Exotic Pests *of* Eastern Forests

USDA Forest Service &
TN Exotic Pest Plant Council

CONFERENCE PROCEEDINGS

April 8-10, 1997 Nashville, TN

Exotic Pests *of* Eastern Forests

CONFERENCE PROCEEDINGS

Presented by:

Tennessee Exotic Pest Plant Council
USDA Forest Service

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Proceedings
Exotic Pests of Eastern Forests Conference

INTRODUCTION

Invasive exotic pest plants, diseases, and insects, have had a dramatic impact on the health and composition of the Eastern forests for many decades. Chestnut blight was discovered in the United States in 1904. Since then, it has virtually destroyed the chestnut population, which once occupied 25 percent of the eastern forest.

In the 1860's, the gypsy moth was accidentally released in Massachusetts. Since then, it has become established in 16 states, and for most of the past 15 years, has defoliated a million acres of hardwood trees each year.

Kudzu was introduced into the United States in 1876, and later distributed to many states in an effort to control agricultural erosion. It did not control erosion; rather, it became one of the most serious pest plants in the southeast, where it now covers seven million acres.

The Exotic Pests of Eastern Forests Conference was developed to make the audience more aware of the many invasive exotic pests in eastern forests, and the impact which they have had on the ecosystem; and to warn the audience of the potential devastation that could occur if prevention and control measures are not developed and utilized soon.

In selecting topics for the Conference, we attempted to address the most serious invasive exotic insect and disease forest pests of the east. However, we emphasized invasive exotic pest plants—because we felt that insects and diseases have had much more "press" over the years, and a large percentage of the audience would be unfamiliar with most of the pest plants discussed. Therefore, about 50 percent of the papers are specific to pest plants; of the remaining papers, about two-thirds are specific to insects or diseases, and one-third address all three categories.

Based on attendance, the many enthusiastic comments, and participation, the Conference was an outstanding success. The primary reason is the quality of speakers. The Planning Team made a special effort to find people who are authorities in their field of expertise, and who are also top quality speakers. We thank each and every one of them for accepting, and for their superb presentations.

At the close of the Conference, the attendees and participants felt that the administrators of the US Departments of Interior and Agriculture should be alerted to the concern which was shared at the Conference; i.e., the seriousness of the exotic pest problem, and they requested an interdepartmental team to provide guidance and support. To this end, a letter addressing those issues has been prepared and will be sent to the Secretaries of those departments, and to Vice-President Gore, who has expressed concern about this issue.

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EXOTIC PESTS OF EASTERN FORESTS PROCEEDINGS

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BIODIVERSITY AND THE EXOTIC SPECIES THREAT

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Abstract. Exotic species invasions, called by one conservation biologist the "least reversible" of all human impacts, cause harm to economies (e.g., fisheries, wildlife populations, tourism), the environment (e.g., in the form of broadcast of pesticides and herbicides), human health and well-being (e.g., allergic responses and the increase in fire severity in some landscapes), and aesthetics (e.g., the amount of mortality in vegetation). These invasions threaten biological diversity by causing population declines of native species and by altering key ecosystem processes like hydrology, nitrogen fixation, and fire regime. The earth is essentially a loaded gun of exotic species problems because (1) evolution in isolation has produced continents with a similar range of environmental conditions but a very different array of species and (2) species generally have an ability for exponential increase, particularly when removed from natural controls on their population growth. As a result, the problem is a global one—the exotic species problem is neither trivial nor transitory. The human-caused mixing of formerly isolated biota stems from a failure to base decisions on the ecological and coevolutionary setting or organisms. We must employ many methods from our management tool box: eradication, containment, biocontrol, monitoring, and, most importantly, prevention.

Introduction

In 1958, the British ecologist C. S. Elton (1958) called dramatic attention to the exotic species problem when he wrote:

> We must make no mistake: We are seeing one of the great historical convulsions in the world's flora and fauna. We might say, with Professor Challenger, standing on Conan Doyle's 'Lost World,' with his black beard jutting out: 'We have been privileged to be present at one of the typical decisive battles of history—the battles which have determined the fate of the world.'

The convulsion that Elton described was the relatively sudden mixing of formerly isolated biota because of purposeful and accidental transport by people. Although I focus today on impacts to natural areas, exotic pests cause a wide range of problems for human economies and even human health (Mooney and Drake 1989, Pycek et al. 1995). These include impacts on: forests, rangeland, lakes, streams, water quality, fisheries, and wildlife populations; aesthetic values that influence the tourism industry; the economic and environmental costs of pesticide use; human health (e.g., allergic reactions to gypsy moth frass); and human life and property (e.g., the possible influence of exotic species on recent fires in residential areas of Berkeley, California, Reichard and Campbell 1996). Exotic species also pose a severe conservation problem—they are one of five major and interacting threats to biological diversity. The other four are: habitat loss and fragmentation, chemical and physical alteration of environment, change in natural process (e.g., hydrology and fire regime), and direct harvest of individual species. Exotics threaten natural areas by reducing or eliminating populations of native species and by altering key ecosystem processes (Vitousek 1990). Devine (1994) suggested that more habitat was lost in South Florida each year to exotics than to development. Coblentz (1990), noting the difficulty of eliminating established populations, called the exotic species problem the least reversible of all human impacts.

In this paper, I will present a general context for the exotic species problem, showing that the earth is a loaded gun of potential exotic species problems--the problem is neither trivial nor transitory. I define the range of impacts caused by exotic plants and suggest policy, research, and management issues that we must face.

The evolutionary backdrop to exotic species problems: evolution in isolation, exponential increase, and coevolution

Two observations figured prominently in the thinking of Charles Darwin as he sought an explanation for life's diversity: First, places that have similar climates but have been long isolated from each other, have different biota and, second, all species have the ability for exponential increase in population numbers given the right circumstances.

As naturalist on the Beagle, Darwin puzzled over the fact that two deserts with similar soils, temperature regime, and precipitation, would have entirely different plants and animals:

> In considering the distribution of organic beings over the face of the globe, the first great fact which strikes us is, that neither the similarity nor the dissimilarity of the inhabitants of various regions can be wholly accounted for by climatal and other physical conditions....There is hardly a climate or condition in the Old World which cannot be paralleled in the New...[yet] how widely different their organic productions [i.e., their species]! A second great fact which strikes us in our general review is, that barriers of any kind, or obstacles to free migration, are related in a close and important manner to differences between productions of various regions.

Interruptions to gene flow, combined with founder affects and historical isolation of lineages, produces this pattern. Continental and other separations are a mechanism that increases the biological diversity of the earth. Preston (1962) published figures that showed that the total number of birds on the planet was at least four times higher than you would predict from the species-area relation for each separate continent. In other words, if you extrapolated from the data for a single continent to an area equivalent to the summed terrestrial habitat of the earth, you would predict a species total only 25% the observed total. Continental isolation is indeed a potent generator of species diversity.

All those additional species on a separate continent, however, become the potential invaders of today's world. For any given climate, there is a place somewhere on another continent with a similar environment that harbors organisms that are potential exotic invaders. For eastern North America, the biggest source area is the humid temperate lands of the other major North Temperate continent:

east Asia. Since east Asia suffered fewer extinctions during the Pleistocene than eastern North America, the potential list of invaders from that area is very high. An added problem is that east Asian and eastern North American have species descended, in part, from the same ancestors, thus creating an added problem: the chance for hybridization between closely related Asian and American taxa and the exchange of pathogens that are adapted to particular genera or even sections within a genus that are found in the two areas. I return to this subject below when I discuss the coevolutionary paradigm.

Ecologist Gordian Orians coined the term "Homogecene" for the modern era in which humans are tending to homogenize the world's flora and fauna through transport across once insurmountable barriers. Much of the transport is purposeful: Reichard and Campbell (1996) reported that, of 235 invasive woody plants in North America, 85% were introduced for ornament and landscape purposes. Other introductions have been made for reducing soil erosion or supporting wildlife populations. While many have written that introductions are accidental, Cairns and Bidwell (1996) noted that "careless" was a better description than "accidental."

Elton (1958) noted that the isolation of biota, at least in terms of higher taxonomic levels, was not constant through the geological record (we would later find the explanation in continental drift and changing climates):

> ...in the very early times, say 100 million years ago in the Cretaceous Period, the world's fauna was much more truly cosmopolitan, not so much separated off by oceans, deserts, and mountains. If there had been a Cretaceous child living at the time...he would have read...'Very large dinosaurs occur all over the world except in New Zealand'...There would have been much less use for zoos.

By implication, if the world's flora was more homogeneously distributed across the continents, there would be little need for botanical gardens to display odd, unusual, or unknown species.

Darwin's second observation was that all species "overproduced" young—that is, they all had a potential for exponential increase:

> There is no exception to the rule that every organic being naturally increases at so high a rate, that, if not destroyed, the earth would soon be covered by the progeny of a single pair...The elephant is reckoned the slowest breeder of all known animals...[yet] after a period of from 740 to 750 years there would be nearly nineteen million elephants alive, descended from the first pair.

The reason that elephants don't cover the surface of the earth is that the environment poses limits to population growth. Some of those limits are biological: species face natural enemies that increase their mortality rates and decrease their growth and reproductive rates. Thus, one explanation for the success of exotic species is that they have an advantage: they have a lower natural enemy load in a new land. Imura and Carstensen (1993) found that enemy loads of kudzu on its home range in Japan were more than twice the level found in the southeastern United States and that the enemies included more kudzu-specific herbivores. The consequence of this argument has a troubling dimension: species likely to invade may not be predictable from their biological traits if the explanation lies in their biological environment.

The power of natural enemies is, of course, seen in the cases of successful biocontrol, like the importation of the South American cactoblastus moth to control the introduced opuntia in Australia (Dodd 1940). In fact, one of the paradoxes of plant introduction is that horticulturists look for plants that are relatively pest-free and, if they obey quarantine regulations, plants are released purposefully without natural enemies. The introduced plant may acquire new enemies—but they will often be generalists rather than specialists. If the introduced plant becomes a pest species, we then must go exploring for biocontrol agents. While the ideal biocontrol agent is highly specific to the problem species, there is a danger, of course, that it will affect native species as well. Like genetic hybridization, this is a special danger for closely related plants: the biocontrol agent is preadapted to the native species, which, in turn, may have no evolved resistance to that control agent. Chestnut blight, an Asian fungus, is a much more effective "control" agent on American chestnut than on the species with which it evolved, Chinese chestnut. Species native in North America that are in the same genus as the Asian chestnut blight did not impact the American chestnut to the degree that the exotic disease did.

From these thoughts we can develop a "coevolution" paradigm. Namely, the biological attributes of a species evolved within a biological setting. If species achieved stability in the presence of their enemies, it was through coevolution: the rapid demise of the host is not advantageous to either host or pest, so hosts evolve some resistance and pests evolve a lowered virulence. Descent from common ancestors contributes to the problem: pest species will be preadapted to invade the related plant, but there will be no coevolved stability.

In summary, evolution in isolation, exponential increase, coevolution, and descent from common ancestors (causing the special problem of congenerics for hybridization and disease and pathogen spread), have an important consequence: we live in a world that is a loaded gun for exotic species problems. We transport species freely across barriers because we forget that the ecological and coevolutionary setting of plants is a key to their identity, population traits, and ability to invade.

Impacts of exotic plants

Impacts of exotic plants range across a wide spectrum (Table 1 from White, in press). Some introduced plants are, in fact, hard to cultivate in particular climatic settings. Others persist after cultivation, but, so far, have not become invaders of natural areas. Others spread vegetatively, but not by seed. Some spread by seed, but only into human created habitats like roadsides. A subset of the species successfully invade natural areas where they may reduce or eliminate native populations and even change the way ecosystems function (e.g., effects on hydrology, fire regime, and nitrogen cycling).

Williams and Fitter (1996) proposed the rule of 10s: that one in 10 introductions persists, one in 10 of those invade, and one in 10 of those becomes a pest. Thus, one in 1,000 introductions becomes a problem. However, there are several caveats to this argument. While not all introductions become pests, those that do are extremely expensive to combat. Also, Williamson and Fitter (1996) show that the data support quite a bit of variation—the one in 10 rule really means one in 5 to one in 20.

A final, and perhaps most serious, caveat is that species evolve: what appears to be a non-invasive introduction now, could become one later. Species that are released from natural enemies might evolve towards higher growth and reproductive rates for that very reason if there is a trade-off between growth rate and pest resistance. Faster growing, but less defended, genotypes might succeed in environments were pest resistance is not required. If its planting density is low and cross pollination limited or if a pollinator is lacking, the selfing genotype will increase through time. Perhaps a species that appears noninvasive will acquire a pollinator or a seed disperser. Perhaps it appears to be a noninvader in bad years and unfavorable places, only to become invasive in other years and in other places. In short, the very trait we are worried about, invasiveness, may itself be variable in space and time. The experiment is not over—many introduced species have not yet had time to prove their invasiveness and we may never be one hundred percent certain that a species is noninvasive. This argues for caution and care.

The conservation response

The exotic pest plant issue will require a diverse tool box of conservation strategies. Because of the difficulty of controlling established exotics, one of the most important strategies is to reduce the number of potential new exotics. Prevention is worth a pound of cure. I have argued elsewhere (White, in press, 1996) that two policies on introductions need to be pursued: (1) risk assessment, combined with early detection and eradication and (2) use of native species for ornament, landscaping problems, and other uses. Risk assessment hinges on our ability to predict invasiveness. Many important research questions remain, and even the most successful risk assessment will require a method for early detection of new invasions (for those species that are introduced accidentally and for those that are not identified as invasive by the screening criteria). Reichard (Reichard and Campbell 1996) has developed screening criteria for potential woody plant introductions that would be a tremendous improvement over the current lack of assessment and regulation. Her data suggest that it may be possible to screen out over 90 percent of pest woody species that are introduced purposefully by botanical gardens and nurseries.

In addition to prevention (including preclearance, exclusion, and detection of infestations), containment, eradication, and biological control are all important an necessary strategies (Westbrooks and Eplee 1996). We will have to have an integrated pest management approach in which restoration of natural processes and native vegetation will play a role. We will have to use an adaptive management paradigm, in which new information from monitoring and evaluation is used to improve our management programs. Because this is a global problem, with North American exports posing just as much a threat as imports from the rest of the world, international communication and cooperation will be required. Since invasiveness on one continent helps predict invasiveness on another (Reichard and Campbell 1996), international coordination is essential. We need an international clearinghouse and register of information on invasive exotics.

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Table 1. The range of exotic plant impacts to biological diversity (from White, in press).

Degree of exotic plant impacts on biological diversity
Species that do not persist after cultivation; dependent on cultivation
Species that persist after cultivation but do not spread
Species that spread locally after cultivation by vegetative means, but not by seed
Species that spread locally after cultivation by seed or seed and vegetative means
Species that spread only in human-created habitats: roadsides, lawns, fields
Species that spread into native habitats, but do not reduce native species
Species that spread into native habitats, reduce or eliminate native species
Species that spread into native habitats, change ecosystem function, alter, composition, and reduce or eliminate native species

Table 2. Traits of successful invaders.

Traits:

- Environmentally fit
- Rapid growth
- Early maturity (flowering)
- Prolific seed production
- Highly successful dispersal (germination, establishment)
- Rampant vegetative spread
- No major pests

Caveats against superficial evaluation:

- *Performance is a function of environment and soil*
- *Reproductive performance can be a function of density and the presence of compatible genotypes, dispersers*
- *Many traits can be genetically variable and can evolve*
  - *Natural selection for genotypes with highest reproductive output*
  - *Evolution of selfing from outcrossers*
- *The biological environment can vary: pollinators, dispersers, and enemies are not constant*
- *Establishment can vary with disturbance and the nature of the ecosystem invaded*

THE EXOTIC PEST PLANT COUNCIL

Brian Bowen, President
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ABSTRACT. The Exotic Pest Plant Council (EPPC) is a proactive organization established to raise awareness about the threat posed by invasive exotic pest plants in natural areas and acts to stop the continued spread of invasive species. EPPC provides fora for sharing information and provides networking opportunities regarding all matters concerning this issue. EPPC was first established in Florida in 1984 and has since become established in California, the Pacific Northwest, and Tennessee. These independent organizations have formed the National Association of Exotic Pest Plant Councils. The different EPPCs share manysimilar goals. In Tennessee, EPPC hosts annual symposia, conducts workshops, and publishes a quarterly newsletter. TN-EPPC has published the Tennessee Exotic Pest Plant list classifying the state's most invasive plants, and has published the Tennessee Exotic Plant Management Manual. TN-EPPC acts in a technical advisory capacity and has helped establish rules for quarantine of exotic pest plants while working to get government agencies out of the business of planting exotics.

The Exotic Pest Plant Council (EPPC) was established in Florida in 1984 in response to invasive exotic plant problems that at the time were not being addressed there. A coalition of agencies emerged that eventually led to the formation of the Exotic Pest Plant Council. This coalition initially focused much of its attention on the control and management of Melaleuca, which today, continues to be a serious problem in South Florida, including the Everglades.

Presently, this organization is comprised of four states and/or regional independent Exotic Pest Plant Councils in Florida, California, the Pacific Northwest, and Tennessee. In October 1995, these four organizations met in California and signed a Memorandum of Understanding, which established the National Association of Exotic Pest Plant Councils (NAEPPC). This affiliation of EPPCs was formed to address issues that go beyond state or regional boundaries that all of us concerned about this problem recognize. The NAEPPC interests in Washington D.C. are represented by Dr. Faith Campbell, who is presently serving as the technical secretary for the National Association of EPPC.

This discussion will primarily focus on aspects of the Exotic Pest Plant Council pertinent to the eastern region, specifically Tennessee. Some discussion will be given to the NAEPPC and its related goals. The genesis of TN-EPPC, established in March 1994, was made possible by the support received from Florida and California. The Pacific Northwest EPPC was formed only months before the TN-EPPC. Interestingly, the MOU, which was signed establishing the NAEPPC in 1995, recognized that one of its areas of collaboration is to facilitate formation of new state or regional EPPCs. The broadening of TN-EPPC's interests to become a regional council is presently under consideration. There has been much interest expressed by other groups outside Tennessee to explore the option of organizing a southeast regional EPPC. This eastern regional conference helps provide a great opportunity for that to possibly be advanced.

The NAEPPC identified four goals and three areas of collaboration which are as follows:

- To improve the Federal Noxious Weed Act to include weeds of natural areas and other pertinent enabling legislation;

- To increase biological control funding;

- To promote good weed control by federal and other land management agencies and organizations using current technologies, including mechanical and chemical methods;

- To improve the methods of prevention of new infestation for exotic pest plants from importation into the USA and through interstate movement.

Areas of collaboration are as follows:

- To implement strategies to increase membership for EPPCs to gain greater support;

- To implement strategies to increase funding to raise awareness of this issue; and

- To implement strategies for formation of new state or regional EPPCs.

This last area of collaboration was actually in effect before the MOU was signed. In establishing TN-EPPC, Florida provided modest funding and a representative to speak at an exploratory meeting held at Vanderbilt University in November of 1993. Florida had also been participatory in California's formation in 1992 as CALEPPC held a similar exploratory meeting. The exploratory meeting at Vanderbilt led to a recommendation that a committee be formed charged with the task of evaluating whether an Exotic Pest Plant Council should be established in Tennessee and to define what some of its goals might be (many of these goals had been defined as a result of the exploratory meeting). This committee determined that formation of this council should be recommended if there was sufficient statewide support. It was determined that this could be tested by hosting the first annual Tennessee Exotic Pest Plant Symposium in March of 1994.

This meeting was held at Cheekwood Botanical Gardens in Nashville, only a few months after the exploratory meeting. Dr. Peter White gave the keynote address focusing on the homogenization of the world's flora citing the predications of the English ecologist Charles Elliot in the 1950s. This first annual symposium also included many other speakers invited back today to address this eastern regional conference. At this symposium, CALEPPC's support was significant. Dr. John Randall was our luncheon speaker the afternoon that TN-EPPC officially became an organization. Dr. Randall, co-founder of CALEPPC, gave a very good account of how CALEPPC was established and what it had accomplished. His encouragement helped us take the next step, which was to form our statewide organization.

A steering committee was formed at this symposium to write the by-laws and explore how non-profit tax-exempt status could be gained. This committee basically evolved into the first TN-EPPC board of directors. Our federal 501C3 non-profit status was attained during our first year, which was a very important accomplishment. The by-laws were also completed soon after TN-EPPC was established. Development of the by-laws and mission was facilitated by borrowing heavily from CALEPPC and Florida's by-laws and mission. There was no reason to reinvent the wheel. The mission and goals of TN-EPPC are:

- To raise public awareness about the spread of invasive exotic plants into Tennessee's natural areas. This is an on-going goal that is perhaps the most important function of this organization. This goal is a part of almost everything that TN-EPPC does;

- To facilitate the exchange of information concerning management and control of invasive exotic plants;

- To provide a forum for all interested parties to participate in meetings and workshops, and an annual symposium to share the benefits from the information provided by TN-EPPC;

- To serve as an educational, advisory, and technical support council on all aspects of exotics; and

- To initiate campaign actions to prevent future introductions.

These goals are similar to the other EPPCs, and represent work in progress. The objectives to accomplish these goals include hosting annual symposia, which TN-EPPC has done since 1994. This year's annual symposium is this regional conference co-hosted by the US Forest Service and its numerous co-sponsors. This regional event demonstrates how EPPC forms partnerships to accomplish these goals whenever possible. Our annual events raise awareness of the issue, and give members opportunities for networking and sharing information.

Information is also shared through TN-EPPC News, which is a quarterly newsletter published since the spring of 1994. TN-EPPC has recently gone on-line with its own home page. The Tennessee Exotic Management Manual has been published to aid resource managers by providing recommendations on how to control and manage 20 of Tennessee's worst pest plants. This manual is especially useful as TN-EPPC sponsors training workshops and makes presentations at other meetings and conferences. TN-EPPC has published the Tennessee Exotic Pest Plant List, which helps target species for control, alerts restorationists to potential problem species, informs the public, and aids those commenting on environmental documents. This helps track new threats by receiving information on exotic plants with unknown status.

Educational materials include the three regional Landscaping with Native Plant brochures for grand regions of Tennessee. The brochures provide information about native plant use as an alternative to exotic plants. The brochures have been highly acclaimed and cited by the popular magazine, "Horticulture." Educational and advisory assistance has been provided to USFS in their production of the "Plants Out of Place" film. TN-EPPC serves in a technical advisory capacity working to get government out of the business of planting exotics.

TN-EPPC has helped to initiate campaigns to stop the spread of invasive exotics. TN-EPPC has worked in cooperation with the Environmental Action Fund (the lobbying organization for Tennessee's environmental organizations) to amend the Exotic Pest Bill in the Tennessee Code Annotated to define exotic pest plants. This enabling language authorizes the Commissioner of Agriculture to quarantine exotic pest plants. TN-EPPC was influential in getting quarantine orders drafted for purple loosestrife and tropical soda apple.

While much still remains to be done, much has been completed since TN-EPPC's inception in 1994. The urgency to continue raising awareness and acting to stop the spread of invasive exotic pest plants is imperative. Unless we are able to make the changes necessary to stop new introductions and work hard to manage and control those species that have already become established, we will not succeed. It is my hope that those of you at this conference will become involved in helping us deal with this serious problem. An important role you can play is through the Exotic Pest Plant Council. The EPPCs welcome your support and participation.

NEW STRATEGIES FOR WEED PREVENTION

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ABSTRACT. Over the past several thousand years, Man has moved many plant species far beyond their historical native range. Many introduced plants that have become established outside of cultivation are benign (so far). However, some introduced species with free-living populations pose a threat to the biodiversity of natural areas and/or diminish the production capacity of managed or agricultural ecosystems. In the United States, 16 federal agencies have formed the Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW). This committee has developed a National Strategy for Invasive Plant Management. Goals of the national strategy are: weed prevention, weed control, and restoration of degraded lands. Research, education, and partnerships are critical to the success of the strategy. Regulatory strategies to protect the United States and other countries from invasive plants include: production of weed-free commodities in exporting countries; preclearance of risk commodities at foreign ports of export; port of entry inspections; and finally, early detection, containment, and eradication, of incipient infestations before they spread. Currently, 10 federal noxious weeds are being eradicated from localized sites in the United States through cooperative projects with affected states.

INTRODUCTION

Throughout history, Man has intentionally and unintentionally transported thousands of different plants and animals far beyond their natural ranges to other parts of the world. Most of these species are beneficial to human society or show no signs of invasiveness (so far). However, hundreds of species now cause serious problems in agricultural and/or natural ecosystems within the United States. In the absence of co-evolved predators and parasites that usually keep them in check in their natural ranges, introduced species that find suitable habitats may thrive and outcompete or displace native species. Over the past several decades, serious problems caused by introduced plants and animals have raised concerns over the movement of species around the world (Elton 1958; Westbrooks 1981; Mooney and Drake 1986; Eplee and Westbrooks 1990; Schmitz 1990; Westbrooks 1991; Westbrooks 1993; Westman 1990; Zamora et al. 1989; Schmitz 1994). While change and disruption in ecosystems have occurred throughout history, the biological invasions that are now resulting from human commerce are truly different with regard to origins, rate of introduction, types of organisms, abruptness and magnitude of change (Wagner 1993).

Recognized invasive species that pose a threat to agricultural and managed ecosystems, or threaten the biodiversity of natural ecosystems, have been termed *biological pollutants* (McKnight 1993; Westbrooks 1993). **Unlike chemical pollutants that typically degrade in the environment, biological pollutants have the ability to grow, multiply, adapt and spread, and cause greater problems over time.**

Some examples of introduced species that have become biological pollutants in the United States include invasive plants, such as witchweed [*Striga asiatica* (L.) O.Kuntze] in the Carolinas; kudzu (*Pueraria lobata* Ohwi) throughout the southeast; and mile-a-minute vine (*Polygonum perfoliatum* L.). In the northeast, leafy spurge (*Euphorbia esula* L.); in the midwest and west, and micoia (L.) in Hawaii. These and thousands of other species have been transported around the globe as hitchhikers, contaminants, or on purpose. In either case, introduced species that become invasive typically receive little attention until they become major problems (Eplee and Westbrooks 1990). By the time a problem is recognized, environmental documentation is prepared, funding is obtained for control, and eradication is often impractical. At this point, an invasive plant becomes a permanent, expanding, and detrimental component of the invaded area.

In depauperate communities such as oceanic islands, exotic herbivorous mammals often become ecologically dominant, lead to wholesale species extinctions within several tropic levels, and cause severe degradation of the environment. In mainland environments, such taxa are more likely to cause decimation of sensitive or endangered species in addition to degradation of the environment (Coblentz 1993). The same adverse effects are often seen when invasive plants are introduced into a new environment.

ECONOMIC IMPACT OF INTRODUCED WEEDS IN THE U.S.

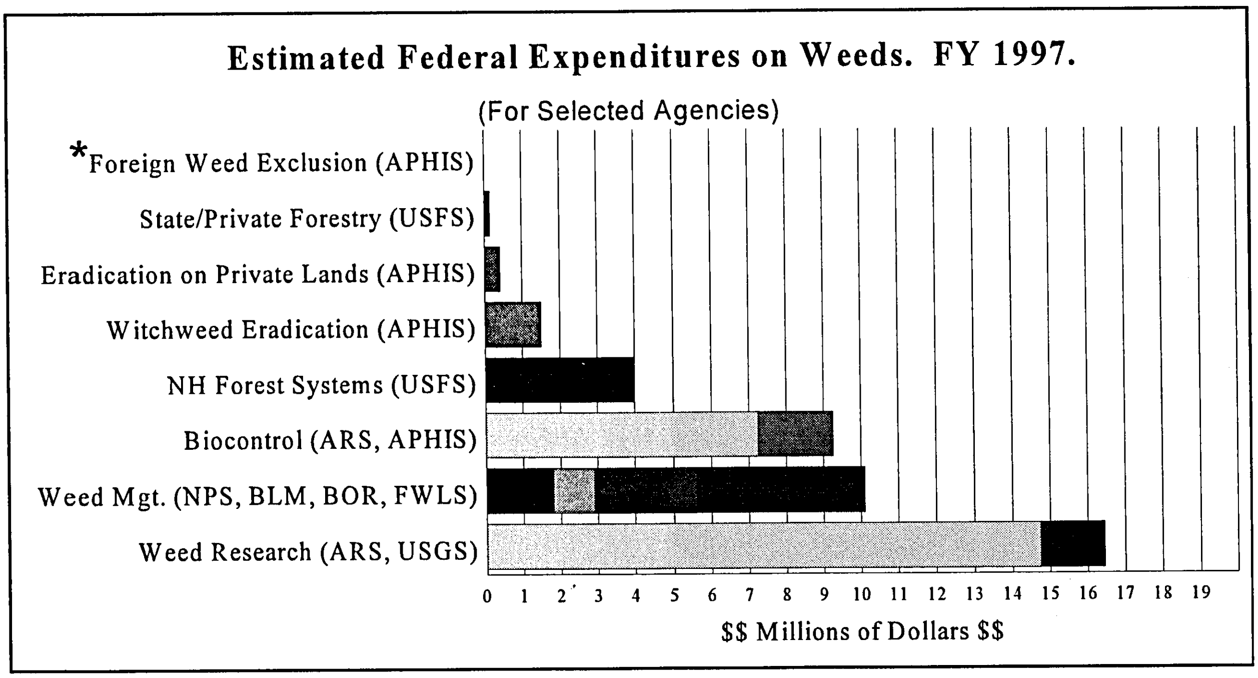
Weed Control Costs in the United States. Weeds cause billions of dollars of losses annually in the United States by competition with crops and by reducing the quality of food, feed, and fiber. During the 1950s, annual losses due to reduced crop yield and quality and costs of weed control were about $5.1 billion per year (USDA 1965). In 1962, $200,000,000 was spent in the United States on herbicides alone for weed control (Montgomery 1964). In 1979, it was estimated that 10-15% of the total market value of farm and forest products in the United States was being lost to weeds, a loss of about $10 billion per year (Shaw 1979). During the 1980s, farmers spent over $3 billion annually for chemical weed control and about $2.6 billion for cultural, ecological, and biological methods of control (Ross and Lembi 1985). At that time, about 17% of crop value was being lost due to weed interference and money spent controlling them (Chandler 1985).

In 1994, it was estimated that the economic impact of weeds on the U.S. economy equals or exceeds $20 billion annually. In the agricultural sector, losses and control costs associated with weeds in 46 major crops, pasture, hay and range, and animal health, were estimated to be more than $10 billion per year. In non-crop sectors, including golf, turf, and ornamentals, highway right-of-ways, industrial sites, aquatic sites, forestry, and other sites, losses and control costs totaled about $5 billion per year. Value of losses was not available for most non-crop sites, but estimates of control costs were determined. The importance of herbicides in modern weed management is underscored by estimates that losses in the agricultural sector would increase about 500% from $4.1 billion to $20 billion per year without the use of herbicides (Bridges 1992; Bridges 1994). **Since introduced**

weeds account for about 65% of the total weed flora in the United States, their total economic impact on the U.S. economy equals or exceeds $13 billion per year.

ROLE OF THE FEDERAL GOVERNMENT IN WEED MANAGEMENT

A number of federal agencies have a variety of responsibilities for dealing with weeds in the United States. Major areas of responsibility include: weed regulation, research, and management. Efforts to prevent the introduction of foreign weeds, as well as their establishment on private lands, are primarily the responsibility of the USDA's Animal and Plant Health Inspection Service (APHIS). APHIS cooperates with state and local agencies, as well as private landowners/managers in eradicating newly introduced weeds on private lands. Natural enemies of introduced weeds are imported under quarantine to control large infestations on private lands (biocontrol). Basic research on agricultural weeds is conducted by USDA's Agricultural Research Service (ARS). Weed research and management on federal lands is conducted by a number of agencies, including the U.S. Forest Service (USDA); U.S. Fish and Wildlife Service (FWLS); National Park Service (NPS); Bureau of Land Management (BLM); Bureau of Reclamation (BOR); U.S. Geological Survey (USGS); Bureau of Indian Affairs (BIA, U.S. Department of Interior); Department of Defense; and the Department of Energy. Estimated annual expenditures for weed research and control by some federal agencies in FY97 are listed below.



*Foreign weed exclusion by USDA APHIS is a part of Agricultural Quarantine Inspection (AQI) at U.S ports of entry. The AQI budget is about $200,000,000.00 per year.

Invasive plants grow, adapt, reproduce, and spread without respect for agency jurisdictions or property boundaries. Therefore, an effective management strategy to thwart alien species often includes a number of participants and activities. Since the biology of a pest is not negotiable, the strategies of action must consider the total biology of the species as well as political and economic issues. There must be a recognition of need to eliminate the alien species, a commitment of will and resources to the effort, and good, practical science to developing control methodologies.

To be fully successful, any effort that is made in response to this serious global problem must bring together a complex set of interests that include private landowners, industry, and government agencies at all levels. One of the first challenges is to create a public awareness of this issue. A further challenge is to focus public and private resources in a partnership approach to deal with specific weed problems while prevention and control remain economically feasible.

In recent months, FICMNEW has developed a National Strategy for dealing with invasive plants in a coordinated fashion. Principal goals of the national strategy are: (1) to minimize further introductions of foreign invasive plants in the United States; (2) to detect, report and assess incipient infestations; (3) to prevent the movement of invasive plants from infested to noninfested areas within the United States; (4) to eradicate or control weeds that have already become established; and (5) to restore degraded agricultural lands, rangelands, and other ecosystems to a healthy and productive state. The strategy will serve as a road map to guide the nation in addressing this growing problem.

REGULATORY STRATEGIES FOR EXCLUSION OF FOREIGN WEEDS

One aspect of the mission of APHIS is to prevent the entry of certain foreign pests into the United States. Foreign pests regulated by APHIS include, but are not limited to invasive plants, insects, plant diseases, animal diseases, and mollusks that are of foreign origin. Plant Protection and Quarantine (PPQ) is an operational section of APHIS that has the responsibility for implementing the exclusion of such pests from the United States. Regulatory strategies for protecting the United States by preventing the entry of harmful non-indigenous species include:

--- **prevention** (requiring or encouraging the production of pest-free commodities in foreign countries to minimize the world movement of recognized pests);

--- **preclearance** (inspection/certification of certain commodities at the port of export, prior to being shipped to the United States);

--- **exclusion** (port of entry inspections and treatments, designed to detect or remove prohibited pests in imported commodities, and to mitigate pest risk of contaminated shipments);

--- **detection** (conducting surveys and communicating with scientists and state agencies for early detection of incipient infestations of prohibited foreign species);

--- **containment** (establishment of regulatory rules and progams to prevent the spread of prohibited species from infested areas);

--- **eradication** (total elimination of incipient infestations of prohibited species by appropriate means); and

--- **biological control** (utilizing biological agents to control certain pests if they cannot be eradicated).

PLANT TAXA LISTED AS FEDERAL NOXIOUS WEEDS

In 1976, 26 taxa of foreign weeds were designated as Federal Noxious Weeds (FNWs). The FNW list now includes 94 taxa with 89 species, all species of the parasitic genera *Aeginetia, Alectra*, and *Striga*; plus all species of *Cuscuta* and *Orobanche* that are not native to the United States. Melaleuca (*Melaleuca quinquenervia* [Cav. T. Blake]), a tree in the myrtle family from Australia that is causing major problems in the Florida Everglades, was added to the FNW list in 1992. Tropical soda apple (*Solanum viarum* Dunal), a serious new weed of pastures in Florida, was added to the list in 1995.

DETECTION OF NOXIOUS WEEDS AT PORTS OF ENTRY

Between 1976 and 1988, resource materials available to APHIS personnel in enforcing the Federal Noxious Weed Act included a list of target species, a short list of high risk commodities, and sampling procedures for inspecting commodities for noxious weeds. At that time, greasy (raw) wool, soil-contaminated equipment, aquatic plant shipments, and seed shipments, had been recognized as high risk vectors for introducing foreign weeds (Westbrooks 1989; Westbrooks and Eplee 1991).

In the mid- to late-1980s, a Noxious Weed Inspection System (NWIS) was developed to enhance the ability of PPQ Officers to detect weed contaminants in high risk commodities at ports of entry. The purpose of the system is to provide officers with information on potential associations of target weeds and commodities that originate in habitats where such weeds could be expected to grow. NWIS is based on the principle that certain weeds are likely to be associated with certain commodities from certain countries. NWIS is comprised of a Federal Noxious Weed Inspection Guide, a Federal Noxious Weed Identification Guide with monographs, line drawings, and range maps on all listed species, and a Noxious Weed Seed Collection. Each PPQ work station at U.S. ports of entry has one set of NWIS materials (Westbrooks 1989; Eplee and Westbrooks 1991; Westbrooks and Eplee 1991; Westbrooks 1993).

NEW WEEDS WITHIN THE UNITED STATES

Strategies for Early Detection, Reporting, and Rapid Response. If noxious weeds do enter the United States, despite regulatory efforts to exclude them, the next goal is to detect, contain, and eradicate incipient infestations before they become entrenched and start to spread. A critical element in this process is early detection. At present, new plant species that are collected in the United States are typically stored at one of the 600+ public or private herbaria that exist around the country. Generally speaking, weed scientists and other plant specialists learn about such new state and national records through word of mouth or through notes published in botanical journals. Experience has shown that if an infestation is detected early, it can be generally contained and eradicated at a relatively low cost compared to what it will cost for control once it becomes established.

One way to enhance early detection and reporting of new infestations of weeds would be to create a Weed Detection Network in each state. Such a network could be established by creating communication links between plant collectors, herbarium curators, and appropriate state and federal agencies. Botanists, farmers, county agents, and land managers, are just some of the people who need to be encouraged to report new plants that they oberve.

To facilitate action on such reports, a state weed team in each state could be established. Such a team would be comprised of state and federal officials from agencies and institutions that are involved with weed management and research in a particular state. The goal of a state weed team would be to develop a coordinated plan of action and to leverage available resources and expertise for dealing with important weeds of common concern. Having one interagency spray crew to cover multi-jurisdictions would be far more efficient and cost effective than having separate county, state, and federal crews in a particular area.

Once a state weed team is informed about a new infestation, it will need input from technical specialists on how to proceed. One way to do this would be to establish a National Rapid Response Weed Team. The purpose of such a team would be to provide technical support to federal, state, and local agencies, in evaluating new infestations of introduced weeds. The national team which would consist of recognized weed regulatory and control specialists from participating federal agencies, would cooperate with weed scientists, botantists, and state plant regulatory officials in affected states. Such an interdepartmental team would provide a shared pool of expertise that is not normally available to individual agencies. When this or a similar system is adopted nationwide, we will be in a much better position to detect new weeds and to respond to them appropriately. Early detection, reporting, and rapid response, are three major goals of the APHIS Noxious Weed Policy Implementation Plan, the U.S. Department of Agriculture Strategic Plan for Weeds, and the National Strategy for Invasive Plant Management.

