Alien Forest Insects and Diseases in Eastern USNPS Units: Impacts and Interventions

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Eastern North America contains one of the most extensive temperate deciduous forests on the planet, extending from southern Canada south to Florida and west to eastern Texas and Minnesota. The only other major regions to be dominated by similar vegetation in the northern hemisphere are in western and central Europe, and eastern Asia (Goode, 1974).

Botanists and biogeographers have long been intrigued by how closely related these distant floras are to one another, with many of the same genera in common and even some of the same species. While these extreme disjunctions are known for a few vascular plants at the species level, they are not at all uncommon for some non-vascular groups such as bryophytes (Allendorf, 1983).

As closely related as these forested regions appear to be, they may have been separated for approximately 10-20 million years (Matthews, 1978). The trees' associated species have probably changed, including those that form parasitic relationships.

Native forest trees in eastern North America have a number of native parasitic insects and fungal pathogens with which they have coevolved (Hepting, 1971). Classically, these organisms are at low population levels only, or reach levels high enough to be lethal to their hosts only when a special set of factors, including recent climate, site characteristics, and status of their own predators and parasites, are met. Most parasites from other continents that have been introduced into eastern North America have probably perished from lack of compatibility with primary host, alternate host, climate, native predators and parasites, or other factors.

Unfortunately, some forest insect and fungal species from other continents have become established all too well here, to the detriment of native forest species. These alien or exotic species pose some of the most difficult challenges to managers of natural areas in eastern North America.

Since these species are usually adapted to a closely related host, they can spread throughout a region and often throughout the entire range of their new host. The American host sometimes possesses no or only ineffective resistance mechanisms. With high populations of the pest, whole stands and ultimately all stands of the host can become infected. With no resistance to this attack, the host dies over large areas, although a common result is an overwhelming reduction in population and reproduction of the affected species, without extirpation. The impact of these losses, however, should be measured not only in *severity* but in *duration.* With only a few years or decades since these pests became widespread, the hosts' long-term survivability is unknown.

This paper examines some of the significant alien insects and fungal diseases that attack eastern U.S. forests. Specific impacts at Great Smoky Mountains National Park are noted, along with suggested management strategies.

ALIEN FOREST INSECTS AND DISEASES OF CONCERN

Table 1 (p. 4) shows ten eastern native tree species that are at risk of significant decline, the alien species responsible, and home range of the pest. It may not be a coincidence that these are all species valued for ornament, shade, timber, or other products. Society's desire to acquire trees with these same characteristics and uses has meant the importation over the years of hundreds of thousands of Asian and European tree seeds and seedlings of the same genera. Chinese chestnut blight, balsam woolly adelgid, Dutch elm disease, and others arrived in North America in this manner. Biological diversity usually yields relative stability in natural communities; interestingly, with eastern North American trees and their imported Eurasian kin, it may also mean eventual vulnerability.

Great Smoky Mountains National Park is a 209,000-hectare natural area in Tennessee and North Carolina that is renowned for its trees, both for number of species (130), and the fact that approximately 57,000 hectares of the park is old-growth forest (Tyrell, 1991). Old-growth forest is a rarity in the eastern United States, but Great Smoky Mountains has more of this uncut forest left than any other site east of the Great Plains (Davis, 1990). Table 2 (pp. 6-7) shows selected USNPS units and some native forest trees at risk of decline due to alien insects or diseases.

White pine blister rust This fungus was accidentally brought into eastern North America about 1898 by agencies involved in reforestation efforts, who had sent eastern white pine seeds to Germany to be reared into seedlings and then shipped back for reforestation (Anderson, 1990). Many alien insects and diseases were inadvertently brought in before such impacts were known,

