/index.html). When gypsy moth populations are dense, the larvae feed on almost all vegetation. In the Eastern United States, the gypsy moth's main ecological effect is on oaks and in oak-dominated hardwood forests.

The effects of defoliation depend primarily on the amount of foliage removed, the condition of the tree at the time it is defoliated, the number of consecutive defoliations, available soil moisture, and the species of the host. If < 50 percent of their crown is defoliated, most hardwoods will experience only a slight reduction in radial growth. If > 50 percent of their crown is defoliated, most hardwoods will produce a second flush of foliage by midsummer. Healthy trees can usually withstand one or two consecutive defoliations of > 50 percent. Trees that have been weakened by previous defoliation or that have been subjected to other stresses, such as drought, frequently die after a single defoliation of > 50 percent.

Natural controls, including introduced insect parasites and predators, fungal and virus diseases, and adverse weather conditions, help control the gypsy moth. A number of tactics have the potential to minimize damage by gypsy moth and to contain gypsy moth populations at levels considered tolerable. These tactics include monitoring gypsy moth populations, maintaining the health and vigor of trees, discouraging gypsy moth survival, treating with *Bacillus thuringiensis* var. *kurstaki*, disrupting mating with pheromone flakes containing disparlure, treating with gypsy moth nuclear polyhedrosis virus, treating with diflubenzuron, and mass trapping. The tactic or combination of tactics used depends on the condition of the site and of the tree or stand and the level of the gypsy moth population. Tactics suggested for homeowners, such as removing egg masses, placing burlap bands around boles, or spraying individually affected trees, are usually too labor intensive for managers to use in forest stands.

The gypsy moth infestation spreads at an average rate of 21 km/year along its border to the west and south. In 1999 following a successful pilot project initiated in 1992, the U.S. Department of Agriculture Forest Service (Forest Service), along with State and Federal cooperators, implemented the National Gypsy Moth Slow the Spread (STS) project across the 1,200-mile gypsy moth frontier from North Carolina through

northern Michigan. The goal of the STS project is to use novel IPM strategies to reduce the rate of gypsy moth spread into uninfested areas. The STS project significantly decreases the new territory invaded by the gypsy moth each year and protects forests, forest-based industries, urban and rural parks, and private property. Estimated spread rates declined from 20 to 40 km/year to 5 to 14 km/year after STS control and eradication methods were employed in an STS project in the central Appalachians. The average rate of gypsy moth spread was 26.5 km/year before 1990 and 8.6 km/year after 1990 (Sharov and Liebhold 1998). More information on the spread of gypsy moth and the STS project may be found on the STS Web site: http://www.gmsts.org/operations.

Although gypsy moth has been present in the United States for > 100 years, it is difficult to explain and predict the extent of the changes it causes in forest vegetation. A major concern is the potential loss of economically significant and ecologically dominant oak species. Most studies of forest compositional changes after gypsy moth defoliation indicate that less susceptible species will dominate the forest.

Hemlock Woolly Adelgid

The hemlock woolly adelgid [*Adelges tsugae* (Annand)] has been in the United States since 1924 (McClure 1994). This serious pest of eastern hemlock [*T. canadensis* (L.) Carriere] and Carolina hemlock (*T. caroliniana* Engelmann) is a native of Asia. Through 2001, hemlock woolly adelgid infestations have been found in > 150 counties in Connecticut, Delaware, Massachusetts, Maryland, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Virginia, and West Virginia. In 2001 alone, 20 additional counties were found to have infestations. At present, hemlock woolly adelgid cannot be controlled in the vast majority of forest settings.

Hemlock woolly adelgid is a sucking insect with an extremely complicated life cycle. Four forms each complete six life stages, some of which develop wings and migrate to feed on spruce. Successful reproduction on spruce has not been observed in North America (Salom 1996b). The forms most damaging to hemlock are wingless and remain on hemlock all year round.

White cottony sacks at the base of the needles are good evidence of hemlock woolly adelgid infestation. These sacks resemble the tips of cotton swabs. They are present throughout the year, but are most prominent in early spring.

When immature nymphs and adults suck sap from their twigs, trees lose vigor and drop needles prematurely. If uncontrolled, the adelgid can kill a tree in a single year. The widespread hemlock mortality that the hemlock woolly adelgid causes is alarming, in view of the importance of hemlock trees to the ecosystems in which they occur.

Application of insecticides is currently recommended for controlling hemlock woolly adelgid in areas where this is feasible (Salom 1996b). Infested trees are drenched with botanical oils and or soaps, or systemic insecticide (imidacloprid) is injected into the trees and or the soil beneath them.

Several native predators feed on the hemlock woolly adelgid, but none of them reduces adelgid populations enough to help the current situation. Two nonnative predators, *Pseudoscymnus tsugae* Sasaji and McClure (a ladybird beetle native to Japan) and *Laricobius nigrinus* (Fender) (a beetle native to the Pacific Northwest), hold promise for biological control of hemlock woolly adelgid infestations. Under certain circumstances, releases of these predators are a feasible and effective control option (McClure and others 2001).

Balsam Woolly Adelgid

Introduced from Central Europe around 1900, the balsam woolly adelgid [*Adelges piceae* (Ratzeburg)] is considered a serious pest of forest, seed production, landscape, and Christmas trees (Salom 1996a). First discovered in Brunswick, ME, in 1908, the balsam woolly adelgid was found in the Southern Appalachian Mountains in the 1950s and has spread to all fir stands in the region since that time. The pest has also found its way into the Pacific Northwest. In the Eastern United States, the adelgid feeds on balsam fir and Fraser fir. Very extensive stands of Fraser and balsam fir have been killed throughout much of these species' range in the East. Because the adelgid does not attack Fraser fir until the trees approach maturity, and because some mature trees escape attack long enough to produce seeds, young Fraser fir trees still exist in their natural range. However, by the mid-1980s, this insect had significantly altered all of the mature Fraser fir-red spruce (*Picea rubens* Sarg.) forest type in the Southern Appalachians.

The balsam woolly adelgid life stages include the egg, three nymphal stages, and female adults. There are no males; females reproduce by parthenogenesis. They are wingless, oval, purplish-black insects about 0.8 mm in length, and are covered with secretions of waxy threads

that appear as a dense white wool mass. A female is capable of laying 200 eggs or more in a cluster near her body. The first-instar crawlers, reddish brown and about 0.4 mm in length, are the only stage of the insect capable of moving and dispersing. Once the crawler finds a suitable feeding location, it inserts its tubelike mouth parts into the bark of the host and remains there for the rest of its life. The second and third instars are about 0.5 to 0.65 mm in length, respectively, and closely resemble the adult.