FEDERAL/STATE NOXIOUS WEED ERADICATION PROJECTS

A Few Success Stories. Currently, about 45 species of the 94 taxa that are listed as FNWs are known or reported to occur in the United States to a limited degree. Over the past 40 years, APHIS and its predecessors have been involved in cooperative federal/state efforts to eradicate a number of these species from the United States. These include:

--- **Witchweed** (*Striga asiatica* [L.] O. Kuntze). 177,000 ha infested in NC and SC; now reduced to 11,000 ha in 17 counties in NC, and in three counties in SC;

--- **Branched broomrape** (*Orobanche ramosa* L.). 283 ha infested in Karnes County, TX;

--- **Goatsrue** (*Galega officinalis* L.). 16,000 ha infested in Cache County, UT;

--- **Mediterranean saltwort** (*Salsola vermiculata* L.). 550 infested in San Luis Obispo County, CA;

--- **Hydrilla** (*Hydrilla verticillata* (L. f.) Royle). 310 km of canals infested in the Imperial Irrigation District, Imperial Valley, CA; now 99% eradicated;

--- **Japanese dodder** (*Cuscuta japonica* Choisy). 1 ha infested in the SC Botantical Garden, Clemson, SC;

--- **Small broomrape** (*Orobanche minor* Smith). Spot infestations in Washington County, VA; Pickens, Abbeville, and Aiken Counties, SC; and in Baker County, GA;

--- **Catclaw mimosa** (*Mimosa pigra* L. Var. Pigra). 405 ha infested in Martin and Palm Beach Counties, FL;

--- **Asian common wild rice** (*Oryza rufipogon* Griffith). A rhizomatous red rice; 0.5 ha infested in the Everglades National Park, FL;

--- **Wild sugarcane** (*Saccharum spontaneum* L.). A rhizomatous wild sugarcane; 13 spot infestations along the southeastern shore of Lake Okeechobee in Martin County, FL, totalling less than 1 ha.

Most of the early weed eradication projects (e.g., witchweed, goatsrue, and hydrilla) involved large acreages. However, in recent years, there has been a general trend toward projects that are smaller in scope and duration (1-2 ha; 3-5 yr). This measure of success is mostly due to increased networking between weed scientists and botantists in recent years. Weeds detected early can be eliminated for less money in less time.

STRATEGIES TO PREVENT THE SPREAD OF ESTABLISHED INVASIVE PLANTS

The first line of defense against introduced invasive plants is **early detection of new infestations.** As already noted, the work of amateur and professional field botantists is critical in early detection and reporting of new plant species as they are observed.

The second line of defense against invasive plants is to **contain and eradicate incipient infestations** as soon as they are detected.

The third line of defense against invasive plants is to **prevent movement into noninfested areas.**

The fourth line of defense against invasive plants is to develop effective and environmentally sound methods and procedures for control of large infestations.

SUMMARY

Harmful non-indigenous plants are biological pollutants that threaten agricultural production and the biodiversity of natural ecosystems in the United States. Federal agencies in the United States, through FICMNEW, are developing a coordinated national strategy for dealing with invasive plants. One role of USDA APHIS in biological protection of ecosystems is to prevent the introduction of foreign invasive plants into the United States. APHIS also cooperates with affected states to combat incipient infestations of Federal Noxious Weeds before they become widespread. The most effective way to deal with invasive plants is to prevent their introduction from other countries, to detect incipient infestations at an early stage, and to implement an effective eradication program before they begin to spread to other farms and states. Money spent on weed prevention is a wise investment that will help to minimize future losses and control costs that are typically associated with widesprad weeds.

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BARRIERS TO EXOTIC WEED MANAGEMENT

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In order to increase effective efforts to reduce the impacts of invasive alien plant species on our natural areas, we must overcome numerous barriers. Some of these are technical in nature, *e.g.*, determining the most appropriate control method for a specific species in a particular ecosystem, or devising a better program to exclude new invasive plant species from our country.

To build the infrastructure that will allow us to tackle such scientific problems, however, we have first to enliven the political will to address the very concept of invasive alien plant species damaging our eastern forests. We face numerous complex challenges in this underlying phase, as well.

A campaign of sufficient scope to be effective requires the understanding and support of the American public. To gain that support, we need to attract people's attention. Our first barrier, then, is people's limited attention span. We are competing with all other enticements, ranging from the newest "blockbuster" movie to the state of the economy.

Once we have people's attention, we should ensure that our proposed solutions make sense to them. Here we confront another obstacle. In my view, at least, reducing the impacts of invasive alien plant species will require significant increases in spending and regulatory authority by federal agencies. The prevailing political culture at present is plainly hostile to such measures. To move ahead, we will have to find both voluntary and cooperative steps and arguments to persuade people that the national government has a constructive role to play here.

Finally, people are most concerned about what impacts them directly, and most weeds do not affect most people in the same way as does the threat of toxic substances in their drinking water. Certain ecosystems have been sufficiently damaged by invading exotic plant species to gain some level of public attention. The principal examples are the tropical and subtropical ecosystems of Hawaii and Florida, and grazing lands in the Intermountain West. Unfortunately, these areas are somehow dismissed as irrelevant to most people's concerns. The Hawaiian islands are seen as too far away and too "exotic."

Let's try to climb over these barricades that block effective "weed" control efforts. Where do we begin?

I believe our first hurdle will be overcoming our own and the public's lack of awareness. We need to obtain information ourselves, then find exciting ways to make it available to the public in hopes it will motivate people to act.

Some of the missing information is at a very basic level. As Dr. John Schwegman, just retired from the Illinois Department of Natural Resources, has pointed out, most Americans don't recognize more than a few plant species, and they have no idea which ones are native, which ones exotic. How do we help our neighbors learn to recognize and appreciate our own flora? This education effort would seem especially important in the eastern forest realm, where we have exotic shrubs, trees, and herbaceous flora replacing their counterparts. Invasion in the forests is not as dramatic as the replacement of sawgrass marsh by *Melaleuca* that is occurring in Florida's everglades ecosystem. People need to be given tools to use in order to appreciate the invasion. The exotic vines are more conspicuous, but even they escape notice. Rock Creek Park in Washington, D.C. has wisely included in its recently produced brochure a set of pictures intended to help the visitor distinguish between healthy forest and a curtain of exotic vines.

Our task is probably made more difficult by the fact that people are naturally more interested in animals than plants. Plants seem more "foreignless," like us. They rarely arouse a humanitarian concern. On the other hand, people manifestly love and seek floral beauty.

While our friends in education, psychology, and marketing are tackling the fundamental questions just raised, more traditional players—scientists and resource managers—can be busy filling in our gaps of knowledge in other, more technical areas.

We lack hard data on the extent of exotic plant invasions, both for most (if not all) individual species, and especially for the overall picture. If we cannot tell the American public how big the problem is, how can we persuade them to spend money and accept restrictions on the plants they can have in their yards in order to solve it?

In a very preliminary attempt to provide a nation-wide picture, I have totaled estimates of the areas occupied by a few species—cheat grass *Bromus tectorum*, salt-cedar *Tamarix* spp., floating aquatic weeds, purple loosestrife *Lythrum salicara*, and *Melaleuca*. Together, these plants displace native plant communities and destroy habitat for wildlife species on more than 169,000 square miles of western grasslands and wetlands. This is an area larger than the state of California; it is 4.6% of the total area of the United States. I have not included here leafy spurge *Euphorbia esula*, yellow starthistle *Centaurea solstitialis*, and other invaders of the western grasslands because I don't know the extent to which they overlap with cheat grass. Surely, however, they infest millions of additional acres, thus further raising the total.

Please note that these data include none of the numerous plants invasive in the eastern forests. The only such plant for which I have been able to find any datum is kudzu *Pueraria montana (=P. lobata; triloba; thunburgiana)*. I believe that the vine that ate the South occupies some 10,000 square miles of our forests—an area about the size of Maryland. If we are going to persuade people to help us combat exotic species in the eastern forest, we need better information about the geographic extent of the invasion by the approximately 100 species of alien plant species already well established in this realm.

Probably, even more important, and certainly more difficult, will be obtaining information on the ecological damage caused by invading alien plant species—especially those in the East. It is a matter of priorities. If the invasion has little ecological impact, should not the public—and we—devote our energies elsewhere? But this decision should not be based on ignorance; a lack of data is not, in my view, satisfactory "proof" that the ecological impact is minor.

Some studies, such as that by Thomas of the National Park Service, have demonstrated that English ivy *Hedera helix* and Japanese honeysuckle *Lonicera japonica* can suppress tree regeneration.[1] Ann Rhoads of the Morris Arboretum has suggested that the replacement of ephemeral spring herbs by biannual or annual herbs such as garlic mustard *Alliaria petiolata (A. officinalis)* may interfere with the recycling of nutrients normally captured in the early spring by the ephemerals, then released to other plants as the early bloomers retreat into dormancy. Scientists need to explore and explain to the public these and other forms of ecosystem damage.

We will be much better off if we can enlist the help of economic interests. Looking at the "weed" problem from the broad perspective, we should be able to do this. The most recent data, to be incorporated in the government's "weed fact book," puts agricultural losses due to weeds at $20 billion per year. But we need much better data to solidify our case.

For some regions and some species, the economic arguments are well advanced—and control efforts have followed. Leafy spurge, spotted knapweed *Centaurea maculosa*, Medusahead wildrye *Taeniatherum caput-medusae*, and other scourges of the West receive considerable attention—relatively speaking—because they harm the livestock industry. Please note, however, the contrasting low level of attention given to the most widespread of the invasive alien plant species, cheat grass. Cheat has invaded one-third of the grasslands of the Intermountain West—158,000 square miles.[2] Cheat is a true "ecosystem changer." It triggers "drastic" ecosystem changes[3] by fueling hotter, larger, and more frequent fires. The fires virtually eliminate native shrubs within a few years. The shrubs matter because they provide key food or shelter to native wildlife including

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antelope, song birds, and the small mammals that are the prey for the large number of raptors found in the region. Despite its ecological importance, cheat is not even included in the Bureau of Land Management's data on invading exotic plant species. I believe this results from the fact that cattle willingly feed on cheat in the spring.

In the east, purple loosestrife, hydrilla *Hydrilla verticillata*, and Eurasian watermil-foil *Myriophyllum spicatum* are the objects of research and control efforts because they interfere with activities by hunters, boaters, and owners of waterfront property—*e.g.*, powerful political constituencies. Unfortunately, most of the vines, shrubs, trees, and herbs that harm natural environments in our forests do not pose significant problems to agriculture or homeowners. It will be challenging to generate the same level of concern about invaders of the eastern forests as long as those plants are not perceived as goring an economically or politically important ox.

The situation is further complicated because a surprisingly high proportion of invasive exotic plants are still sold for use in ornamental horticulture, landscaping, wildlife "enhancement," or soil conservation. Overall, 64 percent of the approximately 340 species identified by my sources as seriously invasive in ecosystems of the continental United States are in the commercial trade. For plants invading the eastern forest, the proportion is even higher, perhaps 80 percent. Looking to future weed problems, I believe that the driving force behind most plant introductions today are these markets. As I will argue below, some proportion of the as-yet-to-be introduced species will also prove invasive. Consequently, the proportion of troublesome species that are in the trade is likely to increase in coming years.

Clearly, building an effective program to contain and suppress plant invasions will require the active cooperation of the trade. People who earn their living by selling plants, and who feel competitive pressures to find "new and improved" varieties to offer, will be asked to consider the greater good and to forego sales of certain species. What's more, increasingly the decisions will be based on a *prediction* that a species may be invasive, rather than observed facts. We are asking much from the industry. I believe the cause of restoring our ecosystems' biological integrity merits the sacrifices sought—but we need to be aware of the magnitude of our request.

I have outlined a suggestion for the content of the needed educational campaign. Now we need to move ahead with it. Scientists and resource managers are only now beginning to get out the message. We need to learn from the advertising industry that is so successful in our country—our message should be repeated *ad nauseam*, like an advertisement for toothpaste.

We can tell people that half of our National parks—194 out of 370—have identified exotic plants as serious threats. Through various documents—e.g., the *National Strategy, Pulling Together*, the "weed fact book," etc.—the federal government is increasing its educational efforts.

Similarly, stewards of 60 percent of preserves managed by The Nature Conservancy report plant invasions to be significant threats. TNC has launched an aggressive educational campaign in Hawaii and on the continent, issued a report on *America's Least Wanted*.

I believe we all wish to involve the other major environmental organizations in this campaign. This may be difficult because the "weed" issue scrambles traditional alliances. Environmentalists are being asked to join forces with chemical companies and livestock ranchers; and to support active management of what they have thought of as "pristine" areas. Furthermore, we want them to abandon their own past advice regarding plantings to "enhance" wildlife habitat. In the case of animal invaders, we are asking fishermen to stop stocking introduced fish into new lakes and streams, and people concerned about humane treatment of animals to accept the killing of various mammals and birds.

A fundamental problem remains: the threat from invasive alien species is often seen as somehow fundamentally different in kind and scope from other environmental threats. It is portrayed as requiring a completely new type of response. I would argue that invasive aliens are not fundamentally different. That is why I welcome use of the term "biological pollution."

No matter whether the threat to our biodiversity stems from chemical pollutants, overharvesting, suburban sprawl, draining of wetlands, or biological pollutants, we cannot put the environment "back the way it was." We *can* reverse the damage or restore some areas and minimize what will occur in the future. I think our message should emphasize the similarities with other environmental threats, even as we acknowledge the need for actions aimed at this specific manifestation.

Finally, we tend to become so focused on the burgeoning problem under our feet that we can't find time to look at the very scary longer term picture:

> Unless we act decisively, exotic plants will do more and more damage in future years.

Those species already introduced into the country continue to spread. On federal lands in the west, exotic plants are spreading at a rate of at least 4,600 acres per day. At this rate, weeds cover a new area the size of Delaware every year.

An estimated 4,000 exotic plant species have been reported as outside cultivation in the United States. In both Florida and California, more than 1,000 exotic species have escaped cultivation; in Hawaii, more than 800. Because a plant species' invasiveness is often recognized only decades after it first became established in the wild, some proportion of these few thousand species now "escaped" but not yet considered "invasive" probably will become troublesome.

Thousands of other plants have been introduced for our gardens or other purposes—more than 8,000 species in Hawaii. Perhaps 10 percent will probably escape when conditions are right.

Finally, new plant species are imported every year. If one extrapolates from current data and concludes that about 10 percent of all vascular plants are "weedy," there could be as many as 26,000 species capable of becoming invasive once they are introduced into new environments.[4]

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[4]Rapoport, E.H. 1991. Tropical versus temperate weeds: A glance into the present and future. In: Ramakrishnan, P.S. 1991. *Ecology of Biological Invasion in the Tropics*. National Institute of Ecology, New Delhi

The current system intended to protect our ecosystems from this onslaught is inadequate. We currently have no requirement that plants of foreign origin be screened for invasiveness prior to their introduction. Conversations have begun with the nursery industry to develop such a program, but many technical and political hurdles will have to be cleared before it is in place.

Meanwhile, international negotiations under the auspices of the World Trade Organization and the International Plant Protection Convention are on the verge of setting the "rules of game" for determining which "plant pests" the United States can exclude from entry. Are these negotiators adequately attuned to the damage caused by invading alien species in natural ecosystems and the impossibility of predicting in advance with anything approaching certainty which pests will cause great threats? How many scientists even knew of the existence of the fungus *Cryphonectria (= Endothia) parasitica* before chestnut blight began sweeping through our forests?

The Exotic Pest Plant Councils, Weed Science Society of America, and the USDA Animal and Plant Health Inspection Service agree that the Service's present authority under the Federal Noxious Weed Act is inadequate to address the problem. While the federal agencies have greatly increased their efforts and are coordinating their programs more effectively, naturally major gaps in both concept and implementation remain. We will just have to expand our own efforts and invite others to join us in moving ahead on all fronts. Our battered but still magnificent forests will reward us for the effort.

Thank you for the opportunity to exchange views with you today. I look forward to many future collaborations.

BEECH BARK DISEASE

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INTRODUCTION. In forests of North America the beech bark disease (BBD) complex affects American beech, *Fagus grandifolia* Ehrh. BBD begins when bark tissues, attacked by the exotic beech scale insect, *Cryptococcus fagisuga* Lind. are rendered susceptible to killing attacks by fungi of the genus *Nectria* (Ehrlich 1934). The principal fungus, *N. coccinea* var. *faginata* Lohm. and Watson (Lohman and Watson 1943), was probably introduced also, but the native pathogen, *N. galligena* Bres., also attacks and kills bark predisposed by *C. fagisuga* (Cotter 1974; Houston 1994a; Mielke et al. 1982). The general framework for BBD's etiology:

BEECH TREES + *C. FAGISUGA* + *NECTRIA* SPP. = > BBD

indicates the chronology of events required for disease development, and points out that although the effects of the insect are necessary, the disease is expressed only after *Nectria* spp. attack and kill scale-altered tissues.

Following its accidental introduction to Nova Scotia around 1890 (Ehrlich 1934), the beech scale spread westward and southward through forests of Canada and the United States. It now occurs throughout New England, New York, much of New Jersey and Pennsylvania, and is present in northeastern Ohio, northeastern West Virginia and northwestern Virginia (Fig. 1). Its recent discovery in the Great Smoky Mountain National Park along the Tennessee-North Carolina border (Houston 1994a,b) has prompted considerable concern.

Course of the disease and its effects: Generally, *Nectria* infections and tree mortality (Fig. 2) occur 1 to 4 years after heavy build-up of the insect on large trees (Fig. 3). The area of current heavy mortality is termed the killing front; regions where severe mortality occurred earlier comprise the aftermath zone (Shigo 1972). In aftermath forests the causal agents are established on small trees of both root sprout and seedling origin that often develop after death or harvest of their progenitors. Most of the new emerging trees and old survivors become cankered and rendered highly defective by the scale-*Nectria* complex (Fig. 4).

Thus, in North America, where the introduced causal complex is still advancing, there are two distinct phases of the disease. The first phase encompasses the effects resulting from the invasions and epidemic buildups of scale and pathogens (killing front); the second phase encompasses the effects of the established causal complex on the survivors and the young, small beech trees emerging in the aftermath of heavy tree mortality or salvage.

In phase one, scale populations build rapidly to high levels. Even though heavy infestations can reduce growth, and, by killing cells in the outer layers of the phellogen, cause bark fissuring, the insect alone rarely damages the cambium (Lonsdale and Wainhouse 1987). Usually, however, infection of bark by one or both *Nectria* pathogens soon follows infestation. Bark exudation ("tarry spots"), which can result from many other causes as well, is often the first sign that bark has been killed by *Nectria*. Massive invasion by the pathogens of scale-infested trees usually ensues; often, more than 50 percent of the beech trees ≥ 10 inches in diameter are killed, and many more are severely damaged. Such losses can be significant. For example, as of 1977 the estimated loss in merchantable timber volume attributed to BBD in Vermont had reached nearly 300 million board feet (including trees dead, dying, or damaged beyond use) (Miller-Weeks 1983). Phase one is now occurring in eastern Pennsylvania and northeastern West Virginia and, no doubt, will occur soon in the recently affected stands in Ohio, Virginia, North Carolina, and Tennessee.

Opening up of stands by mortality or by salvage of diseased trees can lead to the development of dense stands from root sprouts and seedlings and has helped to create, over large areas, stands that are overly rich to beech and impoverished in associated species. Development of these stands ushers in phase two (Houston 1975). With time, the stems in these stands gradually acquire spatial habitats for the beech scale. Infestation of these habitats, which include bark figures and fissures, callused areas around injuries and patches of protective lichens and mosses results in scattered, isolated colonies. Bark beneath the colonies, altered by the insect's feeding activity, may be attacked by *Nectria* spp. resulting in scattered, discreet cankers. The callus that develops around each canker provides additional refuges for scale. Aggregations of cankers develop over time, and trees become increasingly defective, but rarely are they girdled and killed quickly as were their progenitors in phase one.

Eventually, in long-affected stands, severely affected trees lose vigor, grow slowly, and then die, out-lived by more vigorous, less severely diseased and resistant beech trees and trees of other species. In any particular forest the rate and pattern of this shift depend in large part on the relative density and frequency of the beech component, on the distribution patterns of resistant trees, and on management intervention. Thus, harvest operations, even in badly diseased and slowly declining beech stands can initiate once more, the formation of highly susceptible thicket stands.

Some Factors that Influence Disease Development

<u>Stand composition and structure</u> – Stand age and density, tree size, and species composition affect disease severity, especially in forests affected for the first time. Older stands with a high component of large beech trees are most vulnerable, and in such stands tree mortality can be very high (e.g., Valentine 1983). Large old trees with extensive decay, conks, or large broken branches are most at risk and often die rapidly as *Nectria* spp. becomes established (Mize and Lea 1979). One study of forests in Massachusetts and New Hampshire showed that stands rich in hemlock were especially vulnerable (Twery and Patterson 1984).

<u>Environmental factors</u> – Once established in a forest stand, scale populations tend to fluctuate at different rates and amplitudes related, in part, to the temporal phase of the outbreak. I monitored the general changes in annual populations of *C. fagisuga* on trees in plots from Maine to West Virginia (D.R. Houston, unpublished data). In newly infested stands, scale populations built up rapidly to high levels, whereas in long-affected stands, established populations typically were maintained at lower levels and exhibited less dramatic annual fluctuations (Fig. 5), presumably in response to local

climate change. Exceptionally cold winter temperatures and heavy autumn rainfalls, both highly correlated with low levels of BBD development, presumably adversely affected overwintering scale populations and the establishment of new populations in late autumn, respectively (Houston and Valentine 1988).

Predators and parasites – No invertebrate parasites of *C. fagisuga* are known. However, several predators are recognized of which the twice-stabbed ladybird beetle *Chilocorus stigma* Say is the most common. *C. stigma* is most abundant when scale populations are dense and, although it responds numerically to high scale densities, its predatory effectiveness is limited by its propensity to disperse, its failure to feed on all life stages of scale, and, especially, by the high rate of scale reproduction (Mayer and Allen 1983). Although scale populations on individual trees can be markedly reduced when populations of coccinellids are high, the overall effectiveness of these predators is limited.

Bark epiphytes – Some epiphytes growing on beech bark offer favorable spatial habitats for *C. fagisuga* (Ehrlich 1934, Houston et al. 1979). Colonies often develop initially beneath patches of moss and lichen. However, not all epiphytes enhance infestations. For example, in Nova Scotia, some stands on steep, south-facing slopes contain beech trees that are remarkably free of disease compared to others in the general area. These trees are heavily colonized by mosaics of crustose lichens, the predominant species of which are rarely colonized by *C. fagisuga* (Houston 1983b). Such preclusive lichens have thalli that are dense, smooth and epigenous in contrast to the loosely compact, granular-surfaced hypogenous thalli of readily colonized species.

Host resistance – In affected stands, some trees remain free of beech scale and disease (Fig. 6). Challenge trials have shown them to be resistant to *C. fagisuga* (Houston 1982, 1983a). Resistant trees occur in relatively low numbers (< 1.0 percent of the beech stems) and many occur in groups (Houston 1983a). The occurrence of resistant trees in groups is encouraging; groups of resistant trees are easier to recognize than isolated individuals, and potentially are easier to protect in forest management operations designed to discriminate against diseased trees. Isozyme genetic studies have shown that resistant trees in groups originate both from root sprouts (clones) and from seed (families) (Houston and Houston 1986, 1990).

Isozyme patterns unique to resistant trees have not been found (Houston and Houston 1994), and the control of resistance is probably multigenic. Resistant and susceptible trees differ in their bark chemistry. Bark of resistant beech has significantly lower concentrations of some amino acids and total amino nitrogen than does uninfested bark of susceptible trees (Wargo 1988).

Management/Control

Options available to reduce the effects of BBD are determined by the temporal phase of the disease, stand structure and composition, and the harvesting and silvicultural systems available (Mielke et al. 1986, Ostrofsky and Houston 1989). There are two major management situations or problems posed by the disease. The first is how to deal with forests that are about to become, or that have recently been, infested for the first time, and where heavy beech mortality can be expected within a few years. The second problem is how to handle aftermath stands where dense, disease susceptible, and defective stands have developed. In brief, managing recently-infested stands entails a) reducing the proportion of beech, b) discriminating against large, overmature trees with roughened bark and signs of decay, c) removing heavily infested trees, and d) removing advance beech regeneration with herbicides where overstory beech is heavily infested (Mielke et al. 1986).

In killing front and aftermath forests, Mielke et al. (1986) propose that a) dead or declining trees with heavy beech scale populations be removed, and b) susceptible advance regeneration and understory beech be treated with herbicides. They recommend leaving beech with little or no scale or *Nectria* infection. Ostrofsky and Houston (1989) suggest using harvesting systems that by minimizing injuries to beech root systems, should reduce development of root sprouts from roots of susceptible trees.

It is clear that close surveillance of stand conditions and scale populations is important during all stages of disease development. In early stages of an outbreak, scale-free trees may not be resistant but merely "escapes." But, as the outbreak ensues, large trees that remain free of scale, or only very lightly infested, are good candidates for retention in the stand. Infested trees do vary in their levels of resistance to scale and possibly to Nectria. As a consequence, diseased trees persisting in aftermath forests may differ in how seriously they are damaged, e.g., on some trees what appear to be severe bark injuries, actually may be restricted to the outer bark leaving the cambium and wood unaffected (Burns and Houston 1987).

Increasing the relative number of resistant trees seems to be the most promising approach for reducing the impact of this disease in the long run. The results of trials to determine how various harvesting regimes affect the initiation, development, and survival of root sprouts are being analyzed. In addition, studies to determine ways to clone selected resistant genotypes have been conducted. Tissue-culture techniques which use sprouts from root segments and forced buds of mature resistant trees, have brought several genotypes through to rooting (Barker et al. 1995). Still needed are trials to develop ways to grow the tissue culture plantlets in soil and introduce them into the forest.

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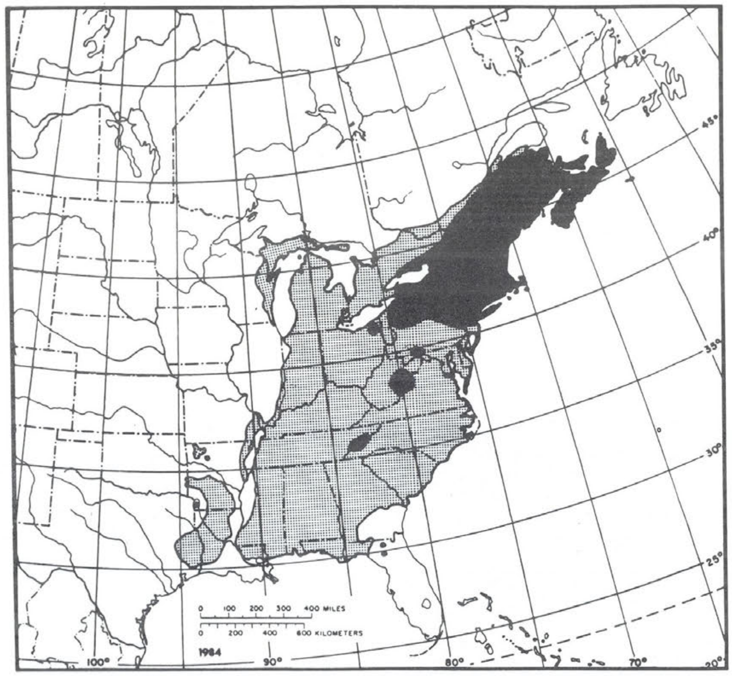


Fig. 1. – Known distribution of beech scale (block areas) as of 1996, in relation to the range of American beech (hatched areas).

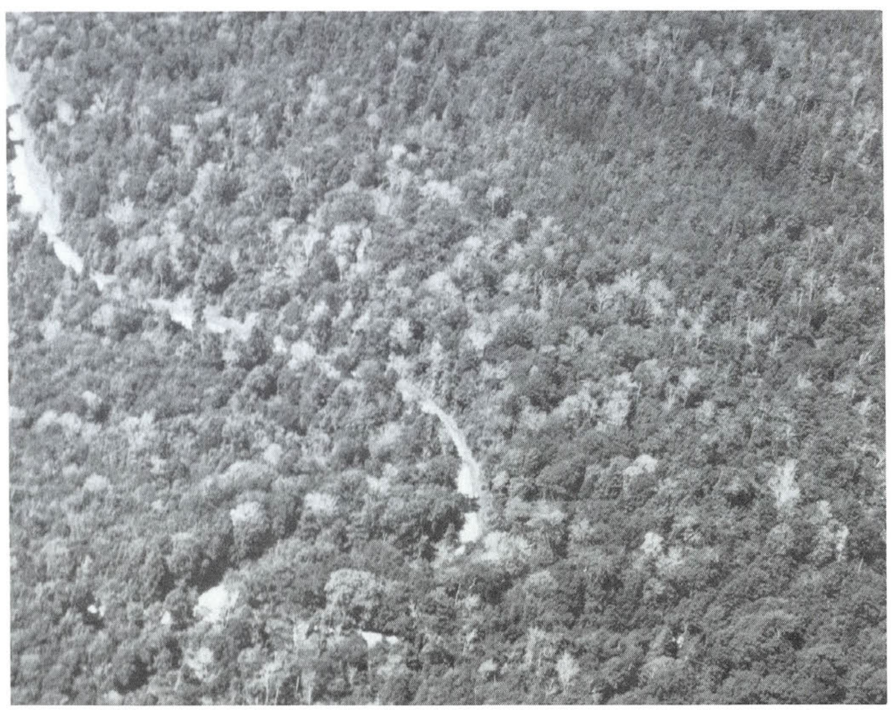


Fig. 2. – High tree mortality can occur when forests are affected by the causal complex for the first time. Over 75% of the large beech in this Vt. forest were dead or dying (bare and gray crowns) in 1971.

Fig. 3. – Heavy infestations of beech scale can cover tree boles with white wax.

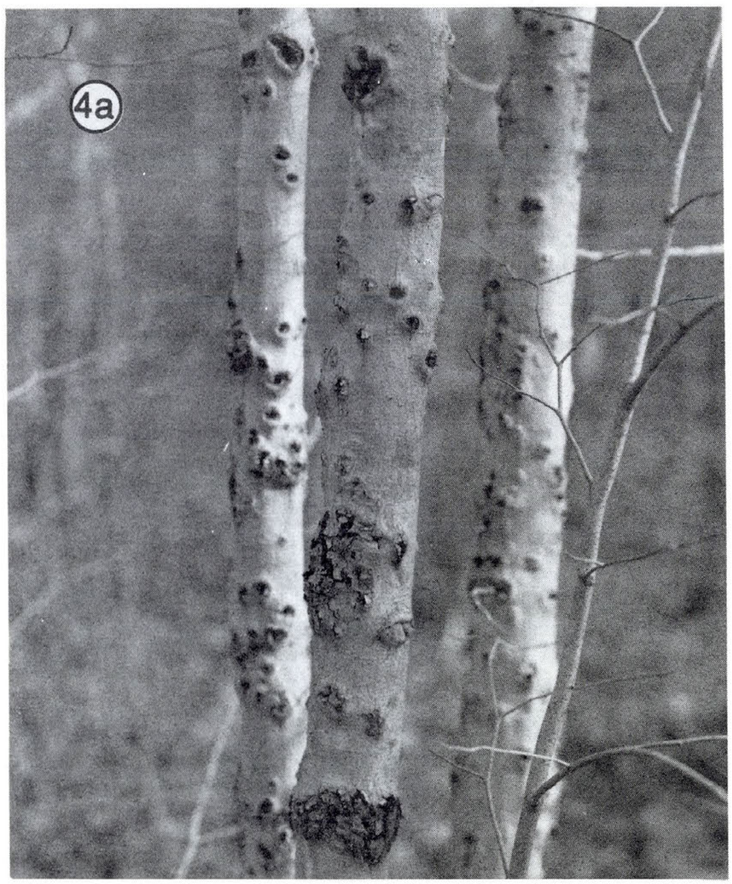
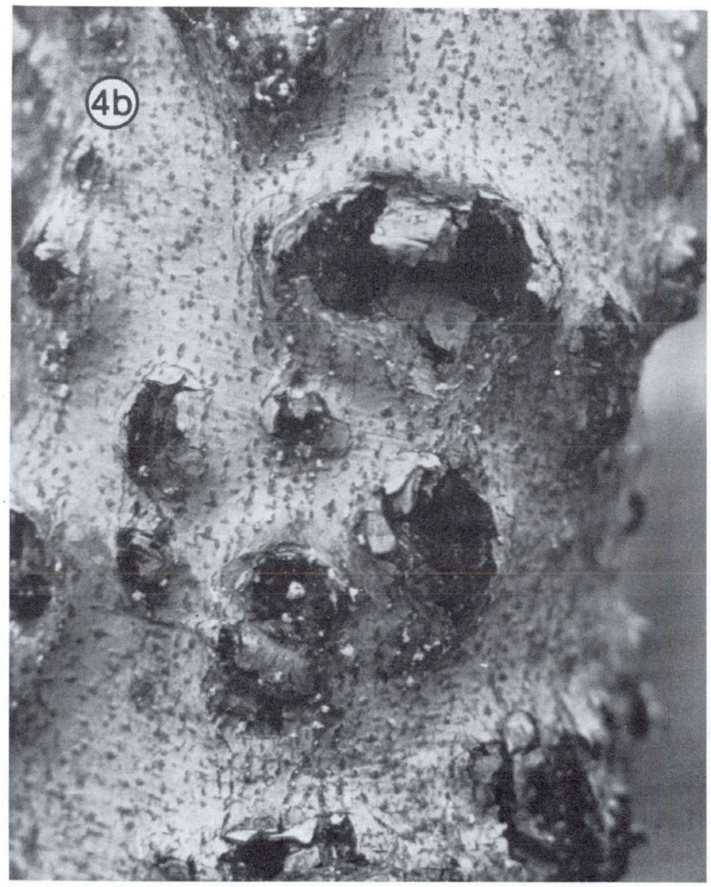


Fig. 4. – Trees in aftermath forests can become severely defective. Initially, cankers are scattered and discrete (a);



...with time cankers provide habitat for scale and new cankers develop and accumulate (b);

...extreme defect sometimes results (c).

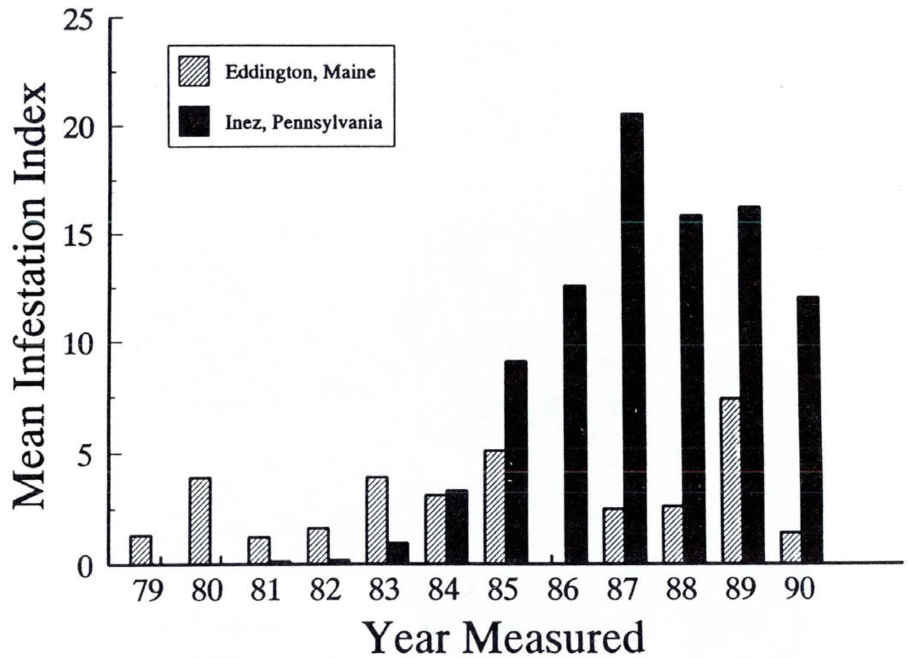


Fig. 5. – Annual population levels of *C. fagisuga* from 1979 to 1990 in the first decade of infestation (Inez, Pennsylvania) and in the sixth decade after initial infestation (Eddington, Maine). The infestation index was calculated as a weighted average of infestation scores for approximately 200 trees per plot. Trace populations were scored as 1, very heavy as 40 (Houston 1994a).

Fig. 6. – A few trees are resistant to beech scale and remain free of disease (center) in contrast to their susceptible neighbors.

METEORS, SPACE ALIENS, and OTHER EXOTIC ENCOUNTERS

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Exotics have had a big impact on our environment. If you do not think so, just look at how many people believe that humans would not exist on this planet were it not for exotics. This belief centers on two main theories: (1) that humans could not have evolved were it not for a huge meteor from outer space striking the earth resulting in extinction of the dinasours, the rise of mammals, and the eventual appearance of humans; and (2) that the development of humans or human ancestors was the result of intervention by aliens from outer space; certainly, this would have been the ultimate exotic introduction! In any case, this is the last you will hear of meteors or space aliens. That is not the kind of exotic encounter you will hear about during the rest of this conference. The exotics we are talking about are just alien plants and animals from other continents. Sometimes though, when I think about what has happened in the past and what we are faced with in the future, these exotics seem almost as scary (and a lot more real) than dinasour killing meteors or space aliens.

During this conference, you will hear much about what has happened in the past when exotics like chustnut blight, white pine blister rust, and Dutch elm disease were introduced into North America. While American chestnut, western white pine, and American elm are not truly extinct like the dinosaurs, they are essentially ecologically extinct in terms of the structure and function that these trees provided to the forest and urban landscapes that they once dominated.

Also important are the actions we have taken to deal with exotic introductions: millions of acres treated with mirex bait to control imported fire ants, millions of acres sprayed with DDT to control gypsy moth, millions of acres treated with herbicides to control noxious and exotic weeds. The monetary cost of these treatments alone have been staggering.

This is all in the past. Let's think about two possible future scenarios:

Future 1. An exotic fungus is introduced into the southern US. This fungus causes a disease in loblolly pine that is not as bad as chestnut blight was to American chestnut or white pine blister rust was to western white pine. This fungus only kills about 75% of the loblolly pine in the South. Other southern yellow pine species are also affected, but to a much lesser extent. What do you think the environmental, social, and economic effects of such an event would be?

Future 2. An exotic bark beetle enters the United States. The beetle is quite small (only 1.5 mm long); it breeds in several species of maple, but prefers sugar maple. The adults feed in twig and banch crotches and leaf axils. The beetles have been in the US for 30 years before they are identified, so they are widely distributed in the eastern US. The beetles cause no significant tree damage, and are of little concern - until an unusual number of dead sugar maples are found in New York, New Hampshire, and Vermont. The beetle is found to be vectoring a new species of fungus that kills 86.5% of the sugar maples from Maine to Minnesota. Again, what do you think the environmental, social, and economic effects of such an event would be?

Do you think these scenarios are too unlikely to even consider? If so, I would like you to think about the globalization of the world economy, the effect of exponentially increasing world trade, the effect of easy air travel, and immigration by people who desire to (and do) bring their native plants into the US along with them, and the effect of trade agreements like GATT on our government's ability to issue protective regulations.

In order to present a balanced view of the exotics issue, I feel compelled to point out that not all exotics are "bad." Most of the food we eat in the US is of exotic origin; many consider having this exotic food available for people to eat to be "good." Honeybees were imported into the US by English settlers; these are also "good" (unless they are Africanized "killer bees"). On the other hand, Spanish explorers imported horse flies, and stable flies; these are "bad" because they literally bite us people on the butt. It is also probably important to remember that perceptions of bugs or fungi or weeds as "good" or "bad" are value judgments that people make. These perceptions/value judgments are important because they govern our personal and society's responses to "opportunities" or "problems."