Table 1. Selected Alien Forest Pests—Eastern North America

Native Host Species	Alien Pest	Original Range of Pest
Fraser fir *(Abies fraseri)*; also *A. balsamea*	balsam woolly adelgid *(Adelges piceae)* • insect	Europe, Asia
sugar maple *(Acer saccharum)*; others	pear thrips *(Taeniothrips inconsequens)* • insect	Europe
American chestnut *(Castanea dentata)*; some oaks; chinquapins	Chinese chestnut blight *(Endothia parasitica)* • fungus	Asia
flowering dogwood *(Cornus florida)*; other American *Cornus*	dogwood anthracnose *(Discula destructiva)* • fungus	probably East Asia
Butternut *(Juglans cinerea)* or white walnut	butternut canker *(Seriococcus clavigineti-juglandacearum)* • fungus	unknown; most *Juglans* in Asia , South-Central Europe
eastern white pine *(Pinus strobus)*; also some western five-needled pines	white pine blister rust *(Cronartium ribicola)* • fungus	Europe
Oaks *(Quercus* spp.*)*; many other genera such as *Acer, Betula, Carya, Populus*	gypsy moth *(Lymantria dispar)* • insect	Europe, North Africa, Asia
American mountain ash *(Sorbus americana)*	European sawfly *(Pristiphora geniculata)* • insect	northern Europe
eastern or Canadian hemlock *(Tsuga canadensis)*; also *Tsuga caroliniana*	hemlock woolly adelgid *(Adelges tsugae)* • insect	East Asia
American elm *(Ulmus americana)*; other eastern elm species	Dutch elm disease *(Ceratocystis ulmi)* • fungus	Europe, Asia

and more careful customs inspections instituted. All North American five-needled species are susceptible to white pine blister rust (Johnson, 1990).

A massive program on federal lands in the Appalachians from the 1930s to the 1960s attempted to eradicate *Ribes* spp. shrubs within 275 meters of significant stands of eastern white pine. In Great Smoky Mountains, at least 150,000 *Ribes* spp. shrubs are known to have been pulled or treated with herbicide during that period. This is probably a conservative estimate since records from the time are incomplete. Current observations at Great Smoky Mountains indicate only minor effects to eastern white pine from blister rust.

Chinese chestnut blight The well-known story of its introduction into New York City and disastrous spread into the Appalachians will not be retold here. The American chestnut is the largest species of its genus, and it occasionally reached trunk diameters of nearly three meters in the southern Appalachians. This was one of our dominant mid-elevation trees, producing abundant mast crops reliably each year. *Not a single mature tree remains,* although specimens that were seedlings and saplings at the time of infestation in the 1920s and 1930s still resprout only to be killed at ground level again before producing nuts. This disease commonly infects scarlet oak *(Quercus coccinea),* causing basal defects of the bole, and kills Allegheny and Ozark chinquapin *(Castanea pumila and C. p. ozarkensis).*

Dutch elm disease This fungus was first found in the United States in Cleveland, Ohio, and New York City in the 1930s, where veneer logs from Europe had been imported (Anderson, 1990). The fungus is dispersed from tree to tree by both introduced (European) elm bark beetle and the native American elm bark beetle *(Hylurgopinus rufipes).* The disease moved south and west across the United States, killing millions of American and other elms native to the region. In Great Smoky Mountains, the disease was seen in the mid-1960s and began a resurgence in the late 1980s. American elms in the park are now at very low numbers, with most remaining trees infected.

Balsam woolly adelgid This small, cottony insect was introduced into Nova Scotia and Maine just after the turn of the century and spread into the southern Appalachians around 1950 (Eagar, 1984). The insect is dispersed on the wind in its first instar, which is its only mobile stage. The adelgid feeds by inserting its mouthparts into the bark, causing cell hypertrophy and thereby disrupting translocation of fluids within the tree. Mortality can occur within 2-7 years of infestation (Johnson, 1980). Although balsam fir and some Pacific northwestern *Abies* spp. are also at risk, Fraser fir appears to be the most acutely affected. European silver fir *(Abies alba),* which coevolved with the adelgid, is able to tolerate infestation by compartmentalizing wounded tissue at the feeding site (Kloft, 1957).