The balsam woolly adelgid generally concentrates either on the outer portions of tree crowns or on the main stem and large branches. Crown infestations are characterized by abnormal drooping of the current shoots and gouting of the outer twigs. The crown becomes increasingly thin, and dieback may occur. Persistent crown infestation can kill a tree over a number of years. Stem infestations usually cause greater damage and mortality. Conspicuous white woolly masses characteristic of stem attack can give the lower bole a whitewashed appearance in the most severe cases. The tree responds to feeding by adelgids in an allergic manner that causes swelling of the sapwood, gouting of the twigs, and increased heartwood formation in the sapwood—a condition called rotholz or redwood. This abnormal growth of sapwood tissue inhibits water flow within the tree.

In forest situations, silvicultural and management techniques can be used to reduce balsam woolly adelgid populations and damage (Salom 1996a). Tree stress may be minimized by thinning overstocked stands, by fertilizing nutrient-poor sites, and by replanting or encouraging more tolerant trees and varieties. There are many different varieties and crosses of Fraser fir, and some varieties are more tolerant of balsam woolly adelgid. A hazard-rating system was developed to aid in management decisions. The main variables used in the system are site elevation, soil moisture regime, percent balsam fir by basal area, total basal area of balsam fir, and stand age. In general, lower elevation dry sites with > 40 percent balsam fir at an older age (45 years of age or more) are most susceptible. Trees between 25 and 45 years of age are moderately susceptible, and trees < 25 years old are least susceptible. In Christmas tree plantations in which only a few trees are infested, it should suffice to rogue and burn those trees. Chemical control can be used effectively on ornamental trees, seed production trees, and Christmas trees (Day and others 2001). Several insecticides are available for use in spraying infested bark and foliage. When feasible, the cutting and removal of infested trees is effective. Cut trees must be wrapped in tarps to ensure that adelgids do not fall off the trees as they are being removed.

Beech Scale and Beech Bark Disease

Beech bark disease (*Neonectria galligena*) is one of the more recent problems to plague Eastern U.S. forests. Beech bark disease refers to a complex consisting of a sap-feeding scale insect and at least two species of *Nectria* fungi (McCullough and others 2001). Beech scale (*Cryptococcus fagisuga* Lind. = *C. fagi* Baer.) was accidentally introduced into Nova Scotia in 1890 on ornamental beech trees from Europe. The scale and associated fungi have spread since that time, and the current range in the United States includes most of New England, northern Pennsylvania, and northeastern West Virginia. Localized infestations of beech scale have been discovered in Virginia, North Carolina, Tennessee, and Ohio (McCullough and others 2001). The overall effect of this insect-disease complex is the mortality of roughly 50 percent of the beech (*Fagus* spp.) trees > 8 inches in diameter (Houston and O'Brien 1983). The resulting forest has a few residual large beech trees and stands of many small trees, often root sprouts from susceptible trees, which are frequently defective.

Beech scale insects are yellow, soft bodied, and 0.5 to 1.0 mm long as adults. They feed on American beech (*F. grandifolia* Ehrh.) and European beech (*F. sylvatica* L.). Adult scales are legless and wingless and have only rudimentary antennae. Reproduction is parthenogenic. This type of reproduction allows for rapid population growth. Beech scale has one generation per year. Immature scales, called crawlers, have functional antennae and are mobile. Crawlers are spread by wind, birds, and people moving infested wood. When a crawler finds a suitable feeding location on a host tree, it inserts its long, tubelike stylet into the bark and begins to suck sap. It then molts to the second crawler stage, which has no legs and is immobile. These produce a white wax that eventually covers their bodies. Thus when trees are heavily infested with beech scale, they appear to be covered by white wool. The small wounds produced by the beech scale's feeding allow the *Nectria* fungi to invade the infested trees (Houston 1994).

Crawlers that fall from trees or are washed off by precipitation usually die. Severely cold weather (-35 °F) that persists for a few days

may kill beech scale, but such weather conditions probably never occur in the Southeast. A small ladybird beetle [*Chilocorus stigma* (Say)] feeds on this scale and is common throughout most of the Eastern United States, but this predator does not reduce scale populations enough to control infestations.

Although the scale feeding alone weakens trees, mortality usually does not occur until the trees have been invaded by *Nectria* fungi. This invasion typically occurs after 3 to 6 years of scale feeding. Most large-diameter beech trees in areas where beech bark disease becomes established are killed. Beech is a very important source of food and habitat for many wildlife species and areas with large beech components may change dramatically as a result of beech bark disease. Some trees are partially resistant to beech bark disease, and a very few are completely resistant. Trees with smoother bark appear to be more resistant, probably because the scales prefer to feed where bark is rough (Houston 1997).

The only control is removal of the trees most heavily infested with beech scale or *Nectria* fungi. Resistant trees should be identified and retained. After it is cut, beech often regenerates by prolific root sprouting. This is undesirable because the sprouts form dense thickets, have little value to wildlife, and eventually increase susceptibility to more beech bark disease infestations. Herbicide control of beech root sprouts is, therefore, often necessary. Increasing the diversity of forest stands in which beech is present will reduce the risks and spread rate of the disease. Care should also be taken to avoid transporting infested firewood or logs to uninfested areas.

Asian Longhorned Beetle

The Asian longhorned beetle [*Anoplophora glabripennis* (Motschulsky)] was discovered in New York City in 1996 and in Chicago in 1998. Tunneling by the beetle larvae girdles tree stems and branches, impeding water and nutrient transport within the attacked tree. Repeated attacks lead to dieback of the tree crown and, eventually, death of the tree (U.S. Department of Agriculture, Forest Service and Animal and Plant Health Inspection Service 1999). The Asian longhorned beetle probably traveled to the United States inside solid wood packing material from China. The beetle has been intercepted at ports and found in warehouses throughout the United States, although New York City and Chicago remain the only two areas where infestations of live trees have been found. Since 1996, > 7,000 trees in the two cities have been killed by the beetle, or cut down and destroyed to stop the beetle's spread. Most of the trees lost were highly valued urban trees that provided shade, wildlife habitat, aesthetic value, and benefits for clean water and air. The Asian longhorned beetle has had an economic impact in the tens of millions of dollars.