Ultimately, you will have to make your own value judgments about these past and future exotic introductions. I hope that I have given you some things to think about. I do not want to unduly influence you, so, in closing, I would like to leave you with two thoughts: these exotics are worse than godawful and we need to do more to deal with them.

THREE AMERICAN TRAGEDIES: CHESTNUT BLIGHT, BUTTERNUT CANKER, AND DUTCH ELM DISEASE

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and
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Abstract. Three North American tree species, American chestnut (*Castanea dentata*), butternut (*Juglans cinerea*), and American elm (*Ulmus americana*), have been devastated by exotic fungal diseases over the last century. American chestnut was eliminated from eastern forests as a dominant species by chestnut blight (*Cryphonectria parasitica*). Butternut is presently being extirpated, as butternut canker disease (*Sirococcus clavigigenti-juglandacearum*) spreads into northern populations. Urban and forest American elm populations have been decimated by Dutch elm disease (*Ophiostoma ulmi* and *O. nova-ulmi*). A combination of basic and applied research has been directed toward developing resistant trees of each species. Resistant American elms are now available for planting in urban settings. The prospects for reintroduction of resistant American chestnut, butternut, and American elm into eastern forests appear to be promising.

Forest ecosystems are subjected to many biotic and abiotic stresses. Native insects and diseases, droughts, windstorms and wildfire periodically impact forests or specific tree species, leaving dead or weakened trees. The effects of these stresses may be manifested locally or over a large area, yet they do not cause species extinction. In contrast, exotic pests can threaten the continued existence of a species (cf. United States Congress, 1993). Often host species have not evolved genetic resistance to exotic pests, as coevolutionary processes have not occurred.

Three prominent North American tree species, American chestnut [*Castanea dentata* (Marsh.) Borkh.], butternut (*Juglans cinerea* L.), and American elm (*Ulmus americana* L.) have been severely impacted by three exotic fungal diseases, chestnut blight [*Cryphonectria parasitica* (Murr.) Barr], butternut canker (*Sirococcus clavigigenti-juglandacearum* Nair, Kostichka & Kuntz), and Dutch elm disease [*Ophiostoma ulmi* (Buis.) Narruf. and *O. nova-ulmi*). Below is a brief account of the impacts of these diseases on their host species, examples of research approaches for disease control, and a prognosis for the future of each species.

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Exotic Pests and American Chestnut

The American chestnut was once the dominant hardwood species in the eastern United States. The tree was important to native Americans because it produced large crops of nuts eaten by wildlife and humans, in contrast to the oaks, hickories, and other trees that have replaced the chestnut (Schlarbaum 1989). The species was used in many different ways by early European settlers, providing food and timber, food for domesticated animals, and tannin. Prior to the European colonization of North America, American chestnut was found in vast stands from Maine to Florida, with the largest trees occurring in the southern Appalachians. During the 19th century, however, introduced fungal diseases would change the species composition of eastern North American forests. An exotic fungal disease, *Phytophthora cinnamomi* Rands, infested southern populations of American chestnut and the related Allegheny chinkapin as early as 1824 (Crandall et al. 1945). This root rot disease, thought to have caused mortality of chestnuts and chinkapins in low, moist areas, constricted the natural range. This fungal disease was followed by the more commonly known chestnut blight, which spread throughout eastern hardwood forests at a rate of 24 miles per year. By the 1950s, virtually all mature American chestnuts had succumbed to the disease. American chestnut is now a minor understory component, existing as sprouts from old stumps and root systems (Anagnostakis 1995).

There have been two primary research approaches to restore chestnuts to the American forest: the use of hypovirulent strains and breeding.

Hypovirulence research: In 1953, European chestnut (*C. sativa*) trees infected with blight were observed to be healing (Biraghi, 1953). Further investigation of this phenomenon revealed that unusual strains of *C. parasitica* were associated with healing cankers (Grente and Berthelay-Sauret 1978). The factors responsible for the healing from the unusual or "hypovirulent" (*sensu* Grente) strains were found to be transmissible to normal strains through hyphal anastomosis, and would convert the normal strains to hypovirulent, thereby demonstrating potential for biocontrol. Subsequently, the presence of unencapsidated double stranded RNA (dsRNA) molecules were discovered in cytoplasm of hypovirulent strains, and the dsRNA was confirmed to be a virus (Day et al. 1977). Using molecular biology, Choi and Nuss (1992a,b) demonstrated that the genes of the virus were the cause of hypovirulence.

A problem with using hypovirulent strains as biocontrol has been the lackof vegetative compatibility with certain virulent strains. Without vegetative compatibility, transformation does not occur, and the virulent strain will eventually cause mortality. Another problem with hypovirulent strains is the relatively limited mode of dispersal. The virus exists in the cytoplasm and therefore, does not become involved in the sexual process, i.e., is not contained in the ascospores. Ascospores are disseminated by wind, while the virus containing conidia are not airborne, and have to rely upon animal or water (rain) vectors for dispersal. Despite these limitations, hypovirulent strains have been used to effect recovery from chestnut blight in certain situations (Scibilia and Shain 1989, Anagnostakis 1990, MacDonald and Fulbright 1991, Brewer 1995).

Molecular biology has been used to address the limitations of hypovirulent strains (Choi and Nuss 1992b). The molecular structure of the virus revealed that there were only two genes that were responsible for causing debilitation of the fungus. These genes were transferred to the fungal nucleus using genetic engineering techniques, thereby allowing for subsequent integration into virulent strains through sexual recombination. For every cross, approximately 50 percent of the progeny will have the debilitating genes. Sexual recombination will also broaden the vegetative compatibility range of hypovirulent strains. The effectiveness and spread of the transgenic fungus are currently being evaluated in field conditions. The fungus has been found to survive for two years, produce hypovirulent spores, and was effective in controlling chestnut blight (Anagnostakis, personal communication).

Breeding research: Two strategies were pursued to breeding a blight resistant American chestnut: breeding within the American chestnut gene pool and hybridization with Asian chestnut species.

1. Breeding with American chestnut populations: Although chestnut blight had essentially removed mature chestnuts from eastern forests, there were occasional surviving trees that were thought to possess some resistance. Enzymatic studies of inner bark tissue revealed resistance differences, albeit low, among trees (Samman and Barnett 1973, McCarroll and Thor 1985). Cross pollinations were made among putative resistant trees, but resistance could not be increased to an acceptable level and so the approach was abandoned (Thor 1978, Schlarbaum, personal observation).

2. Hybridization with Asian chestnuts: Resistance in Asian chestnut species, particularly *C. mollissima* Bl. (Chinese chestnut) and *C. crenata* Sieb. & Zucc. (Japanese chestnut) was evident to scientists in the early 1900's. Breeding and testing programs were initiated by state and federal agencies.

Early (pre-1960) breeding programs: The U.S. Department of Agriculture and the Connecticut Agricultural Experiment Station vigorously tried to breed blight-resistant chestnut trees between the 1930s and the 1960s. The initial hybrids generated by these programs were not as blight resistant as the oriental chestnut parent. To increase resistance, a breeding strategy was adopted that crossed the first hybrids back to a resistant parent, either a Chinese or Japanese chestnut. Unfortunately, this strategy produced trees more similar to oriental chestnut phenotypes, e.g., short and branching, which were not competitive in eastern forests (Schlarbaum *et al.* 1994).

Despite the failure to produce a blight resistant American chestnut, the early breeding programs left an extremely valuable legacy of knowledge and germplasm. Methods were developed for testing trees for blight resistance. Hybrids generated in the later phase of these programs gave the first indication that blight resistance is partially dominant and controlled by only two genes. Additionally, the genetic material accumulated and developed by the old breeding programs has proved to be valuable to current breeding efforts. These materials include: two partially blight-resistant first backcrosses (BC_1), the "Graves" tree, and the "Clapper" tree, first generation hybrids, and pure Chinese chestnut.

Backcross Breeding Strategy: A number of breeding programs are breeding blight-resistant American chestnut trees using the backcross method (Burnham et al. 1986, Burnham 1990). This breeding strategy will transfer blight resistance from Chinese chestnut to American chestnut, while retaining the desirable growth, form, and adaptability of the American chestnut. Highly blight-resistant progeny were recovered after intercrossing first hybrids between Chinese and American chestnut or intercrossing first backcrosses.

There is now evidence that only a few genes control blight resistance in Chinese chestnut, specifically, two or three incompletely dominant genes. The evidence was provided by a combination of crossing and molecular biology. In addition, the use of molecular techniques to accelerate the breeding process is now considered to be feasible. A genetic map of chestnut with regions associated with blight resistance identified, could be used to screen newly germinated nuts for blight resistance. This may enable several generations of backcrossing to be bypassed, yet still produce trees that have proportions of American parentage similar to those of trees bred using conventional backcrossing.

Blight resistant American chestnut may soon be available for general reforestation. The American Chestnut Foundation estimates that by 2012, nuts will be produced from the most advanced breeding lines that can be used in reforestation.

Chestnut gall wasp – another exotic pest of chestnut: Although blight resistant chestnuts may be available in the near future, *Phytophthora cinnamomi* will still effectively restrict planting to upland sites. On these sites, chestnuts will then be challenged by yet another exotic pest, the chestnut gall wasp (*Dryocosmus kuriphilus* Yasumatsu). Infestations by this insect were first reported in 1974 (Payne et al. 1975) and now have spread north into Tennessee and North Carolina. Chestnut gall wasp larvae feed upon bud and flower tissue forming a characteristic gall and producing a toxin that can kill the infested branch. Severe infestations can cause tree mortality.

Butternut Canker Disease and Butternut

Butternut (*syn.* white walnut) is a highly valued hardwood species native to eastern North American forests. The tree is closely related to black walnut (*Juglans nigra* L.) and can occur on cove hardwood, dry, and riparian sites. The wood of butternut is highly valued for carving and for furniture, e.g., cabinets. Butternuts were often planted on farmsteads, close to the house. Nut kernels were used in baking, and cultivars have been selected for orchard production (Millikan and Stefan 1989). The husk surrounding the nut was often used to dye fabrics. In the American Civil War, the color of Confederate uniforms was created using butternut husks as a source of dye.

Currently, many butternut populations are being devastated by an exotic fungal disease that causes multiple branch and stem cankers. The causal agent of butternut canker is *Sirococcus clavigignenti-juglandacearum*, a mitosporic fungus belonging to the large group of Fungi Imperfecti. This large group encompasses those fungi where only the asexual stage of reproduction has been found and the sexual stage remains unknown. Currently, this *Sirococcus* species is thought to be an introduced pathogen, due to its sudden appearance on butternut. The disease was first observed in Iowa in 1967 (Renlund 1971), but is believed to have spread from the southeastern coastal region. The age of the cankers suggests that the fungus first appeared in North America approximately 40-50 years ago (Anderson and LaMadeleine 1978).

In 1995, the Forest Service estimated that 77 percent of the butternuts in the Southeast were dead (USDA Forest Service 1995). Surviving butternuts are now usually found in riparian zones, and the majority of trees are heavily infected and not reproducing. In contrast to American chestnut, butternuts usually will not sprout after stem death. Young trees are subject to mortality, and fungal spores can be carried on the fruit husks (Prey and Kuntz 1982). Therefore, when a population becomes infected, that particular gene pool has the potential to be permanently lost. The rapid decimation of butternut populations has been considered so severe that the U. S. Fish and Wildlife Service has listed the species as a "species of Federal concern."

In response to the devastating effects of the butternut canker, two research and development efforts have been formed to address this problem. The USDA Forest Service, North Central Experiment Station, initiated a cooperative effort with northern states and northern National Forests to locate surviving butternuts and graft putative resistant trees into clone banks to preserve the germplasm. Cooperators are instructed on identification of butternut canker and conservation of germplasm (Nicholls et al. 1978, Ostry et al. 1994). Research is being conducted to develop laboratory and field protocols to screen trees for resistance, host range studies, *in vitro* clonal propagation (Pijut 1993), and the role of insects in dissemination of the fungus. A continuing series of progress reports document the research activities of this group.

A coalition has also been formed in the southeastern United States, by the University of Tennessee, USDA Forest Service, Southern Region and Southern Forest Research Experiment Station, Great Smoky Mountains National Park, Tennessee Division of Forestry, and USGS Biological Research Division. This coalition is working to locate surviving trees or populations, characterize sites, identify trees with putative resistance, develop screening methodology for disease resistance, study fungal physiology, and preserve germplasm.

Progeny/gene conservation tests were established at five locations in 1994 and three additional locations in 1995. One planting was established under infected butternut trees for increased disease pressure. This planting will be closely monitored for disease spread and resistant genotypes or resistant families. Seeds collected in 1996 are presently being grown at the East Tennessee State Nursery to provide experimental material for additional plantings and research activities.

Pathology studies have centered around developing screening methods to identify butternut resistance. These studies include wounding and mycelial inoculation of seedlings under different fertilization regimes, wounding and spore inoculation of seedlings, and log inoculations to study pathogenicity. When possible, different genetic families (open-pollinated) are used for inoculation. Additionally, research has been conducted on physiology and transmission of the fungus.

Currently, the lack of knowledge about the physiology and genetics of *Sirococcus clavigignenti-juglandacearum* hinders the formation of a comprehensive strategy for protecting the butternut species. The survival of large butternut trees in localities where the majority of butternut trees have been destroyed suggest that genetic resistance may be present. Resistance is present in nut selections from another *Juglans* species. Heartnut [*Juglans sieboldii* var. *cordiformis* (Maxim.) Rehd.], a Japanese walnut nut selection, has shown resistance to butternut canker and could be used in a breeding program. Using either natural resistance or resistance in heartnut, a backcross breeding approach coupled with the development of a methodology for disease resistance screening has the potential to restore this important tree species to eastern forests.

Dutch Elm Disease and American Elm

American elm usually occurs in a mixture of other hardwood species, commonly on bottomland sites with rich, well-drained loam soils. The species' distribution is throughout eastern North American forests, extending well into the Great Plains. The streets of North American cities were once lined with American elms, a fast growing, stress tolerant tree, with a vase-shaped crown. Wood from the species was used for furniture, flooring, construction, hardwood dimension, and veneer.

Forest and urban populations of American elm have been devastated by two strains of Dutch elm disease (DED), a non-aggressive strain (*Ophiostoma ulmi*) and an aggressive strain (*O. nova-ulmi*). The disease entered the country on shipments of unpeeled veneer logs from Europe. Dying American elms were first observed in Cleveland, Ohio in 1930 (May 1930). The disease spread through eastern forests from three infection centers (cf. Stipes and Campana 1981) and had spread through most of country by 1977. Dutch elm disease has proven to be the most devastating shade tree disease in the United States (Karnosky 1977).

Some forest populations, however, still contain large American elms, ca. 29"+ dbh. Other native elm species, such as red elm (*Ulmus rubra* Muhl.), can be infected with DED, but appear to have greater resistance.

Attempts to breed resistance into American elm using other *Ulmus* species generally failed. American elm is a tetraploid, while other elm species have diploid chromosome complements (Santamour 1969), and a reproductive barrier exists between the two ploidy levels. Fortunately, American elms exist that are susceptible to infection, but are tolerant to the disease. Tolerant trees are clonally propagated by rooted cuttings. Dr. A. M. Townsend, The U. S. National Arboretum, estimates that only 1 in 100,000 American elm trees is tolerant to Dutch elm disease (Becker 1996). Two new cultivars, "Valley Forge" and "New Harmony," were released by the U. S. National Arboretum in 1996 (U. S. National Arboretum, 1996). A small number of American elm trees which have survived the two DED epidemics are identified each year over the wide range of this species. Seeds or cuttings from each tree subjected to an established screening protocol are selected for tolerance to this deadly wilt disease. Ideally, different resistances can be brought together by hybridizing widely separated elms. To this end, pollen from the trees which survived DED epidemics is being used in controlled crosses with DED tolerant selections.

A cooperative project between the USDA Forest Service and the U. S. National Arboretum has been initiated to study the genetics of host resistance in the field and at the molecular level. Four tolerant selections have been crossed. The resulting progenies will be DNA fingerprinted and evaluated for disease tolerance to construct a genetic map. The genetic map could be used to guide further tree selection in breeding programs and to understand quantitative inheritance of disease tolerance. It is estimated that at least 10 percent of the progeny trees will have DED tolerance greater than the parent trees.

Although trees with good tolerance to DED have been found, very little is known about the mechanisms of tolerance. Research has been conducted to identify American elm defense reactions at the biochemical level using cell suspension cultures (Gringas et al. 1997). It will be important to recognize similarities and differences in the mechanisms of DED tolerance in the varied selections to enable the synthesis of unique genetic combinations. In addition, any breeding programs directed toward improving disease resistance would benefit from a reliable tissue culture screening method. Such a technique could be used to eliminate years of effort in the evaluation of germplasm. The cultures will also be used to isolate defensive chemicals and identify genes responsible for tolerance. Differences among cell cultures in toxin tolerance and changes in gene expression shown by the amount and type of newly synthesized proteins have been detected. Studies by USDA Forest Service scientists are planned to investigate the impact of elm cell secretions on the fungus and associated toxins.

Reintroduction of American Chestnut, Butternut, and American Elm

A critical question that arises in relation to reintroduction of these species to eastern forests is whether they can reoccupy the niche they formerly held and successfully compete and reproduce. For butternut and American elm, there are enough existing naturally reproducing populations that detailed studies can be made on the silvicultural requirement for successful establishment. No such studies can be made on American chestnut on sites within the former natural range. However, there is indirect evidence on the growth characteristics of the species that suggest a strategy.

Blight-resistant American chestnut trees will probably have no difficulty in reclaiming certain sites from the relatively slower growing oaks and hickories. Species such as yellow-poplar (*Liriodendron tulipifera*) and red maple (*Acer rubrum*) will be vigorous competitors, but the growth rate of chestnut seedlings suggest that chestnut will be able to compete with these seedlings (Schlarbaum, personal observation). In blight-free regions in the midwest, chestnut seedlings have been able to usurp niches formerly filled by oak and other northern hardwoods. Chestnut sprouts in clear cuts provide indirect evidence of the species' growth rate potential. American chestnut sprouts dominate the site until infected by the blight fungus.

Another significant problem is in the mechanics of generating enough seed for widespread reforestation of these species. Seed production from the endpoints of breeding programs usually occurs in a seed orchard, under the auspices of a university, state, or federal tree improvement program. Unfortunately, government-based tree improvement programs are rapidly disappearing due to the relatively high cost and long time periods required to generate tangible products associated with this type of research and development program (Schlarbaum 1995). Until this trend is reversed, general reforestation with resistant genotypes of these species will be hampered.

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Alliaria petiolata

Adapted from: ELEMENT STEWARDSHIP ABSTRACT

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SUMMARY

Garlic mustard (*Alliaria petiolata*) is a biennial herb that invades forested communities and edge habitats, where it spreads rapidly and apparently displaces native herbaceous species, often within ten years of establishment. The plant has no natural enemies in North America, and is difficult to eradicate once established. Thus, the best and most effective control method for *Alliaria* is to prevent its initial establishment.

In shaded and partially shaded communities lacking *Alliaria* the preferred method is to monitor annually, and remove all *Alliaria* plants prior to seed production. Once *Alliaria* is established, the management goal is to prevent seed production until the seed bank is depleted, potentially 2-5 years. Cutting of flowering stems provides the most effective control with minimal or no side effects, but has a high labor cost. Burning and herbicide application both provide effective control at a lower labor cost, but each has potential drawbacks: Fire may increase total presence of *Alliaria* unless a second and third consecutive fire are conducted; fire may alter groundlayer composition; and herbicides may negatively impact some native groundlayer species.

BIOLOGY

Alliaria petiolata [(M. Bieb.) Cavara and Grande] is an obligate biennial herb of the mustard family (Brassicaceae). The genus name *Alliaria* refers to the garlic or *Allium*-like fragrance of the crushed leaves, an unusual odor for the mustard family. The species name *petiolata* refers to the petiolate leaves.

Alliaria seeds germinate in early spring, beginning in late February or early March, and concluding by mid May in northern states and Canada (Cavers et al. 1979, Kelley et al. 1991, Roberts and Boddrell 1983). In northern Illinois, germination coincides with emergence of spring beauty (*Claytonia virginica*) and false mermaid weed (*Floerkea proserpinacoides*).

Seedling density in heavily infested forests was recorded at 5,080/m^2 at the cotyledon stage, and 2,235/m^2 at the 2-3 leaf stage, in Illinois (Nuzzo unpublished), and approximated at 20,000/m^2 in Ohio (Trimbur 1973).

By June seedlings develop the characteristic rosette of first year plants. Basal leaves are dark-green and kidney-shaped with scalloped edges, 6-10 cm diameter, and have pubescent petioles 1-5+ cm long (flowering stem leaves are alternate, sharply-toothed, triangular, 3-8 cm long and wide, and gradually reduced in size towards the top of the stem).

Immature plants can be confused with other rosette forming species, especially violets (*Viola* sp.), white avens (*Geum canadense*), and *Cardamine* sp. *Alliaria petiolata* can be distinguished from these plants by the strong garlic odor in spring and summer. In fall and winter *Alliaria* can be distinguished by examining the root system. *Alliaria* has a slender, white, taproot, with a distinctive "s" curve at the top of the root, just below the root crown. Axillary buds are produced at the root crown and along the upper part of the "s."

First year rosettes are sensitive to summer drought (Byers 1988) and approximately 95% die by fall (Nuzzo 1993b). By mid-fall rosettes average 4-10 cm diameter and are dark green to purplish in color. The rosettes continue to grow in winter during snow-free periods when temperatures are above freezing (Cavers et al. 1979). Natural mortality continues through winter: Total survival rate from seedling to adult stage varies from 1% (Nuzzo 1993b) to 2-4% (Cavers et al. 1979).

Alliaria is an obligate biennial: all plants that survive the winter produce flowers, regardless of size, and subsequently die (Cavers et al. 1979, Byers and Quinn 1988, Bloom et al. 1990). Plants only 5 cm tall, with 3-4 leaves, have been observed with flowers and seeds. The majority of plants are taller, averaging 0.7 to 1.0 m when in flower. Flower stalks begin to elongate in March or April, and flowers open early April through May. This is some 6-10 weeks after new seedlings germinate; in established populations generations overlap, and two cohorts can be seen from March through June. *Alliaria* flowers can be self-or cross-pollinated (Cavers et al. 1979, Babonjo et al. 1990).

Plants usually produce 1-2 flowering stems, although robust plants have been recorded with up to 12 separate flowering stalks. Flowers are produced in spring in terminal racemes, and occasionally in short axillary racemes. Some plants produce additional axillary racemes in mid-summer. Flowers are typical of the mustard family, consisting of four white petals that narrow abruptly at the base, and 6 stamens, two short and four long. Flowers average 6-7 mm in diameter, with petals 3-6 mm long. Seeds develop in a linear silique, with siliques forming on the lower part of the inflorescence while flowers are still opening on the upper part. *Alliaria* produces an average of 16.4 ($\pm$ 3.0) seeds/silique (range 3 to 28), and 21.8 ($\pm$ 22.5) siliques/plant (range 2 to 422; Nuzzo unpublished, Cavers et al. 1979). Seeds ripen and disperse between mid-June and late September (Cavers et al. 1979, Kelley et al. 1990).

Seeds are dormant at maturity and require 50 to 100 days of cold stratification to come out of dormancy (Byers 1988, Lhotska 1975, Baskin and Baskin 1992). The dormancy period lasts eight months in southern locales (Baskin and Baskin 1992, Byers 1988) and 22 months in northern areas (Cavers et al. 1979).

Unlike some forest crucifers that fail to germinate under leaf cover, *Alliaria* seeds germinate in both light and dark after dormancy is broken (Bloom et al. 1990, Byers 1988). Light alone will not stimulate germination during cold stratification (Byers 1988). The majority of seeds germinate as soon as dormancy is broken (Roberts and Boddrell 1983, Baskin and Baskin 1992). A small percentage of seed remains viable in the seed bank for up to four years (Roberts and Boddrell 1983, Baskin and Baskin 1992).

Alliaria spreads exclusively by seed (Cavers et al. 1979). Seeds typically fall within a few meters radius of the plant. Wind dispersal is limited, and seeds purportedly do not float well, although seeds readily attach to moist surfaces (Cavers et al. 1979). Anthropogenic distribution is the primary dispersal mechanism (Lhotska 1975, Nuzzo 1992b, 1993a). Seeds are transported by natural area visitors on boots and in pant cuffs, pockets, and hair, and by roadside mowing, automobiles and trains (Nuzzo 1992b). Seeds are widely dispersed in floodwaters. Seeds may be dispersed by rodents or birds; isolated plants are frequently found at the bases of large trees in forest interiors. Seeds may possibly be distributed directly or indirectly by white-tailed deer (*Odocoileus virginianus*).

In southern locales *Alliaria* populations are even-aged, alternating annually between immature plants and adult plants (Baskin and Baskin 1992), probably due to the 8 month seed dormancy. In northern climates *Alliaria* populations can be even-aged in early stages of invasion, and then become multi-aged as the seed bank builds up. *Alliaria* is frequently overlooked at low density levels. In many sites *Alliaria* can be present for a number of years before appearing to "explode" in favorable years. Once *Alliaria* reaches this level of infestation control is difficult to achieve.

IMPACTS

Alliaria is one of the few alien herbaceous species that invades and dominates the understory of forested areas in North America. The phenology is typical of cool-season European plants, and *Alliaria* grows rapidly during early spring and late fall when most native species are dormant. *Alliaria* invades forested communities and edge habitats, where it spreads rapidly and apparently displaces native herbaceous species, often within ten years of establishment. After just four years of co-occurrence with *Alliaria*, cover of the ephemeral herb toothwort (*Dentaria laciniata*) was reduced >50% (Nuzzo 1992a). Toothwort plants associated with *Alliaria* were stunted, yellowed, and failed to flower.

HABITAT

Alliaria is most widespread in the midwestern and northeastern United States and in southern Ontario, where it invades wet to dry-mesic deciduous forest (Cavers et al. 1979, Nuzzo 1992a, 1993a), and also occurs in the partial shade characteristic of oak savanna, forest edges, hedgerows, shaded roadsides, and urban areas, and occasionally in full sun (Nuzzo 1991). *Alliaria* is common in river-associated habitat, particularly in the Northeast (Nuzzo 1993a), and in both upland and floodplain forest communities in the Midwest.

Alliaria grows on sand, loam, and clay soils, and on both limestone and sandstone substrates, occurs rarely on drained peat soils, and does not occur on muck soils. *Alliaria* frequently grows in well-fertilized sites (Cavers et al. 1979), and is described as a nitrophile by Passarge (1976) and Wilmanns and Bogenrieder (1988).

MANAGEMENT

The goal of *Alliaria* management is to prevent seed production. *Alliaria* spreads only by seed, and has a short-lived (2-5 years) seed bank; in theory, preventing seed production for a maximum period of five years should result in elimination of *Alliaria* from a site, if no additional seeds are introduced.

The primary management objective in areas lacking this plant is to prevent establishment, by annually monitoring for and removing all *Alliaria* plants. The primary management objective in infested sites is to prevent seed production. Cutting flowerstalks is effective in small populations. Fire and herbicides are useful for larger populations but both have potential side effects. No method provides 100% control.

Growing season mortality reduces *Alliaria* seedling populations by >95% between spring and late fall (Nuzzo 1993b); hence, control is most economical when undertaken in late fall or early spring, prior to flower production. Late fall is usually the preferred season for control, as native plants are dormant and management can be conducted until snow covers the ground. If weather is unfavorable in fall, control can still be conducted in early spring. Delaying control until spring can be risky, as native herbs may begin growth earlier than anticipated, and weather may limit or prevent management activities.

Biological control may be the only regionally effective method of controlling this species, but as of 1997 no formal program had been established.

BURNING

Prescribed burning can provide effective control of *Alliaria* when fires burn completely through the affected area, and are conducted for at least two consecutive years (Nuzzo 1991). Kill appears related to a critical increase in rootcrown temperature, effected by a slow fire, or by a fast fire that also removes all litter.

Low-intensity fires are ineffective (Nuzzo 1991). A slow mid-intensity fire can reduce adult density by 50% (Nuzzo 1991). A fast high-intensity fire that removes most litter can effectively reduce adult cover (Nuzzo et al. 1996). However, fast fires may leave a thin layer of litter. This 1-2 cm layer is sufficient to protect root crowns, which subsequently produce multiple flower stalks from axillary buds, increasing total seed production (Nuzzo et al. 1996). Removal of the litter layer increases seedling survival after fire, and can result in a larger population after a single burn (Nuzzo et al. 1996). Thus, after a single fire, total *Alliaria* cover can increase due to survival of adult plants, and/or to enhanced seedling survival. After two consecutive fires total cover is greatly reduced (Nuzzo et al. 1996).

Spring and fall fires are equally successful in reducing cover of *Alliaria* rosettes (Nuzzo 1991). Spring fires also reduce seedling presence if conducted during the germination period (Nuzzo 1991). However, burning enhances survival of seedlings that germinate after fire, by removing the smothering leaf litter (Nuzzo et al. 1996).

Use of fire as a management tool should be tailored to the specific community. Removal of the litter layer may facilitate invasion by disturbance adapted species, including *Alliaria*, particularly if there is little native groundlayer present at the site. Fires should only be conducted when at least two consecutive fires can be scheduled; burning only once may increase *Alliaria* abundance. Impact of consecutive fires on the community should be considered, including changes in groundlayer composition.

Fire is not a realistic management tool in upland communities that have become fire-resistent, due to decreased fuel loads and flammability resulting from replacement of overstory oaks (*Quercus* sp.) by cherry (*Prunus serotina, P. virginiana*), ash (*Fraxinus* sp.), black walnut (*Juglans nigra*), and hackberry (*Celtis occidentalis*). Invasion of the understory by buckthorn (*Rhamnus cathartica*) and honeysuckle (*Lonicera tatarica, L. xylosteum*) also reduces fuel loads.

CHEMICAL

Dormant season herbicide application can provide effective control of *Alliaria*, but poses a potential threat to native herbaceous and graminoid species.

Round-up

Round-up (glyphosate) applied at 1%, 2%, and 3% concentrations to dormant rosettes in late fall or early spring reduced adult cover by >95% (Nuzzo 1991, 1996). Control was slightly greater with higher Round-up concentrations. Seedlings that germinate after application are not affected by the herbicide, as Round-up has no soil residual. Roundup applied after germination will significantly reduce seedling populations (Nuzzo 1991).

Round-up results in some native species loss, particularly when applied in spring, as it is a non-selective herbicide. Semi-evergreen species including phlox (*Phlox divaricata*), wild ginger (*Asarum canadense*) and sedges (*Carex* sp.) are reduced by Roundup (Nuzzo 1996). At the community level, Round-up did not affect mean species richness or total mean herbaceous cover, but did significantly reduce cover of both sedges and grasses, at both 0.5% and 1% concentrations (Nuzzo 1996).

Basagran

Growing season application of Basagran (Bentazon) at 0.56-1.12 kg AI/ha (0.50-1.0# AI/acre) reduced rosette cover by 90-95% (Nuzzo 1994). Dormant season application nonsignificantly reduced rosette cover >90% (compared to 70% reduction in the control plots)(Nuzzo 1996).

Basagran did not affect species richness or herb cover, and had minimal effect on graminoid cover. *Alliaria* seedlings were not affected by treatment. Basagran is a post-emergent contact herbicide that targets dicots and is used to control mustards in agricultural fields.

CUTTING

Cutting flowering plants at ground level results in 99% mortality, and eliminates seed production. Cutting at 10cm above ground level results in 71% mortality and reduces seed production by 98%

(Nuzzo 1991). Ability of cut flowerstems to form viable seed is unknown. Cavers et al. (1979) suggest that vivipary (germination of seeds while still in the silique) does not occur, although all seeds remained viable during the observation period. Until more information is available, cut stems should be removed from the site, or piled and composted.

Cutting with a weed whip provides quick removal of flowering stems, but also may remove other desirable species. Some native species, such as *Trillium*, are severely impacted if cut. Most other species are not substantially damaged, and the benefits of removing *Alliaria* outweigh the temporary reduction in growth and reproduction of native groundcover species.

Pulling is very labor intensive but effective if the upper half of the root is removed. *Alliaria* frequently snaps off at or just below the root crown when the flower stalk is pulled, leaving adventitious buds which send up new flower stalks. Pulling can result in substantial soil disturbance, damaging desirable species and bringing up *Alliaria* seeds from the seedbank. Soil should be thoroughly tamped after pulling to minimize chances for re-establishment of garlic mustard or other weedy species. Alternatively, soil may be kept disturbed to stimulate germination of *Alliaria* seeds and subsequent depletion of the seedbank, if seedlings are removed before maturing. In general, cutting is a less destructive method of control than pulling but is effective only during flower stalk elongation, whereas pulling can be conducted throughout the growing season.

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GLOBAL GYPSY—THE MOTH THAT GETS AROUND

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Abstract. It is difficult to document the total economic impacts of exotic insect pests on eastern U.S. forests. Annual losses to a single introduced pest, the gypsy moth, *Lymantria dispar* L., have exceeded $30 million from 1980 to 1996. The complicated behavior and actions of humans in accelerating the spread of this "global gypsy" are discussed. Examples of predicted economic impacts derived from pest risk assessments are given that demonstrate potential losses to other exotic insect pests.

Invasive pests are among the most serious threats to biological diversity in U.S. forest ecosystems. Additionally, they disrupt forest management and cause enormous financial loss. Efforts by the USDA Animal and Plant Health Inspection Service to detect and prevent new introductions cost an estimated $200 million annually. Despite efforts within the United States and with U.S. trading partners, additional pests are being introduced and some will become established. In this country, some 380 exotic insects and diseases attack native and exotic trees and shrubs (Hack and Byler 1993). The complete history of various invasive insects--from introduction via known pathways to establishment and spread—as well as their total economic and ecologic impacts can only be estimated. However, there is substantial documentation of the devastating effects of the gypsy moth, *Lymantria dispar* L., the dominant exotic insect pest of U.S. eastern forests. As a result, this "global gypsy" can serve as a template for appreciating the economic consequences of invasions by exotic forest pests.

Since its accidental introduction into Massachusetts from France in 1869, gypsy moth has spread southward and westward by larval dispersal and inadvertent movement of the insect in various life stages by humans (annual rate of 21 km) (Fig. 1) (Liebhold et al. 1992, 1995). Attempts to slow its spread into the highly vulnerable forests of the Southeast and Mid-South have been accelerated by estimates of $100 to 500 million in savings over the next 25 years (Leuschner 1991). Research and pest management programs have provided a basic understanding of the ecology of gypsy moth and its impact on forests, and biologically based technologies have been deployed to suppress the European strain of this insect (Doane and McManus 1981).

New introductions of the European strain of gypsy moth are controlled aggressively. Still, the Asian strain, with females capable of flight (Wallner et al. 1995) and larvae with a broad host range (Baranchikov 1989), would render efforts to constrain it technically difficult and more expensive. Following the introduction of the Asian strain of gypsy moth into the northwestern United States and Canada on Russian grain ships (Bogdanowicz et al. 1993) and into North Carolina on U.S. military equipment from Germany (Hofacker et al. 1993) eradication efforts during the 1990's exceeded $30 million. The military experience is instructive. During 1993-95, milvans and vehicles were inspected and presumed free of gypsy moth and transhipped from Wilmington, North Carolina, to 48 locations throughout the United States (Fig. 2). However, this activity could have founded widespread infestations if they were infested.

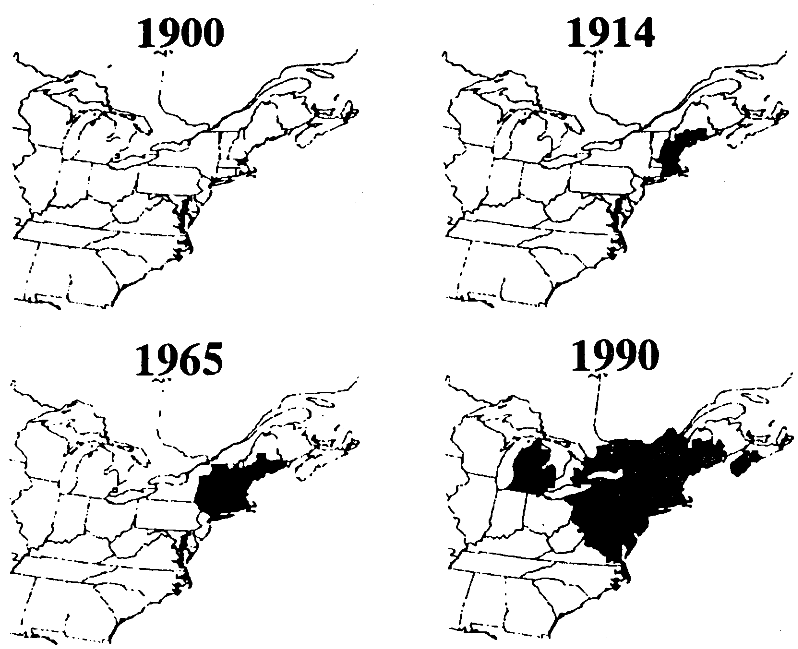

Figure 1. Establishment and spread of gypsy moth in the United States.

Gypsy moth is a polyphagous defoliator but prefers oak and poplar (Montgomery and Wallner 1988). Defoliation by this forest pest may increase seedling mortality, reduce tree growth and the production of mast for wildlife (Gottschalk 1990a), and cause occasional massive tree mortality (Allen and Bowersox 1989). The effect of several defoliation episodes on shifts in stand species composition is not well understood (cf. Campbell and Sloan 1977; Gansner et al. 1993), but the adverse impact of gypsy moth on aesthetic, recreation, and home values has been documented (Payne et al. 1973). During the last major outbreak when more than 16 million acres of mixed hardwood were defoliated, timber losses in the State of Pennsylvania alone exceeded $72 million. This does not include more than $9 million expended by that state on spray programs. From 1968 to 1985, Pennsylvania incurred $219 million in losses from gypsy moth defoliation (Gottschalk 1990b). Because gypsy moth is an episodic pest outbreaks do not occur annually, so variables such as the number of years of defoliation, tree vigor, and other environmental stressors influence its impacts. Trees weakened by defoliation are more susceptible to attack by secondary organisms like the two-lined chestnut borer and shoestring root rot fungus (Wargo 1977).