Fraser fir is restricted to several small mountainous areas in Virginia, North Carolina, and Tennessee. About 74% (19,717 hectares) of all spruce-fir forest in the southern United States is in Great Smoky Mountains (Dull *et al.,* 1988). Since its discovery in 1963 in Great Smoky Mountains, the adelgid has killed almost all the adult fir in the park. Only four mountain peaks in the highest elevations still have small remnants of mature fir forest, and this will succumb in the next few years. Trees do not become significantly infested until about twenty years of age, which is also about the age at which they first begin to produce seed crops. Research is underway to determine if the Fraser fir

Table 2. Some Species at Risk in Selected USNPS Units

	Juglans cinerea	*Tsuga canadensis*	*Ulmus americana*	*Cornus florida*	*Castanea dentata*	*Acer saccharum*	*Quercus* spp.
North Atlantic							
Cape Cod							•
Acadia		•	•			•	•
Saratoga		•	•		•	•	•
Morristown	•		•	•	•	•	•
Fire Island							•
Gateway		•	•	•			•
Rocky Mountain							
T. Roosevelt			•				
Wind Cave			•				
Badlands			•				
Mid-Atlantic							
Colonial			•	•			•
Shenandoah	•	•	•	•	•	•	•
Del Wat Gap	•	•	•	•	•	•	•
Valley Forge			•	•		•	
New River	•	•	•	•	•	•	•
Richmond			•	•			•
Allegheny Pg	•	•	•	•	•	•	•
Johnstown	•	•	•			•	•
Assateague I				•			•
Southeast							
Cp Hatteras			•				•
Blue Ridge	•	•	•	•	•	•	•
Grt Smoky	•	•	•	•	•	•	•
Shiloh			•	•	•	•	•
Cumb'l'd I			•				•
Congaree			•	•		•	•
Big So Fork	•	•	•	•	•	•	•
Mammoth C	•	•	•	•	•	•	•
Obed River	•	•	•	•	•	•	•
Natchez Tr	•		•	•	•	•	•
Cumb'l'd Gp	•	•	•	•	•	•	•

	Juglans cinerea	*Tsuga canadensis*	*Ulmus americana*	*Cornus florida*	*Castanea dentata*	*Acer saccharum*	*Quercus* spp.
Ft Donelson			•	•		•	•
Everglades							•
Chick-Chatt			•	•	•	•	•
Ft Caroline				•	•		•
Big Cypress							•
Cp Lookout				•			•
Horeshoe Bd	•			•			•
Midwest							
Pipestone			•				
Voyageurs			•				
Slp Bear Du	•	•	•		•	•	•
Cuyahoga V	•	•	•	•	•	•	•
Ozark River	•		•	•		•	•
Pictured Rck		•	•			•	
Effigy Mnds	•		•			•	•
Isle Royale			•			•	
Ind Dunes	•		•	•	•	•	•
Wilson's Cr			•			•	•
G W Carver			•				
Apostle Islds		•				•	•
National Capital							
Catoctin	•	•	•	•	•	•	•
Antietam			•	•		•	•
Manassas		•	•	•		•	•
Rock Creek	•		•	•	•	•	•
Pr William				•	•		•
G Wash Pky		•	•	•	•		•
Southwest							
Big Thicket			•	•		•	•
Jean Lafitte			•				
Hot Springs			•	•			•
Buffalo River			•	•		•	•
Big Bend							•

Note: *Sorbus americana* is at risk in Acadia, Shenandoah, Delaware Water Gap, Blue Ridge Parkway, Great Smoky Mountains, Voyageurs, Pictured Rocks, and Apostle Islands. Source: NPFLORA, GIS Division, USNPS, Denver, 1992.

will remain a viable part of the park ecosystem.