The Asian longhorned beetle is also a serious pest in China where it kills hardwood trees. In the United States, the beetle prefers maple species (*Acer* spp.), including boxelder (*A. negundo* L.), Norway (*A. platanoides* L.), red (*A. rubrum* L.), silver (*A. saccharinum* L.), sugar (*A. saccharum* Marsh.), and sycamore (*A. pseudoplatanus* L.) maples. A complete list of host trees in the United States has not been determined. An updated list is available at http://www.na.fs.fed.us/spfo/alb/index.htm. Because not all hosts are known and because the beetle has been restricted to urban forests thus far, it is difficult to predict its potential effects on natural forests. It appears, however, that Asian longhorned beetle may have the potential to irrevocably alter many eastern forest ecosystems.

There is usually one generation of Asian longhorned beetle per year, although the life cycle may take as long as 2 years. Adult beetles are usually present from May to October, but they can be found earlier in spring or later in fall if temperatures are warm. Adults typically stay on the trees from which they emerge, but they may disperse short distances to a new host to feed and reproduce. Adult females chew oval to round egg-laying sites in the bark of the tree and place a single egg in each. Each female is capable of laying 30 to 70 eggs. These hatch in 10 to 15 days, and the larvae tunnel under the bark and deep into the wood where they eventually pupate. Emerging adults create a perfectly round exit hole three-eighths inch in diameter. Adult beetles are 1 to 1.4 inches long and have striking white marks against a jet black body. The antennae are longer than the body and have black and white bands.

Currently the only effective means to eliminate Asian longhorned beetle is to remove infested trees and destroy them by chipping or burning. To prevent further spread of the insect, quarantines have been established to avoid the transportation of infested trees, branches, and wood from the area. Early detection of infestations and rapid treatment response are crucial to successful eradication of the beetle. Early

detection is difficult, time consuming, and costly, and to be effective, it must involve tree climbers and surveyors in bucket trucks. Since 2000, unattacked potential host trees have been injected with the systemic insecticide imidacloprid as a preventive treatment. Researchers are assessing the biological control potential of a variety of the beetles' natural enemies in Asia.

INVASIVE NONNATIVE FOREST PLANTS

Millions of acres of forest land in the Southeast are being increasingly occupied by nonnative invasive plants, which are also termed exotic weeds. Their range, infestations, and damage are continually expanding. All Federal parks and forest lands in the Southeast have nonnative infestations (Hamel and Shade 1985, Hester 1991). The actual infested acreage, spread rates, and damage estimates are still unknown, although this information is essential for planning containment and eradication strategies and programs (U.S. Congress Office of Technology Assessment 1993). The Forest Service and State partners have initiated a cooperative survey of 42 invasive nonnative plants within the region and another 20 species in Florida; however, it will take several years to collect initial data (for a list, see "Nonnative Invasive Plants of Southern Forests" at http://www.srs.fs.usda.gov/fia/manual/Nonnative_Invasive_Plants_of_Southern_Forests.pdf).

Invasive plants are able to outcompete native species. They reproduce rapidly because of the absence of predators from their native ecosystems, and eventually form dense infestations that exclude most other plants, except certain other nonnatives (Randall and Marinelli 1996). Other reasons for their invasiveness are that they are naturally robust plants or have been made so through plant breeding efforts; that most are perennials with tough roots or rhizomes; that many are still being sold as ornamentals and some are widely planted for wildlife use and soil stabilization; that most produce abundant seeds or spores that are spread widely by birds, wind, and water; and that their seeds or tubers persist in the soil (Randall and Marinelli 1996). It remains unclear what percentage of nonnative plants arriving in the Southeastern United States become invasive. One problem in determining this is the nature of invasive plant spread, which can be characterized by a short-to-lengthy lag phase preceding an exponential spread phase (fig. 14.2). In many species, e.g., kudzu, tallowtree, wisterias, etc., the lag phase can be very protracted and can mask eventual problems. This spread function also explains why eradication is most possible during the early lag phase.

Occupation and infestations by nonnative pest plants decrease forest productivity, threaten forest health and sustainability, and limit biodiversity and wildlife habitat in the Southeast (Wear and Greis 2002). Alterations to ecosystem structure, functions, and processes are occurring, but study of these effects has just begun (Ehrenfeld and others 2001). Some invasives, such as cogongrass [*Imperata cylindrica* (L.) Beauv.], can alter natural fire regimes and increase risk of wildfire occurrence and damage (Lippincott 2000). Nonnative plant "biological pollution" is one of the greatest threats to biodiversity across the southern landscape, attacking our highly valued nature preserves and recreational lands. Adjoining croplands, home sites, pastures, and wetlands contain invasive plant species that will eventually affect forests. These nonnative invaders (often called nonindigenous, alien, or noxious weeds) include trees, shrubs, vines, grasses, and forbs. In all there are about 70 infestation-forming, terrestrial plant species invading forests and their edges in the temperate parts of the Southeast. Thirty of these are discussed briefly here to provide a general sense of identifying characteristics, common pathways of introduction, mechanisms of invasiveness, ecosystem effects, and range of current occupation. Not discussed here are the approximately 70 tropical and subtropical nonnative species currently invading south Florida.

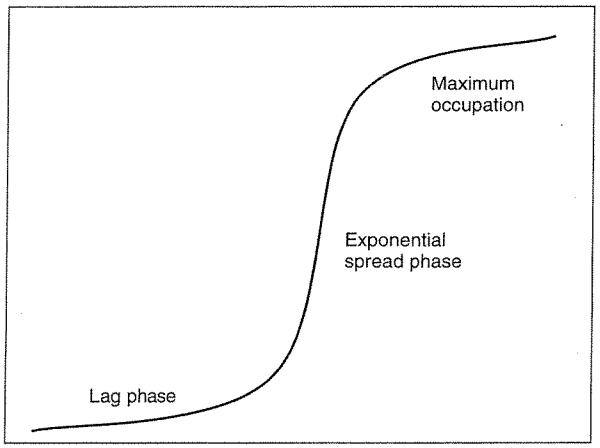

Figure 14.2—Logistic spread model for invasive nonnative plants.

Invasive Nonnative Trees

Nonnative tree species hinder management of forests, rights-of-way, and natural areas by replacing native plants. This dramatically alters habitat and may alter important natural processes. Almost all of the invasive nonnative trees are hardwoods. Some presently occur as scattered trees, while others form dense stands. Most spread widely by prolific seed production and animal dispersal, while existing infestations increase by abundant root sprouting.

Tree-of-heaven or ailanthus [*Ailanthus altissima* (P. Mill.) Swingle] was introduced to North America as an ornamental in 1784 from Europe, although it originates in Eastern China (Miller 1990). A short-lived species with no timber value, ailanthus grows up to 80 feet tall with long, pinnately compound leaves, slightly fissured gray bark, and large terminal clusters of greenish flowers in early summer. Flowers and other parts of the plant have a strong odor. It is a dioecious species and spreads by seeds from female trees. It is shade intolerant, flood intolerant, and allelopathic. Ailanthus establishes after disturbance and increases by root sprouts, often forming dense thickets that displace native vegetation. It occurs throughout the Southeast and is most abundant in Kentucky, Virginia, and Tennessee.