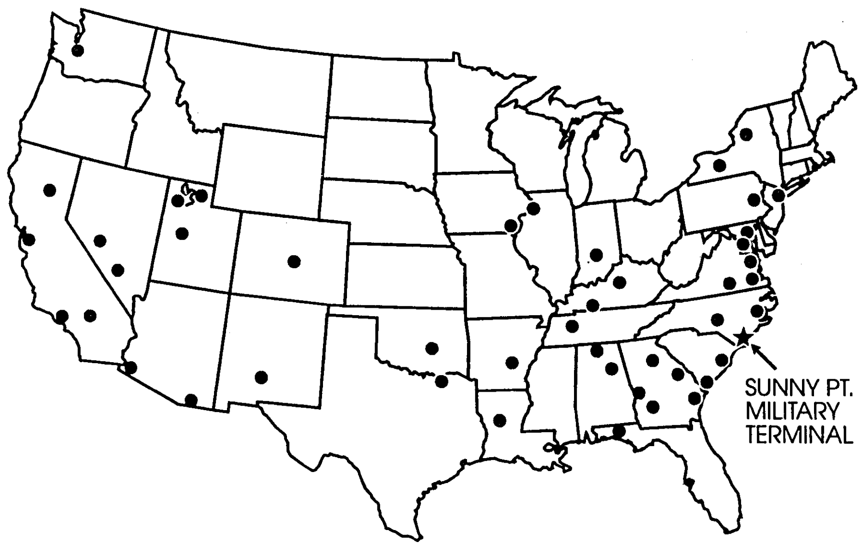

Figure 2. Transshipment locations of Department of Defense equipment through the Sunny Point military terminal, Wilmington, North Carolina, from Germany, 1993-95.

Average annual expenditures for gypsy moth eradication, suppression, and research in United States from 1980 to 1994 totaled $30 million (1995 dollars) (Fig. 3). This figure does not include $8 million for deploying 400,000 pheromone traps for monitoring ($20/trap). These yearly costs will increase as gypsy moth reaches the highly susceptible forests of the South, mid-South, and West, which contain high proportions of preferred host trees. Similar estimates of economic and environmental costs for other invasive organisms may be difficult (Wallner 1996), but accurate assessments will be critical in gaining political and economic support to establish programs to eradicate and/or control exotic insect pests (Wallner in preparation) and sustain current programs. And competition for resources to confront new introductions will only increase in the future.

The ecological "ripple effect" of exotic pests is nearly impossible to predict. For example, at least two significant changes occurred in the aftermath of the chestnut blight, which eliminated more than 8 million American chestnut trees, one of the most important tree species of eastern U.S. forests (Kuhlman 1978). Oak replaced chestnut which created more extensive forests susceptible to gypsy moth. Also, oak cohorts did not adapt well on sites previously occupied by chestnut and now are senescing due to environmental stress (Starkey et al. 1989). Thus, Appalachian forests are experiencing delayed consequences of two exotic agents introduced more than a century ago.

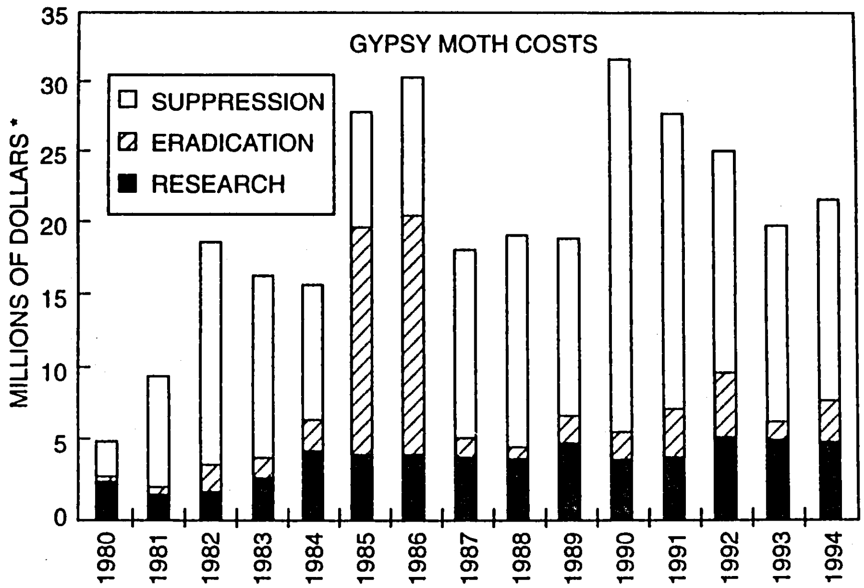

Figure 3. Yearly costs for gypsy moth eradication, suppression, and research programs in the United States, 1980-94.

Two organisms, gypsy moth and zebra mussel, were responsible for a congressionally mandated report on harmful nonindigenous species in the United States (Office of Technology Assessment 1993). As mentioned previously, the available literature and this congressional report make it clear that there are few data on the economic impacts of specific exotic forest pests. Niemela and Mattson (1996) acknowledge this problem bluntly: "When the outrageous economic and ecological costs of the wanton spread of existing exotics and continued entry of new ones becomes common knowledge, there will be a public outcry to mitigate the potentially dire consequences." Lacking precise economic loss estimates, land managers and regulators will be hard pressed to provide justification for what if any action should be taken and the priorities in selecting among several exotic pest programs. As an entire ecosystem is devastated by an exotic insect, we can comprehend how insidious and sometimes overwhelming the effects can be. However, predicting which ones may survive and have a negative economic impact is not easy.

About 40 percent of the major insect pests in the United States are exotic. The use of pest risk assessment (PRA) procedures, common in evaluating the potential hazard associated with international commodity trade (Orr et al. 1993), has proven useful in identifying insect pests that could be imported into this country on unprocessed wood from several foreign countries. For example, the potential cumulative economic impact from the introduction of insects from Siberia and New Zealand could be as high as $60 billion (Table 1). While these estimates may seem excessive, they are consistent with those given in the Office of Technology Assessment report, which estimates losses to introduced insect pests from 1906 to 1991 at $92 billion.

TABLE 1. Estimated economic impacts to U.S. forest resources from selected introduced insect pests from Siberia and New Zealand (1990 dollars).

	Cumulative costs			
	Best case		Worst case	
	Insects	Diseases	Insects	Diseases
	Millions of dollars			
Siberia[a]	35,210	295	60,000	2,254
New Zealand[b]	45	7	295	69

[a] Source: USDA For. Serv. Misc. Publ. 1495 (1991).
[b] Source: USDA Misc. Publ. 1508 (1992).

Of all introduced insects, those with parthenogenetic capabilities have the best chance of becoming established (Neimela and Mattson 1996). Examples include the adelgids, about 50 species of which attack conifers in North America. Two introduced species that gained entry into this country on nursery stock devastated mature trees in fragile forests. The balsam woolly adelgid (European origin) threatens to eliminate relic stands of Fraser fir in the southern Appalachian Mountains (Dull et al. 1988), while the hemlock woolly adelgid (Asian origin) is decimating eastern hemlock forests from New England to North Carolina (Souto et al. 1996). Neither species have been subjected to the PRA process nor have their economic effects been assessed despite direct and indirect impacts on the host resource. For eample, nursery sales of eastern hemlock have plummeted due to the hemlock woolly adelgid. Comparable impacts by other exotic pests include those on the dogwood nursery trade from dogwood anthracnose.

A recently completed PRA for importing unprocessed wood from Mexico acknowledged the severe potential impact of adelgids on conifers. Adelgids are known to damage pines in Mexico, but their distribution and economic impact are not well known. Should a Mexican *Pineus* species become established in the U.S. southern pine region, some 8½ million acres could be at risk. Assuming losses totaling $243 per acre for mortality, growth loss, and replanting, annual costs could approach $20 million. Using a discount rate of 4 percent, losses in net value over the next 30 years would amount to $258 million. Comparable estimates of loss in other forest ecosystems from invasions by exotic insects would be invaluable to the PRA process and aid in establishing priorities for allocating scarce resources.

The genesis of this conference was to create an atmosphere of sharing information on exotic insect pests, increase our understanding of their complex roles, and underscore the critical importance of cooperation among various agencies. The continuing challenge to land managers will be to prevent loss of forest productivity while deterring further erosion of eastern U.S. forests. Research must be able to anticipate questions concerning potential impacts of exotic pests. For example:

Is eradication the first and only consideration?

Should we modify our concepts of ecosystems that already have been altered by exotic pests?

Can we manage, much less restore, ecosystems altered by invasive pests?

As resources become limiting, who will decide which exotic pest receives priority attention?

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THE OTA REPORT ON HARMFUL NONINDIGENOUS SPECIES[1]

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ABSTRACT. At least 4,500 species of foreign origin have established free-living populations in the United States, of which about 15% cause severe economic or environmental harm. Between 1906 and 1991, just 79 species caused an estimated $97 billion in losses. Virtually every economic sector and area of the country is affected, with some of the biggest problems in the east. Usually, exotic species reach the United States with human help, often via international trade. Rates of entry fluctuate, but never drop to zero—creating an even-greater economic and environmental burden. Neither domestic policies nor international agreements have been very successful when it comes to preventing new problems and managing old ones.

Background: OTA in Cyberspace

In October 1993, the Congressional Office of Technology Assessment (OTA) released "*Harmful Non-Indigenous Species in the United States*." This report synthesized, for the first time, the status of such species, their impacts, and related policies across geographic, taxonomic, and institutional lines. Because of the report's popularity and because Congress abolished OTA in 1995, only a few printed copies are available in federal respository libraries. However, the report can be downloaded from two web sites[2]. Also, it is part of a 1996 set of CD-ROMs containing OTA's entire 24-year body of work.[3]

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[1]Acknowledgements: Much of the work reported here was part of an assessment done for the Congressional Office of Technology Assessment. Elizabeth Chornesky, Peter T. Jenkins, and Steven Fondriest co-authored that work with me. We had the help of numerous expert contractors, advisory panelists, and reviewers.

[2]The Princeton University web site contains all of OTA's reports plus additional material related to the agency's closing—http://www.wws.princeton.edu/~ota/. This site duplicates material on the "OTA Legacy" CD-ROM. The National Academy of Sciences web site contains text (without photogaphs) of OTA reports published by the Government Printing Office in its final 3 years: http://www.ota.nap.edu/l

[3]The "OTA Legacy" CD-ROM sells for $23 at the Government Printing Office (Stock No. 052-033-01457-2; telephone orders: 202/512-1800; FAX orders: 202/512-2250; mail orders: Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7974).

The 400-page book contains information on deciding wheher species are likely to be harmful; state and federal law; how nonindigenous species relate to genetically engineered organisms; the activities of federal agencies; details of species' impacts; and original data on a variety of topics, e.g., a list of new introductions between 1980 and 1993, the range of environmental education efforts underway, and exemplary state efforts.

Some things have changed for the better since the report was published. Two new federal interagency groups meet regularly to discuss exotic weed issues. One has worked hard to develop a national strategy. The 1990 law on indigenous aquatic species was reauthorized last year. The Nature Conservancy, Audubon Society, Brooklyn Botanic Garden, and others, published educational material on invasive plants. A number of regional studies are available on the Chesapeake Bay, San Francisco Bay, Florida, and California's wilderness areas and wetlands. On the other hand, some new exotic pests are making headlines, old ones have spread, and none have figured prominently in discussions of foreign trade agreements. OTA's analysis is a reminder that severe problems need correcting—fast. We can no longer claim ignorance of the problems and their scope.

Economic and Environmental Impacts

From 1906 to 1991, just 79 harmful exotic species caused documented losses of $97 billion, mostly in control costs and losses of marketable goods (Table 1). A worst case scenario for 15 potentially high-impact exotics adds another $134 billion in future losses. These species belong to every taxonomic group. They affect many national interests: agriculture, forestry, industry, human health, and natural areas. A single species, such as the zebra mussel, can cause massive losses for both private and public sectors, e.g., to public utilities, which must unclog water intakes; to landowners, who must clean irrigation channels; and to fish and wildlife agencies, which maintain the health of aquatic systems.

Zebra mussels, gypsy moths, imported fire ants, and a few other invasive pests, typify just one type of nonindigenous species, the type most likely to show up in economic data. They are highly visible; they are subject to special exclusion or control programs; and their economic costs are readily identifiable. Many harmful exotic species do not fit this model. They may be visible only to experts, if at all; usually no control is attempted; and their impacts are not easily quantifiable. Total cumulative costs have rarely been compiled even for the first group, and the second has been largely ignored. Therefore, any cost estimates represent only a fraction of the total. When estimates for nonindigenous agricultural weeds are factored in, for example, current annual costs are likely to reach several billion dollars, more in high impact years.

Environmental impacts are more difficult to quantify than economic ones. Nevertheless, they can be severe and harmful nonindigenous species have exacted a significant toll on U.S. ecosystems. These effects range from wholesale ecosystem changes and extinction of indigenous species to more subtle ecological changes and increased biological sameness. The introduction of nonindigenous species is closely correlated with the disappearance of indigenous ones in Hawaii and on other islands. Elsewhere, species that alter fundamental ecosystem properties may have as much, if not more, long-term impact. For example, melaleuca in the Florida Everglades system has converted grasslands and other natural areas into single-species forests. Wild hogs have damaged forest understory in the Great Smoky Mountains National Park. In the west, cheat grass invasions have changed both the magnitude and frequency of wildfire. This, in turn, has altered the grasslands' hydrology and nutrient flow, accelerating further changes in species composition.

Current Numbers and Rates

The cumulative number of foreign nonindigenous species in the United States has climbed steadily and swiftly in the past 200 years (Fig. 1). At least 4,500 nonindigenous species of foreign origin have established free-living populations in the United States. This is surely an underestimate. Scientists in Florida will publish a detailed look at the state's situation this year. They show higher numbers for established exotic fish; amphibians and reptiles; and birds. For example, the number of established amphibians and reptile species has been revised from 25 to 36 species.

On average, 15% of foreign species trigger severe economic or environmental damage and about 40% cause some harm. Once troublesome species become established, they are rarely eliminated and new ones are constantly added. From 1980 to 1993, more than 200 foreign species were first introduced or detected in the United States. At least 59 of these are known or expected to be harmful. No one officially tracks newly introduced species. OTA's attempt was limited so these numbers are probably low, too.

The rate of harmful introductions fluctuates in response to social, political, and technological factors. New state and federal plant quarantine laws slowed the introduction of insect pests and plant pathogens after 1912. The switch from dry to wet ship ballast decreased weed introductions, but increased those of aquatic organisms. The rate of new introductions does not appear to be increasing in this century, although it is far higher now than natural rates and rates in the last century. The rate never drops to zero and the cummulative effects of current nonindigenous species are much like compound interest. In a number of states, nonindigenous plants now comprise 10, 20, or even 30 percent of the flora. In Hawaii, at least one-half of the state's wild plants and animals are nonindigenous. Together, harmful nonindigenous species create an ever-growing economic and environmental burden for the country.

Pathways of Introduction

Species first reach the United States by many pathways, but usually with human activity, transport, or the habitat modifications that provide new opportunities for species' establishment. Numerous harmful species arrived as unintended byproducts of cultivation, commerce, tourism, or travel. For instance, numerous European insects were first detected in Rochester, New York, when the city supported an extensive nursery industry and large numbers of plants were routinely unloaded there.

Nonindigenous species contaminate bulk commodities, packing materials, shipping containers, or ships' ballasts. In one survey, at least 367 distinctly identifiable taxonomic groups of plants and animals were found in the ballast water of ships arriving in Oregon from Japan. The chance for importing pests with unprocessed wood continues. The current Asian longhorned beetle outbreak in New York is likely a result. This insect is attacking maples and horsechestnuts. In China, it attacks hardwoods like elms, poplars, and willows. Weeds continue to enter the country as contaminants with seed; both plant and fish pathogens have arrived with diseased stocks. Some new species stow away on cars or other conveyances, including military equipment.

Other harmful alien species were imported as crops, ornamentals, livestock, pets, or aquaculture species—and later escaped. Of the 300 weeds of the western United States, at least 36 escaped from horticulture or agriculture. A number of invaders were imported and released for seemingly beneficial roles in soil conservation, fish and hunting, or biological control, and turned out to be harmful. A few illegal introductions also occur.

Different groups of organisms arrive by different pathways. Some fish are imported to enhance sport fisheries; others are illegally released by acquarium dealers or owners or escape from aquaculture facilities. Insects and aquatic and terrestrial mollusks usually hitchlike with plants, commercial shipments, baggage, household goods, ships; ballast water, or aquarium and aquaculture shipments.

Far more is known about pathways of foreign species into the United States than the routes by which nonindigenous species have spread beyond their natural ranges within the country. Once here, exotics spread both with and without human assistance. For example, a 1989 survey found that cabbage seedlings shipped to New York from Georgia, Maryland, and Florida, were infested with an average of up to eight larvae of the diamondback moth per hundred plants. The recent 12-state outbreak of rabies in the northeast have been traced to Florida raccoons which were moved to West Virginia in 1977. Double-crested cormorants are now an indigenous host for the previously foreign velogenic Newcastle disease. An estimated 5,000 birds died from western Nebraska to eastern New York in 1992.

For most established or recently detected exotics, little systematic reporting occurs and control efforts are uneven. Species that are commercially distributed or officially recommended for various applications can spread especially quickly. Whatever their route of arrival, highly damaging species now occur throughout the country in patterns that change constantly.

On average, 12 percent of intentional introductions - which usually receive at least some screening - cause harm. The comparable figure for unintentional introductions is 44 percent. For fish, mollusks, and terrestrial vertebrates, though, intentional introductions are harmful in about the same or greater numbers than unintentional ones. This suggests poor decision-making and/or complacency in screening for potential harm.

Decision-making standards are becoming more stringent and many introductions that were encouraged in the past are no longer allowed. However, there are still no reliable predictors of a given species' invasiveness so each decision about import and release is hampered by uncertainty. Three interrelated problems remain largely unsolved: determining levels of acceptable risk; setting thresholds above which more formal and costly decision-making approaches are invoked; and identifying tradeoffs when deciding in the face of uncertainty. Federal attempts to identify the risks of potentially harmful exotics have many shortcomings. Most regulatory approaches use variations of "clean" (allowed) or "dirty" (prohibited) lists of species or groups. Specific procedures vary in stringency throughout different agencies; risks to non-agricultural areas are often ignored; and generally, new imports are presumed safe unless proven otherwise.

Despite their limitations, efforts to prevent new introductions of harmful species are the country's first line of defense. Port inspection and quarantine are imperfect tools so prevention is only part of the solution. Some organisms are more easily controlled than intercepted. Aiming for a standard of "zero entry" has limited returns, especially when prevention efforts come at the expense of rapid response or long-term control. When prevention fails—for technical or political reasons—rapid response is essential. The managers can choose to eradicate, contain, or suppress pests; these choices are not necessarily easy or obvious. The choice may be not to control already widespread organisms, or those for which control is likely to be too expensive and/or ineffective.

There are no "silver bullets" for control now and troublesome gaps may appear in the next 10 years. Chemical pesticides play the largest role in management currently, even for land managers that traditionaly have opposed widespread chemical use. In the future, an increased number of biologically based technologies will probably be available. These are slow to come on line, hampered by problems in balancing risk and regulation; in moving research to its application; in educating users; and in resolving commercial considerations. Development of new biological and chemical pesticides entail the same difficulties: ensuring species specificity, slowing the buildup of pest resistance to the pesticide, and preventing harm to non-target organisms.

Domestic Policies

At least 20 federal agencies are involved in some aspect of promoting, controlling, excluding, importing, or researching indigenous species. Each forms its own responses—responses that have been largely uncoordinated. The U.S. Departments of Agriculture and the Interior play the largest roles. Federal agencies manage about 30 percent of the Nation's lands, many with grim problems with exotic species. The Bureau of Land Management estimates that noxious weeds expand their acreage by 14 percent each year, or 2,300 acres per day. The National Park Service, with fairly strict policies regarding nonindigenous species, finds invasions threatening the very characteristics for which some parks were set aside.

State laws on nonindigenous species vary from lax to exacting and use a variety of legal apparatus. They are relatively comprehensive for agricultural pests, but only spotty for invertebrate and plant pests of non-agricultural areas. States play a larger role than the federal government regarding fish and wildlife. Several present exemplary approaches. Yet many state laws are weak and their implementation inadequate. Major U.S. laws also receive their share of criticism. Typically, they require cumbersome and time-consuming list-making and their application is not comprehensive.

Complaints regarding the work of federal and state agencies abound. States find it difficult to determine why and when federal programs begin and end. The federal government fails to stem a local or regional problem, unable to see it as an incipient national concern. Agencies respond too slowly to new problems. Earmarking for highly visible programs gets priority, risking that new pathways, and new types of problems will be neglected. Some agencies fail to screen plant imports for weediness and make problems worse. Generally, there is a lack of communication among policymakers and the effectiveness of many programs cannot be accurately assessed.

CONCLUSION

Many expect increasingly negative impacts from introductions of nonindigenous species. Global warming adds a wild card that could vastly alter patterns of species movement. These are forecasts, based on nearly irreversible current trends. It is possible to envision a different future—one in which beneficial exotics contribute much to human well-being, native species are preserved, and harmful aliens are managed effectively. Deciding the worthiness of this vision is a cultural, political, even spiritual choice that will forever affect the biological heritage of the United States.

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Table 1. Cumulative U.S. losses from selected harmful alien species, 1906-1991

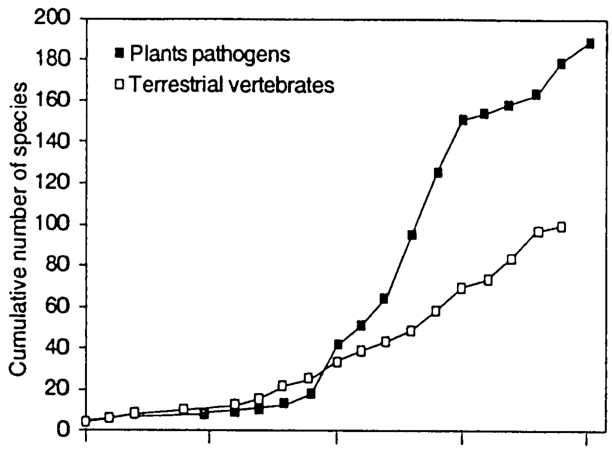
Category	Species analyzed (number)	Cumulative loss estimates (millions of dollars, 1991)	Species not analyzed[a] (number)
Plants[b]	15	603	—
Terrestrial vertebrates	6	225	>39
Insects	43	92,658	>330
Fish	3	467	>30
Aquatic invertebrates	3	1,207	>35
Plant pathogens	5	867	>44
Other	4	917	—
Total	79	96,944	>478

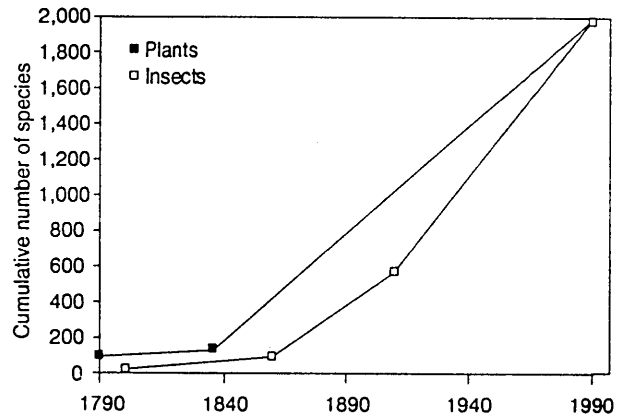
[a] Based on estimated numbers of known harmful species per category (figure 2-4).
[b] Excludes most agricultural weeds; these are covered in box 2-D.

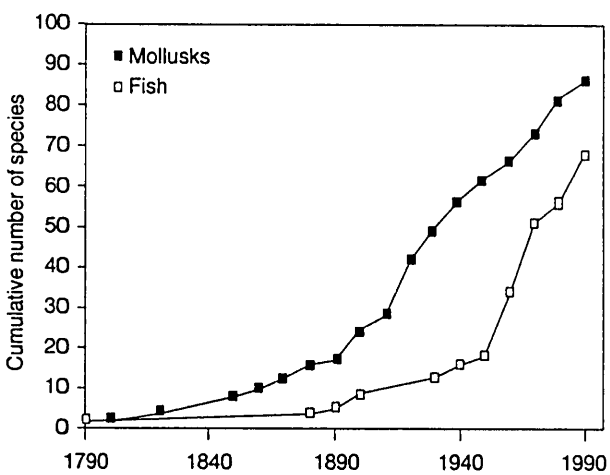
NOTES: The estimates omit many harmful NIS for which data were unavailable. Figures for the species represented here generally cover only one year or a few years. Numerous accounting judgments were necessary to allow consistent comparison of the 96 different reports relied on; information was incomplete, inconsistent, or had other shortcomings for most of the 79 species.

SOURCE: M. Cochran, "Non-Indigenous Species in the United States: Economic Consequences," contractor report prepared for the Office of Technology Assessment, March 1992.

Figure 1. Cumulative numbers of exotic species with foreign origins in the U.S.







SOURCES: Summarized by the Office of Technology Assessment from: J.C. Britton, "Pathways and Consequences of the Introduction of Non-Indigenous Freshwater, Terrestrial, and Estuarine Mollusks in the United States," contractor report prepared for the Office of Technology Assessment, October 1991; W.R. Courtenay, Jr., "Pathways and Consequences of the Introduction of Non-Indigenous Fishes in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; K.C. Kim and A.G. Wheeler, "Pathways and Consequences of the Introduction of Non-Indigenous Insects and Arachnids in the United States," contractor report prepared for the Office of Technology Assessment, December 1991; R.N. Mack, "Pathways and Consequences of the Introduction of Non-Indigenous Plants in the United States," contractor report prepared for the Office of Technology Assessment, September 1991; Sailer, R.I., "History of Insect Introductions," *Exotic Plant Pests and North American Agriculture*, C.L. Wilson and C.L. Graham (eds.) (New York, NY: Academic Press, 1983), pp. 15-38; C.L. Schoulties, "Pathways and Consequences of the Introduction of Non-Indigenous Plant Pathogens in the United States," contractor report prepared for the Office of Technology Assessment, December 1991; S.A. Temple and D.M. Carroll, "Pathways and Consequences of the Introduction of Non-Indigenous Vertebrates in the United States," contractor report prepared for the Office of Technology Assessment, October 1991.

[a] Figure only includes data on species with known introduction dates for plant pathogens (n = 188), terrestrial vertebrates (n = 100), mollusks (n = 85), and fish (n = 68). Graphs for plants and insects are based on rough estimates.

BIOLOGICAL CONTROL OF PURPLE LOOSESTRIFE IN NORTH AMERICA

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INTRODUCTION

In recent years, interest in a biological method to control problem plants in natural areas in the United States has grown (US Congress 1993). All federal agencies must comply with standards to reduce the use and dependence on chemical control of weeds. But, biological methodologies are not readily available, nor have they been well-endorsed or financially supported. Despite an excellent safety record (Harris 1988; Crawley 1989), skepticism concerning the safety and effectiveness of exotic insect introductions for weed control remains high among the general public, administrators, and even scientists. The successful control of *Hypericum perforatum* (Huffaker & Kennett 1959) and others that followed, have demonstated that long-lasting, cost-effective, environmentally sound and effective control programs, can be implemented. But, despite an increase in the number of programs initiated, the ability to select and to establish control agents has not progressed to a point where the rate of success has improved (Crawley 1989). Basic questions about the kind of herbivore species to introduce, impact of single and multiple species herbivory, and release strategies, remain unanswered. The control program targeting purple loosestrife (*Lythrum salicaria* L.), a Eurasian wetland perennial responsible for the degradation of many prime wetlands throughout temperate regions of North America (Thompson et al. 1987; Malecki et al.1993), is intended to emphasize the need for research investigations during pre- and post-release phases of the program.

THE CONTROL AGENTS

Detailed investigations in Europe began in 1986 with surveys for potential control agents and investigations about their life-history, distribution, impact, and host-specificity (Blossey 1993; Blossey et al. 1994a, b; Blossey and Schroeder 1995; Blossey 1995b). Biological attributes of herbivores (host specificity, fecundity, impact, etc.), have served as guidelines for selection of control agents (Harris 1973; Goeden 1983); however, such characteristics are often difficult to observe in the field. Therefore, species proposed for introduction were selected based on information about (a) impact on the target weed in the field, (b) host specificity, (c) distribution, and (d) feeding niche on *L. salicaria.*

Six species were selected as the most promising control agents for further investigations. These were a root-mining weevil, *Hylobius transversovittatus*, attacking the main storage tissue of purple loosestrife; two leaf-beetles, *Galerucella calmariensis* and *G. pursilla* capable of completely defoliating individual plants and entire *L. salicaria* populations; a flower feeding weevil *Nanophyes* *marmoratus*; a seed feeding weevil *N. brevis*; and a gall midge, *Bayeriola salicariae*, attacking leaf and flower buds.

Demonstrated host specificity is of overriding importance before any control organism can be released. During the screening program for purple loosestrife, we conducted various tests and compared results of different methods (Blossey et al. 1994a, b; Blossey and Schroeder 1995). After initial host specificity screening results became available, a questionnaire concerning the potential impact of this program was sent to the Departments of Agriculture and Natural Resources in 32 states (Blossey et al. 1994a). The questionnaire asked for the occurrence, special concerns (rare or endangered) and ecological importance of *Lythrum alatum* and *Decodon verticillatus*, two plant species where some feeding by potential control agents had occurred. The questionnaire asked whether respondents would favor a release of biological control agents over a potential negative impact on *D. verticillatus and alatum.* While the majority fav releases, responses ranged from extreme opposition to enthusiastic support (Blossey et al. 1994a). Often a split occurred between the two agencies in a state, with the most common concern being lack of sufficient information to appropriately evaluate danger to native plants. This, and the second most commonly expressed concern, that the introduction of another exotic species might create another problem similar to purple loosestrife, illustrate the necessity to assess and publish the impact on target and non-target host plants after insects have been released. Without scientific evaluation, the safety of biological control will remain subject to doubt and if public concerns are not taken seriously, suffer further restrictions. Conflict resolution will always be a part of biological control, and only sound scientific analysis can offer guidance to necessary decisions. For example, based on the available information, one of the agents under consideration, *B. salicariae*, because of a wider host range, was not proposed for introduction (Blossey and Schroeder 1995).

Based on the available knowledge at the time of introduction of the first control agents in 1992, the following predictions emerged (Malecki et al.1993): (1) all species will become established throughout the current range of *L. salicaria* in North America; (2) the root feeder *H. transversovittatus* and the two leaf-feeders *G. Calmariensis* and *G. pusilla*, will be most important in reducing large populations. The flower and seed feeders will stabilize smaller populations, further reducing seed output in such a way that not every disturbance will lead to a new outbreak of *L. salicaria*; (3) combinations of agents will have greater control effect than any species alone; (4) control of *L. salicaria* will be achieved more rapidly in mixed plant communities with competition for space and nutrients; and (5) purple loosestrife abundance will be reduced to 10% of its current level over 90% of its range.

NORTH AMERICA—1992 TO PRESENT

Despite a long history of using insects for weed control and a considerable improvement in procedures, only about 60% of released agents become established (Crawley 1989). The influence of factors such as agent taxonomy, climatic pre-adaptations, number of individuals released, numbers and timing of releases, predators, and weather conditions in determining the fate of releases, lack scientific evaluation and are largely observational (Crawley 1989; Lawton 1990). In the control program against *L. salicaria*, agents were collected from climatically different source populations and releases occurred across North America. Experiments were started to determine the best release procedure. Agents became established across the entire continent regardless of the source populations, the number of agent releases, time of release, stage released, or whether caged releases or openfield releases were conducted (Hight et al. 1995).

Harris (1981) proposed that biocontrol agents be considered stress factors; the aim being to increase stress load until the balance is tipped towards the disadvantage of the target weed population. Myers (1985) argued that frequently good control has been achieved by a single agent replacing another less successful one. Introducing several control agents could potentially result in the suppression of a formerly successful species by a competitively superior species (Ehler and Hall 1982). Crawley (1989), however, could not find any evidence that multiple species introductions have ever led to the replacement of effective agents by economically less successful ones. On the contrary, agent combinations were recently reported to be more destructive to plants than a single species alone (Fowler and Griffin 1995). Masters et al (1993) found that spatially separated herbivores interact via their common host plant. Root-feeders showed a reduced performance if their host plant was simultaneously attacked by an above-ground herbivore. Above-ground herbivores showed improved performance on plant individuals simultaneously attacked by a root-feeder. Whether these interactions have any influence on the success of weed biocontrol in systems where above- and below-ground herbivores were released needs further study. We are currently conducting these experiments for the *L. salicaria-Galerucella-Hylobius* system. This is a good example of how an on-going biological control program can benefit from simultaneously conducted basic research, and vice versa.

Mass rearing is often an integral part of a biological control program since control agents are generally in short supply. A major concern has been potential negative side effects of laboratory mass rearing (e.g., adaptations to rearing conditions) and reduced quality of the produced insects (Hopper et al. 1993). We have experimented with various field and laboratory mass rearing techniques (Blossey and Hunt 1997), and found a reduced fecudity and increased mortality associated with increasing duration of artificial rearing conditions. We now prefer to mass produce all species outdoors for one generation and allow subsequent overwintering. Between 1994 and 1996, over 400,000 leaf-beetles were shipped to 26 different states and Canada to collaborators in a wide range of organizations (universities, State Departments of Agriculture and Natural Resources, National Wildlife Refuges, Bureau of Reclamation, Tennessee Valley Authority, and Animal Plant Health Inspection Service); many have started their own mass rearing program. We believe that we need to be concerned about the quality of insects released, not the quantity, and recommend outdoor mass rearings. Releasing fewer, but fitter, individuals might be a much more successful approach and quality control should accompany every mass rearing program.

Increased attention is given to follow-up studies to monitor target plant and control agent populations. The lack of published evaluations might (hopefully) reflect the lag time between releases and documented successes since the biocontrol community has long agreed on the necessity of these studies (Schroeder 1983; Sheppard 1992). The future of biological weed control is intimately linked to the demonstrated safety and efficacy of our programs. For example, releases of control agents against *L. salicaria* in the state of Wisconsin were only allowed once the Department of Natural Resources agreed on a monitoring plan for insect and plant populations.

An important consideration is the many different ways to monitor insect or plant populations. Our goal has been to develop standardized monitoring guidelines sophisticated enough to allow valuable scientific evaluation, but at the same time, simple enough to allow participation by wildlife managers or their staff with little guidance. Preliminary versions of a monitoring guide have been tested in 1995 and 1996, and a final version will be distributed by the end of 1997.

THE MAGIC FORMULA FOR SUCCESS?

A number of factors have contributed to the rapid growth of a coordinated biocontrol effort for purple loosestrife in the United States. *L. salicaria*, based on its rapid spread, projected range, and severity of impact, was identified among the most harmful non-indigenous species in the United States (US Congress 1993). This designation created interest for improvements in management approaches, including biological control, across the entire continent. From its inception, the biological control program against *L. salicaria* has been a multi-agency effort. The overseas exploration by the International Institute of Biological Control was conducted in association with the USDA Agricultural Research Service (ARS), and the US Fish and Wildlife Service.

The initial success of the interagency effort led to the formation of a scientific advisory group (Purple Loosestrife Working Group, [PLWG]), with representation from several US federal and state agencies, universities, and Canada. Since 1986, this working group provided continual guidance on all aspects of our biological control program.

One of the major accomplishments has been to keep federal and state agencies actively involved, informed through internal annual reports, and through participation in decision-making processes. This broad-based involvement has facilitated maintenance of secure funding since 1985. Particularly important was the ability to pool resources from a variety of sponsors, thus, in the absence of major grants, the cooperation across political and agency boundaries has been extremely benefcial. Once the first insects became available in 1992, they were distributed to 7 states and to Canadian cooperators. Workshops held in Colorado and Minnesota in spring 1993 introduced interested agencies to life-history of control agents, mass rearing techniques, follow-up studies, and monitoring techniques. In addition to regular meetings of the PLWG, we now conduct annual planning meetings for the future of the control program.

Purple loosestrife is not an agricultural weed. People actively involved in the control program are often resource managers, essentially a new audience for biological weed control. Their willingness to participate in basic research has enabled us to implement a scientific approach to the entire program with the intention to improve biological control as a science. The leadership provided by Cornell and the willingness to share research results has created a unique cooperative environment that allowed the program to move forward at a fast pace. Last, but not least, early results indicate that the selected control agents are going to be effective.

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SIBERIAN FOREST INSECTS: READY FOR EXPORT

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Introduction. Existing publications on Palaearctic insect invaders to North America forests are devoted exclusively to Europe-U.S. comparisons (Niemela, Mattson, 1996). This is understandable from both geographical and historical points of view. But as the history of mankind continues, new economical relations are established which, unfortunately, make new possibilities for the introductions of pests. The recent discovery in New York of a cerambycid beetle *Anoplophora glabripennis* native to Asia (USDA Forest Service, 1996) and the well known "Asian Gypsy Moth Case" (Wallner, 1996) are the reminders that the forests of Northern and Northeastern Asia are an important source of exotic pests. The largest part of this region belongs to the Russian Federation.

The forested territory of Asian Russia could be devided in two parts (Fig. 1): Siberia (from Urals to the Khabarovsk Kray) and the Far East (with administrative units of Khabarovsk and Prymorsky Kray, Amurskaya, Magadanskaya, Kamchatskaya and Sakhalinskaya Oblast'). The forest land of this region spans a wide range of latitudes, elevations, precipitation, and soils. More than 60 percent of forests in Asian Russia grow on the permafrost (Pozdniakov, 1986).

Comparison of the forest composition of Siberia and Northern North America shows that they are similar in type, but differ in species composition. In Siberia 81% of the forested territory is covered with conifers. Nearly all of the conifer forest is composed of six species: *Larix sibrica*, *Larix dahurica*, *Pinus silvestris, P. sibirica, Abies sibirica* and *Picea obovata*. Larch forests dominate both in area (62%) and in growing stock (52%) (Falaleev, 1985).

Even a brief comparison shows the similarity of Asian Russian forests to that of Northwestern North America. In the Western U.S., 82% of forests are conifers (Powell et al., 1993), but the list of the woody species is slightly longer than that of Siberia and the Russian Far East. Though Siberia and Northern U.S. and Canada are dissimilar at the species level of woody plants, these regions are much more similar on the genus level. There are at least 16 genera of trees found in both areas (e.g. *Abies, Alnus, Betula, Colylus, Crataegus, Juniperus, Larix, Picea, Pinus, Populus, Rhamnus, Salix, Sorbus, Tilia, Ulmus,* and *Viburnum*). Taxonomic diversity of these genera in Siberia is comparable with those in the different regions of the Northern U.S. and Canada (Table 1).

The taxonomic diversity of forest insects in Asian Russia is comparable with those of boreal zones of Northern America. For example, 218 and 212 species of bark beetles (*Scolytidae*) were reported from Asian Russia and Canada respectively (Danks, 1979; Yanovskiy, 1996).