Gypsy moth This is currently the most publicized alien in eastern forests. The moth escaped in Medford, Massachusetts, in 1869 and has slowly spread west and south so that it now generally infests a large region from New England west to Michigan and south to North Carolina. Much has been published on this pest (USDA–Forest Service, 1981) and millions of dollars expended. About 100 old-world parasites of the gypsy moth have been released in eastern North America; several have become widely established, but effective control has been minimal. Although earlier instars of the larvae favor some tree species over others, later instars are voracious and will consume the foliage of all but a few eastern tree species, especially when high larval populations are reached (USDA–Forest Service, 1981). High populations occur in oak-dominated forest stands. Outside the generally infested zone described above, isolated outbreaks (usually one to several thousand hectares in size) are eradicated upon detection. There has been a trend in the last 10-15 years to switch from aerially applied broad-spectrum insecticides to target-specific agents. Currently a bacterium *(Bacillus thuringensis)* is the agent most commonly used to suppress or eradicate gypsy moths; it was used on 68% of the 460,000 hectares treated in 1991. Unfortunately, it is lethal to all early instar lepidopteran larvae. Much interest is now centering on developing adequate supplies of a viral product (Nucleopolyhedrosis virus, or NPV) that is specific to *Lymantriidae,* the family in which gypsy moths and tussock moths are classified.

Beginning in the 1980s, populations of gypsy moth have been discovered nearly all around Great Smoky Mountains in the southern Appalachians. All the "spot infestations" have been or are being eradicated. Approximately 38%, or 80,000 hectares, of the park may be susceptible to significant defoliation, based on work by MacKenzie (1991). About 12,000 hectares is probably old growth, perhaps the largest amount of old-growth oak left in eastern North America (as derived from Pyle, 1985).

Dogwood anthracnose This fungus was first found near Chehalis, Washington, in the mid-1970s on *Cornus nuttallii,* the Pacific dogwood. Dying flowering dogwoods were reported in the New York City area in 1978 (Pirone, 1980). Like some native fungi, dogwood anthracnose forms numerous lesions on leaves but then grows into twigs and branches. Trees die over 3-5 years, usually from the ground up. Cool, moist habitats favor the growth of the anthracnose; in such areas stands of 1,000 stems per hectare can die without a single surviving tree or seedling. By 1982 it was found in the Blue Ridge of Maryland (Mielke and Langdon, 1986), and in 1987 was found in northern Georgia and western North Carolina. In the southeastern United States it appears to be relegated to mountainous and upland regions. By 1991 dogwood anthracnose had been laboratory-verified from 126 counties in the southeastern United States. Dogwood anthracnose was not confirmed in Great Smoky Mountains until 1988. Baseline monitoring plots were established that same year across the entire park, and showed almost 60% of the plots to be without the fungus and another 27% to be lightly infected. Annual monitoring clearly shows a decline within dogwood plots; by 1991 only 15% were uninfected, while 65% were now in severe epidemic (Windham, Montgomery, and Langdon, 1992).

Butternut canker A detailed and thorough monograph on fungal diseases of butternut in 1923 (Graves, 1923) failed to find any trace of this canker disease, which is now crippling the tree almost rangewide. The U.S. Forest Service Forest Pest Management section has found an 80% decrease in butternut in South Carolina and North Carolina in the last twenty years of its forest inventory program (Anderson, 1990). The fungus enters the trunk, branches, twigs, and even the nuts and forms a small canker up to about 10 centimeters in length. The fungus completes it life cycle in one year, but reinfects the last tree, often at wounds left by previous cankers. Mortality appears to be more the result of a chronic decline rather than acute attack. More alarming is the apparent suppression of nut crops by fungal activity within the immature nut, and subsequent abortion. At Great Smoky Mountains, seventy butternut trees have been monitored for four years, with only a small number of nuts produced in a single year; almost all were on two vigorous trees in full sun.

European mountain ash sawfly It is known to occur in Europe and Asia as well as North America, where it was first recorded in 1926 at Haines Falls, New York. By 1964 the sawfly had been observed throughout New England and southern Canada, west to Michigan, and south to Pennsylvania (Forbes and Daviault, 1964). Isolated but severe defoliations of American mountain ash were found in the southern Appalachians in the 1980s. The larvae feed gregariously and exclusively on American mountain ash and can completely strip a tree of foliage by the time feeding peaks in August. The resulting reduction in tree vigor is particularly critical in the habitat of mountain ash where growing seasons are short (i.e., high elevations and northern geographical areas).