Silktree or mimosa (*Albizia julibrissin* Durazz.) was introduced as an ornamental from Asia in 1745. It is a leguminous tree, 30 to 50 feet tall. It has feathery, pinnately compound, deciduous leaves, smooth light brown bark, and showy pink spring and summer blossoms, yielding abundant dangling seedpods that persist into winter. The seedpods float, which aids in long-distance spread along waterways, and seeds remain viable for many years. Infestations are spreading along rights-of-way, fencerows, and riparian zones, and are encroaching into adjoining forested areas after disturbance, especially into pine plantations. Partially shade tolerant, mimosa invades the forest midstory and replaces native shrubs by root sprouting. It is becoming increasingly common along roadsides throughout the Southeast and is most abundant in Mississippi, Alabama, and Georgia.

Princesstree or paulownia [*Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud.] was introduced from East Asia in the early 1800s. It is grown as an ornamental and in scattered plantations for speculative production of high-valued wood for export to Japan. It has large heart-shaped leaves with fuzzy hairs on both sides, and in early spring produces showy pale violet flowers that yield clusters of pecan-shaped capsules, each filled with thousands of tiny winged seeds. Paulownia reproduces by abundant seeds and root sprouts, replacing native vegetation, including young trees that might otherwise reach the overstory. It is shade intolerant and invades after disturbance. This deciduous tree grows to 60 feet tall. Because it sprouts rapidly, it often obscures scenic vistas along roadsides. It occurs throughout the Southeast and is presently most abundant in central Tennessee and Virginia.

Chinaberrytree (*Melia azedarach* L.) is another Asian introduction. This traditional ornamental is commonly found around old home sites. It grows to about 50 feet tall and is spread by birds, which disperse its seeds. It has lacy, bipinnately compound dark green leaves and produces pale blue flowers in spring. The flowers yield round yellow fruit that persist during winter. Infestations spread by means of abundant seeding and root sprouting along rights-of-way to adjoining land that has been disturbed. Because it is somewhat shade tolerant, it is increasing in the midstory of pine plantations in parts of the South. The fruit are poisonous to humans and livestock but have potential use as natural pesticides. Chinaberry is common throughout the Southeast and is most abundant in Arkansas, Louisiana, Mississippi, Alabama, and Georgia.

Tallowtree or popcorn tree [*Triadica sebifera* (L.) Small, formerly *Sapium sebiferum* (L.) Roxb.] is a shade-tolerant tree that grows to 50 feet tall. It has light green heart-shaped leaves that turn scarlet in the fall, long drooping flowers in spring, and bundles of white, waxy, popcornlike seeds that remain attached to the tree in fall and winter. The abundant seeds are spread by birds and on water. Tallowtree is a prolific root sprouter and forms monospecific stands (Bruce and others 1997). It was introduced from China to the U.S. gulf coast in the early 1900s, and the U.S. Department of Agriculture encouraged its use as a seed oil crop from 1920 to 1940. Tallowtree is still being sold and planted and is thought to be the most rapidly invading tree species in the region. Tallowtree seedlings are shade tolerant and yet grow rapidly in full sun (Jones and McLeod 1990). Its waxy seeds were traditionally used to make candles, and it has current value as a honey plant for beekeeping and limited pulpwood use. It forms dense stands, and because it tolerates flooding, tallowtree replaces bottomland hardwood reproduction and understory plants in wetland

forests throughout the Coastal Plain (Jones and Sharitz 1989). It is also spreading into upland forests from widespread ornamental plantings. It occurs in all the Southern States except Oklahoma, Kentucky, and Virginia, and there are severe infestations in coastal areas of Texas, Louisiana, Mississippi, and Alabama.

Invasive Nonnative Shrubs

Invasive nonnative shrubs often occur with invasive tree species and present similar problems. Herbicide control options are similar to those for trees, but foliar sprays are often more effectively used against shrubs than against trees. All of the most common invasive shrubs are abundant seed producers, and their fruits are often consumed and spread by birds.

Chinese privet (*Ligustrum sinense* Lour.) and European privet (*L. vulgare* L.) are shade-tolerant tall shrubs or small trees growing to about 30 feet in height. These common southern ornamental shrubs were introduced from China and Europe in the early to mid-1800s and have already become some of the most severely invasive species. They form dense stands in the understory of bottomland hardwood forests and exclude most native plants and replacement reproduction. These privets are also increasing in upland forests, fencerows, rights-of-way, and special habitats throughout the region. They drastically alter habitat and critical wetland processes. Both species have leafy stems with opposite leaves < 1 inch long. Chinese privet is semievergreen, and European privet is deciduous, but the two species are nearly identical in all other respects. Both have showy clusters of small white flowers in spring that yield drooping clusters of small, spherical, dark purple berries during fall and winter. Birds spread seed very effectively, but privet stands also increase in density by stem and root sprouts. Both species occur throughout the Southeast.

Multiflora rose (*Rosa multiflora* Thunb. ex Murr.) is an erect-to-arching shrubby rose growing to about 10 feet tall and taller when it climbs into trees. The recurved thorny stems have pinnately compound leaves with 3 to 7 leaflets. White rose flowers are produced in many clusters in spring, and red rose hips, which are spread by birds, appear in fall to winter. Sprouts and runners that root consolidate and expand infestations. The species was introduced from Japan and Korea in the 1860s as an ornamental. Later, Government programs encouraged its planting for use as living fences for livestock containment and as wildlife habitat. Infestations have been confined to pastures but are now extending into forest edges and interior forests, including wetlands. The species occurs throughout the Southern and Eastern United States.

Bush honeysuckles—Amur honeysuckle [*Lonicera maackii* (Rupr.) Herder], Morrow's honeysuckle (*L. morrowii* Gray), tatarian honeysuckle (*L. tatarica* L.), and sweet breath of spring (*L. fragrantissima* Lindl. and Paxton)—are generally deciduous multistemmed shrubs 6 to 16 feet tall with arching branches. The leaves are distinctly opposite, usually oval to oblong in shape, and range in length from 1 to 3 inches. Fragrant, tubular flowers occur in pairs from May to June and are creamy white in most species, but turn yellow or pink to crimson in varieties of tatarian honeysuckle. Red-to-orange berries in pairs are abundant on plants in fall to winter, and seeds are long lived in the soil. All were introduced from Asia in the 1700s and 1800s as ornamentals and wildlife plants. They are widely invading and forming exclusive understory layers in lowland and upland forests, replacing most native plants and preventing regeneration of native trees. Most alarming is the increased occupation of wetlands. These invasive species occur everywhere in the Southeast except Louisiana and Florida and are most abundant in Kentucky and Virginia.