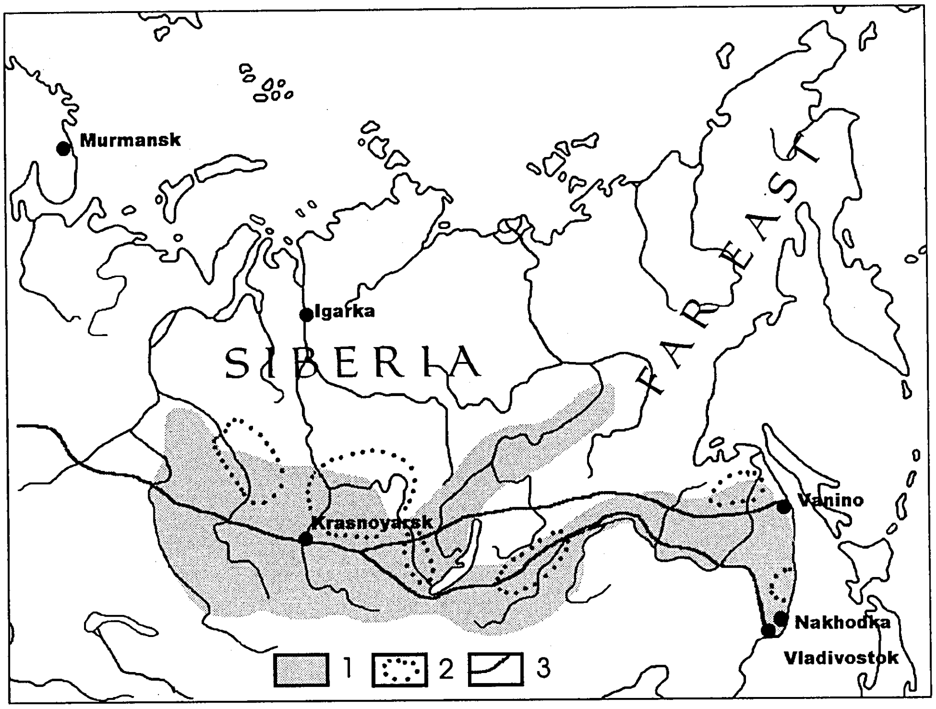

Figure 1. Forest insect injury zones and areas of logging and transportation in Siberia and the Russian Far East.
1 – area of most severe outbreaks; 2 – primary areas of logging; 3 – Trans-Siberian railroad.

Only 90 species of insects are of real economical importance in the forests of Siberia and the Far East (Baranchikov, Montgomery, 1996). The main folivores are: *Dendrolimus superans*, *Lymantria dispar* and *Zeiraphera grizeana* on *Larix*; *Lymantria monacha* (Fig. 2) and *Bupalis pinearius* on *Pinus*; *D.superans* on *Abies* and *Choristoneura murinana* on *Picea*. The major wood borers are: *Ips cembrae* and *Xylotrechus altaicus* on *Larch*; *Ips sexdentatus* and *Tomicus piniperda* on *Pinus*; *Monochamus urussovi* on *Abies*; and *Ips typographus* on *Picea*. The following three species are the most widespread and destructive:

Fir sawyer beetle (*Monochamus urussovi* Fisch.) is a transpalearctic species occuring in coniferous forests from Finland to the Pacific Ocean (Fig. 2). The insect infests nearly all species of *Pinaceae* but the firs (*Abies*) are most heavily damaged. The beetle vectors the phytopathogenic fungus *Ceratocystis* sp. During their feeding on the crown, the adult beetles remove strips of bark and infect branches with the fungus spores. The developing fungus kills tiny branches on the periphery of the crown, weakens the tree and reduces resin flow. This makes oviposition and larvae development of the beetle more successful. To our knowledge fungus is pathogenic only for fir species. In Siberia, *M. urussovi* is frequently found on birches (*Betula*), but causes little damage to it.

The life cycle of *M. urussovi* typically lasts for 2 years. The beetles fly from late May or early June through September. A female lays eggs under the bark, one at a time; eggs hatch in 16 to 30 days. From the second instar and up to pupation the larvae gnaw tunnels in the wood. Winter is usually spent in the larval stage. Before pupation, larvae form pupal chambers in the wood, separated from the surface by a thin layer of bark and wood where they pupate. The pupal phase lasts from 4 to 5 weeks; adults emerge by gnawing a round hole 6 to 12 mm in diameter through the bark.

Table 1. Number of tree species per woody plant genus in Siberia and Northern United States and Canada (Data from Koropachinskiy, 1983; Elias, 1980; introduced species not included).

Plant Genera	Siberia	Alaska	Western Canada	North-western U.S.	Eastern Canada	North-eastern U.S.	Northern North America
Abies	1	-	3	5	1	1	8
Alnus	5	2	4	4	1	3	7
Betula	8	1	2	2	5	6	7
Cornus	2	1	2	3	2	4	6
Craetagus	4	-	2	2	6	11	12
Juniperus	5	1	2	3	1	1	4
Larix	3	1	2	3	1	1	3
Picea	2	3	4	3	3	3	7
Pinus	3	-	6	9	2	8	17
Populus	6	3	3	4	4	5	8
Prunus (Padus)	1	-	3	3	4	8	10
Rhamnus	4	-	1	2	-	2	3
Salix	11	8	14	13	10	12	25
Sambucus	1	-	1	1	2	2	4
Tilia	1	-	-	-	1	2	2
Ulmus	4	-	-	-	3	5	5
Euonymus	2	-	-	1	-	1	2

M. urussovi is one of the most destructive pests of firs in Northern Asia. The pest increases its number in *Abies* forests damaged by defoliating insects, fires and windfalls. Having infested the damaged parts of the forest, the beetle population becomes dense enough to attack, weaken and kill healthy stands. By attacking healthy fir stands dense beetle populations can maintain outbreak levels indefinitely, causing the death of fir forests over enormous areas. In the late 1950's in the Tomsk Oblast' (Western Siberia), the pest destroyed 2 million m3 of fir wood stock. This caused the collapse of forest enterprises in that region for years and previously planned construction of a railway was delayed significantly slowing the industrial development of the whle area. In 1971-1976, an outbreak of M. Urussovi destroyed 300,000 hectares of fir forest in Krasnoyarsk Kray in the Central Siberia (Isaev et a., 1988).

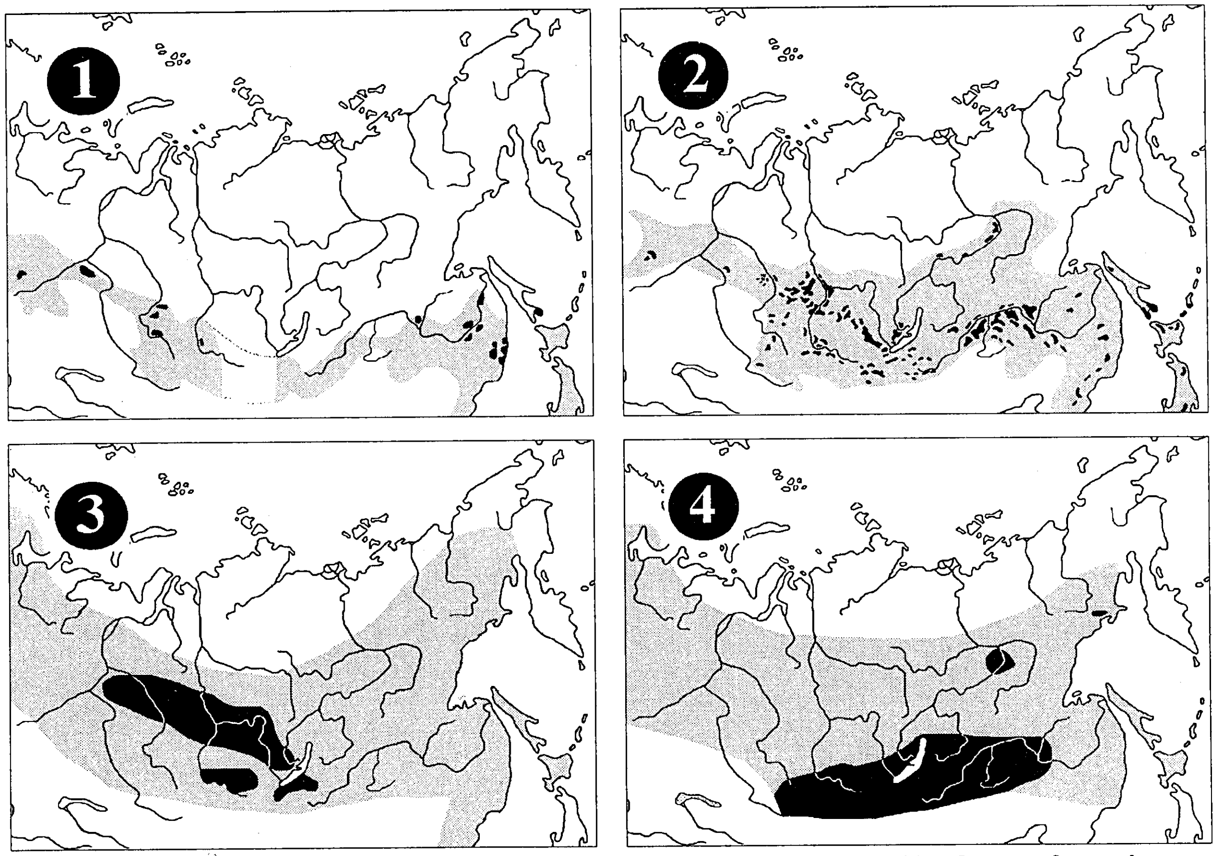

Figure 2. Distribution (grey) and areas of economic importance (black) of some forest insect pests of Northern Asia: 1 – *Lymantria monacha*; 2 – *Dendrolimus superans*; 3 – *Monochamus urussovi*; 4 - *Ips cembrae*.

Larch bark beetle (*Ips cembrae* Heer) is known in Russian literature as *Ips subelongatus* Motschulsky. It is a transpalearctic species occurring from Europe to Japan (Fig. 2). In Siberia it attacks all species of larch, spruce (*Picea*) and pine, but larch is the principal host on which outbreaks occur.

The pest has 2 generations per year in the southern regions of Siberia where the yearly sum of temperatures above 10 C° is more than 1500 and the frost-free period lasts more than 2.5 months. The adult beetles hibernate, mostly in the litter, then emerge from late May to early June , attack trees and lay eggs. Larval and pupal stages occur from June to early July. First generation beetles emerge and attack trees in July. The larval and pupal stages occur from late July to mid-August. New adults start emerging in mid-August. They feed on the same tree if the previous density was not too high, or migrate to neighboring trees. In Europe, *I. cembrae* adults have been recorded feeding in tree crowns, much like the bark beetles of the genus *Tomicus*. Such crown feeding has not been recorded in Siberia.

In Northern Asia, *I. cembrae* is particularly destructive in the larch forests of the south taiga forest-steppe complex. The distinguishing features of these stands are enhanced aridity and high temperatures in summer, the conditions under which *I. cembrae* can produce two generations. When the forest is damaged by factors that
kill more than 20% of the trees, the bark beetle can become epidemic and outbreaks occur. During the outbreak it can infest resistant larch forests adjacent to the damaged ones, thus making the losses much greater.

Siberian moth (*Dendrolimus superans sibiricus* Tschtvrk.) is widely distributed in Urals, Siberia, and the Far East (Fig. 2). Outbreaks occur in *Abies sibirica, Pinus sibirica, Picea spp.* and *Larix* spp. forests, although larvae feed on most conifers in the family *Pinaceae.*

The length of the life cycle varies from two to four calendar years depending on population density. The larvae of the males have 5 to 9 instars, those of the females 6 to 10; typically males have 5 and females 6. The larvae are up to 110 mm long. Moths fly from the end of June to the beginning of August and lay eggs on needles or branches. Commonly two winters are spent in the larval stage; second to third instars and fifth to sixth instars overwinter coiled up, under the forest litter. Pupation occurs from mid-June to late July in cocoons in tree crowns. During outbreaks, a large portion of excessively dense populations has a life cycle of two calendar years and the rest have a three year cycle. As a result, the adults of two generations emerge simultaneously and the population increases sharply. At the depression phase, some portion of the population have a four calendar year life cycle, where three winters are spent as larvae.

D. superans is the major defoliator of coniferous forests in Asian Russia. In the fir-dominated forests of Central Siberia there were 10 outbreaks since 1873, the last 5 were carefuly documented. They occured in 1935-1947, 1950-1959, 1962-1969, 1978-1985 and 1989-1997 defoliating 0.7, 2.6, 0.9, 0.1 and 1.1 million ha respectively. These forests all died, either directly from the defoliation or from the increasing attacks of the fir sawyer beetle or fire. In the South Siberia, *D. superans* outbreaks take place in larch forests. Outbreaks on larch are not as destructive as those on firs because larch is very tolerant to defoliation.

The ways of possible introductions of Siberian forest insects are through the sea ports of Asian Russia. The overall dry cargo shipments through all Russian ports in the year to July 1996 were 34 million tonnes of which 24 million were exports. The largest Russian port is Novorossyisk on the Black sea, handling 16% of all Russian cargo. The northern port of Murmansk represents 8% and combined Far Eastern ports (Nakhodka, Vladivostok, Vostochny and Vanino) represent the largest concentration at 31% of the total Russian capacity. Large amount of cargo shipments, a deficit of manpower, and the complex economic situation in Russia make the task of the Russian Far East Quarantine Service extremely difficult (Gordon, 1996). International cooperation should be enhanced to prevent transmision of exotic organisms. The mutual Russian-U.S. project on monitoring the population level of lymantriid moths in the Far Eastern port areas was started in 1993 (U.S. Department of Agriculture, 1996). It was agreed that insect outbreaks in the nearby forests should trigger mitigation measures.

Trains transport 97 % of all cargo that enters and leaves the port area. The main transport artery of Asian Russia is the Trans-Siberian railroad (Fig. 1). For much of its length, the railroad goes through the areas known as "the zone of forest insect injury" - the area of the most severe outbreaks and forest damage (Epova and Pleshanov, 1996). Open railroad cars with wood and containers are exposed to many kinds of natural infestations during the 2-6 weeks that it takes them to go through Siberia. Currently, lymantriid pest populations are monitored at the Far Eastern ports area, but this activity is not enough. On the vast area from Urals to Pacific Ocean, flying gypsy moth females can freely put eggs on the containers at the railway stations which are brightly illuminated at night.To more efficiently prevent the occurrence of pest insects on cargo we need the entomological information from all of the Siberian zone of potential infestation, as well as port areas.

Mutual efforts between Russia and U.S.A were set on technology and information transfer regarding pest risk assessment and control of potential pests. Besides the lymantriid survey project, mentioned above, efforts were made to access existing scientific information on species of risk and on the methods of their control (U.S.Department of Agriculture, 1991; Wallner et al., 1995; Baranchikov et al., 1996; Baranchikov and Montgomery, in prep.).

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ECONOMIC EFFECTS ON INVASIVE WEEDS ON LAND VALUES
(from an Agricultural Banker's Standpoint)

CHARLES WEISER

The year was 1954, four young 4-H members were traveling to a livestock judging workout. Ben Barrett, the county agent, stopped the car and escorted the young men to a weed patch located on the adjacent railroad right-of-way. **"Take a good look—this is leafy spurge. If you ever see it in your area, let me know. It is almost impossible to control."**

My next encounter with leafy spurge came in the spring of 1963. As Assistant Ward County Extension Agent, I became aware of leafy spurge infestation in Ward County. There were an estimated 2,000 acres in a seven-township area centering on the "Brooks Ranch" area. It was found in patches from 200 square feet to 10 acres in size. These patches were in road ditches, coulee bottoms, and fence lines.

The county agent and myself used square rod demonstration plots and personal contacts to try and convince landowners to organize a control program. We had very little success.

The excuses were many:

1. It's too expensive; the state should pay the bill;

2. It came in along the railroad; they should clean it up;

23. What's the problem—it's been here since the mid 30's and hasn't spread very fast.

A few individuals started control programs on their land, and those areas are relatively clean today.

By 1972 (10 years later), the acreage infested in Ward County had doubled to around 4,000 acres. There was now some spurge in all 57 townships in the county. The concern level of the landowners had increased, and the county began a limited control program along county roads, but control on private land was limited due to the high cost per acre of chemical control.

By 1982 (10 years later), the acreage doubled again to around 8,000 acres. The county commissioners were considering scrapping the control on roadsides; they had not seen very much done on the private land, and wondered why they were spending money on road ditches if the adjacent landowners didn't do anything. At the same time, the state legislators changed the weed laws, allowing counties to levy 3 mills of property tax to be used for weed control. In addition, the Legislature appropriated state funds which were divided among the counties which levied the 3 mills. The combination of county and state funds could be used to cost share spurge control on private lands.

This cost share approach on private lands was instituted in 1983. In my county and state, funds cover 70% of the cost. The landowner pays apprximately 30%.

The acreage of leafy spurge continued to increase to a high of around 12,000 acres in 1990.

After watching control results from1983 to 1990, more and more farm operators took part. Estimated acreage infested in 1994 showed a drop to around 10,000 acres of which 8,000 had control measures applied.

Over the time frame of 1962 to 1992, the area of leafy spurge in North Dakota doubled every 10 years from 200,000 acres in 1962 to an estimated high of 1,000,000 acres in 1992.

In 1994, Agricultural Economists at North Dakota completed studies of the annual economic impacts of leafy spurge on grazing lands and wildlands in the four state area (North Dakota, South Dakota, Montana, and Wyoming).

The methods and detail of the studies are available from North Dakota State University (NDSU). In the interest of brevity, please allow me to summarize their findings for North Dakota.

Annual Grazing Land Impact in North Dakota

Grazing Acres	1,426,000
Infested Acres	625,900
% Infested	5.48%
Lost AUM's of Grazing	459,000
Value lost AUM's	6,876,000
Lost expenses & returns	17,317,000
Direct economic impacts	24,193,000
Secondary (economic impacts)	53,989,000
Combined economic impact	78,182,000

Annual Wildland Impacts in North Dakota

Wildland acres	4,899,000
Infested acres	350,300
% Infested	7.15%
Reduction Soil Water Conservation	514,100
Reduction Wildlife Recreation	2,111,600
Direct Economic Impact	2,625,700
Secondary Economic Impact	5,291,000
Total Economic Impact	9,790,000

Annual Impact on Grazing		$78,182,000
Annual Impact on Wildlands		9,790,000
	TOTAL:	**$87,972,000**

Take this annual loss over 10 years and the resulting combined loss is staggering!

Now, let's look at the effects of this weed on land values.

The basic value of any income producing investment is based on the projected income flow the investment will produce. This holds true for stocks, bonds, land, apartment buildings, etc.

If the income stream shrinks, so does the value (price) of the investment. Likewise, if income streams increase, so does the value of the investment.

Alien plants which invade native grazing lands, all affect carrying capacity negatively. They crowd out productive and usable forage plants lowering carrying capacity. As carrying capacity shrinks, so does the income stream. As income streams shrink, so does value of the asset.

Remember the Brooks Ranch? Leafy spurge acreage increased to the point where over 50% of the acres were infested. The owners decided to sell. Two brothers who were neighbors purchased the ranch in 1975, at full market value. Farm Credit Services financed the purchase. Within three years, they had deeded back most of the pasture land to Farm Credit Services and were financially distressed.

It took Farm Credit Services until early 1991 to sell the property. I visited with Jeff Haugen, the appraiser for FCS regarding prices and value. He said his knowledge of sales indicated that this type of pasture should have sold for $100 to $125 per acre. Because of the lowered carrying capacity due to leafy spurge, the price dropped to $40/acre. Jeff, also related that he was surprised it was that high. By the time it was sold, much of the pasture was 100% covered by spurge.

This drop in value of 60% is a real loss in value.

Another documented case came from Klamath County, Oregon. In the year 1988, a 1,360 acre ranch was taken over by the county to cover unpaid taxes caused by unproductivity because of leafy spurge. Estimated value for similar clean land was $125 to $150/acre. ($170,000 to $204,000).

The county put the ranch up for sale with minimum bids set at $17,000 for taxes due. The first try at selling failed with bids below that level. Eventually, it was sold to a party who lives in California for $27,500, with the stipulation he had to control the spurge. In 1995, I called Francis Roberts, the county weed supervisor in Klamath County, to confirm the information. He indicated he had confirmed the prices with county officials and had called the current owner. The owner had spent close to $60,000 through 1994 (6 years) on control measures. The weed supervisor indicated he has a serious problem and has made little headway in control. This drop in value from $170,000 to $27,500 shows a loss of approximately 83% in value on this ranch.

As an agricultural lender, I am interested in the longterm values of my collateral. Most agricultural loans run for terms of over 10 years up to 20 to 30 years. If my collateral value declines due to invasive alien weeds, my loan may be in jeopardy. Likewise, reduced income due to alien invasive weeds lowers income from the land. This lower income will affect the borrower's ability to repay the loan.

Because of these effects on value and income, I am not interested in real estate loans where my collateral has invasive alien weeds.

All invasive weeds cause loss of native plants and changes in wildlife habitat. Losses of desirable habitat translates to losses of wildlife numbers. A case in point is the loss of elk habitat in Montana due to infestation of spotted knap weed. Another is wetland degradation due to purple loosestrife.

In some areas, noxious invasive weeds are an out-and-out eyesore. They cheat us of the surroundings we once found a pleasure to behold.

An unqualified impact of aliens and invasive weeds on less intensively managed wildlands is their potential to act as a nusery or seed bank from which to spread.

The bottom line is a devastating loss in incomes, land values, wildlife habitat, and the aesthetic value of wild places.

Our natural resource heritage depends on everyone's involvement.

You, as land managers, cannot stand by and let alien weeds continue to expand their range because it is "too" expensive to control them.

The highest cost you will ever pay is the lost income and drop in value as the alien plants take over.

The lowest cost is for early and continued control at first appearance. That first $1 spent on small patchs will save income, land values, and the extremely high costs of control later!

There is an old Indian proverb. "We don't inherit the land from our ancestors, we borrow it from our children."

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EXOTIC INVASIVE PLANTS IN SOUTHEASTERN FORESTS[1]

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ABSTRACT. Invasive exotic plants usurp forest productivity, hinder forest-use activities, and limit diversity on millions of acres of forest land in the Southeast. Infestations of these plants and their range are constantly expanding. This paper examines the various aspects of the problem. Outlined are the biology, origin, range, uses, and herbicide control for 14 of the most prevalent exotic trees, shrubs, vines, and grasses. Losses on forest lands will continue to increase until importation of new exotic species is controlled, Integrated Weed Management Programs are organized, and effective control procedures are implemented. Biological control technology using insect and pathogenic predators from the plant's home country offers the best long-term solution for subduing exotic invasive species.

INTRODUCTION

Millions of acres of forest land in the Southeast are being occupied increasingly by non-indigenous harmful plants---exotic escapes. The actual infested acreage and spread rates of encroaching exotic plants are unknown, even though this information is essential for planning eradication and containment strategies (U.S. Congress Office of Technology Assessment 1993). Kudzu and Japanese honeysuckle alone occupy over 7 million acres each and their spread rates are increasing (Watson 1989, Craver 1982). Exotic plant biopollution threatens plant and animal biodiversity across the landscape and continues to capture our highly valued nature preserves and recreational lands. All federal park and forest lands in the Southeast have exotic infestations (Hamel and Shade 1985, Hester 1991). The current problems with exotic imports grow worse, with no foreseeable declines.

The purpose of this paper is two fold: (1) to bring attention to the problem of exotic plants in the sub-tropical part of the Southeastern Forest Region, focusing on the most troublesome invasive species; and (2) to begin to mobilize support for organizing Integrated Weed Management Programs for these species. Herbicide control research is summarized to foster proactive treatment of new infestations as a means to minimize spread. The severe problem with tropical exotic invaders in Florida has already prompted the development of integrated management programs for those species, which is beyond the scope of this paper. It is however recognized that some tropical exotic species in Florida are advancing into the sub-tropical parts of the Southeastern Forest Region (e.g., cogongrass, tallowtree, and Japanese climbing fern) and represent common problems.

[1]Paper in conjunction with a poster presented at the Exotic Pests of Eastern Forests Conference.

Ecology of exotic plants

Exotic plants can spread rapidly because of our mobile society with "hitch-hiking" seeds and the intentional transportation of ornamental and forage plants (Randall and Marinelli 1996). Crucial aspects of exotic plant ecology that influence control strategies are as follows:

a. Invasive exotics continue to spread because natural predators were not imported from the plant's home range and native predators in the U.S. are too weak;

b. After an exotic plant is introduced there is a "lag phase" of decades to centuries before an exponential spread phase (Baskin 1996). Thus, some species that currently appear non-invasive may eventually begin to spread rapidly. Kudzu is an example that has an apparent lag phase of 10 to 20 years before a rapid spread phase;

c. Most invasive exotic plants spread through abundant seed production, and perennial species spread by well-protected, below-ground rhizomes;

d. Invasive exotic plants can prevent or retard natural succession and reforestation by forming dense infestations, often in mixtures. Control measures for one species can release non-susceptible cohorts;

e. Invasion by exotics continues to decrease biological diversity within natural reserves and parks, and detract from their primary mission (Natural Areas Association 1992);

f. The partial shade tolerance of some exotic species (i.e., Chinese privet, Japanese honeysuckle, lespedeza bicolor, tallowtree, and Japanese grass) allows them to become established under developed forest canopies;

g. Kudzu, Japanese honeysuckle, privets, mimosa, and Japanese grass are invading riparian habitats to the exclusion of native understory species and hardwood regeneration;

h. The initial spread of exotics along highway and utility right-of-ways, "disturbed habitats," and riparian systems, greatly facilitates migration into extensive forest areas; and

i. Because many "disturbed habitats" occur in cities, exotic plants can present severe problems for urban forestry programs, which is made more difficult by exotic species mixtures.

Control and eradication of exotic plants

Current control methods for invasive exotics are expensive, lengthy, and risky because total eradication is required to prevent reestablishment. Effective site-eradication procedures require multi-year treatments, continued monitoring, and follow-up treatments. All infestations on adjacent lands must be treated to prevent reinvasion. This seldom occurs without the leverage of noxious weed laws that places liability on neighbors that do not treat and allow reentry. Unfortunately, infestations common along highway, railroad, and utility right-of-ways are rarely treated for eradication, fostering widespread immigration to adjacent lands. In addition, many federal and State agencies have policies that prevent the use of the most effective herbicides for a particular exotic species. This results in extremely high control costs (often without eradication) on highly valuable sites. It is also becoming clear that older infestations and those near streams, marshes, and other special habitat, and those having abundant seed banks, are probably impossible to eradicate with current methods.

Past research studies for developing eradication methods were often limited in duration (only one or two years) and habitats (one site). Appropriate long-term support and funding has been lacking. Biocontrol projects offer a logical, long-term solution but none have been attempted in the

Southeastern Region. The high investments and long-term research required for biocontrol programs have been made only for western rangeland exotic plant species, and more recently for tropical exotics in Florida. The mixture of ownership that characterize eastern and southeastern forests presently stymies organized efforts, compared to the dominance of federal lands and interests in the West.

Integrated Weed Management Programs

Integrated Weed Management Programs incorporating all effective control treatments are needed with appropriate research funding and cost-share treatment programs for landowners. Integrated weed management is a system that utilizes all proven methods based on the best available scientific facts, current technology, and economic considerations. Integrated Weed Management Programs combine methods of control using: preventative measures (e.g., legal controls such as quarantines, inspections, and embargoes), biocontrol agents using natural parasites and predators, herbicides, prescribed burning, mechanical and manual treatments, and developed commercial uses.

Problems in organizing Integrated Weed Management Programs

The extensive weed infestations in southeastern forests often go unseen by the public—hidden invaders. Conflicting attitudes between user groups (e.g., horticulturists, hunters, seed producers, etc.) and landowners with exotic infestations as well as between urban and rural constituents hinders organizing aggressive control programs. Imported plants with developed uses in agriculture and horticulture can be become noxious invasive plants in forests. Widespread chemophobia often reenforces a do-nothing approach to site eradication methods that use herbicides, even though herbicides are now endorsed by conservation groups for treating some sites. In the past, a general attitude of resignation at all levels of both the public and private sectors in the Southeastern Region has hindered gaining support for integrated control and containment programs.

Federal and state governments have no unified policy for limiting entry, reacting to emergency importation, or fostering integrated control methods (U.S. Congress Office of Technology Assessment 1993). There is no regional agency or organization that has clearly-defined responsibility or jurisdiction to organize regional Integrated Weed Management Programs. The formation of state exotic pest plant councils may eventually fill some of this gap. And recently, federal agencies have started to address noxious weed problems in a unified manner by forming the Federal Interagency Committee for Management of Noxious and Exotic Weeds.

Prevalent Exotic Plant Species Invading Southeastern Forests

The exotic plants discussed below are some of the most noxious for forestry and other land use sectors in the Southeast. General descriptions of their biological nature and range have been compiled from several sources (Duncan 1975, Dean 1988, Foote and Jones 1989, Radford et al. 1983, Brown and Kirkman 1990, Randall and Marinelli 1996). An extensive literature search has yielded some herbicide control recommendations. However, very few recommendations for forested areas were found. It is apparent that more research is urgently needed. Only the most effective herbicide treatments are outlined. More details and other options are included in the cited research papers.

EXOTIC TREES

Exotic tree species hinder reforestation and rights-of-way management because of scattered isolated infestations. Silktree is continually spreading along stream networks and tallowtree has extensive infestations in wet forests, replacing native species. These species occur in mixtures with other exotic invasive plants on disturbed habitats.

Albizia julibrissin Durazzini — silktree or mimosa

Nature: Leguminous, small trees growing 30 to 40 ft that reproduce by seed and root sprouts.
Origin: Native to Tropic America.
Range: Along roadsides and forest borders from MS to FL and north to KY and VA.
Uses: A traditional ornamental with infestations originating from old homesite plantings.
Herbicide control: Only control recommendations of *A. pigra* are available, which are soil applications of tebuthiuron (Spike) and foliar applications of clopyralid (Transline)(Sutton and Langeland 1993). Clopyralid controls only legumes and is often safe on surrounding non-leguminous species.

Melia azedarach L. — chinaberry

Nature: Medium tree growing to about 50 ft that spreads by prolific seeding.
Origin: Introduced from Asia and traditionally planted at home sites in the Southeast.
Range: Forest borders and disturbed habitat throughout the Southeast but rare at high elevations.
Uses: Traditional ornamental and potential uses of extracts as pesticides.
Herbicide control: No control research reports found.

Sapium sebiferum (L.) Roxb. — tallowtree, popcorn tree

Nature: Shade-tolerant, small trees growing to 40 ft that spreads by bird-dispersed seeds (Jones and McLeod 1989).
Origin: Introduced from China to the U.S. gulf coast in early 1900's .
Range: Coastal plain from NC south to FL to TX with severe infestations on wet forest sites and coastal prairies in east TX to FL. Occurs as ornamental in OK and AR.
Uses: Waxy seeds traditionally used to make candles. Honey plant for beekeeping. Ornamental.
Herbicide control: No control research reports found.

EXOTIC SHRUBS

Exotic shrubs often occur with exotic tree species and present similar problems. The most extensive invader in forested areas is chinese privet that is replacing native riparian species and prevents regeneration of bottomland hardwood-pine forests. These exotic shrubs have value for wildlife forage, and are often established by hunter groups.

Lespedeza bicolor Turcz. — bicolor

Nature: Shade-tolerant, leguminous shrub up to 10 ft tall that spreads by bird- and animal-dispersed seeds.
Origin: Introduced from Japan.
Range: Piedmont and coastal plains in SE.
Uses: Wildlife food for birds and soil stabilization.
Herbicide control: No control research reported.

Ligustrum japonicum Thunb. Japanese privet
Nature: Shade-tolerant, tall shrub or small tree growing to about 35 ft, with evergreen leaves, that spreads by bird-dispersed seeds and by rhizomes.
Origin: Introduced from Japan and Korea.
Range: NC and SC to GA west to TX.
Uses: Ornamental and wildlife food and habitat.
Herbicide control: Glyphosate (Accord and Roundup) has demonstrated control on horticultural potted plants (Neal and Skroch 1985).

Ligustrum sinense Lour. Chinese privet
Nature: Shade-tolerant, tall shrub or small tree growing to about 30 ft, with evergreen leaves, that spreads by bird-dispersed seeds and by rhizomes.
Origin: Introduced from China.
Range: Scattered throughout MS north to TN and KY and east to AL, GA, SC, and NC.
Uses: Ornamental and wildlife food and habitat.
Herbicide control: No control research reports found.

Rosa multiflora Thunb. ex Murr multiflora rose
Nature: Erect shrub up to 10 ft tall with arching stems that forms dense thickets, that spreads by bird-dispersed seeds.
Origin: Introduced from Japan and Korea in 1860's and widely promoted in the 1930's by conservation agencies for cover, wildlife food, and "living fence."
Range: Fence rows, pastures, and thin woodlands, ME to MN south to FL and west to TX.
Uses: Wildlife food and cover, and livestock fences.
Herbicide control: Foliar sprays of metsulfuron (Escort) and metsulfuron and dicamba plus 2,4-D (Veteran 720) in the spring (Derr 1989, Underwood and Sperow 1985).

EXOTIC VINES

Exotic vines are some of the most troublesome invaders because they form the most dense infestations. Kudzu and Chinese wisterias can overtop even mature forests, while Japanese honeysuckle can form dense cover below the canopy. Reforestation after harvest of infested stands require high-cost treatments. Japanese climbing fern is a relatively new entry that is extending its range through wind-blown spore dispersal and infestations on forest margins along rights-of-ways and disturbed sites.

Lonicera japonica Thunb. Japanese honeysuckle
Nature: Shade-tolerant, climbing and trailing semiwoody vine with evergreen leaves that spreads by stolons and seeds. This is the only exotic of 7 species of Lonicera in SE.
Origin: Introduced from Japan.
Range: Eastern U.S.
Uses: Valued as deer browse in Piedmont and erosion control.
Herbicide control: Foliar sprays of metsulfuron (Escort) plus surfactant at 2 oz ai/a in May (in Georgia) with tolerance by pine seedlings (Edwards and Gonzalez 1986). Foliar sprays of glyphosate (Accord and Roundup) at 1.5% v/v in December (in Delaware) (Regehr and Frey 1988).

Lygodium japonicum Thunb. Sw.   Japanese climbing fern
Nature: Rhizomatous delicate vine, climbing and twining to form clumps that can cover shrubs and trees. One of three species of climbing fern (the others--*L. palmatum* in the Blue Ridge and *L. microphyllum* in FL—are native.)
Origin: Introduced from Japan
Range: Lower halves of SC, GA, AL, MS, and LA, and central FL.
Uses: Ornamental
Herbicide control: No control research reports found.

Pueraria montana (Lour.) Merr. (formerly *Pueraria lobata* (Willd.) Ohwi)   kudzu
Nature: Leguminous, trailing or climbing, semi-woody vine that spreads by vine growth, rhizomes, and seeds (Miller 1996).
Origin: Introduced from Japan with the home range in China into MS, AL, GA, and SC.
Range: Roadsides, fields, and forests throughout the Southeast and scattered north to OH to CT.
Uses: Erosion control, livestock feed, and folk art.
Herbicide control: Foliar sprays of picloram (Tordon), picloram plus 2,4-D, or tebuthiuron (Spike) for successive years applied from June to September (Miller 1986, 1988). Other options provide partial control and may be useful in specific situations .

Wisteria sinensis (Sims) DC   Chinese wisteria
Nature: Leguminous semiwoody vine (or shrub) that spreads by vine growth and seeds. One of four species in SE with one other being exotic but rare, *W. floribunda* (Willd.) DC. (Japanese wisteria), while the native or naturalized *W. frutescens* (L.) Poiret is the more frequent.
Origin: Introduced from Asia.
Range: Piedmont and coastal plains from VA to LA and north to AR and TN.
Uses: Ornamental
Herbicide control: Glyphosate (undiluted Accord) immediately applied to cut vines in November (Thomas 1993).

EXOTIC GRASSES

Exotic grasses present severe competition for establishing forest plantations on abandoned row-crop and pasture lands. Some of these are generally considered naturalized, e.g., bermudagrass (*Cynodon dactylon* (L.) Pearsoon), crabgrass (*Digitaria* spp. Heister), and giant fescue (*Festuca arundiacea* Schreb.), and are not listed here. Most exotic grasses spread and reside along highway and utility right-of-ways, where eradication treatments are not applied.

Imperata cylindrica (L.) Palisot   cogongrass
Nature: Dense, erect perennial grass that spreads by prolific seed (short-lived) production and rhizome movement in fill-dirt. A South American species, *I. brasiliensis*, is less invasive. Both species invade new forests and prevent establishment of planted seedlings.
Origin: Native to Southeast Asia and listed as the world's seventh worst weed (Holm et al. 1977).
Range: All MS, lower AL, and isolated infestations in SW GA and SC (Bryson and Carter 1993). State-wide eradication program in LA apparently successful.
Uses: Forage initially projected without success and initially for soil stabilization.

Control: Imazapyr (Arsenal AC) and glyphosate (Accord), singly or in combinations, with multiple applications (Townson and Butler 1990).

Microstegium vimineum (Trin.) A. Camus Japanese grass, stiltgrass, Nepal microstegium
Nature: Dense, mat-forming annual grass that roots at nodes and is shade tolerant and occupies various habitats including creek banks, floodplains, forest roadsides and trails, damp fields, and swamps (Barden 1987).
Origin: Native to temperate and tropical Asia, it was introduced near Knoxville, Tennessee around 1919 (Fairbrothers and Gray 1972).
Range: MS to FL north to AR, KY, OH, NY and CT.
Uses: None
Control: Glyphosate (Accord) and sethoxydin (Vantage, formerly Poast) as dilute foliar sprays in late summer (Johnson 1997).

Sorghum halepense (L.) Pers. johnsongrass
Nature: Dense, erect perennial grass that reproduces by seed and rhizomes. Invading new forest plantations.
Origin: Introduced from Mediterranean region of Africa.
Range: Throughout the Eastern and Midwest U.S. and lower NM, AR, and CA.
Uses: Livestock pasture.
Control: Sulfometuron (Oust) plus imazapyr (Arsenal AC) applied in April-May for suppression to establish loblolly pine (Dougherty et al. 1991, Nelson and Franklin 1990)

RECOMMENDATIONS

Weed scientists and extension specialists in the region need to coordinate efforts and be aggressive in performing research projects aimed at developing integrated control approaches for these species. Legal and policy strategies are needed at all governmental levels to prevent future importation and spread, as well as, to support development of regional-scope integrated management programs. Extension specialists can help to educate various public sectors to the need for weed management, the cost-benefits, and how to perform effective control treatments.

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HOW ILLINOIS KICKED THE EXOTIC HABIT

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Introduction

For the purpose of this paper, an exotic species is defined as "a plant or animal not native to North America." The history of folly surrounding the premeditated and accidental introduction of exotic animals has been well-documented (De Vos et al. 1956, Elton 1958, Hall 1963, Laycock 1966, Ehrenfeld 1970, Bratton 1974/1975, Howe and Bratton 1976, Moyle 1976, Courtenay 1978, Coblentz 1978, Iverson 1978, Weller 1981, Bratton 1982, Vale 1982, and Savidge 1987).

In 1963, Dr. E. Raymond Hall wrote, "Introducing exotic species of vertebrates is unscientific, economically wasteful, politically shortsighted, and biologically wrong." Naturalizing exotic species are living time bombs, but no one knows for sure how much time we have. For example, the ring-necked pheasant (*Phasianus colchicus*), touted as the Midwestern example of a good exotic introduction, has recently developed a nefarious relationship with the greater prairie chicken (Tympanuchus cupido) in Illinois. Parasitism of prairie chicken nests by hen pheasants and harassment of displaying male chickens by cock pheasants are contributing to the decline of prairie chickens in Illinois (Vance and Westemeier 1979). The interspecific competition between the exotic pheasant (which is expanding its range in Illinois) and the native prairie chicken (which is an endangered species in Illinois) may be the final factor causing the extirpation of the prairie chicken from Illinois; it has already been extirpated from neighboring Indiana.