Mountain ash has been declining in recent years in Great Smoky Mountains. Throughout most of its high-elevation habitat, trees are dying back from the crown and many have died completely. Decline syndromes are often a combination of such stress factors as repeated defoliation, poor air quality, adverse weather, and habitat degradation. (In the case of the mountain ash, the loss of the Fraser fir component is probably a factor.) While the exact cause of death is unknown, a four-year study of plots in the spruce-fir forests showed 45% mortality of mountain ash (Durr, pers. comm., 1991).

Hemlock woolly adelgid This adelgid is in the same genus as the balsam woolly adelgid *(Adelges)* and is believed to be an East Asian insect. First found on *Tsuga* spp. on the Pacific coast of North America, it caused little damage to natural areas. An introduction into the mid-Atlantic states, however, is causing widespread injury and loss (McClure, 1987), and it has recently entered Connecticut and Massachusetts. The insect is spread by wind, arboreal foraging birds, and many other means. In Shenandoah National Park in Virginia, work on conifers did not reveal any hemlock woolly adelgids in 1980, nor were these insects found during searches for it in 1985 at Catoctin Mountain Park in Maryland. By 1992, hemlock in both parks were infested. At Shenandoah, 88% of hemlock stands have the adelgid (Keith Watson, pers. comm., 1992). In early 1991 it was located as far south on the Blue Ridge Parkway as Floyd County, Virginia, near the North Carolina border (USNPS, 1992). The insects exhibit mass feeding behavior at the base of hemlock needles, which generally weakens the tree, although trees can die in one year (McClure, 1987). On the Blue Ridge Parkway in Virginia, this pest has also been found attacking the Appalachian endemic Carolina hemlock *(Tsuga caroliniana)*. Great Smoky Mountains probably does not have the hemlock woolly adelgid at this time, but the park is thought to contain some of the largest old-growth Canadian hemlock stands remaining anywhere, and an inventory is in progress.

Pear thrips This small winged insect was first found on pears in California in the 1920s and on sugar maples in New England in 1979. It is also known to feed on other trees, including the following genera: *Betula, Fraxinus, Pinus,* and *Fagus* (USDA–Forest Service, 1989). It feeds on buds in late winter and early spring, but its effects are not noticed until later. Feeding by pear thrips damages a maple's foliage as well as the next year's buds, reducing the tree's ability to manufacture food and causing branches to die back. This has created great concern in the New England sugaring industry. In 1988 it damaged 189,000 hectares of sugar maple in Vermont (Vermont Agency of Natural Resources, 1988). The thrips are now in the mid-Atlantic states, but varying populations make it difficult to detect and track. This pest is not currently known from the southern Appalachians, but abundant hosts (including old-growth stands) and favorable climatic conditions make its spread here likely.

SPECIAL PROBLEMS IN THE MANAGEMENT OF ALIEN FOREST INSECTS AND DISEASES

Native or alien? Some of the pests discussed above are not *absolutely* known to be introduced. This is not as remarkable as it may first appear, given that most in this category are fungi, which are not as well known as insects. In their home range these fungi may be very inconspicuous and during early expansion in North America may have initially resembled the irruption of native fungal diseases. An assessment of all available information, however, usually presents a pattern of first-time colonization. Historical reports of outbreaks—or the lack of them—and monographs of tree diseases by U.S. Department of Agriculture workers early in this century are invaluable, yet 100% confidence in assigning non-native status may not be possible. Delaying all actions until the origin is known is not necessary nor in the best interest of threatened resources. Use of legal standards of action prove useful. Detection and monitoring should be started after consultation with a forest pathologist establishes that there is a "reasonable suspicion" that a disease may be a recent introduction. No suppression actions should be undertaken unless evidence accumulates beyond reasonable scientific doubt.