Autumn olive (*Elaeagnus umbellata* Thunb.) is a deciduous, bushy shrub growing to 20 feet tall. It has alternate leaves that are dark green above and silvery beneath. It produces abundant spherical red berries with silvery scales in the fall. Introduced from China and Japan, and still widely planted for wildlife habitat, reclamation of strip mines, and shelterbelts, autumn olive is being spread rapidly and widely by birds and other animals. It is becoming a scattered understory shrub in open forests throughout the Southeast, to the detriment of native trees and shrubs.

Silverthorn or thorny olive (*E. pungens* Thunb.) is a popular ornamental evergreen bushy shrub with long limber shoots projecting to 20 feet when supported by tree limbs. It has alternate leaves, which in spring are silver and scaly on both top and bottom and which by midsummer have become dark green above and silvery beneath. Thorns are widely scattered on its branches and are subtended by brown-scaled red fruit that appear in spring. The fruit are consumed and widely dispersed by wildlife, which results in scattered infestations. This widely planted ornamental shrub was introduced from China and Japan. A shade-tolerant species, it replaces

native understory vegetation and prevents natural tree regeneration. It occurs in all Southeastern States except Texas, Oklahoma, and Arkansas.

Winged burning bush [*Euonymus alata* (Thunb.) Sieb.] is a shade-tolerant, deciduous, bushy shrub up to 12 feet tall with opposite leaves along stems with four corky wings. Introduced from Northeast Asia in the 1860s, it is still widely planted as an ornamental. In fall, the leaves turn bright red, while orange fruit appear as stemmed pairs in leaf axils. Birds and animals are attracted to the fruit and spread seed widely. *E. alata* is increasingly invading forests, pastures, and prairies. It forms dense stands that exclude native plants and eventually stop native tree regeneration. This problem is spreading in Oklahoma, Kentucky, Tennessee, Virginia, Georgia, North Carolina, and South Carolina.

Invasive Nonnative Vines

Nonnative vines are among the most troublesome invaders because they often form the densest infestations, making control efforts difficult, especially the application of herbicide. Many of these vines overtop even mature forests and often form mixed infestations with nonnative trees and shrubs.

Japanese honeysuckle (*L. japonica* Thunb.), the most prevalent invasive nonnative vine, is a shade-tolerant, climbing and trailing woody vine with semievergreen, opposite leaves. Paired white to yellow flowers in early summer yield blackish berries in fall and winter. Introduced from Japan in 1806, it is the most widespread and invasive nonnative plant species. It occupies multiple strata in lowland and upland forests, replaces native vines, and alters habitat and ecosystem processes. Japanese honeysuckle is sold as an ornamental and has some value for erosion control. It is also planted and cultured in wildlife food plots and sustains deer herds during winter. It occurs throughout the Southeast and is spread by widely rambling vines that root at nodes, as well as by bird-dispersed fruits.

Kudzu [*Pueraria montana* (Lour.) Merr., formerly *P. lobata* (Willd.) Ohwi] is a woody leguminous vine with lobed trifoliate leaves. It is spread by vines rooting at nodes and by animal- and water-dispersed seeds. Introduced as an ornamental from Japan in 1876, kudzu was planted extensively for erosion control and forage in Government-sponsored programs from 1920 to 1950. It forms dense infestations that exclude native plants, halting forest productivity and changing habitat on millions of acres of land. Kudzu is increasingly invading riparian habitat along rivers and streams by means of floating seedpods. Hydrologic impacts from this mode of spread are anticipated. Kudzu has become a popular southern icon and provides some raw material for folk art. The Forest Service has initiated a biocontrol program for kudzu (Britton and others 2002).

Oriental or Asian bittersweet (*Celastrus orbiculatus* Thunb.) is an attractive but very invasive vine with elliptic to rounded deciduous leaves 2 to 3 inches broad and long, alternating along a woody vine with drooping branches. Clusters of scarlet fruit appear in fall and remain during winter at most leaf axils. The fruits are widely spread by birds. Oriental bittersweet was introduced from Asia in 1736. The showy berries are used as home decorations in winter, and these decorations contribute to spread when discarded. Oriental bittersweet colonizes disturbed forests and along forest edges, spreading into interior forests, forming expanding thickets, and decreasing plant diversity. It is invading from the Northeast and is not yet found in Oklahoma, Texas, Louisiana, or Mississippi. American bittersweet (*C. scandens* L.) has flowers and fruit only in terminal clusters and does not form extensive infestations.

Air yam (*Dioscorea bulbifera* L.) and Chinese yam (*D. oppositifolia* L., formerly *D. batatas* Dcne.) are twining and sprawling vines with heart-shaped leaves and small dangling, yamlike tubers (bulbils) at leaf axils in mid-to-late summer. These tubers drop and form new plants. Although the vines are deciduous, they grow rapidly and can cover small trees in one growing season. Native *Dioscorea* species do not produce "air potatoes," nor do they form infestations that cover trees. Chinese yam is from Asia, and air yam is from Africa. Both were introduced as possible food sources in the 1800s, but are now cultured for ornamental or medicinal use and are often spread by unsuspecting gardeners. Once established, these vines colonize persistently because the prolific bulbils form new plants as they scatter downslope. The vines expand throughout the understory to form exclusive infestations. Their distribution is scattered throughout the Southeast, with air yam occurring mostly in the southern Gulf Coastal Plain and Chinese yam more common in the Appalachians.

Wintercreeper or climbing euonymus [*Euonymus fortunei* (Turcz.) Hand.-Maz.] is a trailing, climbing, or shrubby evergreen plant with opposite, thick, dark green or green-white variegated leaves. It is shade tolerant, spreads to form a dense ground cover, and climbs by aerial roots. Abundant reddish-hulled orange fruit appear in fall and are widely spread by birds. Introduced from Asia as an ornamental ground cover and still widely planted, *E. fortunei* continues to form dense exclusive infestations that decrease diversity, hinder access, and alter habitat. It occurs in Kentucky, Virginia, Tennessee, Mississippi, Alabama, Georgia, North Carolina, and South Carolina.