In 1953, Klimstra and Hankla wrote, "In connection with the development of a pheasant adapted to southern conditions, the compatibility of pheasants and quail (*Colinus virginianus*) needs to be evaluated. It would be unwise to establish a game bird that would compete with another desirable species." It has been recently discovered that ring-necked pheasants also parasitize quail nests (Westemeier et al. 1989). Management at Illinois' prairie chicken preserves now include pheasant control 12 months of the year.

Michigan is apparently not moved by the potential threats that exotic animals pose (Huggler 1991). They recently released the Sichuan or "brush" pheasant (Phasianus colchicus strauchi) into the wild, and Indiana officials are considering the same move. The preferred habitat of the Sichuan pheasant and the ruffed grouse (*Bonasa umbellus*) overlap. Consequently, if the "brush" pheasant becomes fully naturalized, it may become a serious competitor to the native ruffed grouse.

The raccoon dog (*Nytereutes procynoides*), a member of the dog family, apparently is native to Asia. Between 1927 and 1957, they were introduced to Europe both intentionally and acci-dentally as escapees from fur farms. As a result of their high reproduction rate, omnivorous feeding habits, and general lack of enemies, they have spread rapidly throughout northern and western Europe. Later, like the nutria (*Myocuster coypus*), they were brought to the United States as fur-bearing stock. Raccoon dogs prefer forested, riparian habitats, marshes, and dense cover surrounding lakes. They are opportunistic, eating a wide variety of plants and animals, including eggs, fish, and carrion. They are the only canid that hibernates, but they are not "deep sleepers." On warm days, they forage and in the southern parts of their range, they do not hibernate at all (Ward and Wurster-Hill 1990). If raccoon dogs were to escape captivity and become fully naturalized, they have all the characteristics to become a serious predator of many native species of wildlife.

On July 23, 1983, it became illegal to possess, propagate, or release a raccoon dog in Illinois. But three separate fur farms had purchased raccoon dogs before the law was passed. On July 11, 1984, the Illinois Department of Conservation paid $41,000 to buy the raccoon dogs from those fur farmers.

The rusty crayfish (*Orconectus rusticus*), originally sold as fish bait, is an aggressive exotic species that replaces native crayfish (Page 1985). Four species of crayfish are currently listed on Illinois' endangered species list. The establishment of rusty crayfish in Illinois would be a serious threat to these native species. Consequently, as of June 29, 1990, the importation, possession, and sale of live rusty crayfish was banned in Illinois.

The Issue of Exotic Plant Materials

Dr. Hall was right about the dangers of introducing exotic vertebrates, and his analysis applies to the introduction of exotic plant material as well (Reed 1977). Unfortunately, less is appreciated about the tremendous damage that is occurring to our continent's ecosystems due to the escape and naturalization of exotic plants (Bratton 1982); Harty 1986; Mooney and Drake 1986). In Illinois, as elsewhere, the perceived merits versus the perceived impacts associated with introducing exotic plant species are argued as a matter of philosophy among wildlife biologists, soil conservationists, foresters, landscapers, and ecologists. However, evidence is mounting to indicate that the introduction of exotic plant species has resulted in major ecological damage and caused serious management problems.

Multiflora rose (*Rosa multiflora*) is the classic Midwestern example of an exotic species run amuck, aggressively overgrowing pastures and abandoned farm ground. It was originally promoted in the 1940s for use as a living fence, erosion control, and wildlife food and cover, with the added assurance during its initial promotion that it would not spread or become a nuisance. These claims seem naive in retrospect. Nevertheless, variations of the same scenario have been used to promote autumn olive (*Elaeagnus umbellata*), bush honeysuckle (*Lonicera tatarica*), amur honeysuckle (L. *maackii*), and many other exotic species. Klimstra (1956) was one of the first to point out the problems associated with the widespread planting of multiflora rose; moreover, he questioned the REAL versus the PERCEIVED value of multiflora rose for wildlife habitat planting.

In Illinois, 811 species, or 29 percent, of the state's flora are naturalized from foreign countries (Henry and Scott 1980). Not all these species can be classified as problem species today, but Tartarian honeysuckle, amur honeysuckle, tree-of-heaven (*Ailanthus altissima*), thistle (*Carduus nutans*), Canada thistle (*Cirsium arvense*), crown vetch (*Coronilla varia*), giant teasel (*Dipsacus* *laciniatus*), European beach grass (*Elymus arenarius*), tall fescue (*Festuca pratensis*), sericea lespedeza (*Lespedeza cuneata*), multiflora rose, Japanese honeysuckle (*Lonicera japonica*), purple loosestrife (*Lythrum salicaria*), white poplar (*Populus alba*), smooth and shining buckthorn (*Rhamnus cathartica* and *R. frangula*), and Johnson grass (*Sorghum halepense*), are just a few examples of exotic plant introductions causing farmers, foresters, land-managers, and grounds-keepers considerable problems in various regions of the state (West 1984; Schwegman 1988).

Moreover, autumn olive, osage orange (*Maclura pomifera*), and winged-euonymus (*Euonymus alatus*), three of the long-term "neutrals" in the game of exotic roulette, have now adapted sufficiently to Illinois' conditions that they, too, are becoming naturalized weeds, spreading from plantings into the landscape (Nyboer and Ebinger 1978, Ebinger and Lehnen 1981, Ebinger et al. 1984, Nestleroad et al. 1987). Ebinger (1983) summarizes the problems that naturalized exotic shrubs (multiflora rose, Japanese honeysuckle, autumn olive, winged-euonymus, and blunt-leaved privet (*Ligustrum obtusifolium*) are causing managers of natural areas in Illinois. Additionally, climbing euonymous (*Euonymous fortunei*) and oriental bittersweet (*Celastrus orbiculatus*), two popular ornamental vines, are becoming invaders in southern Illinois forests (Schwegman 1991, personal communication).

Why Did We Plant Exotics in the First Place?

The common refrain associated with the promotion of exotic plant materials is that "they are hardy, disease free, have few, if any, insect pests, reproduce or propagate easily, and provide food or cover for wildlife." These characteristics are precisely what makes exotic species such serious competitors when released into a new ecosystem or habitat.

Two recent examples of this scenario are the release of "Elsmo" lace-bark elm (*Ulmus parviflora* Jacq.), and "Redstone" Cornelian cherry dogwood (*Cornus mas* L.) by the Soil Conservation Service (Plants for Conservation 3(1) January 1991, and Plants for Conservation 3(2) July 1991). Siberian elm (*Ulmus pumila*) was promoted to replace American elm (*Ulmus americana*) as a streety tree after the American elm was devastated by an introduced pathogen that caused Dutch Elm disease. Siberian elm failed in its original purpose, but was successful at naturalizing into many parts of the country. Now lace bark elm is being promoted to replace Siberian elm. From an ecological standpoint, we seem to be trapped on a devil's merry-go-round. *Cornus mas* has been in the landscaping trade for years, known as Cornelian cherry (Rehder 1960); it seems unfortunate that we would now be promoting it for conservation purposes. There are at least 11 species of shrubby dogwoods native to the eastern United States. These native species offer equivalent soil conservation benefits and an abundance of fruits for wildlife with no ecological risks.

Sawtooth oak (*Quercus acutissima*), a species from Asia, provides another example of promoting an exotic species as an alternative wildlife food plant (Hopkins and Huntley 1979). Thirty-six years ago, Klimstra (1956), pointed out the potential problems associated with planting multiflora rose. Similarly, Coblentz (1981), has pointed out the lack of foresight and, more importantly, the lack of hindsight in promoting the exotic sawtooth oak over the 37 species of oaks native to the southeastern United States for mast production for wildlife.

In spite of the mounting evidence of the ecological dangers associated with exotics and the skyrocketing costs of controlling them, exotic species continue to be tested and promoted for the same worn-out reasons:

1. wildlife habitat plantings (autumn olive and bush honeysuckle);

2. landscaping purposes (blackthorn and purple loosestrife);

3. wood and fiber production (Princess tree [*Paulownia tomentosa*] and tree-of- heaven);

4. soil conservation practices (crown vetch and multiflora rose); and

5. forage improvement (Johnson grass and tall fescue).

What Is At Risk Because of Exotic Plants?

Entire plant communities, such as fens, bogs, and marshes, can be significantly altered by invasive plant species, such as purple loosestrife (Thompson et al. 1987). Endangered species, such as Kankakee mallow (*Iliamna remota*) may be crowded out of its last habitat by multiflora rose and the bush honeysuckles (Glass 1986, personal communication). Common plants, such as bluebells (*Mertensia virginica*) are being crowded out of forests by garlic mustard (Iverson et al. 1991). The native high-bush cranberry (*Viburnum trilobum*) is known to hybridize with the ornamental, *Viburnum opulus*. This may result in the loss of the native genotype, or it could result in creating an aggressive hybrid species similar to the case of *Spartina anglica* (Thompson 1991).

Oak reproduction is a major concern of foresters, ecologists, wildlife biologists, and natural area managers, and naturalized exotic shrubs and vines are now being identified as serious competitors to oak regeneration. A recent example is oriental bittersweet, which is becoming a serious pest on many hardwood regeneration sites in the Appalachians (McNab and Meeker 1987).

What Are The Costs Associated With Exotic Introductions?

Although the economic cost of controlling exotic introductions can be calculated, the ecological damage cannot be measured in dollars. For example, Brandenburg Bog in northeastern Illinois, was purchased to preserve, protect, and perpetuate a rare calcareous fen community. Purple loosestrife is invading the fen, and it may be beyond eradication (Heidorn 1986, personal communication). The direct cost of this exotic species to the State of Illinois in this example is at least $379,000, the cost of purchase in 1973. However, "Brandenburg Bog is the premier calcareous fen in the state and as such is irreplaceable" (Schwegman 1988).

How Illinois Kicked The Exotic Habit – A Case History

The Illinois Department of Conservation nurseries began producing autumn olive in 1964. By 1982, our nurseries were distributing more than 1,000,000 autumn olive seedlings a year, which represented about 20 percent of the state nursery's production of all species combined (Sternberg 1982). We also produced large numbers of bush honeysuckles.

In 1983, our Seedling Needs Committee met to review the needs of the department relative to seedling production. This is a standing committee comprised of representatives from the divisions of Wildlife Resources, Forestry, Public Lands, Planning, and Natural Heritage. The issue of exotics and the role of the state nurseries in their production, was addressed by the committee. The committee agreed that further production of exotic plant materials in our nurseries was not necessary if suitable native species could be grown as substitutes for the exotics. The concept of substituting native species for exotic species is compelling when one considers that:

1. native species comprise 99 percent of the wildlife species we manage habitat for, and they evolved with native plant species. Furthermore, there is no hard evidence to support the contention that exotic plant materials are superior to native species for wildlife (Martin et al. 1951);

2. there is no reason to believe that native species of trees and shrubs cannot be grown in nurseries using techniques similar to those we use to grow exotics (Schopmeyer 1974);

3. when developing landscaping plans for state parks, conservation areas, and other Department of Conservation facilities, it seems more appropriate to use native plant materials in keeping with the natural setting (Hightshoe 1988); and

4. future management problems caused by introducing new exotic plant materials could be reduced if we promoted and planted native species for conservation purposes.

Today, our nurseries produce 67 species of native trees and shrubs for use in developing wildlife habitat, reclamation projects, and community restorations (Table 1). The seeds necessary to propagate these native species are collected from state parks and conservation areas by our wildlife biologists, foresters, natural heritage biologists, site superintendents, maintenance workers, and volunteers.

TABLE 1. Native trees and shrubs grown at Illinois Department of Conservation nurseries

Acer rubrum	Red maple
Acer saccharinum	Silver maple
Acer saccharum	Sugar maple
Aronia melanocarpa	Black chokeberry
Betula nigra	River birch
Carya illinoensis	Pecan
Carya ovata	Shagbark hickory
Carya ovalis, C. cordiformis, C. glabra, C. tomentosa	various Hickory species
Carya texana	Black hickory
Celtis occidentalis	Hackberry
Cephalanthus occidentalis	Buttonbush
Cercis canadensis	Redbud
Cornus obliqua	Pale dogwood
Cornus racemosa	Gray dogwood
Cornus stolonifera	Red osier dogwood
Corylus americana	Hazelnut
Cratagus crus-galli	Cock-spur thorn
Crataegus phaenopyrum	Washington hawthorn
Diospyros virginiana	Common persimmon
Fraxinus americana	White ash
Fraxinus pennsylvanica	Green ash
Gymnocladus dioica	Kentucky coffee-tree
Ilex decidua	Swamp holly
Juglans nigra	Black walnut
Juniperus virginiana	Red cedar
Liquidambar styraciflua	Sweet gum
Liriodendron tulipifera	Tulip tree
Malus ioensis	Iowa crab apple
Morus rubra	Red mulberry
Nyssa sylvatica	Sour gum
Pinus resinosa	Red pine
Pinus strobus	White pine
Pinus taeda	Loblolly pine
Platanus occidentalis	Sycamore
Prunus americana	Wild plum
Prunus serotina	Wild black cherry
Quercus alba	White oak
Quercus bicolor	Swamp white oak
Quercus imbricaria	Shingle oak
Quercus lyrata	Overcup oak
Quercus macrocarpa	Bur oak

Quercus marilandica	Blackjack oak
Quercus michauxii	Basket oak
Quercus nuttallii	Nuttall's oak
Quercus pagoda	Cherry-bark oak
Quercus palustris	Pin oak
Quercus prinoides var. *acuminata*	Yellow chestnut oak
Quercus rubra	Red oak
Quercus shumardii	Shumard's oak
Quercus stellata	Post oak
Quercus velutina	Black oak
Rhus aromatica	Fragrant sumac
Rhus copallina	Dwarf sumac
Rhus glabra	Smooth sumac
Rhus typhina	Staghorn sumac
Robinia pseudoacacia	Black locust
Rubus allegheniensis	Common blackberry
Sambucus canadensis	Elderberry
Symphoricarpos arbiculatus	Coralberry
Taxodium distichum	Bald cypress
Vaccinium arboreum	Farkleberry
Viburnum lentago	Nannyberry
Viburnum recognitum	Smooth arrowwood
Viburnum trilobum	High-bush cranberry

In 1977, the Illinois nursery system moved forward once more by producing big bluestem (*Andropogon gerardii*) and Indian grass (*Sorghastrum nutans*) seed for prairie reconstructions. By 1980, our Mason Tree Nursery had expanded its operation to include 37 different species of prairie forbs. In 1983, 35,000 prairie forbs were obtained from 596 m^2 of bed space (Wallace et al. 1986).

The grass and forb program has been very successful. Production for 1991 included 54 forb species and 7 grass species (Table 2); 293,457 prairie forb rootstocks were grown in 1,900 m^2 of bed space. In addition, attempts to grow woodland herbaceous species have been initiated with 13 species currently involved (Table 3). Approximately $4 million in capital improvements at the Mason Nursery has increased seed bed space from 16 ha to 40 ha and built a 279 m^2 greenhouse for herbaceous production. The facility is also equipped with a grass seed cleaning and processing facility and a center pivot irrigation system, which will allow expansion of the grass seed collection area to 16 hectares (Pequignot 1992, personal communication).

Besides attempts to eliminate exotic species from our nursery operations, educational articles discussing the problems with exotic plants and animals have been published in our department's official publication, Outdoor Highlights (Harty 1985; Schwegman 1985, 1988). Moreover, a colorful flier was prepared that explained the problems associated with planting purple loosestrife and recommended measures for its control. Species-specific alert fliers were produced for garlic mustard

(*Alliaria petiolata*), rudd (*Scardineus erythrophthalmus*), rusty crayfish, and zebra mussels (*Dreissena polymorpha*). A slide tape program describing the problems associated with exotic plant species in Illinois was also produced for use in educating the general public.

TABLE 2. Native prairie forb and grass species grown at the Mason Tree Nursery, Topeka, Illinois

FORBS	
Allium cernuum	Nodding onion
Amorpha canescens	Leadplant
Anemore cylindrica	Thimbleweed
Asclepias sullivantii	Prairie milkweed
Ascleplas tuberosa	Butterfly-weed
Aster laevis	Smooth aster
Aster novae-angliae	New England aster
Astragalus tennesseensis	Ground plum
Baptisia lactea	White wild indigo
Baptisia leucophaea	Cream wild indigo
Boltonia decurrens	Decurrent false aster
Calcalia plantaginea	Prairie Indian plantain
Camassia scilloides	Wild hyacinth
Ceanothus americanus	New Jersey tea
Coreopsis lanceolata	Tickseed coreopsis
Coreopsis palmata	Prairie coreopsis
Coreopsis tripteris	Tall tickseed
Dalea candida	White prairie clover
Dalea foliosa	Leafy prairie clover
Dalea purpurea	Purple prairie clover
Desmanthus illinoensis	Illinois mimosa
Desmodium canadense	Showy tick trefoil
Desmodium illinoense	Illinois tick trefoil
Dodecatheon meadia	Shooting star
Echinacea pallida	Pale coneflower
Eryngium yuccifolium	Rattlesnake master
Helianthus occidentalis	Western sunflower
Heliopsis helianthoides	False sunflower
Heuchera richardsonii	Prairie alumroot
Hieracium longipilum	Hairy hawkweed
Iliamna remota	Kankakee mallow
Iris shrevei	Wild blue iris
Lespedeza capitata	Round-headed bush clover
Lespedeza leptostachya	Prairie bush clover
Liatris aspera	Rough blazing star
Liatris pycnostachya	Prairie blazing star

Liatris spicata	Marsh blazing star
Monarda fistulosa	Wild bergamont
Napaea dioica	Glade mallow
Parthenium integrifolium	American feverfew
Physostegia virginiana	False dragonhead
Polytaenia nuttalli	Prairie parsley
Potentilla arguta	Prairie cinquefoil
Prenanthes aspera	Rough white lettuce
Ratibida pinnata	Drooping coneflower
Rosa carolina	Pasture rose
Rudbeckia subtomentosa	Fragrant coneflower
Silene regia	Royal catchfly
Silphium integrifolium	Rosinweed
Silphium laciniatum	Compass-plant
Silphium terebinthinaceum	Prairie-dock
Solidago rigida	Rigid goldenrod
Tradescantia ohiensis	Spiderwort
Zizia aurea	Golden alexanders
GRASSES	
Andropogon gerardii	Big bluestem
Panicum virgatum	Switch grass
Schizachryium scoparium	Little bluestem
Sorghastrum nutans	Indian grass
Spartina pectinata	Cord grass
Sporobolus heterolepis	Prairie dropseed
Stipa spartea	Porcupine grass

Thirty-four (34) vegetation management circulars were prepared by various authors for the Illinois Nature Preserves Commission. These circulars provide information about specific exotic plant species and management recommendations for their control or eradication. Many of these circulars have been published in the Natural Areas Journal.

In addition to these efforts, two other publications, *Landscaping for Wildlife*, and *Illinois Prairie: Past and Future – A Restoration Guide*, promote the use of native species and point out the problems associated with exotic plant species.

Another significant step forward was the development of a windbreak manual for Illinois (Bolin et al. 1987). This is a cooperative effort by the University of Illinois, Department of Forestry, Cooperative Extension Service, the USDA Soil Conservation Service, and the Illinois Department of Conservation. The issue of exotics was addressed early in the planning of this manual, and the committee, which is comprised of inter-agency foresters, wildlife biologists, and natural-heritage biologists, recommended 30 native trees and shrubs and three nonnative species as suitable for use for windbreaks and snow trips in Illinois (Table 4). The three nonnative species to Illinois, Norway spruce (*Picea abies*), blue spruce (*Picea pungens*), and Douglas-fir (*Pseudotsuga mensiesii*), have been planted throughout Illinois for many years and have not been found to reproduce spontaneously from seed. This has proven to be a prudent compromise.

TABLE 3. Native woodland herbaceous species grown at the Mason Tree Nursery, Topeka, Illinois

Actaea pachypoda	Doll's eyes
Arisaema triphyllum	Jack-in-the-pulpit
Asarum canadense	Wild ginger
Claytonia virginica	Spring beauty
Dentaria laciniata	Toothwort
Dicentra cucullaria	Dutchman's breeches
Isopyrum biternatum	False rue anemone
Jeffersonia diphylla	Twinleaf
Panax quinquefolius	Ginseng
Polygonatum commutatum	Solomon's seal
Sanguinaria canadensis	Bloodroot
Smilacina racemosa	False Solomon's seal

The Illinois Department of Transportation has also been quite cooperative regarding management of exotics along right-of-ways and cloverleafs adjacent to Department of Conservation properties. For the past three years, the Department of Conservation and the Soil Conservation Service (SCS) have been working cooperatively to collect seeds from native shrubs for the SCS to evaluate at their Elsberry Plant Improvement Center in Missouri.

TABLE 4. Native tree and shrub species recommended for windbreaks and snow trips in Illinois (Bolin et al. 1987)

Amelanchier arborea	Shadbush
Aronia melanocarpa	Black Chokeberry
Cornus alternifolia	Alternative-leaved dogwood
Cornus drummondii	Rough-leaved dogwood
Cornus obliqua	Pale dogwood
Cornus racemosa	Gray dogwood
Cornus stolonifera	Red osier dogwood
Corylus americana	Hazelnut
Crataegus crus-galli	Cock-spur thorn
Crataegus mollis	Red haw
Crataegus phaenopyrum	Washington hawthorn

Hamamelis virginiana	Witch-hazel
Ilex verticillata	Winterbery
Juniperus communis	Common juniper
Juniperus virginiana	Red cedar
Malus ioensis	Iowa crab apple
Picea abies	Norway Spruce
Picea pungens	Blue spruce
Pinus strobus	White pine
Prunus americana	Wild plum
Prunus virginiana	Common chokecherry
Pseudotsuga menziesii	Douglas-fir
Symphoricarpos orbiculatus	Coralberry
Taxus canadensis	Canada yew
Thuja occidentalis	Arbor vitae
Viburnum acerifolium	Maple-leaved arrowwood
Viburnum lentago	Nannyberry
Viburnum prunifolium	Black haw
Viburnum rafinesquianum	Downy arrowwood
Viburnum recognitum (V. Dentatum)	Smooth arrowwood
Viburnum rufidulum	Southern black haw
Viburnum trilobum	High-bush cranberry

Seventeen species are currently being evaluated for their wildlife food and cover value (Table 5).

TABLE 5. Native shrubs being evaluated as food and cover plants by the Soil Conservation Service's Plant Improvement Center, Elsberry, MO

Amelanchier arborea	Shadbush
Aronia melanocarpa	Alternate-leaved dogwood
Cornus drummondii	Rough-leaved dogwood
Cornus obliqua	Pale dogwood
Cornus racemosa	Black chokeberry
Cornus alternifolia	Gray dogwood
Corylus americana	Hazelnut
Juniperus virginiana	Red cedar
Prunus americana	Wild plum
Prunus virginiana	Common chokecherry
Ribes americana	Wild black currant
Thuja accidentalis	Arbor vitae
Viburnum lentago	Nannyberry
Viburnum prunifolium	Black haw
Viburnum recognitum (V. dentatum)	Smooth arrowwood
Viburnum trilobum	High-bush cranberry

On January 1, 1988, Illinois passed the Illinois Exotic Weed Act. Exotic weeds are defined as "... plants not native to North America which, when planted, either spread vegetatively or naturalize and degrade natural communities, reduce the value of fish and wildlife habitat, or threaten an Illinois endangered or threatened species."

There are currently three listed species—Japanese honeysuckle, multiflora rose, and purple loosestrife. It is unlawful to sell, buy, offer for sale, or distribute seeds, plants, or plant parts without a permit issued by the Illinois Department of Conservation. A violation of the act is a Class B misdemeanor, and listed plants are confiscated and destroyed.

On May 25, 1989, the Director of the Illinois Department of Conservation signed a department policy on the planting and removal of exotic plant species. The policy lists 12 species which cannot be used on DOC property and lists five species which can be used only for short rotation, research, or erosion control (Table 6).

TABLE 6. List of exotic plant species and their permissible uses on Illinois Department of Conservation properties as authorized by Policy Manual Code No. 2450 dated May 25, 1989

Scientific Name	Common Name	Permissible Uses
Celastrus orbiculatus	Round-leaved Bittersweet	None
Coronilla varia	Crown vetch	None
Elaeagnus umbellata	Autumn olive	None
Euonymus alatus	Winged euonymus	None
Euonymus fortunei	Climbing euonymus	None
Festuca elatior	Tall fescue	Critical erosion area
Lespedeza cuneata	Serecia lespedeza	Cover crop and nigrogen fixation
Lonicera japonica	Japanese honeysuckle	None
Lonicera maackii	Amur honeysuckle	None
Lonicera tartarica	Tartarian honeysickle	None
Lythrum salicaria	Purple loosestrife	None
Melilotus alba	White sweet clover	Short rotation cropland
Melilorus officinalis	Yellow sweet clover	Short rotation cropland
Pueraria lobata	Kudzu	None
Rhamnus frangula	Glossy buckthorn	None
Robinia	Black locust	Strip mine reclamation, nurse crop in black walnut plantation, mixed with 34 other species in forest application with unfavorable site conditions
Rosa multiflora	Multiflora rose	None

SUMMARY

Once exotics become naturalized, they often change community species composition, alter structure, and reduce natural diversity of native plant and animal communities. Moreover, if an exotic becomes naturalized and spreads throughout a system, getting it out of that system is like trying to unscramble an egg.

It is the responsibility of all natural resource professionals to provide proper and prudent management advice to private and public landowners and managers. To continue to ignore the documented consequences associated with introducing exotic species in the name of soil conservation, wildlife management, or reforestation, would fall short of this obligation.

A giant step forward is necessary to head off the invasion of exotic plant materials into the natural landscape. We must redirect our reforestation and wildlife habitat restoration efforts away from exotics and toward the utilization of native plant species that are compatible with native ecosystems.

Illinois is extremely fortunate to have natural resource agencies and resource professionals who have taken decisive action in addressing the issue of exotic species.

Laycock (1966) described the pursuit of exotic species as a "perpetual relay race with one generation passing the stick to the next." I am happy to report that the Illinois Department of Conservation has not dropped the baton. It is the author's hope that this paper will stimulate activity in other states to address the issue of exotic species within their jurisdiction.

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HIGHWAY CORRIDOR RESPONSIBILITY

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INTRODUCTION

As highways cross the nation they provide safe travel for the vacationers, commuters, truckers, the military, farmers, congressmen, our families, and friends. Highway corridors provide safe passage for many plant invaders as well. Highway vegetation managers manage millions of acres of rights-of-way that cross your land. It is imperative that we understand each other's management strategies and cooperate as much as possible. If we do not, plant invaders that have no respect of political boundaries will prevail. This paper examines why roadside vegetation managers operate the way they do. Both negative and positive examples of current practices are noted. Future practices are predicted.

State and interstate highways are typically maintained by state highway agency crews. A few states, such as Wisconsin and Tennessee, engage county maintenance forces to do vegetation management. It should be understood that the Federal Highway Administration does not own or have management responsibilities over the many acres of roadsides that parallel our nation's roadways; but rather serves as an advisor and information resource for all the states. States do not own all of the roadsides, but rather lease much of the right-of-way. As a consequence, adjacent landowners often participate in vegetation management on these lands. Some states allow farmers, in particular, to harvest hay from the rights-of-way during drought years. Utility companies have access to these same roadsides. The intended users of a roadside are errant vehicles that require a recovery zone to minimize injury. Of course, that same land accommodates directional and information signs. The roadsides are, therefore, operational areas for many uses. These uses must be considered by vegetation managers.

Each state makes vegetation management decisions based on the years of experience in that state. Vegetation management policies have evolved differently in different places due to climate constraints, policy changes, public demand, and all the uses mentioned. Safety will always be the number one requirement affecting decisions. In the past, many decisions were affected by an unwritten, but widely known, policy of managing our nation's roadsides as if they were our nation's front lawns. This notion prevailed in the 1930's, when many state roadside development programs were begun. When herbicides became technically available in the 1950's, spray-mow approaches became the norm to give the public that manicured look. In the 1970's, after the energy crunch, roadside maintenance quickly changed due to the increased cost of labor-intensive management. Alternatives were sought, and in many states, more ecological solutions were found. The idea of "working with nature," reducing chemical use, timing mowings, and adding prescribed burns, defined the ecological approach. As new management tools were sought, the idea of integrated roadside vegetation management (IRVM) emerged as the common sense approach of the 80's. What if we no longer used a blanket approach, or one size fits all, but used the right tool for the right problem, site-specifically! With that background in common, each state's vegetation policy continues to be unique because of the other factors that influence decisions.

Some decisions made by state highway agencies (SHA) that have had negative environmental consequences, have included nameless states who have: l) mowed around and saved Tree of Heaven (*Ailanthus altissima*) to save a tree, 2) planted Black Locust (*Robinea pseudoacaia*) because the seedlings were free, 3) planted Purple Loosestrife (*Lythrum salicaria*) for beautification purposes, and 4) pictured Kudzu (*Pueraria lobata*) in a wildflower brochure, and so on. The public, who knew about the predictable consequences of these invasive plants, viewed these decision-makers as thoughtless.

Some SHA decisions with positive environmental consequences include: l) the Florida Department of Transportation, motivated by the invasion of Tropical Soda Apple, now requires weed-free certification of sod used in construction projects, 2) the Tennessee Department of Transportation successfully funded a biocontrol study on Musk Thistle, 3) the Utah Department of Transportation has trained its workers to identify and control new invasive plants at Utah's borders, 4) a six-State partnership of Texas, Oklahoma, Missouri, Kansas, Iowa, and Minnesota have taken inventory and are developing a coordinated vegetation management plan for a highway corridor from Mexico to Canada, 5) the Iowa Department of Transportation has backed an ecotype approach to native seed production and use on planting projects to outcompete noxious weeds, 6) a coalition of SHAs and industry recently produced a guide to Integrated Roadside Vegetation Management, and finally, 7) in 1997, four State Departments of Transportation endorsed support for the National Strategy for Invasive Plant Management. These states demonstrate a proactive trend towards highway corridor responsibility.

CONCLUSION

It will take time for all states to get on board with the IRVM approach. They continue to make the best decisions they can with the information they have at the time. This author can foresee a time when each state has its own IRVM plan for all segments of highways it has inventoried. In the meantime, exotic plant pests continue to move across the country through highway corridors. Teasel has been seen from Arkansas to Idaho. Russian olive spreads from the midwest to the southwest. Johnsongrass migrates from the south northward. Kudzu now adapts to cold climates! Purple loosestrife is spotted in every state. Leafy spurge and knapweed extend from the deciduous forest throughout the plains.

Obstacles to highway agencies controlling these invasive species remain. Many states in the northeast and the south still do not have state noxious weed lists that help identify priorities for IRVM. Some state agencies have not yet embraced IRVM. Additionally, some SHAs are still planting invasive plants like Oxeye daisy, dame's rocket, queen anne's lace, smooth brome, sweet clover, and crownvetch. All of these are known to be invasive by land managers. All appear on one or more state's noxious weed lists and, therefore, should be suspect in adjacent states. To further complicate invasive species control, funding for this roadside activity has not been historically significant. As state agencies "do more with less," invasive species control or integrated roadside vegetation management will have less resources. These are the obstacles that roadside vegetation mangers are up against. They need public support and influence to obtain the resources they need to learn more and do better!

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SELECTIVE HERBICIDE APPLICATIONS FOR LOW IMPACT VEGETATION MANAGEMENT OF EXOTIC SPECIES AND ENHANCEMENT OF NATIVE PLANT COMMUNITIES

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Selective and specific management for the control of exotic (non-native) plants is necessary for preservation of native plant communities. Managers of federal, state, or county land holdings and parks, wildlife areas, recreation areas, and historic sites are frequently charged with selectively managing the enhancement of desirable or native plant communities. In addition to exotic plant control programs, selective management may include vegetation control on fence rows, road rights-of-way, boundary line corridors, trails, and understory brush control for aesthetics.

Most invasive exotic plants are opportunistic and tend to establish more frequently on sites that have had some form of soil disturbance. They are typically very fast growing, and therefore, are able to outcompete the native, slower growing vegetation. Mechanical removal of exotics causes soil disturbance, which creates a favorable environment for re-invasion (usually seed germination) of the same exotic weeds and/or additional exotic plant problems.

Selective removal of the undesirable exotics usually acts as a "release treatment" for native desirable plants by allowing sufficient light, moisture, and nutrients for survival and maximum growth. Response by native plants is very rapid, and in many situations, eliminates the need for planting or moving native species onto a site. Leaving native plants, sedges, and grasses undisturbed reduces soil erosion and provides unfavorable conditions for reinvasion of exotics.

Herbicide treatments applied properly cause minimal soil disturbance, thus creating a favorable environment for expansion and development of native plants, as well as an unfavorable environment for re-invasion of exotics. Also, leaving the native plants, sedges, and grasses undisturbed, increases their ability to compete, and the potential for rapid expansion and occupation of the area.

The knowledgeable manager chooses methods and herbicide treatments that are environmentally compatible, effective, and economical. A proper understanding of herbicide labeling, uses, and precautions, is of utmost importance for a successful program. Potential for damage to untreated, desirable plants must be understood, particularly where soil active herbicides are used. Improper use of soil active herbicides near or within the root zone of sensitive plants can cause injury or death to desirable plants.

HERBICIDES, APPLICATION METHODS AND RECOMMENDED PROCEDURES

Directed Basal Bark Treatments

Basal bark applications are effective for selective control of saplings less than two inches basal diameter and other sensitive species. Basal applications offer the advantage of a low profile application, selective control of target plants only, and can be applied with hand backpack equipment. Selected stems are removed while desirable plants are left to naturally and rapidly occupy sites. When properly applied, complete control of foliage, stems, and roots is possible.

Applications can be made year-round, but are most efficient when easy access to the base of undesirable stems is possible. During hot weather (above 90 degrees), some volatilization is possible, especially with diesel mixtures and may cause injury to non-target sensitive species that are in close proximity to target plants.

Basal treatments can be used in combination with cut surface treatments when large undesirable trees are mixed with smaller stems. Freshly cut stumps should be treated with water soluble amine herbicide formulations labeled for this use; previously cut stumps (up to several months old) may be treated with low volume basal herbicide mixtures.

An effective basal mixture contains Garlon 4 (an oil soluble formulation) in an oil diluent. Oil carriers such as JLB Oil Plus, JLB Oil Plus Improved, Arborchem Basal Oil, CWC Basal Diluent, Hygrade oil, Penevator or generic mineral or vegetable oil, have been found to be very effective diluents. These products are also generally less offensive to the applicator and environment than diesel or kerosene. Always check the product label for specific rates, uses, directions, precautions, hazards, etc.

Low Volume Basal

Basal treatments can be applied to a range of stem sizes up to very large trees, however, as bark thickness increases, more herbicide is needed and efficacy is sometimes reduced. The lower 12 to 24 inches of target stems should be sprayed wet with the spray mixture, and applications should be made in a manner to completely encircle the stem or trunk but not to the point of run off. In situations where complete control of undesirable woody plants is required, good coverage of the bark is necessary. Low volume basal treatments are generally very effective, with little need for follow-up treatments, however, this method can become costly in stands containing large numbers of undesirable trees. Low volume basal treatments are typically mixed at 15 to 30 percent herbicide concentrate in oil and is applied at relatively low volumes to basal portions of target stems as described above. The higher percentages of Garlon 4 are typically used for larger diameter, thick bark, and difficult to kill species.

Basal applications with Garlon 4 mixtures control a wide range of woody plants and are particularly effective against Brazilian Pepper and Australian Pine. When properly applied, complete control of foliage, stems, and roots is possible. Generally concentrations of 4 – 10% are effective on sensitive species such as small Brazilian peppers and Australian pines less than 8 inches in diamater. Large Brazilian peppers (up to several feet in basal diameter) and Australian pines (up to about 20 inches in basal diameter), can be effectively controlled with basal treatments; however, they require thorough coverage of the lower stem with the recommended mix ratios (15% to 30% Garlon 4 in oil) or retreatment may be required.

In areas of dense infestations, retreatments may be required due to missed stems, new seedlings, and root suckers. Usually, one or two follow-up spot treatments at nine months to one year intervals will provide complete removal. Large plants that are not completely killed should be retreated. Retreatment should be made to the parts of living stem(s) and resprouted stems.

Melaleuca trees with a diameter less than one inch should be treated with a basal bark application of Garlon 4, as discussed above; malaleuca trees greater than one inch in basal diameter have formed bark that is too thick for penetration with basal mixtures and effectiveness drops off sharply.

Streamline Basal

This is the fastest and most economical basal bark application method for controlling woody plants; sometimes less control can be expected for larger trees when compared to low volume treatments. It is especially appropriate on areas with stump resprouts and multiple stems. Best results are achieved on young, vigorously growing juvenile stems two to three inches or less in basal diameter.

When treating multiple (clump) stems, less than about 1.5 inches in diameter at breast height (DBH), apply the mixture to one side of the stem(s) in a back-and-forth swinging motion about 10 to 24 inches above the base of the plant. For single stems, apply to the bark with an up and down motion, hence, placing more of the herbicide mixture on the stem. For stems 1.5 to 3 inches DBH, the herbicide should be applied completely around the tree in an initial band of two to three inches; within about an hour after application, the herbicide should spread down the stem six inches or more. For stems greater than three inches DBH, the herbicide should be applied completely around the tree in an initial band of six to eight inches; within an hour after application, the herbicide should spread 10 inches or more down the stem.

Melaleuca trees with a diameter less than one inch may be treated with a basal bark application. As discussed above, melaleuca trees greater than one inch in basal diameter have formed bark that is too thick for penetration with basal mixtures and effectiveness drops off sharply. For streamline basal applications, Garlon 4 is usually mixed at rates of 12 to 20% in mineral or vegetable oil. The percentage of Garlon 4 is sometimes increased or more of the mixture is applied for large, difficult-to-kill species.

Recommended Equipment and Configurations

The Solo Model 475 with diaphram pump or Swissmex SPI are examples of effective and commonly used backpack sprayers. For low volume basal applications, the spray tip should be a narrow angle (15–25 degrees) flat fan tip nozzle such as a TP 1502 or TP 1503 or TP 2502/TP2503; a solid cone nozzle; or an adjustable conejet such as a Tee-Jet 5500-X8 or equivalent. Any of these tips may be installed in the spray wand that comes with the spray unit. A better alternative is a brass tip shut off wand such as the Model 31 with tip shut off or a Spraying Systems Model 30 Gunjet, available from Chemical Containers, 813/638-1407 or other equipment suppliers.

For Streamline applications the backpack sprayer is usually equipped with a Spraying Systems Model 30 Gunjet and a TP-0001 tip or DE-1 disc. Experienced applicators often use a TP-0002 or DE-2 disc; however, less experienced applicators often waste much of the spray mixture with these tips. The DE discs cost about one-third as much as the TP tips, and they produce a better straight stream spray pattern. The Gunjet may be attached to most backpack spray units that produce pressures between 20 to 50 psi. All backpack sprayers and spray guns should have chemical resistant seals for the herbicides and carriers being used. These are also available from Chemical Containers, 813/638-1407 or other equipment suppliers.

Brewer International, Vero Beach, FL, markets a low volume oil carrier as JLB oil plus containing mineral oil and Limonene, or JLB oil plus improved containing vegetable oil and Limonene. CWC Chemicals, Inc., and others, market a low-volume basal mineral oil for basal applications. For streamline or low volume applications using CWC or other mineral oils that do not contain an adjuvant, an oil soluble adjuvant should be added at about 5%.