Detection Not all forest insect and disease infestations are apparent on the landscape, even when the host is undergoing rapid loss and decline. The insidious character of these infestations is usually related to the abundance and habitat type of the host, and also to the speed at which decline of individual trees occurs.

Most insects and diseases require initial identification or at least verification of identification by specialists. Fungi will sometimes have to be cultured in a laboratory before taxonomic classification is certain. Newly discovered diseases must undergo a pathological verification process known as Koch's Postulates (Anderson, 1989). Dogwood anthracnose, known since the 1970s, was not scientifically described as a new species, *Discula destructiva,* until 1991 (Redlin, 1991). This was especially confusing since a number of varieties were being described. The U.S. Forest Service's Forest Pest Management (FPM) offices and state universities, which may be reached through local cooperative extension service offices, are the best sources of assistance in detection and verification.

Monitoring If the decision to begin monitoring a tree species has been made, consultation with the regional FPM office is essential. Most insect and fungal diseases have already had standardized monitoring methodologies established. Those that have not should be patterned after monitoring protocols for similar pests, again in consultation with FPM.

At a minimum, monitoring should be designed to detect loss of, and, if possible, decline in, the host species. Sensitivity to detecting host decline is critical when dealing with pathogenic fungi, since quantification of their populations is extremely difficult. Insect populations can be sampled during the most apparent life stage, i.e., egg masses, larvae, pupae, or adult, and a number of techniques have been published for some species (Doane and McManus, 1981). Multiple sampling methods can be used, but when the pest has more than one generation per year (e.g., balsam woolly adelgid), proper timing is critical for reliable data. If possible, reproduction in the host, site changes, and alteration of ecological processes should also be considered when scoping out potential issues for inclusion in monitoring.

The numbers of some host trees have been so decimated from their natural levels that associated native species, especially taxa obligate on the host, are much reduced or presumed extinct. Such is the case with the American chestnut. Several insects known to be closely associated with the tree have not been found in recent decades (USFWS, 1984). In another example, eight species of nationally rare bryophytes are threatened with extirpation at Great Smoky Mountains due to the loss of their obligate substrate, mature Fraser fir (Smith, MacFarland, and Davison, 1991). If possible, an inventory of obligate species should be undertaken, and those taxa prioritized for monitoring. The Natural Heritage Office in each state capital should be able to provide guidance on rarity ranking and prioritizations.

Interventions Before making the decision to intervene in a natural area to protect resources, USNPS Integrated Pest Management policy requires that we identify both the level of intolerable injury to the host, and the point in pest levels where action needs to be taken to prevent significant injury from occurring. Direct suppression, changes in habitat, or both may also be incorporated into pest management, but the most target-specific, effective actions should always be chosen. The U.S. Forest Service FPM offices have been given the coordination and funding role for emergency suppression of forest insect and disease pests on all federal lands. Their role is to help agencies meet the particular land management objectives of the affected park, forest, refuge, or military installation. Funding is received by a benefitting agency only after it has submitted a prioritized list of projects and the local FPM office has completed a biological assessment of each project. These monies can be used for actual suppression and for pre- and post-treatment monitoring of pest and host. They *cannot* be used for research, environmental assessments, or other purposes, as per interdepartmental agreement.

Conventional use of biocides, especially target-specific agents, are useful for delaying the loss of threatened hosts when other production techniques are on the horizon, or when the need for a biocide is strongly cyclical. Undertaking a long-term protection program based solely on the application of biocides is usually defensible only in special situations involving resources of extreme value or the establishment of "micro refuges" of the host (see the "Special Ecological

Areas" concept in USNPS Guideline NPS-77).

Use of biological control agents has been successful against many alien insects, but not against many fungi. Classical biocontrol reunites an alien pest with its natural predators and parasites from which it was released by being imported into the new continent without them, or by their having been lost during the initial colonization. It is not a panacea, but should be applied to more forest pests. The process is expensive and takes years to develop before organisms are ready to be released with confidence that the introduction will not be detrimental to non-targets. Much coordination is required between federal and state agencies. The U.S. Department of Agriculture's Agricultural Research Service is one of the coordinating agencies.