Japanese climbing fern [*Lygodium japonicum* (Thunb. Ex Murr.) Sw.] is a viney deciduous fern with lacy, finely divided leaves and green-to-orange-to-black wiry stems that climb and twine over shrubs and trees. Native to Asia and tropical Australia, it was introduced to North America from Japan as an ornamental and is often spread by unsuspecting gardeners. It is one of three species of climbing ferns in the Southeast. The American climbing fern [*L. palmatum* (Bernh.) Sw.] and Old World climbing fern [*L. microphyllum* (Cav.) R. Br.], another nonnative which grows in Florida, have once-divided leaves. All are perennial plants that grow from creeping rhizomes and are spread by wind-dispersed spores. Dispersal of spores from nonnative species results in rapid spread and widely scattered dense infestations that cover native herbs, shrubs, and eventually trees. *L. japonicum* is invading from the South to the North and has yet to arrive in Oklahoma, Tennessee, or Kentucky.

Chinese wisteria [*Wisteria sinensis* (Sims) DC.] and Japanese wisteria [*W. floribunda* (Willd.) DC.] are woody, leguminous vines with long pinnately compound leaves and showy spring flowers. They spread by adventitious rooting and are less commonly dispersed by seeds. These traditional southern porch vines were introduced from Asia in the early 1800s. They usually spread slowly, although more rapidly near rivers and streams. They form dense infestations mainly around old home sites, often in mixtures with other nonnative plants. Both hinder reforestation and commonly occur as scattered patches throughout the Southeast. The native or naturalized American wisteria [*W. frutescens* (L.) Poir.] does not form dense infestations.

Nonnative Invasive Grasses

Nonnative grasses spread along highway rights-of-way and then into adjoining forest lands. Most nonnative grasses are highly flammable and increase fire intensity. Intense fires tend to kill plants with which the grasses occur and thus facilitate the spread of the grasses after wildfire or prescribed burns. Wildland firefighters and forest home sites are subjected to increased risks where nonnative grasses form heavy infestations. Repeated applications of herbicides are required for control.

Cogongrass [*Imperata cylindrica* (L.) Beauv.] is a dense, erect perennial grass. Its wide yellowish green leaves have off-center midveins and finely sawtoothed margins. It was introduced from Southeast Asia in the early 1900s, first accidentally and then intentionally for soil stabilization and use as forage. It has been rated as the world's seventh worst weed (Holm and others 1979). It spreads by windblown seeds in early summer and by rhizome movement in fill dirt along highways, often yielding circular infestations. This grass is highly flammable. It is mostly shade tolerant. Dense infestations increasingly occupy forest openings, open forests, and rights-of-way in the Southern Gulf Coast States and eventually exclude most native plants. Forest regeneration is hampered and habitat destroyed. This process is hastened by burning (Lippincott 2000). Cogongrass is spreading northward from the Gulf Coast States and had not reached North Carolina, Tennessee, Virginia, Kentucky, Arkansas, or Oklahoma as of 2001.

Nepalese browntop [*Microstegium vimineum* (Trin.) A. Camus] is an annual grass. Stems are from 1 to 3 feet long with alternate, lanceolate leaves to 4 inches long. It forms dense mats and consolidates occupation and spreads by prolific seed production in late summer. Seed remain viable for 1 to 5 years. This shade-tolerant weed is native to temperate and tropical Asia and was first collected near Knoxville, TN, in 1919. It increasingly occupies creek banks, flood plains, forest roadsides and trails, damp fields, and swamps. It spreads into adjoining forests, where it forms exclusive infestations and displaces most, if not all, native understory plants. It occurs throughout the Southeast except in Oklahoma.

Chinese silvergrass (*Miscanthus sinensis* Anderss.) is a densely clumped perennial grass with upright to arching long, slender leaves with whitish upper midveins. It can grow to a height of 5 to 10 feet. Silvery to pinkish loose plumes appear

in fall. Viability of the seed is unpredictable. Native to Eastern Asia, *M. sinensis* has been planted in all States for landscaping, recently using sterile cultivars. It is spreading from older fertile plants in all States except Arkansas, Oklahoma, and Texas. Still widely sold and planted as an ornamental, it is highly flammable. It forms dense infestations along rights-of-way and in disturbed upland forests, excluding native vegetation and altering habitat.

Invasive Nonnative Forbs and Subshrubs

Forbs are broadleaf herbaceous plants, while subshrubs are semiwoody. They are usually treated with foliar herbicide sprays or pulled by hand.

Garlic mustard [*Alliaria petiolata* (Bieb.) Cavara & Grande] is an aptly named biennial herb; all parts of the plant have a garlic odor. It grows in small-to-extensive colonies under forest canopies. In the first year, the plant appears as a basal rosette of leaves that remain green during winter. In the second year, stems emerge and grow, becoming 2 to 4 feet tall. Leaves are broadly arrow-point shaped with wavy margins. The flowers form in terminal clusters, and each flower has four white petals. Introduced originally as a medicinal herb from Europe in the 1800s, garlic mustard is displacing native forest understory plants and drastically altering habitat. This species produces prolific seed that can lie dormant in the soil for 2 to 6 years, building large seed banks. Germination occurs only in spring under favorable conditions. A biocontrol program has been started at Cornell University (Blossey and others 2001). Garlic mustard is invading from the Northeast and has yet to arrive in Florida, Alabama, Mississippi, Louisiana, or Texas.

Shrubby lespedeza *(Lespedeza bicolor* Turcz.) and Chinese lespedeza [*L. cuneata* (Dum.-Cours.) G. Don] were both introduced from Japan. Shrubby lespedeza is a shade-tolerant bushy legume that grows up to 10 feet tall. It has three leaflets and produces small purple-pink peatype flowers with white centers. Chinese lespedeza is a semiwoody plant up to 3 feet tall with many small, three-leaflet leaves feathered along erect, whitish stems. It forms tiny cream-colored flowers during summer. Both species produce abundant single-seeded legumes, but dispersal mechanisms are poorly understood. They have been planted extensively for wildlife food and soil stabilization. They are still planted for quail food, and plants often invade surrounding forests, replacing native plants throughout the Southeast.

Invasive Plant Control

The most effective and efficient strategy for control is early detection and effective early treatment of initial invaders. Any successful effort to combat and contain invasive nonnative plants requires an integrated vegetation management approach (Miller 2003, Tennessee Exotic Pest Plant Council 1996). Integrated programs incorporate all effective control methods, which may include (1) preventive measures, i.e., legal controls such as quarantines, border inspections, and embargoes; (2) biocontrol by means of natural predators and diseases; (3) herbicide technology; (4) prescribed fire; (5) livestock overgrazing; and (6) mechanical and manual removal. Preventive measures and biocontrol programs are best organized on a regional basis. Biocontrol agents are largely unavailable now, and although projects to identify such agents are underway, it will take years to develop them (Simberloff and Stilling 1996). Only through careful and precise research and development can effective biocontrol agents that minimize impacts on nontarget organisms be identified.