Ready-to-Apply Basal Products

Chopper is a ready-to-apply basal product. The application and equipment is as described for streamline basal. With Chopper, the visual effects may not occur until months after application. Provides limited to no control of blackberry, dewberry, locust, redbud, hollies, winged elm, hawthorn, and magnolia. This product is soil active and can cause damage to desirable plants in close proximity to treated stems. This product is used mostly in forestry and to a lesser extent in right-of-way vegetation management.

Directed Foliar Spray Applications

Power driven ground equipment and backpack sprayers can be effectively used for exotic plant treatments to control undesirable woody plants. Power driven ground equipment is commonly used to spray large/tall plants or large areas. Properly adjusted equipment should deliver a uniform spray with nozzle pressures of about 30 to 80 psi and should generate large spray droplets to reduce potential for spray drift. Higher spray pressures produce many small spray particles, which may drift onto sensitive desirable plants adjacent to the treated area.

Application is made by directing the spray on the target foliage, being sure to spray the growing tips and terminal leader. Techniques must be employed to prevent the spray from contacting foliage of desirable plants—DO NOT spray the desirables, it may kill or injure them.

Commonly used power equipment consists of portable power driven spray units mounted on a truck or all terrain vehicle. A wide variety of pumps, tanks, and accessories are used. The most common and maintenance-free pump is a diaphragm pump driven by a gasoline engine, or a self-contained 12 volt pump unit. Routinely used spray guns are Spraying Systems Model 2 and 2A Gunjets. These are adjustable spray guns which produce patterns ranging from a solid stream to a wide cone spray. These spray guns may produce small spray particles at the cone spray setting, resulting in spray drift. Chemical Containers, Inc. (813/638-1407) assembles a dual spray Gunjet that accommodates two flat spray tips with different volumes and patterns. The spray gun can immediately be switched from one spray tip to the other by rotating the spray head. The two most commonly used spray tips for the spray gun are TP 0512, TP 4010, or TP 4020. These tips produce few fine spray particles so spray drift potential is reduced.

Backpack spray applications are used primarily for selective applications to control widely spaced plants less than six feet tall. Target plants are usually sprayed until the crown is wet, but not to the point of run-off. Application is made by directing the spray on the target foliage, being sure to spray the growing tips and terminal leader. Techniques must be employed to prevent the spray from contacting foliage of desirable plants—DO NOT spray the desirables, it may kill or injure them.

The Solo Model 475 backpack with diaphragm pump or Swissmex SPI are examples of effective and commonly used backpack sprayers. A spray tip such as a TP 2503 or TP 2504 that produces large spray droplets very effectively reduces spray drift and potential for damage to the desirable species. The 2503 spray tips may be installed in the spray wand that comes with the spray unit, or a Model 30 Gunjet with the 2503 or 2504 spray tip may be attached to either of the backpack spray units. If an adjustable tip is used, a Tee-Jet 5500-X8 or equivalent is recommended (these produce more fine spray droplets). All backpack sprayers and spray guns should have chemical resistant seals for the herbicides being used.

Commonly used herbicides for foliar applications are Garlon 3A, Garlon 4, Arsenal AC, and Roundup or Accord. Always check the product label for specific rates, uses, directions, precautions, hazards, plant sensitivity, etc.

<u>Cut Surface Treatments</u>

Tree injection, frill or girdle, and cut-stump treatments are the commonly used cut-surface treatments for exotic species. These methods are generally used to eliminate larger undesirable species. One advantage of cut-surface treatments is that very little equipment is required for application and therefore, is very economical. Also, cut-surface treatments in combination with basal or directed foliar applications are very effective management strategies where both large and small undesirable stems are selected for removal. Most cut surface treatments can be applied at any time of the year.

Herbicides commonly used for cut-surface treatment in exotic plant control programs are Garlon 3A, Arsenal, and Velpar L. Garlon 3A undiluted, or diluted in a 1:1 ratio with water for injection (hack 'n' squirt) or cut stump is very effective for controlling Brazilian pepper and Australian pine. Velpar L diluted in a 1:1 ratio with water is effective for controlling Brazilian pepper and Melaleuca trees. Arsenal AC diluted in a 1:1 ratio with water is particularly effective for controlling Melaleuca trees. Arsenal and Velpar L have soil activity, so caution should be exercised when applied near desirable plants or trees. Always check the product label for labeled uses, directions, precautions, certain hazards, etc.

A dye is often added to the herbicide or herbicide mix to aid in treatment monitoring, especially when the applications are done on a contractual basis. When dyes are used, application equipment usually requires more maintenance, especially regular cleaning.

Tree Injection Method (Hack 'n' Squirt)

Tree injection can be made with tools designed specifically for making the cut in the tree and simultaneously applying the herbicide to the opening, such as the Jim-Gem injector. A simpler but equally effective method is to use a hatchet to make the cut and a squirt bottle to apply the herbicide to the opening. In any case, the wounds should angle downward through the bark into the sapwood - waist high for hatchet and injectors at the base of the tree. Space single cuts evenly around the tree trunk with the spacing between the cuts as recommended by the product label. When a hatchet and squirt bottle are used, apply the herbicide to the cut when the hatchet is removed. The squirt bottle should have chemically resistant seals and produce about 1 ml for each pull of the application handle.

Frill or Girdle Method

This method usually involves cutting completely around the tree into the sapwood with an ax or hatchet. Completely wet the cuts with the herbicide using a squirt bottle, or a small pressurized spray unit. When making tree injection or frill applications, additional cuts and/or increased herbicide rates are usually required for trees 10 inches in diameter and larger or damaged trees.

Cut Stump Treatment

Freshly cut stumps should be treated as soon after cutting as possible; within minutes is usually the most effective. A delay of more than two hours between cutting and herbicide treatment can reduce the effectiveness of the herbicide. A pressurized backpack sprayer or spray bottle is very effective for this application. The cambial area and sapwood (about the outer 1-inch of the stump) must be thoroughly sprayed with the herbicide. Smooth, level stumps, free of bark tears, sawdust, or other debris, can be most easily and effectively treated. Stumps that have been cut previously up to about 8 months, may be treated effectively with the previously described basal bark spray mixture. The outer edges of the stump should be sprayed, until the spray runs down the sides of the stump. If the stumps are high above the ground, the application may be made as a basal bark treatment.

Selective Kudzu Control With Herbicide Transline

Kudzu is a most prolific vine frequently growing a foot each day. It climbs to the top of shrubs, trees, buildings, and electric poles, damaging or killing most other plants within its path. It is a difficult plant to control since it spreads by both seeds, root sprouts, and vines. Mechanical trimming and cutting is not effective because the large tuberous root system has a tremendous capacity to resprout after cutting. In the Southeast, managers of recreation areas, parks, campgrounds, historic sites, vistas, fence rows, roadsides, right-of-ways (pole/guy wire treatments), forests, wildlife openings, etc., usually have a need to control kudzu, but would prefer to accomplish this without affecting the desirable vegetation. Transline herbicide is a new product that provides selective kudzu control. Transline has a narrow control spectrum primarily affecting legumes, thistles, and other composite weeds; usually causing little or no permanent damage to other plant species, even when sprayed on their foliage. On some heavily sprayed, non-legume broadleaf tree species, minor leaf curling or other leaf tip damage may occur. If so, recovery is usually within a few weeks. Since Kudzu is a legume—**TRANSLINE KILLS IT.**

Management Options

Kudzu eradication programs require a commitment to annual spraying and usually take a minimum of three growing seasons to accomplish. The age of the Kudzu patch determines the level of difficulty in accomplishing the eradication. Usually, the first spray application is followed with spot spraying on the remaining plants each year for a period of about three years. Older Kudzu patches may require longer follow-up periods. Burning a Kudzu patch during the winter prior to a summer treatment makes it easier to spray a site and usually reduces the amount of vines in trees.

Kudzu spray treatments should be applied beginning in late June and can be applied until late September or October, as long as the plants are actively growing and not under drought stress. Application during active vegetative growth and just prior to or during flowering is the best time to apply. A frequently recommended mix is 32 fluid ounces of Transline in 100 gallons of water, and 1/2 to 3/4 percent of a good non-ionic surfactant should be added to improve wetting and penetration. When spraying, do not exceed the maximum label rate of 21 fuild ounces of Transline per acre. Where some damage to neighboring trees or other woody plants can be tolerated (or is desired), the addition of Garlon 4 Herbicide at 1 to 2 quarts per 100 gallons as a tank mix with Transline can improve the long-term control of kudzu. This is especially desirable in old, established kudzu patches.

Transline spray mixtures should be applied to all or at least the majority of the kudzu foliage - wetting the foliage to the point of run-off. Sometimes Kkdzu may have grown so high in a tree or on a power pole that the spray will not reach the taller leaves. In these situations be sure to completely spray all of the lower leaf surfaces to run-off. Caution should be exercised around high voltage power lines.

Kudzu treatments with Transline can be expected to provide season-long control in almost all cases and some residual control for the first half of the next season following the treatment. Newly established kudzu patches (1-3 yrs) are easier to control, older patches (4–9 yrs) are more difficult, and 10- to 15-yr-old patches are the most difficult to control. Broadcast treatments are usually required for one or sometimes two years with spot mop-up treatments in the third and possibly subsequent treatment seasons. Usually, mop-up treatments on larger patches in the second or third growing seasons after the initial treatment can be treated with a backpack sprayer. Also, small kudzu patches, fence rows, poles and guy-wires, right-of-way encroachments, etc., usually less than one acre, can be treated with a backpack sprayer.

Powered spray equipment should be capable of high volume spray coverage, spraying the foliage to the point of run-off. Generally, the equipment used for high volume foliage treatments consists of a handgun, hose and reel, and a truck or trailer mounted spray tank and powered spray pump. A wide variety of pumps, tanks, and accessories are used. The most common and maintenance-free pump is a diaphragm pump driven by a gasoline engine, or a self-contained 12-volt pump unit. Routinely used spray guns are Spraying Systems Model 2 and 2A Gunjets. These are adjustable spray guns which produce patterns ranging from a solid stream to a wide cone spray. These spray guns may produce small spray particles at the cone spray setting, resulting in a spray drift. Caution should be taken to avoid or minimize fine spray particles by lowering pressure to the optimum setting for the spray tip being used. Chemical Containers and other suppliers market a Spraying

Systems Model 30 Gunjet with a roll-over spray valve. This valve allows two spray tips to be mounted on the spray gun, with immediate switching from one spray tip to the other. Examples of commonly used spray tips in this system are Teejet 0512 and 4020 tips. These are flat spray tips that minimuze fine spray particles. Power driven ground equipment that is properly adjusted should deliver a uniform spray with nozzle pressures of about 45 to 80 psi and should generate large spray droplets to reduce potential for spray drift. Higher spray pressures produce many small spray particles, which may drift onto adjacent property.

The Solo Model 475 with diaphragm pump or Swissmex SPI are examples of effective and commonly used backpack sprayers. A spray tip such as a TP 2503 that produces large spray droplets very effectively reduces spray drift and potential for drift. The spray wand that comes with the spray unit may be used, however, a better alternative is a brass tip shut-off wand such as the Model 31 with tip shut-off (available from Chemical Containers) or a Spraying System Model 30 Gunjet. A narrow angle (15-25 degrees) flat fan tip such as TP 1503 or TP 2503 is often used with these wands and guns. If an adjustable tip is used, a TeeJet 5500-X8 or equivalent is recommended. All backpack sprayers and spray guns should have chemical resistant seals for the herbicides being used.

IPM – HOW IT WORKS IN THE SMOKIES

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Many of the basic components of integrated pest management have been known for centuries. Farmers have burned fields in the early spring to reduce insects and disease organisms in their overwintering state; gardeners have removed weeds mechanically by plow and hoe; timing of planting and harvest can be planned to escape the most damaging life stages of certain pests. IPM is simply the integration of a variety of control techniques with knowledge of both the host and pest ecology, and the importance of monitoring and long-term consequences. The objective is to minimize both pest damage and adverse ecological impact. The National Park Service adopted integrated pest management as an agency policy in 1980, and in the following three years, reduced pesticide use by 70%. At Great Smoky Mountains National Park, IPM strategies are used for control of exotic plants as well as for structures and forest insect and disease problems.

IPM is both a decision-making process and a strategy; a standard definition is "the selection, integration, and implementation of pest control, based on predicted economic, ecological, and sociological consequences." IPM seeks maximum use of naturally occurring pest controls, including weather, disease agents, predators, and parasites. In addition, IPM utilizes various biological, physical, chemical control, and habitat modification techniques. Monitoring is an important aspect of IPM: it determines the need for and timing of treatments, and is a measure of success/failure for a given technique.

Before development of synthetic pesticides, people relied on simpler methods of pest control, such as cultivation, hand- picking, controlled burns, and herbal remedies. In general, there were fewer exotic pests; in the US today, we have over 4,500 species of foreign origin pests that have established free-living populations. Many of these are beneficial, but others have a significant adverse effect on health, agriculture, natural areas, and industry. After World War II, synthetic pesticides such as DDT and 2,4-D became widely available, and were used with little regard for long-term consequences. Typically, these pesticides were broad-spectrum and affected many non-target species, including such beneficial organisms as pollinators and natural predators and parasites. Calendar spraying was standard, particularly in agriculture. Pesticides were applied on a set schedule regardless of observed need. Evaluation was minimal and treatments were applied at the first sign of injury or even as a preventive measure.

As we now know, there were many problems with the post-war enthusiasm for synthetic pesticides. Pests—plant, invertebrate, and microbial—could become resistant within a surprisingly short time. Resurgence of pest populations could occur when natural enemies ("beneficials") were killed, resulting in pest populations even higher than before treatment. Secondary pests could prove worse than the original target, e.g., mites following after loopers were killed. Residual chemical had long lasting effects—DDT is a famous example of increasing effects ascending the food chain and persisting for years. Cancer and hormonal disruption were a common result of many synthetic pesticides, and health hazards to humans are still surfacing. In addition, spiraling costs caused even those unconcerned about environmental effects to have second thoughts. Nature bats last.

IPM has many advantages. With minimal disruption of natural controls, both cost and effort may be reduced. Damage to non-targets is reduced, as well as undesirable environmental effects. IPM is most likely to produce a permanent solution, and is cost-effective in both the long- and short-term.

The National Park Service mandate is to preserve resources unimpaired for future generations; the primary threats to resources in all parks are exotic species and air quality. The National Park Service has had a policy since 1930 of controlling exotic species, including plants, animals such as European wild boar, and some exotic forest pests, such as gypsy moth and Dutch elm disease. Exotic plants are a problem in parks because they:

1. displace native species and alter habitats. An example is Japanese grass, a shade-tolerant exotic that can invade the entire herbaceous layer. This has a particular competitive advantage in areas with high deer populations, since deer dislike it;

2. many exotics are much more labor-intensive to maintain. For example, lespedeza planted along roadsides must be mowed much more often than lower-growing species;

3. some exotics are capable of hybridizing with natives, which alters the genetic resource. Oriental bittersweet is one example;

4. cultural landscapes are important resources in many parks and may be obscured by exotics. Multiflora rose, for example, can spread from one plant to cover an entire homesite in only a few years, as can privet, daylily, and other common ornamentals;

5. disturbed areas, such as forests impacted by fire, gypsy moth, or southern pine beetle, are quickly invaded by such exotic trees as ailanthus or princess tree if a seed source is within 4–5 miles;

6. marginal habitats, such as riparian areas or cliffsides, are often habitat for rare plants that are easily out-competed by exotics like mullein or mimosa.

The National Park Service also manages many structures, developed areas, and historic/cultural resources, as well as natural areas. IPM has many applications throughout the agency. All pesticide use is approved either at the regional or Washington level, and least toxic alternatives are required.

The Great Smoky Mountains National Park is one of the largest areas in the eastern US managed as wilderness—over 800 square miles in size—and also the most heavily visited park in the NPS, with 9 million visitors each year. Over 1,600 species of vascular plants have been recorded for the Park, and of these, about 350 are not native. Only about 35 present a significant problem. The Park has been working to eradicate a few of these—mostly kudzu—since the 1950s, but our current program has been in place since the late 1980s. In 1989, a park-wide survey was conducted, focusing primarily on disturbed areas such as roadsides and old homesites, which provided a good base for future eradication efforts. Information was gathered on each species from literature review, database searches, and exchanges with other land managers. The first principle of IPM is to know the biology of the target species: how does it reproduce and dispurse? What is its typical habitat? Is it evergreen, annual, or biennial? What are its natural ecemies and weakest life stage? What are the most effective, least toxic means of control? The Park, in cooperation with TNEPPC, recently compiled much of the most useful information in a manual for management of exotic plants for Tennessee, which is now available. After information is gathered, a thorough survey and prioritization process follows. Important factors in prioritization include:

1. what is the level of impact and what resources are threatened, e.g., rare plant sites;

2. how invasive is the species, e.g., those spread easily by windborne seeds or carried by birds or water, and shade tolerance;

3. threat to natural processes, and

4. feasibility of control.

Monitoring and accurate record-keeping are crucial. At GRSM, a database (dBASE) program was developed to analyze site and treatment data. The program compiles information into reports which assist with seasonal planning. For example, a priority report identifies the highest priority species for a given season and location. Other reports, such as hours worked, amount of herbicide used, and total treatment areas, are used to compile data for annual summaries.

Treatment methods frequently used include hand-pulling (large volunteer groups are helpful for such species as garlic mustard, mullien, barberry, and mush thistle), selective herbicides, timing of application (evergreen exotics, such as Japanese honeysuckle, English ivy, and privet can be treated during the winter when many non-target natives are dormant, cut/stump treatment, and basal bark herbicide applications. Post-treatment evaluations and experimental trials are incorporated.

Prevention is the first line of defense against exotics. Regular inspections of disturbed areas, particularly on the boundary are conducted, and Park neighbors who share exotic sites have been contacted. Soil brought into the Park for construction projects is inspected for such obvious problems as Johnson grass rhizomes or mush thistle growing in the source area. Education is a large component; the Park works closely with TNEPPC and other agencies to help inform the public of the threats posed by exotics and to encourage native alternatives for landscaping. Use of volunteers, particularly school groups, helps to educate as well as accomplish work.

HANDS ON EXOTICS

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ABSTRACT. To lead, teach, rear, bring up, instruct, train, show, inform, guide, direct, inspire, and foster expansion of knowledge—that is education. Environmental education has been defined (Disinger 1993) as the interdisciplinary process of developing a citizenry that is knowledgeable about the total environment, including both its natural and built aspects, that has the capacity and the commitment to engage in inquiry, problem-solving, decision-making, and action that will assure environmental quality. Goals of environmental education include awareness, knowledge, attitudes, skills, and participation. This background will build a foundation for making decisions—and this can make the difference.

This session will present some history and background on "hands on" exotic environmental education programming and volunteer projects in the urban forest of the Warner Parks. Examples of specific educational programs, projects and strategies—including volunteer projects, brochures, grants, school programs, adopt programs, workshops, an active citizen support group and more—will be highlighted. Learning through participation and direct experience is a focus of these programs. Some future exotic projects (like videos and inner city programming) will be discussed.

Introduction

I am happy to be here today to talk to you about a local approach to hands-on exotics. My presentation will focus on people and environmental education—especially people directly experiencing exotics. One definition of environmental education ((EE) Desinger 1993) is the interdisciplinary process of developing a citizenry that is knowledgeable about the total environment—including both its natural and built aspects—that has the capacity and the commitment to engage in inquiry, problem-solving, decision-making, and action that will assure environmental quality. Goals of EE include awareness, knowledge, attitudes, skills, and participation. I will also discuss the Warner Park Exotic Plant Removal and Restoration Program, including history, strategies, programs, projects, our educational campaign, Friends of Warner Parks, and volunteers, partnerships, and future plans.

The Warner Parks and the Nature Center

The Warner Parks, one of eighty parks owned and operated by the Nashville Metropolitan Board of Parks and Recreation, are located in southwest Davidson County in the Harpeth Hills. Established in 1927, and named after two brothers, Percy and Edwin Warner, who were active Park Board Members, its 2681 acres make it one of the largest city parks in the country. The Warner Parks reside in the outer basin section of the Central Basin of the Interior Low Plateau Physiographic Province. This results in an interfacing of plant communities common to the Basin and plant communities common to the Highland Rim, which surrounds the Basin (many of the park's knobs are outliers of the Rim). The remnant forest ecosystem is a second growth forest that has retained much of its original species composition and some areas of the park are now considered moderate growth with a number of large, old trees. Braun (Braun 1950) describes this area as in the Western Mesophytic Region, which is transitional between the Oak-Hickory and the Mixed-Mesophytic Regions.

In 1980, the Warner Parks received recognition from the Tennessee Department of Environment and Conservation's Division of Natural Heritage, and were listed as a Registered State Natural Area. The park was recognized in part for its excellent representation of Nashville Basin forest community types and outstanding examples of large specimen trees. Today, one of the worst resource management problems in the park is the explosion of exotic pest plants and the loss of biodiversity.

The Warner Park Nature Center was established in 1973, in part with a Youth Conservation Corps Grant administered by the U.S. Forest Service, with a mission to:

- provide quality environmental education and responsible recreation

- help protect, preserve, restore, and manage the park ecosystem and all natural resources

- raise awareness, foster respect, and share enthusiasm for the natural environment

We try to achieve this mission with our programs, facilities, and staff as well as research projects, and park management projects. The nature center also serves as a regional resource center for a wide variety of information.

Program History

The Warner Park staff identified exotic pest plants as a serious problem in the 1980s (thanks in part to Vanderbilt Botanist Dr. Robert Kral, who has regularly brought his students here for years). In 1987, the Warner Park Master Plan was published and was the first written documentation of exotics as a problem. It also listed action recommendations. This plan also called for a Park Superintendent position to be created, which occurred in 1988. In 1989, the superintendent asked the Nature Center to come up with a plan for dealing with exotics. Brian Bowen researched the problem and came up with a plan of attack for Bush Honeysuckle (*Lonicera maacki*, the main pest plant we had decided to focus on). Friends of Warner Parks (FOWP), our 2000-member wonderful citizen support group, supported this project from the beginning. We collected journals, books, and literature, and we built notebooks with articles for the library (with FOWP funds). The staff tried various methods in the park and came up with a plan to "capture a hill" that was in relatively good condition in the park's interior and then work out from there. The pilot project included using volunteers on special "Volunteer Exotic Removal Days" to clear this area. During the first year, 225 volunteers removed 40,000 shrubs. Education was a major part of our program and we tried to get the word out as much as possible. In 1990, we developed a successful exotic partnership with the Tennessee Recreation and Parks Association (TRPA). A responsible landscaping resolution, suggesting landscaping with natives and listing specific invasives not to use, was passed by the TRPA and FOWP boards, and later by 20 other groups (some national). The Resource Management Section of TRPA, with FOWP and the Nature Center, received a grant from the Tennessee Recreation and Parks Education Foundation (matched by FOWP). As a result, we published an educational brochure entitled "Invasive Exotic Plants Threaten Biodiversity," which has been reprinted three times.

Warner Park Exotic Strategies

Management strategies include: creation of a management oversight committee to plan out and review strategies (includes park superintendent, resource management specialist, nature center director, FOWP director and volunteer coordinator, maintenance supervisor, FOWP stewardship chair); removal plan of removing the exotics from the interior and also from a 100-meter buffer zone to separate the most degraded area of the park; training of park staff on identification and removal techniques; mowing schedules (to keep exotics out) and development of a field management notebook; staff removal of plants in sensitive areas; working with neighbors on prevention, and more. A main way we are removing exotics today is through Friends of Warner Parks, paying park maintenance staff to work on weekends to cut and treat.

Education has been our most important and successful strategy for dealing with exotics. Our educational campaign has included: school programs (10,000 students per year), other group programs (Sierra Club, Garden Clubs, over 120 programs per year, etc.), public programs (landscaping with natives, honeysuckle wreath-making, wildflowers, etc.), public volunteer days, special volunteer projects (clubs, alternative spring break, etc.), high school naturalist intern program, summer work-earn-learn programs for teenagers, urban nature programs, nature center native landscaping projects (show and tell, setting an example, trying new plants, etc.), restoration area and removal areas on the nature center grounds for demonstration purposes, and more.

Other methods of "spreading the word" have included: Warner Watch and many other newsletters, newspaper articles, radio, our library, literature, magazine articles, native landscaping brochure and accompanying list of local nurseries that sell natives, Tree Trust, exhibits, conferences, workshops, inservices, and awards.

Friends of Warner Parks and Volunteers

FOWP has played a tremendous part in the success of the Warner Park Program. FOWP is a volunteer organization dedicated to the preservation, protection, and stewardship of the Warner Parks. They advocate:

- protection of the natural integrity of the parks

- a wide range of recreational programs and activities which are consistent with the parks' natural and historical integrity

- maintenance and enhancement of the beauty of the parks and their historical structures

- promotion of educational programs which inspire appreciation and stewardship of this unique resource

FOWP has expanded the volunteer removal days (November–March), developed crewleader training inservices and manuals, recruited and supervised loads of volunteers, created an "Adopt a Part of the Park" program to keep areas clear after they have been cleared initially, established a successful removal partnership with prisoners, and much more.

In 1991, Warner Park was listed as case study #1 in a document prepared by the North American Association for Environmental Education (NAAEE), or the U.S. Office of Technological Assessment, titled Public Education Efforts in the U.S. Regarding Prevention and Management of Non-Indigenous Species. Friends of Warner Parks successes are documented. The NAAEE has a project to encourage a master plan for environmental education and networking for each state. Exotics training and education could be an important part of these plans.

Partnerships

Partnerships have made our program possible. From the very beginning, when we were reaching the problem, we have found enthusiastic partners everywhere. We made many successful contacts with the Landscaping Resolution (TRPA and 20 groups). Some of the many partners include: TNEPPC, Natural Heritage Division of the Tennessee Department of Environment and Conservation, Sierra Club, Tennessee Ornithological Society, Tennessee Wildlife Resources Agency, Tennessee Division of Forestry, USDA Forest Service, Metro Nashville Beautification and Environment Commission, TN Native Plant Society, private landscaping companies, and many, many more. One current partner is our neighbor, Cheekwood Botanic Garden. We are working with them annually on a joint landscaping-with- natives program. They donate leftover wildflowers for our demonstration garden, and this year in an innovative swap, they are paying to remove exotics from the park in exchange for use of some park greenhouses while their greenhouses are being refurbished.

Current and Future Projects

One recent success story involves a new park neighbor—an apartment development called The Grove at Devon Hills. In an effort to prevent more introductions, the park superintendent and the FOWP director met with the owner of this new neighbor and explained the problems with invasive exotics. The owner allowed us to review their landscaping plans and they deleted several species from the plan due to our recommendations. Some new projects we are working on involve expanding our resource management plans to other metro parks, using video to get the word out, continuing to expand our inner city nature program (we have hired a full-time urban naturalist and established a satellite nature program in an inner city park). Two other ways we hope to make a difference are the creation of a new position, resource management specialist (grant-funded), to lead us ahead in our hands on exotic program and to open a field station facility to house our resource management program (underway now).

CONCLUSION

Although the problems with invasive exotics are complex, overwhelming, and often seem impossible, our park motto is tied to the wonderful beech trees found in the Warner Parks—"We are going to 'keep on fighting' for our valuable natural resources." Hands on education and learning directly from nature are the keys to success. Awareness, knowledge, attitudes, skills, and participation, are our goals.

ECOSYSTEM RESTORATION:
A SYSTEMS APPROACH TO EXOTIC PLANT CONTROL

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Ecosystem restoration is a systems approach because it relates to all of the thousands of interrelated and interacting systems within the ecosystem. Ecosystem restoration also changes your role in the forest from observer to participant. Some of the goals of ecosystem restoration are to improve the health, vigor, and diversity of the ecosystem—and these goals can and must be quantitatively measured. The concepts and processes of ecosystem restoration will be illustrated by a specific example with an emphasis on the application and methods of prescribed burn, which can be very useful in the control of exotic pest plants.

INTRODUCTION

Many of you are under a mandate to provide a regular supply of timber products and may be wondering how ecosystem restoration relates to your situation. Some of you may be under a mandate **not** to interfere with the forest except to remove the exotic pest plants and may be wondering how ecosystem restoration relates to your situation. Some of you may be operating under a belief system that says, "If we get rid of all the exotic pest plants in the forest, then the forest will take care of itself and will not need people." I am asking all of you to briefly accept that you are part of nature, and that you are obligated to be a nurturing participant in the forest. You may find some useful ideas in this discussion of ecosystem restoration. Some of what you now know may be challenged by these ideas about ecosystem restoration.

PERCEIVING THE NEED TO RESTORE

Perceiving the need to restore requires a combination of the ability to see the forest clearly, without prior assumptions, and a belief system that will allow you to be a nurturing participant in the forest. For this reason, it is useful to me to think in terms that include people as part of nature. In this paper, I refer to them as two distinct and separate entities. Therefore, I will use the term "the rest of nature" to mean all living and nonliving things in the universe **except** people.

Our culture, and thus, our educational system, teaches that people can only have a negative effect on "the rest of nature." Nearly all ecologists describe the original ecosystems—meaning the ones that the first Europeans found here—in terms of "the rest of nature" and almost always disregard as insignificant the activities of the indigenous people that were present. This viewpoint does not take into account the effect of 20 million or more indigenous people who both occupied and actively cared for the "Garden of Eden" which the settlers first found (Anderson 1997, Martinez 1996, Olson 1996, and Cronon 1983). This belief system does not help us to understand how we can recreate that

"Garden of Eden." Again, please accept, at least for the moment, that people can be nurturing and have a positive influence on "the rest of nature."

With these ideas in mind, I looked at the forests in the Brecksville Reservation of the Cleveland Metroparks, Ohio. I discovered that unhampered by the aforementioned assumptions and enabled by a belief system that allows me to be a nurturing participant in the forest, I could see the need to restore this forest. I could see the decline in vigor of the even age oaks in the canopy, of the understory oak forest components, and even of all members of the herbaceous layer. In addition, the second age class of white oaks did not find space in the canopy and died due to the lack of proper light.

WRITING A QUANTITATIVE BEHAVIORAL STANDARD

Once you have perceived the need to restore, your next step is to write a quantitative behavioral standard (QBS) to guide you in your restoration efforts. Having determined why the forest is unhealthy, you simply write a description of how it will be when it is healthy and this becomes the QBS. QBS is a term which I coined specifically to measure progress in the restoration process. In our example of the Brecksville Reservation, the forest is overstocked (Ginrich 1967). This means that there are too many trees and too many square feet of basal area of trees per acre to have fully healthy oak trees. So, the QBS in this case would be: *At least 75% of the species on the list of oak-hickory forest ecosystem indicator species will set seed at least once in every five years*. The restorative effort will be to reduce the stocking percentage from the current 120% down to 70% and monitor the changes in the ecosystem. The reduction of stocking percentage will also make space in the canopy for a second age class of white oak.

Note that the QBS is quantitative. It contains measurable numbers. It is behavioral because you are measuring changes in the behavior of plants. It is also a standard—which means that it can be "held up" to the existing forest to see if you are moving toward or have reached the stated goals. Another characteristic of a QBS is that a knowledgeable person with a day or less of training can perform measurements to determine the forest's progress toward the specified standard. The QBS is not limited in its quantitative standards—it can relate to percentage of flowering, seed setting, and production of offspring; number of nesting birds; breeding salamanders; etc. But, it must define measurable quantities—to say "the forest is doing better" means nothing. You can and must quantitatively define what "better" means, by translating it into a QBS.

It is often helpful to have a reference ecosystem on which to model your QBS. In the example of the Cleveland Metroparks forest, I used the original land survey which was conducted in 1811 for the Brecksville township. Sometimes a nearby forest may be a useful model. A careful study of the types and quality of ecosystems in the area in which you are working is most useful. A recognized reference, such as *The Vegetation of Wisconsin* (Curtis 1959), is useful well beyond the state of Wisconsin because it examines regional forest types, fully characterizing their plant associations.

PLANNING THE RESTORATIVE EFFORTS

Because this forest had very low vigor in all layers, (i.e., the canopy and oak forest components of the understory and herbaceous layer), the restorative efforts were aimed at increasing vigor of all layers. Therefore, one part of the QBS stated: *White oak and shagbark hickory will produce seedlings more than once every 15 years.* In order to achieve this, restorative efforts were targeted at reducing the stocking percentage of the oak. The intent was to improve the health of the individual trees, thereby increasing their ability to produce viable acorns. Enough acorns need to be produced so that some would remain after predation to produce seedlings. The restorative efforts were designed to reduce the stocking level from the current 120% down to 70%—with the target number based on Gingrich's study of oak tree health (Gingrich 1967). In practical terms, this means that 103 trees, averaging 13 inches in diameter, were cut on 2.5 acres. This opened up space in the canopy for the second generation of oak trees. This reduced the percentage of canopy to well less than the 85% needed for white oak regeneration (Curtis 1959).

Another part of the restorative effort focused on the understory of this oak-hickory forest. Sugar maple had become pervasive in the understory, supressing the growth of other woody and herbaceous species present. This great increase in sugar maple, as compared to its frequency at the time of the original land survey, has been well documented (Ebinger 1986). This pervasive sugar maple growth was limiting the amount of Photosynthetic Active Radiation (PAR) reaching the forest floor. PAR is defined specifically as wavelengths between 400 to 700 nanometers, and is the critical segment of the sun's light spectrum which plants require to be able to conduct photosynthesis (Attridge 1990). It is possible to have light reaching the forest floor, but if it does not include the PAR segment in the proper amounts, then the plants are essentially in the "dark." Herbaceous plants or seedlings of the forest floor must likewise receive adequate PAR in order to flower and seed. Therefore, another part of the restorative effort was to remove the sugar maple understory, using prescribed burning and cutting. Together, these actions were intended to meet the specified QBS of 75% flowering of the oak-hickory forest species, as stated above.

The declining condition of the forest, the QBS, and the restorative efforts are interrelated as follows: Inverting the conditions which you want to change in the forest defines the QBS and the restorative efforts are the means by which you bring about the desired changes and achieve the QBS. The end result of using the QBS method is that you are assured that you have measurably succeeded in "curing" what is wrong with the forest.

DESIGNING A MONITORING SYSTEM

In monitoring progress of the Brecksville restoration, we used 91 sets of stratified random quadrats, with three quadrats per set. In a 0.01 hectare circle, trees are measured and identified every three years. In a 4 x 4 meter quadrat, all woody stems under 6 inches are measured and identified and mayapple are monitored. In a 1 x 1 meter quadrat all herbaceous plants are monitored and acorn counts are made. The 4 x 4 and 1 x 1 quadrats are monitored often during each growing season. Other data are also collected on these quadrats. Forms were developed so that all data were properly collected and all data are entered into a Paradox-based database.

DATA COLLECTION

Volunteer Earth Restorers established most of the quadrats and have done over 90% of the data collection in the Brecksville Reservation. These volunteers have done an excellent job. Please do not think of volunteers as "children of a lesser god." The fact that they are not paid for what they do does not mean that it must be of lesser quality (Smith 1991 and 1995).

IMPLEMENTING THE RESTORATIVE EFFORTS

As a practitioner, the implementation is the exciting part. However, without first developing the QBS and a monitoring progam, you will never know where you are going in the restoration process. Or, as it says in Alice in Wonderland, **"If you do not know where you are going, any road will get you there."** The order in which we implemented the restorative efforts in Brecksville were: (1) prescribed burn, (2) understory removal of the sugar maple and beech, and (3) canopy opening, i.e., describing the stocking rate. Separate areas were treated with different restorative programs as follows: (1) burn only, (2) burn and cutting of the understory only; or (3) burn, understory cutting, and canopy opening. The monitoring of these differing treatments enabled the evaluation of each restorative effort. Since cutting of trees and saplings is easy to understand, I will not cover it in this paper, and will instead go into prescribed burning in some detail.

Another part of the QBS stated that: *Non-native, exotic species will constitute less than 10 percent of the total above-ground stems.* The main restorative effort that we used to meet the exotic pest plants elimination goal of the QBS and to begin understory removal was prescribed burning. Prescribed burning is defined as fire (1) applied in a skillful manner, (2) under exacting weather conditions, (3) in a definite location, (4) for a specific purpose, and (5) to achieve certain results. By monitoring after a small prescribed burn, we determined that the certain results that we could obtain were to kill about 90% of all the above-ground stems of 2 inches or less in diameter of all species without damage to trees or herbaceous plants. We burned when all species were dormant.

The burn window that we always used was:

wind direction	any
wind velocity	less than 3 miles per hour in the forest at eye level (which means that no leaves are changing location)
relative humidity	30-55% (35-45% preferred)
temperature	32-65 F (Dixon et al 1989)
fuel moisture	Pass the "bucket test" – see below (Moore 1991)

The bucket test consists of simply picking up a small portion of all the leaf layers intact, placing them in a metal bucket, taking a leaf from the top layer, lighting it, and dropping it into the bucket. What is left in the bucket after the fire is similar to what will be left in the forest after the fire. If there are two layers of leaves left in the bucket, then there will be two layers of leaves left in the forest. Often it is necessary to do the bucket test in different moisture situations in different parts of the forest to get an accurate picture of what will happen. The "bucket test" allows you plan burns that leave leaf litter or remove it all, depending on the prescription and reason for burning.

A few points need to be kept in mind when planning a prescribed burn. First, a prescribed burn will top kill ALL above-ground stems that are 2 inches or smaller in diameter. Yes, that includes honeysuckles, buckthorn, and so on. Second, always remember that weather controls a fire, NOT people. All people can do is plan and ignite a fire so that weather will control it. In almost twenty years as fire boss, burning forests and tallgrass prairies, we have never had any injuries. We burned only what we planned to burn and achieved the results that we expected. Finally, please be aware that many states and agencies have a certification or licensing requirement before you are allowed to conduct a prescribed burn.

HERBACEOUS LAYER ENHANCEMENT

In a study that was done in England, it was clear that adding herbaccous species as plants maximized survival rate, but it is costly and very labor-intensive. Use of seed came in a close second and has the important advantage of lower cost and less labor (Francis 1995). In this study, the important factor was seeding or planting in bare soil. My own studies have indicated the same. When you think about putting small seed on leaf litter or under leaf litter, you know that the seed does not have enough stored food to either get a radicle down to soil or shoot up through the leaf litter. Prescribed burning was used to remove the leaf litter in our study.

THE STRUCTURAL HEALTH OF THE SOIL

Just as a reminder, you need to pay very careful attention to avoid compacting the soil or interfering in any way with the functioning of the soil microbes or mycorrhizal fungi. Without passages in the soil for air and water to go into the soil and carbon dioxide to come out, the plants will not be healthy (Harris 1996).

EVALUATING RESTORATIVE EFFORTS

This is the simplest part. You can compare the first year of data with the second and successive years' data and see if you are moving in a direction that will enable you to meet the goals outlined in your QBS. Be aware that there may be some ups and downs in the progress of the restoration. If you find that you are not accomplishing the QBS, you may need to reevaluate your restorative efforts. Remember though, change is not sudden in a forest.