Increasingly, effecting genetic changes in hosts is being attempted as a long-term intervention to protect native forest trees from being lost to disease. Usually this has been an effort to develop a superior breed of tree for commercial use. Often the result is a general-purpose cultivar that has undergone a significant reduction of genetic material from its natural state.

Searching for resistant host individuals is a worthwhile endeavor and should be done in areas with the heaviest infection. "Resistant" trees get infected but survive, although in varying degrees of vigor, while "immune" trees (those individuals that *cannot* get infected) are almost never encountered. Putatively resistant trees should have scions taken from them and grafted or rooted, in a horticultural setting, to facilitate screening verification of resistance. If resistant, propagation should be strongly considered, both to disseminate the resistant stock through the wild population and for further breeding work. Putatively resistant flowering dogwoods found at Catoctin Mountain Park, and butternut from throughout its range, are currently undergoing screening (M. Windham, pers. comm., 1991; Minnesota Department of Natural Resources, 1990).

Using Old World trees of the same genera as the threatened tree to bring in resistance in a hybrid was tried unsuccessfully with American and Oriental chestnuts species early in the century. Some workers believe these efforts used strategies that doomed them to fail, and a new breeding strategy (Hosier, Burnham, and Read, 1985) has been developed that is being pursued by the American Chestnut Foundation in Minnesota and Virginia. This strategy starts with an initial cross of American and Chinese chestnuts, but their progeny get "back-crossed" to other American chestnuts for three generations, being inoculated and evaluated for resistance at each generation. Finally they are interbred as a group and screened for resistance once more. The result is a *population* of chestnuts that are about 95% American, yet contain the resistance of the Oriental parent. The Foundation has second back-crossed progeny under cultivation at this writing, and most physical characters expressed, even at this stage, are American.

Managers of natural areas need to be aware that native tree species that have undergone hybridization in the above manner may still not be suitable for re-introduction into natural zones. It is to be hoped that embryonic screening for resistance can speed up the current generational time for each screening (approximately five years), so that additional back-crossed generations can remove all significant traits of the exotic parent. Some major universities and non-governmental organizations such as the American Chestnut Foundation offer excellent opportunities to cooperatively develop resistance for park species at risk—but currently about twenty years is required to produce the resistant group.

Beyond intervention If the alien forest insect or disease problem is so acute that most or all of the host will be lost in spite of intervention alternatives, *ex situ* preservation should be considered. This is being accomplished now for Fraser fir. The U.S. Forest Service also is planning to collect flowering dogwood seed from southeastern National Forests at risk for dogwood anthracnose for germination and protection at a site where the fungus will not thrive or be controlled chemically (R.L. Anderson, pers. comm.).

Another last-ditch step is to quickly and comprehensively document the life history and role of the host before it is diminished. Such studies should include a quantified characterization of primary and marginal habitats, distribution, phenology, and breeding systems. Long-term monitoring of plots containing the host will eventually elucidate the taxa that replace it at formerly dominated sites. At Great Smoky Mountains, studies of Fraser fir, American chestnut, flowering dogwood, American mountain ash, and butternut either have been completed, are underway, or are planned.

By helping understand the role of missing pieces, this information may contribute to successful future re-introduction programs and studies of natural systems.

SUMMARY

Alien forest insects and diseases have had and are having a major impact on natural zones in many eastern USNPS units. Despite devastation of some species, some pest problems are not easily recognized and certainly not easily managed. A process exists for receiving funding for suppression, in cooperation with the U.S. Forest Service, but biocontrol and breeding of resistance into native species has not been undertaken in earnest, although many federal, state, and non-governmental organizations are interested in the same general aims of such projects.

Unfortunately, park efforts may only be able to focus on characterizing the ecological role of a soon-to-be-diminished native tree species. One can only hope that development of advanced technologies in upcoming decades will allow mitigation and re-introduction actions.

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