Current treatment options for specific areas usually involve herbicides, prescribed fire, grazing, and mechanical or manual removal. Fire, grazing, and mechanical cutting treatments usually control only the aboveground plant parts, reducing their height but suppressing the plants only temporarily. Manual treatment usually involves grubbing or pulling plants. This is very labor intensive and is practical only where plants and infestations are small. Thus manual treatment has limited but effective application in special habitats, such as recreational trails or nature preserves, and as a rapid means of first-sight elimination. Mowers, chain saws, and brush cutters remove aboveground plant parts, while leaving roots and rhizomes. Tree shears, root rakes, and harrows can cut and dislodge woody and rhizomatous plants, but leave soil bare for probable reinvasion and possible erosion if it is not rapidly stabilized with native plants. Nonetheless, these soil-disturbing techniques can start reclamation programs when multispecies infestations of invasive woody plants are encountered.

Herbicide treatments often can be more easily and effectively applied following these other treatments. Herbicide treatments also minimize soil disturbance and leave the soil seed bank in place to reestablish native plants. Carefully planned and executed herbicide applications can specifically target nonnative plants and minimize impacts to native plants

(Miller 2003) (http://www.invasive.org/weeds.cfm and http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs062). Well-developed applicator-directed techniques for selective control of nonnative trees and shrubs are tree injection and girdle treatments, basal sprays and wipes, cut-stem applications, and foliar-directed sprays (U.S. Department of Agriculture, Forest Service 1994). Directed treatments of nonnative vines and forbs usually involve foliar sprays applied with backpack sprayers. For treating extensive inaccessible infestations, broadcast applications of sprays and pellets using helicopter and tractor-mounted systems may be required. Yet even in broadcast treatments, the use of carefully timed selective herbicides can safeguard native plants. If the treatment is to be safe and effective, herbicide applicators must read, understand, and follow the herbicide label and its prohibitions before and during use. Continued surveillance and followup treatments are often required to control nonnative plant infestations.

Site Rehabilitation after Nonnative Plant Control

The rehabilitation phase is the most essential final part of an eradication and reclamation program. Fast-growing native plants that will outcompete any surviving nonnative plants must be planted or released. Native plant seeds and seedlings are becoming increasingly available (http://plant-materials.nrcs.usda.gov/). If the soil seed bank remains intact, native plant communities may naturally reclaim many areas after nonnative plants are controlled. Constant surveillance, treatment of new unwanted arrivals, and rehabilitation of current infestations are the necessary steps in managing nonnative plant invasions.

CONCLUSIONS

We have learned much that can help us control invasive nonnatives in the future. An important point is that the cost of controlling nonnative invasives increases greatly the longer control measures are deferred. This suggests that the best approach might be to find ways to improve our ability to prevent invasions or to control invasions before they become crises.

Prevention

The entry and spread of invasive organisms could be stopped by effective legal and policy barriers. Such barriers could range from Federal, State, and county laws that prohibit importation to sanitation of equipment and vehicles before they leave infested zones.

It is helpful to examine opportunities to prevent intentional and unintentional introductions separately. Most invasive nonnative plants have been imported intentionally, in ignorance of their potential invasiveness. Yet, plant exploration and international seed exchange continues. Present regulations only examine incoming plant material for the presence of insect pests and pathogens or contamination with listed noxious weed seed. A system to test invasiveness of plant introductions was developed in Australia in the 1990s and has been helpful in addressing the problem (Mack and others 2000). Several such systems have been proposed (Reichard 2001).

Prevention of spread also requires examining the Internet sales of nonnative plants and animals. This remote means of mail order shipments of nonnative organisms will only increase the global problem. Retail sales within the United States of even federally listed noxious weeds like *I. cylindrica* persist with unproven sterility of cultivars being sold. Only a rapid phasing out of the sale of known invasive nonnative plants will halt the spread through commercial networks.

Unintentional introductions require a different approach. Inspection processes developed for agricultural products have inherent weaknesses in preventing the importation of forest pests. International trade agreements specify that import regulations will only address pests known to be present on the commodity in the exporting country, and for which a risk assessment has been performed. Provisional regulations can be adopted when insufficient data about the pest exist, but the risk assessment process must be initiated. The mitigation measures must be those that protect our resources with the minimum disruption of trade. Crop plants are similar the world over, and it is generally known which pests pose problems. When pests of natural ecosystems are considered, the major difficulty is in knowing which ones might prove invasive.

Biological and ecological characteristics of the pests themselves may render them particularly effective as nonnative invasives. Among these high-risk characteristics are a cryptic nature, which helps them avoid early detection, and extended diapause or dormant periods, which help them survive transit and quarantine. Other characteristics can also increase the probability of pest establishment. Asexual reproduction, for example, reduces the minimum population size needed to establish the pest in a new land. The presence of related hosts, usually at least

in the same genus as the original host, increases the risk that a pest will be successful. Importation in association with host material, such as nursery stock or seed, makes establishment much more likely. Additional factors suggested by Pimentel and others (2000) as contributing to pest invasiveness include a lack of natural enemies, an ability to switch to a new host, an ability to be an effective predator in the new ecosystem, the availability of suitable habitats, and high adaptability to novel conditions.

Unfortunately, the supposition that we will know or should know in advance which pests to study, assess as risks, and quarantine has not been borne out by historical experience with any introduced forest pest. Information about the biology and distribution of known pests could possibly be shared more effectively across international borders. However, only a small percentage of the insects and microbes that inhabit forest ecosystems have even been described to date (Campbell 2001). A different approach may be needed to regulate importation of articles likely to contain forest pests.

The present policy of the United States is that imported articles are "innocent until proven guilty." This has also been called the dirty list approach; it requires study of particular articles to prove that they pose an unacceptable risk. In contrast, the inverse policy of "when in doubt, keep it out," or clean list approach, requires study of particular articles to prove they are safe, prior to importation. This is a more conservative approach, but for all the reasons given above, it may be more appropriate to introduction pathways for forest pests. Studies to develop environmentally friendly and economically feasible standard treatments for major import pathways might prove a better investment than continuing to develop regulations on a country-by-country and pest-by-pest basis.

Detection and Monitoring

Detecting early entry is a main defense against unintentionally introduced harmful organisms. Improved detection technology is needed to reduce risk, as the sheer volume of international trade has overwhelmed the present regulatory system. Advances in molecular technology, such as real-time microarrays, which can test for the presence of up to 30,000 organisms in 15 minutes, need to be adapted for implementation on a broad scale. The expense of installing such systems at all ports of entry may seem exorbitant today because this technology is new. But as this technology becomes more widely used, its application to this critical interface may become economically feasible. Again, such technology is only effective against known pests. Monitoring is the basis for effective control and containment programs, both for targeting efforts where the organisms are located and for judging the effectiveness of control measures.

Control, Containment, or Management

Early detection can make it possible to eradicate invasive pests in specific circumstances. If eradication efforts prove ineffective, the next control efforts should be an attempt to provide containment; i.e., to stop the spread. Containment efforts can protect adjoining forests, counties, and States. At present, individual landowners must defend their properties through their own control activities. Sometimes interagency cooperation could be useful. An example of this is the interagency weed team concept U.S. Department of Agriculture, Animal and Plant Health Inspection Service developed to promote prompt eradication across land ownerships. Control methods include cultural methods, pesticide applications, sanitation, physical and mechanical control, and biological control. When invasive organisms cannot be completely controlled or eradicated, then cost:benefit or similar analyses are used to choose which infestations should be managed to minimize ecological degradation, human hazards, and economic loss.

Restoration

Unless affected forest ecosystems can be made more resistant, they will probably be reinvaded. It may be impossible to restore an affected ecosystem to its prior condition because of the residual influence of the pest infestation and because the ecosystem lacks resiliency. At present, it appears feasible only to establish plant components that are resistant to nonnative invasive organisms and leave it to natural processes, such as plant succession, to complete the process.

Research

The current situation with nonnative invasive organisms shows clearly that inadequate research has been applied and applied too late. The recent discovery that interspecific hybridization can occur when nonnative pathogens or nonnative and native pathogens meet (Spiers and Hopcroft 1994), highlights the urgency of further research.

Sometimes such interactions can result in new host ranges (Brasier and others 1999, Newcomb and others 2000) or increased aggressiveness (Brasier 2001). Only through research and technology development for each of the key elements of IPM and successful implementation of proven strategies may current invasions be halted and future invasions be prevented. Because our resources are limited, and the supply of invasive pests is virtually unlimited, landscape-level analyses should be used to learn which ecosystems are most at risk and to prioritize control efforts. Also, methods for screening plant introductions must be developed (Committee on the Scientific Basis for Predicting the Invasive Potential of Nonindigenous Plants and Plant Pests in the United States 2002).

Education and Extension

Informed individuals are needed to combat the invasive nonnative problem. Much of the problem from invasive organisms is perpetuated and exacerbated by an unaware and poorly informed populace. Our Federal Government was designed to react slowly to broad swells of concern raised by the constituency to the attention of its leaders. Managers can only react when they perceive the threat and have the resources, and the citizen consumer will stop spreading nonnative organisms when they are made aware of the dangers. Public education programs might be more successful if we inform the traveling public, in advance of their foreign travel, of the threat to our natural resources from smuggling forbidden products. Once they have made their purchases and packed them away in their suitcases, the option to ignore this issue is much more tempting.

Similarly, a proactive "plant natives" program (http://plant-materials.nrcs.usda.gov) might be easier to promote than the negative message "Don't buy nonnative pest plants." Beneficial characteristics of native plants, such as better adaptation to local climate, less irrigation requirements, and the joys of restoring natural ecosystems in your own backyard should be stressed in homeowner education programs. In fact, many Government land management agencies could set a good example by making improvements in their own landscape designs in this regard. The problem of fighting invasive nonnative pests seems overwhelming, but the war must be won one battle at a time.

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RELEVANT WEB SITES

Asian Longhorned Beetle

http://www.na.fs.fed.us/spfo/alb/index.htm

http://www.aphis.usda.gov/lpa/issues/alb/alb.htm

http://www.uvm.edu/albeetle/

Balsam Woolly Adelgid

http://fhpr8.srs.fs.fed.us/idotis/insects/bwa.html

http://www.ext.vt.edu/departments/entomology/factsheets/balwoade.html

http://fhpr8.srs.fs.fed.us/hosf/bwa.htm

Beech Bark Disease

http://www.na.fs.fed.us/spfo/pubs/fidls/beechbark/fidl-beech.htm

http://www.invasive.org/symposium/houston.html

Chestnut Blight

www.ppws.vt.edu/griffin/accf.html

http://www.apsnet.org/online/feature/chestnut

http://www.forestpests.org/southern/Diseases/chsntblt.htm

http://www.forestpests.org/southern/

http://www.srs.fs.fed.us/pubs/rpc/1999-03/rpc_99mar_33.htm

Dogwood Anthracnose

http://www.na.fs.fed.us/spfo/pubs/howtos/ht_dogwd/ht_dog.htm

http://fhpr8.srs.fs.fed.us/pubs.html

Dutch Elm Disease

http://www.na.fs.fed.us/spfo/pubs/howtos/ht_ded/ht_ded.htm

http://www.fs.fed.us/na/morgantown/fhp/palerts/ded/elm.htm

http://www.ext.nodak.edu/extnews/askext/treeshr/1423.htm

Nonnative Plants

http://www.se-eppc.org/

http://www.aphis.usda.gov/ppq/weeds/ (Federal Noxious Weed Program)

http://www.nrcs.usda.gov/technical/invasive.html (Natural Resources Conservation Service's Web sites related to invasive plants)

http://tncweeds.ucdavis.edu/handbook.html (The Nature Conservancy's Weed Methods Control Handbook)

General Nonnative Forest Species Information

http://www.pestalert.org/

http://spfnic.fs.fed.us/exfor/

http://www.forestryimages.org/ (for forest health images)

http://www.ceris.purdue.edu/napis/ (National Agricultural Pest Information System Web site)

http://www.invasivespecies.gov/

http://www.invasive.org (photos of invasive nonnative species)

General Web Site

http://www.issg.org/database/welcome/ (Global Invasive Species Database)

Gypsy Moth

http://na.fs.fed.us/wv/gmdigest/

http://www.gmsts.org/operations (Slow-the-Spread Web site)

http://www.gypsymoth.ento.vt.edu/vagm/index.html

http://www.fs.fed.us/ne/morgantown/4557/gmoth/

Hemlock Woolly Adelgid

http://www.fs.fed.us/na/morgantown/fhp/hwa/hwasite.html

http://www.ento.vt.edu/~sharov/hwa/

Sources of Native Plants for Reclamation

http://www.plant-materials.nrcs.usda.gov/

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