CONCLUSIONS

I hope each of you has found something useful in this brief discussion of forest ecosystem restoration. For those of you that are mandated to provide a regular supply of timber products, you may find it interesting that this mandate can fit in with ecological restoration. The Chief Forester of the Ohio Department of Natural Resources has outlined this idea as follows: If we can thin the stand (which is also called reducing the stocking percentage) of an oak forest and reliably get a second age class of oak, we can revolutionize the gathering of timber products because we can harvest trees and not the forest. For those of you that are mandated not to interfere with the forest, except to remove exotic pest plants, you may have found useful ideas that can help you modify that mandate. For those of you that operate under the belief system that says the forest does not need nurturing people, perhaps this discussion has challenged that belief system enough that you are now a little uncomfortable with it. Perhaps you will try being nurturing to the forest and see how it goes for you and the forest. I feel better about me when I am being nurturing to both forests and people.

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MILE-A-MINUTE WEED IN THE NORTHEAST

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Mile-a-minute, *Polygonum perfoliatum* L., is an introduced weed from eastern Asia that is rapidly colonizing non-crop areas in Pennsylvania and surrounding states. Since its introduction into the United States, in south-central Pennsylvania, in the 1930s (Moul 1948), the mile-a-minute weed has spread to other regions of Pennsylvania, Delaware, Maryland, New Jersey, New York, Ohio, Virginia, and West Virginia (Mountain 1977).

Identification and Life History

Mile-a-minute is an annual plant easily recognized by its viney stems and light green-blue, triangular leaves (1-2.5 inches across). Other identifying features include numerous sharp, downward curving spines on the stem, petiole, and main leaf veins, a saucer-shaped sheath, which encircles the stem at the nodes, and spherical iridescent blue fruit about 0.25 inches in diameter, borne in terminal clusters from mid-July until frost. Each fruit contains a single spherical, shiny, black achene or seed (0.1-0.15 inches in diameter).

In southern Pennsylvania, seed germination begins in early to mid-March and continues through April. By the middle of June, the stems (often two or three main stems per plant) average six feet or more in length. The stems continue to elongate throughout the growing season, and under favorable growing conditions reach 20 feet or more in length before eventually being killed by fall frost. Flowering begins in early July and continues throughout the remainder of the growing season. Each plant is capable of producing numerous seed (at least 50 to 100 seeds per plant) which are deposited on site or are spread to other sites by possibly water, birds, rodents, or man (Mountain 1989).

Typical habitats for mile-a-minute weed are roadsides, edges of woods and thickets, nurseries, forest clearcuts, utility right-of-ways, and damp areas, such as low meadows and stream banks (Mountain 1989). Mile-a-minute weed establish and grow best in sunny locations with an abundance of plant litter such as leaves, duff, or brush on the soil surface. On recently harvested forest sites, mile-a-minute weed frequently grows on woody debris piles at log landings and on debris windows formed during site preparation. Mile-a-minute weed seems to prefer and grow best on moist sites containing abundant organic matter. While the plant will tolerate light shade, it rarely grows in closed canopy forests. When it does occur within a forest stand, it is usually in areas beneath openings in the canopy.

In south-central Pennsylvania, where many forest sites are heavily infested with mile-a-minute weed, it commonly interferes with forest regeneration. Following overstory removal and site preparation, dense, almost pure communities of mile-a-minute weed become established and dominate the site by forming a dense canopy covering anything less than 10 feet in height. It has been observed to smother out Japanese honeysuckle (*Lonicera japonica* Thunb.), elderberry (*Sambucus canadensis* L.), and species of Rubus (Moul 1948). In Pennsylvania, mile-a-minute weed is believed to contribute to the mortality of planted loblolly pine (*Pinus taeda* L.) seedlings (Charles Brown, personal communication).

Control of Mile-A-Minute Weed

While it is unlikely mile-a-minute weed can ever be eradicated, control measures are needed to limit its further spread and interference with desired plants. Until recently, little information existed on the control of mile-a-minute weed. Mechanical control, i.e., mowing, hand-pulling, and cultivating, appears feasible for small infestations; however, chemical control is generally needed for large scale control. Preliminary studies by Mountain (1989) indicated that several herbicides were effective in controlling mile-a-minute weed. These herbicides included Attrex 4L (atrazine), Velar L (hexazinone), Roundup (glyphosate), Oust 75W (sulfometuron methyl), and Pursuit (imazethapyr). Similarly, McCormick and Hartwig (1995) showed that a number of herbicides commonly used in forestry were effective in controlling mile-a-minute weed. Pre-emergency treatments of Arsenal (imazapyr), AAtrex Nine-O, Velpar L., and Oust 75W, were very effective in controlling mile-a-minute weed as were post-emergence treatments of Roundup and Arsenal. Studies conducted by Hartwig (1997) and Kuhns and Harpster (1997) found that AAtrex 4L, Goal 1.6E (oxyfluorfen), Oust 75W, Princep 4L (simazine), and Ronstar 50W (oxadiazon), applied as a pre-emergence treatment, provided effective control of mile-a-minute weed, and that post-emergence applications of AATrex 4L, Finale 1S (glufosinate), Garlon 3A (triclopyr), Goal 1.6E, Oust 75W, Ronstar 50W, and Roundup, were effective. Of the herbicides found to be effective in controlling mile-a-minute, only 1.6E has been specifically labeled for mile-a-minute weed control in Pennsylvania. Currently, there are no known effective biological controls for mile-a-minute weed.

Seed Dormancy and Germination

Unlike other weedy species of *Polygonum*, little work has been done on the reproductive biology of mile-a-minute weed. In particular, information on seed dormancy and germination requirements of mile-a-minute weed is needed to predict the likelihood of this weed to spread to other climatic regions of the United States.

Some of the earliest research conducted on seed dormancy and germination requirements was conducted by Wilbur Mountain (Pennsylvania State botanist). Results of his unpublished study showed that mile-a-minute seeds required a period of cold wet stratification to germinate (at least 6 wks), and that maximum germination occurred sooner for scarified seeds (rubbed with sand paper) than for non-scarified seeds.

Johnson (1996) also studied the dormancy and germination requirements of mile-a-minute seed. His study tested seed germination response to scarification, cold-wet and warm-wet stratification treatments over time, and differing germination temperatures. Results of this study showed that mile-a-minute seeds were capable of germinating over a wide range of temperatures from 40-68 F, and that at least nine weeks of cold-wet stratification (2 C) were needed for the germination of unscarified seeds. Seeds subjected to warm-wet stratification did not germinate. Gerlach Okay (1997) also demonstrated the need for cold stratification for the germination of mile-a-minute seed. These findings have two important implications. First, the ability of seed to germinate under cool temperatures in early spring gives this weed a competitive edge over other annual and perennial plants which do not germinate or initiate growth until later in the growing season. Secondly, the need for an extended period of cold stratification suggests that it is unlikely mile-a-minute weed will become a problem in the warmer regions of the Southeast.

Johnson (1996) also conducted a study on the retained viability of mile-a-minute seed stored under natural conditions. Mile-a-minute seeds were buried at different depths (0-4 inches) in a forest and a field soil followed by retrieval and germination at regular intervals over a period of two years. The results of the study showed that mile-a-minute seeds can remain viable in the soil for at least two years. Seeds removed after 24 months of burial in the forest soil had viabilities of over 95% at all depths. The study also found that only seeds retrieved in the spring germinated. None of the seeds retrieved in the fall following one and two years of burial germinated, yet they remained viable. These findings explain why the removal of mile-a-minute plants from a site before fruiting production occurs, and, assuming no seed migration into the site, often does not prevent the occurrence of new seedlings the following year. These findings also suggest that pre-emergence herbicides are likely to be most effective when applied in early spring.

SUMMARY

Mile-a-minute is a fast-growing annual weed which often invades and dominates plant communities growing in open areas. In Pennsylvania, mile-a-minute weed has hindered the establishment of woody seedlings in recently harvested forest areas. Control of mile-a-minute weed is possible using either mechanical or chemical methods. Mile-a-minute weed continue to spread to new areas in the Northeast and mid-Atlantic regions. Natural resource managers should be on the lookout for this weed in their areas and try to control it to limit its spread.

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IMPORTED ANTS IN THE SOUTHEAST

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ABSTRACT. Two species of imported fire ants were introduced into the U.S. at Mobile, Alabama. The black imported fire ant, *Solenopsis richteri* Forel, was introduced around the early 1900's while the red imported fire ant, *Solenopsis invicta* Buren entered in the late 1930' or early 1940's. The red imported fire ant is the most widespread of the two and presents the greatest problem. From Mobile, these fire ants have spread naturally by such means as mating flights, and floating of colonies on rivers and streams after floods. Most importantly, the ant has spread artificially by the aid of man during shipments of nursery stock containing queens and small colonies. Currently, it infests more than 275 million acres (111 million hectares) in 11 southern states and Puerto Rico.

This ant has had a substantial impact in the U.S. on humans, agriculture, wildlife and other organisms in the environment. The most serious problem caused by this ant is its stinging of humans which in some cases, has caused serious injuries and even death of hypersensitive individuals. They continue to spread and the increasing incidence of the polygyne (multiple queen) form poses additional problems not only to humans and agricultural crops, but also to wildlife, and the biodiversity of habitats.

Chemicals are the most widely used and, for the present time, most effective control method available against fire ants. They can be applied in several ways but generally 2 approaches are used: (1) contact insecticide treatments with drenches, sprays, dusts, granules, aerosols, and fumigants, and (2) toxic baits. Both contact insecticide treatments and baits have advantages and disadvantages with the specific situation determining which to use. Contact insecticide treatments are advantageous in that they act quickly (a few hours or days), the chemical is applied directly on the mound, and they only affect the fire ant. The disadvantages are that the queens often escape treatment so complete elimination of the colony does not occur and they are more labor intensive. The advantages of broadcast bait treatments are that they are more economical because they are less labor intensive, larger areas can be treated quickly, and small unseen colonies are also eliminated. The disadvantages are that the baits are relatively slow-acting (requiring several weeks), treatments can be greatly effected by weather conditions, and baits can harm nontarget ant species.

The development of newer, safer and more environmentally compatible methods of control, such as biological control, is a high priority in fire ant research. Research in basic biology, ecology, and population dynamics of this exotic pest is mandatory if we hope to be able to implement a holistic approach for control.

NATIVES: *NEW! BETTER! IMPROVED!*

Meredith Clebsch
Nursery Propagated Native Plants
5737 Fisher Lane
Greenback, TN 37742

Stumbling Blocks:

Lack of knowledge—it's a whole new idea for many.
- rarely taught in school.
- landscapers interested but ignorant.
- landscape managers interested but ignorant.
- homeowners interested but ignorant.

Image of natives replacing exotics creates nursery industry paranoia.
Availability—a major frustration as demand rapidly increases.
Government regulation—'forced' to use natives with little help=bad vibes.
Natives may not be the answer in every situation.
Horticulture=new plants. Must work with the industry.
Nursery industry—generally conservative. Natives are 'progressive.'
Will take time.
Local ordinances—defining "weeds."
Water use issues less pronounced than in the west.

Building Support

Education—involve schools, scouts, garden clubs, prisons... in management.
(Issue a *Sand County Almanac* to every child and to new homeowners?)
Public demand (i.e., $$$) will sway the market. It already has.
Understanding the big picture should be stressed.
Long term as apposed to short term thinking must be learned.
Notion of 'stewardship' should be instilled.
Provide demonstration sites. Visual. Interactive.
Provide specific instructions for work crews.
Government agencies need a "Regional Plant Communities Coordinator" to communicate ideas.
Focus on groups that benefit from use of native plants:
- hunters
- birders
- most outdoor recreationists
- maintenance departments
- tax payers
- corporate image

gardeners—better balance of pests/beneficials
children
homeowners

Ordinances for building and construction: leave the natives, have an education package for new homeowners. Get them involved in the beginning.

"Sell the sizzle!"

Sell them benefits, not plants.
Don't have to always emphasize just "native."
What are the tangible benefits?
- Functional natural beauty
- >biodiversity
- healthy
- *Fun! Relaxing!* —a feel good landscape
- educational

Treat them as mainstream.
Intelligent landscaping—"You've made a smart choice"
Creation—not destruction of habitats
Good for the planet
<u>Short-term vs. long-term benefits</u>
Sustainable non-consumptive

Don't just sell to them, *Teach them*

Give people the real facts, the BIG picture, and let them decide
Stress *fewer* exotics, not *none*.
Choose plants carefully so buyers succeed.
Local and regional 'plant' organizations should provide lists and current info to guide nurseries, landscapers and homeowners.
Help them identify problem plants.
Be patient.

THE MINNESOTA PROGRAM: COMMUNITY PARTNERSHIPS FOR EFFECTIVE PEST CONTROL

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Introduction

Oak wilt, a fungal disease of all oak species, continues to be the primary cause of oak mortality in Minnesota. The oak type covers over 650,000 acres in Minnesota and is made up of six species. Forest industry adds $1 billion to the state's economy by harvesting and utilizing oak. In our communities, oak is our most valuable shade tree providing energy conservation, beauty, sound and visual protection, and wildlife habitat.

Since 1987, surveys have identified just over 6,000 infection centers in 19 southeastern counties. Most of the disease is concentrated in the urban areas of the Twin Cities and Rochester, but most rural counties also have notable numbers of infection centers as well. While the question of whether or not oak wilt is native or exotic to Minnesota can be legitimately debated, there is little question that it poses a far greater risk to urban forest ecosystems than it does to rural systems. In urban areas, where trees are frequently wounded during the spring by activities ranging from home construction to tree pruning, the disease spreads much like an exotic, by leapfrogging and moving with little natural control.

Even though the fungus is closely related to the Dutch elm disease fungus taxonomically, it is not another Dutch elm disease in its spread. It is not as easily spread by insects and existing centers can be effectively controlled by severing the root systems between infected and healthy trees.

A federally-assisted program began in 1991 and will draw to an end this December (1997). During this period time, over 4,500 infection centers will have been treated in the seven county project area (Anoka, Chisago, Dakota, Isanti, Ramsey, Sherburne, and Washington). As of August, 1996, over 1,000,000 feet of control line had been established. During this time, prevention programs have been developed by communities that have lowered the incidence of new disease dramatically.

The Oak Wilt Suppression Program

It has been known for many years now that oak wilt can be controlled through the development of an integrated program of prevention and suppression. Until recently, organized efforts focused only on prevention action based on education. Active suppression efforts were largely left to individual communities and homeowners on a pay-as-you-work basis.

Active oak wilt suppression revolves around two activities: (1) suppression of the disease at active infection centers and (2) elimination of spores likely to generate new infection centers away from existing infection centers. Three practices, intended to deal with oak wilt, are approved for cost share assistance. These are (1) mechanically severing root grafts by vibratory plowing to a depth of 54" (60" plow blade), (2) trenching to a depth of 48" where the vibratory plowing is not possible, and (3) to eliminate the ability of the disease to form new infection centers by eliminating spore producing trees (SPT) through removal and treatment of freshly killed trees.

The first shot in Minnesota's War with Oak Wilt was heard in 1991 when the Minnesota DNR and the US Forest Service cooperatively purchased a vibratory plow for oak wilt work in the heart of the Oak Wilt epidemic, Anoka County. The plow was titled to Anoka County under a five year contract that required the maintenance and availability of the plow for 5 years. In order to encourage plow use by communities in an organized fashion, the plow was made available to work on public and private lands in communities that had an oak wilt action plan. This was step one in community involvement. The plow has been quite busy since 1992.

Beginning in July of 1992, the DNR began to distribute federal cooperative suppression funds to communities that (1) have an action plan, (2) that lie on the Anoka Sand Plain, and (3) have completed an oak wilt inventory. These funds, approximately $1.6 million have been distributed since 1991, were provided to communities as a block grant from which they could draw to fund their program on an as need basis. The use of these funds requires a 50:50 match by the local community. The match can include any combination of community dollars, private homeowner dollars, and "in-kind" time by community employees and citizen volunteers.

We choose to "grant" monies to communities as a block at the beginning of the program rather than the traditional "contract program" in which a community would undertake the work, pay the bills, and then bill the state for the cost share. Given the budgetary limitations extant in many communities, this approach would effectively eliminate local community participation by creating a cash flow problem. Even though communities would be assured that expended funds would be replaced, many communities, particularly smaller ones, do not hold sufficient cash reserves to fund a reimbursement program. By granting a block of funds and requiring that communities set them aside in a special, dedicated account for oak wilt, we were able to avoid creating a cash flow problem for local units.

Criteria For Participation

The Forest Health Committee, an arm of the state's Shade Tree Advisory Committee ***(STAC)***, developed a series of criteria for community participation in the Oak Wilt Suppression Cost Share Program (CSP). The administering agency, DNR-Forestry, adopted these guidelines and provided program assistance, both technical and fiscal, to communities operating within the guidelines. The basic guidelines are:

1) Participating communities must develop a control plan that addresses the entire community. This plan must cover the entire community within three years. This does not mean "treatment" within three years, but implementation of an over all plan for the entire community within three years. This plan must include details of a budget, an estimate of expenditures, an implementation strategy, an education program to educate builders and developers, identify staff including tree

inspectors and professional foresters capable of oak wilt work, requirement for appropriate oak wilt control work on all control sites, and proper accounting and reporting procedures;

2) Participating communities must update their oak wilt inventory on an annual basis. This includes identification of new infection centers and reporting of suppression actions. In addition, communities must evaluate spore production potential for trees in control areas and assure that appropriate treatments are taken to prevent the movement of spores;

3) Participating communities must adopt a tree disease control ordinance in compliance with state statutes (Chapter 18.023); and

4) Participating communities must assure that all control work is done in accordance with current control recommendations as approved by the Forest Health Committee. This includes inspection of treated sites for "escapes" for at least three years after treatment.

Working With Builders and Developers

There is little doubt that home construction causes oak wilt. As sure as April melts the snows of winter, spring brings home construction in Minnesota. Few activities seem to create more new oak wilt infection centers than the concentrated wounding of trees caused by construction. I have some times wondered if oak wilt drops by city hall to get a list of building permits in the spring. How else could it know? Sixty percent of our centers arise from new construction. Many communities have developed effective programs for protecting trees on construction sites. It is clearly to their advantage to do so. Wooded lots bring premium prices, commonly 20 to 40%. In addition, homes with trees usually bring better prices when sold, raising tax revenues by 5-10% in a state with market valuation-based property taxes.

The City of Blaine (Anoka County) requires the preparation of a tree protection plan by a qualified forester for any lot with "significant" trees (usually >6" D.B.H.). In effect, they require the treatment of tree disease before the home can be built, thereby reducing subsequent costs after service lines are in place. Without doubt, the most effective provision is the requirement that protective fencing be erected around significant trees. Done largely to prevent soil compaction, this fence prevents wounding of oaks to a significant degree. Enforcement is simple, building inspectors (electrical, plumbing, etc.) will not inspect a house if the tree preservation fence is not in place. The word does get out. You would be truly amazed how fast the fence gets repaired when the cement truck has to wait, churning its load, waiting for an inspection that is delayed waiting for fencing to be replaced.

Giving The Communities "Ownership"

I encourage communities in the CSP to tell home owners where the cost-share monies come from, but I have yet to slap a hand for a flier that failed to mention the federal or state role. Most homeowners see their local tree inspector on site and get the cost share check from the city clerk. It becomes their program. Years ago, I was on a citizen advisory committee that designed a program to plan trees in a "bad neighborhood" with vandalism problems. We gave the homeowners the trees, they planted them on the boulevard, at least most of them, but the real amazement came the next year when we checked survival. Ninety eight point eight percent. Out of 500 trees, only a scant few had died. Vandalism? Two trees. Homeowners saw these trees as theirs. I heard several stories of a "spirited defense" of a tree by the homeowner. **OWNERSHIP COUNTS!**

In the case of the oak wilt program, the communities and their citizens see these programs as "theirs." Its hard to find a DNR or USFS logo anywhere. The recommendation is obvious. Design your program to give the program a local, home-grown feel. As the administrator of the program, it used to drive me nuts that I was less than all knowing in my project. Someone, a homeowner or my boss, would call with a question about some specific action in community X. I didn't know the answer on many occasions. My answer, to the homeowner, was to call their community program manager.

The bottom line is that the local community programs do not need to be photocopies of each other to be effective. Actually, I suspect, they work better if they aren't. Let the program flow into the way business gets done in the community. Serendipity rules here. One unplanned benefit, is that effectively every participating community has begun to take responsibility for handling requests for information about tree health. We, DNR, have become technical consultants and advisors. One community ultimately made their forester an "environmental protection officer" looking after wetlands and "green" areas. Another community formed a Tree Board to administer the oak wilt program. Ultimately they hired a community forester and tree inspector. They now have spring tree sales. Hallelujah!.

Administrivia: The KISS Principle

Keep the administrative detail simple. Many communities avoid state and federal programs unless they are mandated into them. Why? Simple. Administrivia. We have a contract with each community that sets forth some very simple rules. One, keep the funds in a separate account. Don't get them lost in with park and recreation accounts or even Dutch elm disease funds. Two, assume that communities have legitimate accounting and purchasing systems. Use them. Don't require an entirely new set of rules, procedures, and what have you. Three, keep reporting simple. I'm not a finance officer and don't pretend to be one. Keep your reporting forms to one page and questions to what you really need to generate the reports you need for you fiscal reporting. Let the finance people do their job, both in your organization and in the local community. Follow the KISS Principle, Keep It Simple.

Praise Good Work

My mother left me with much wisdom, although I didn't know it at the time. She used to tell me "If you can't say anything nice, don't say anything at all." The communities will make mistakes. Don't land on them like a ton of bricks, bend over and help fix the problem. You only score points for successes. I work with over 125 communities in 70+ grant programs. Have they made mistakes? You betch'a. Have we fixed them? Uh-huh. I have yet to see any thing that approaches blatant misconduct. Lighten up, this isn't brain surgery.

Moreover, compliment good work. We held a very public award ceremony this past August. Attended by over 150 people, our senior senator gave the keynote, the local congressman drove the plow for the millionth foot, 12 communities were given an oak tree and a plaque for their excellent work. Work that had been evaluated by the state's Forest Health Committee. Twenty communities showed up along with the Boy Scouts and enough media to keep 5 media specialists quite busy. It was quite a day. We, the program administrators and grantors, had the chance to say, "Thank you, Well Done." Many of these "Honor Role" communities went back home and had another ceremony to plant their tree. Really good thunder rolls on and on. So does a good compliment. Don't be afraid to hand a few out.

Summary

Building on the foundations laid by this and other programs, we will continue developing partnerships with local communities by providing cost-share monies and technical assistance. These programs will operate at the local level, blending in with other community services following guidelines commonly established by MSTAC and other advisory groups.

DOGWOOD ANTHRACNOSE:
HOW COLLABORATION WAS USED IN THE SOUTHERN UNITED STATES TO EFFECTIVELY DEAL WITH A NEW TREE DISEASE

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ABSTRACT. Dogwood anthracnose, caused by the fungus *Discula destructiva* was found in the Southern United States in 1987. Since that time millions of flowering dogwoods have been killed and disfigured by this disease. As soon as the disease was discovered a group of state and federal personnel formed a working group to develop an action plan for dealing with the disease. Collaboration was the key word from the beginning of the working group. A key to the success of the working group was a spirit of cooperation with out concern for who was going to get credit. Each time the working group met information was shared and cooperative action plans were developed to address the most pressing questions. The group established a network and mailing list where information was shared back and forth on a daily basis. The formation of a steering committee provided additional direction and organizations such as the Southern Appalachian Man in the Biosphere added additional support. As the issues on impact and rate of spread were addressed the focus of the working group shifted to research. The working group still meets to coordinate activities.

Dogwood anthracnose was first reported as a disease of flowering dogwood *Cornus florida* L. in the United States in 1978. Since that time it has caused serious losses to flowering dogwoods in the forest and in ornamental plantings over large portions of the Eastern and Southern United States. The fungus that causes the disease was fully described and identified as *Discula destructiva* sp. nov. in 1991 (Redlin 1991). This paper briefly describes the symptoms, distribution, impacts, and control procedures. Most of the paper will be devoted to a discussion of how collaboration was used in the Southern United States to effectively deal with this disease.

Dogwood Anthracnose

Symptoms

Initial symptoms of dogwood anthracnose are small tan leaf spots that develop into large tan blotches. Often a purple border occurs between dead and healthy tissues and occasionally the entire leaf is killed. In many cases, infected mature leaves are aborted prematurely; in other cases, infected leaves cling to the stems after normal leaf fall. Infections often expand from leaves into small twigs and symptoms typically start in the lower crown and progress up the tree.

The dieback of twigs and branches in the lower crown led to the original name of "lower-branch dieback" (Pirone 1980). Numerous epicormic shoots form along the entire length of the main stem and on major branches of infected plants. These shoots frequently become infected and die and the fungus proceeds from the shoots into the main stem.

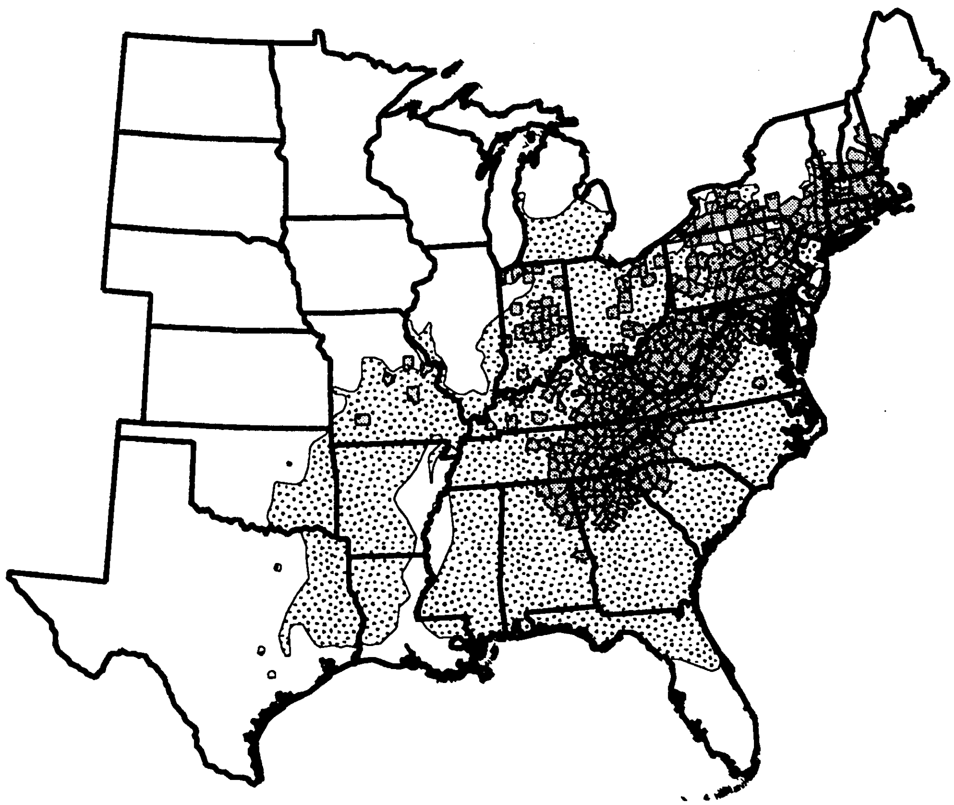
The fungus causes cankers that can kill the tree. Cankers may not be present on all the dead trees. Larger trees often die 3 to 4 years after the first symptoms are found in the leaves while young trees die the same year they are infected.

The disease kills dogwoods of all sizes, but it is most severe on young seedlings and in understory forest dogwoods. Infection of dogwoods is most likely to occur during cool, wet weather in spring and fall, but can occur at any time during the growing season. Ornamentals are often disfigured without being killed, particularly if they are growing in open, sunny sites (Anderson et al. 1994; Mielke and Daughtrey 1989).

Distribution

The following map shows the natural range of flowering dogwood and distribution of dogwood anthracnose in the eastern United States. For a county to be recorded as affected there only has to be one infected tree in a county. Therefore, the counties reported as affected can range from severely affected to a few trees. In general, the disease is more common in cooler wet environments, especially at higher elevations. The map is from the ATLAS forest health protection data base maintained by the USDA Forest Service in Asheville, NC.

Dogwood Anthracnose - 1995



Range of Dogwood

Occurrence by County

USDA –Forest Service
Forest Health Protection
Asheville Field Office

Data from 1995 Conditions Report

January 17, 1997

Impact

Dogwood anthracnose has spread rapidly and covered a significant part of the flowering dogwood range. The impact of dogwood anthracnose has varied from slight to total mortality. In the South, above 3,000 feet in elevation most of the trees have died. Below 3,000 feet elevation the most significant damage has occurred to trees on cool wet areas. Dogwoods on dryer sites, especially in the sun, have sustained less damage. Those in full sun show little damage and are doing well. The reason for this cause/effect relationship is not clear but it may be due to environmental conditions that are condusive for disease development (Windham 1990).

Mortality estimates vary from 79 percent at the Catoctin Mountain National Park in Maryland (Schneeberger and Jackson 1989) to 56 percent at the Great Smoky Mountain National Park to 23 percent in a southwide survey conducted from 1988 to 1993 (Knighten and Anderson 1993).

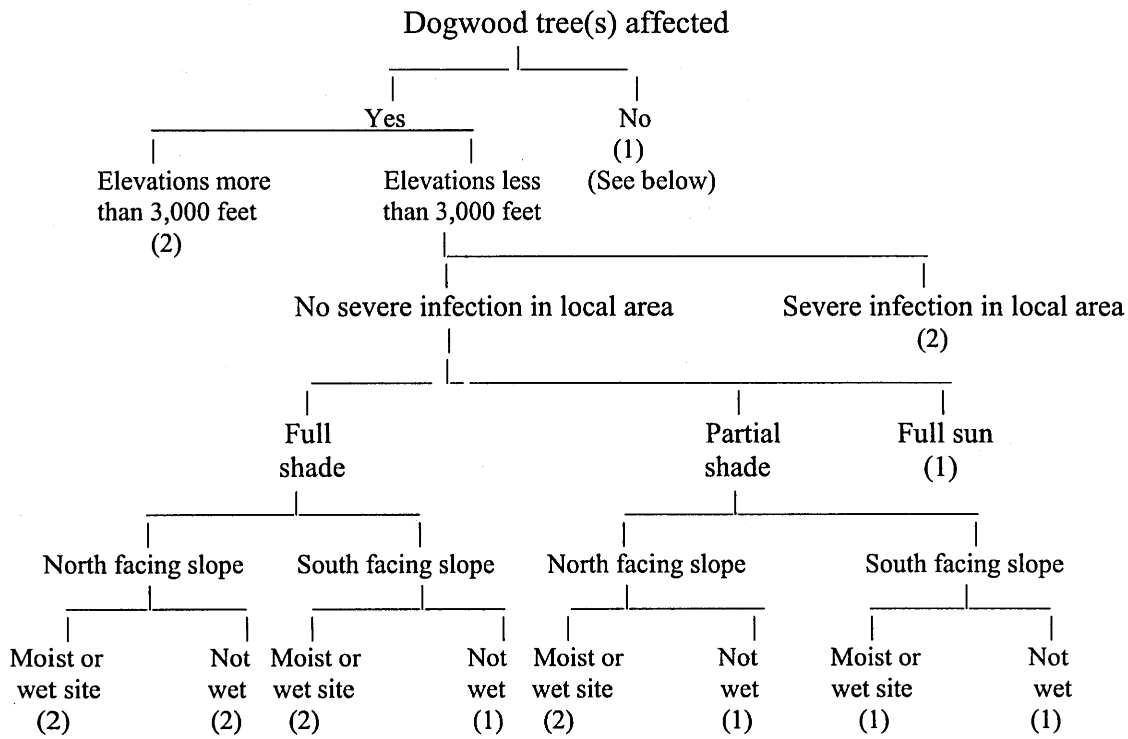
The disease impacts seem to be less severe on the hotter and dryer sites. Trees below 3,000 feet elevation in full sunlight are expected to survive and do well.

Control Procedures

Control procedures are not available at this time for dogwoods grown in the forest environment. However, a number of techniques are available to deal with the disease in generally high-value settings, such as recreation sites or urban settings.

Managers and homeowners can consider planting new flowering dogwoods if they are willing to follow the Decision Key and the Ten Essential Steps outlined in the diagram on the next page:

Dogwood Anthracnose Decision Key



(1) Apply 10 essential steps; omit fungicide and monitor

(2) Use 10 essential steps, use other tree species or consider resistant trees when they become available

Ten Essential Steps to Prevent/Control Dogwood Anthracnose

1. Know the symptoms of dogwood anthracnose and other problems that commonly affect dogwoods. Inspect trees frequently to detect the presence of the disease in its early stages.

2. Select healthy planting stock. Never plant diseased stock. Purchase trees from a reputable nursery. If symptoms are seen on the planting stock, dispose of the infected trees. Avoid transplanting trees from the forest, especially from mountainous areas.

3. Select reasonably well-drained planting sites with fertile soils. Avoid sites along streams, lakes, or ponds where moisture will remain on the foliage for many hours after sunrise. In high-hazard areas, plant flowering dogwoods only in full sun.

4. Planting holes should extend well beyond the root system of your planting stock, and should be filled with a rich mixture of soil and humus. Be sure the root collar is placed at ground level.

5. Mulch around newly planted and existing trees to a depth of 2-4 inches. Be sure the mulch does not touch the stem, and avoid using dogwood leaves or chips.

6. Prune and completely remove or destroy dead wood in the tree and leaves on the ground yearly. Avoid flush cuts, being sure to leave the branch collar. Prune all epicormic branches in late summer.

7. Water weekly during droughts. Water in the morning and avoid wetting the foliage.

8. Fertilize to provide nutrient-rich soil. Have soil tested to be certain what quantities of nutrients are needed.

9. Avoid mechanical and chemical injuries to the trees. Lawnmower and string-trimmer wounds are particularly troublesome.

10. Apply fungicides registered for prevention or control of dogwood anthracnose when it is necessary to do so. Fungicides should be applied as buds are breaking in the spring and at least twice thereafter as the leaves are expanding. Check with your local Extension Service about registration and use before applying any fungicide (Knighten and Anderson 1993).

Collaboration in Southern United States

Dogwood Anthracnose was first reported in 1978. It was causing a widespread, rapid deterioration of flowering dogwood in New York and Connecticut. In 1983, Daughtrey and Hibben reported a lower branch dieback disease with the same symptoms on flowering dogwood in New York , Connecticut, New Jersey, and Pennsylvania. They made observations on trees in Planting Fields Arboretum, Oyster Bay, Long Island, and a woodland site at the Brooklyn Botanic Garden Research Center in Ossining, NY. They reported the cause of the disease to be a species of *Discula sp.* , and that the reason for a sudden onset of anthracnose over part of the northeastern range and its coincidental outbreak on western flowering dogwood was unknown.

In October of 1987, unusual numbers of dogwoods were reported dying on the Cohutta Ranger District on the Chattachoochee National Forest in northern Georgia. All of the symptoms matched those of dogwood anthracnose. Foresters estimated that the affected area covered about 30,00 acres of Cohutta Wilderness. *Discula sp*., the causal organism of dogwood anthracnose, was isolated from samples from the affected area.

The Chattahoochee and Oconee National Forest Supervisor and State Forester of Georgia were notified of the occurrence. Soon thereafter, a professor from Clemson University reported an unusual problem with the dogwoods in Cashiers, NC. This area was checked and *Discula sp.* was found. In this case, the affected area was much larger than 30,000 acres. The State Forester of North Carolina was notified, and a meeting of state and federal personnel from the affected and adjacent States was held in Dillard, GA in February 1988. A key factor in the success of this group was the open sharing of information and a spirit of collaboration. All agreed to cooperate and share information openly without fear of who was going to get credit. A mailing list was created and updated where the most current information was shared on a frequent basis. This group became a dogwood anthracnose working group and agreed that the top priority in 1988 was to assess the disease distribution. The Southern Region of the USDA Forest Service distributed a southern version of the dogwood anthracnose pest alert.

By the second meeting of the working group in May of 1988, the disease had been found in Georgia, North Carolina, South Carolina, Tennessee, and Virginia. It was reported that the disease affected trees of all sizes and was more common in the mountains and cool, wet valleys. Six nurseries in North Carolina and one in South Carolina were reported to have diseased trees. Fungicide trials were started in Georgia and Tennessee by the University of Tennessee and University of Georgia and a joint pilot-test proposal was prepared by the working group for submission to the Washington Office. The North Carolina pest control forester proposed that permanent plots be established on a 15-minute grid across the affected area to assess the current and future impacts. These plots were installed by state and federal personnel in each of the respective states. In June of 1988, the fungus had been found in so many locations that the USDA Forest Service and the University of Georgia began to provide sample identification services. In September, the working group developed a news release, but it was decided not to send the release until more information was collected. After this point, the information became known to the press and public. As a result, the group news release was never issued. The National Park Service did distribute a news release from the Great Smoky Mountain National Park. Dogwood anthracnose and its impact received major media coverage.

At this time, a lot of work was being done, and the working group concept was producing results. A third meeting of the dogwood anthracnose working group was held in October 1988. By this meeting a funding proposal had been submitted to the USDA Forest Service, Washington Office for consideration (Found in 49 counties in the South). Sixty permanent plots had been established to assess impact. Birds were discussed as possible vectors, and fungicide studies in Georgia and Tennessee had not produced positive results. One important concern was the inability to inoculate trees under controlled conditions. A high priority was placed on this task by the working group. In

November of 1988 the Great Smoky Mountain National Park, in cooperation with the University of Tennessee, completed a survey of the park and found the disease was widespread.

In January of 1989, the Regional Forester for the Southern Region of the USDA Forest Service called a meeting of the federal and state cooperators to discuss dogwood anthracnose. At this meeting, a list of priorities was developed for survey, impact assessment, and research, and a dogwood anthracnose steering committee headed up by the State Forester of Georgia was developed to help with the biological, political, and funding aspects of the problem. The steering committee met two times and helped establish political support, priorities, and funding.

In March 1989, eight national forests were surveyed to assess the distribution. At the same time, a greenhouse inoculation test was completed with positive results. It was found when seedling leaves were pretreated with an acid mist, fungus spores routinely produced infections on them. Results led to a controlled acid rain study where a positive correlation was established between simulated acid rain and infection in the greenhouse. Funding was approved by the USDA Forest Service, Washington Office for a pilot test of control techniques, and several studies were started by the State Foresters, USDA Forest Service, the University of Tennessee, University of Georgia, and the National Park Service.

In the spring of 1989, the media coverage picked up considerably. The story ran in dozens of newspapers and on radio and TV. CBS National News did a Saturday segment on the disease. Realizing the need to provide the best information possible to the public, the USDA Forest Service, the University of Georgia, and the State Forester of Georgia developed and published a booklet on how to manage dogwoods. To keep public officials informed, a briefing package was developed by the USDA Forest Service. The package included a briefing paper and a list of people to be contacted. The Southeastern Forest Experiment Station assigned one person to work part-time on the disease in 1989 (found in 57 counties in the South).

In September of 1989, the working group met again to discuss progress. The impact plots showed the disease had increased from 1/2 million acres in 1988 to 2.2 million acres in 1989. The National Park Service announced that it would investigate mycological aspects of the problem. Forest Service research officials reported that they would be working on epidemiology. In 1989, the Southeastern Forest Experiment Station added a full-time scientist to work on dogwood anthracnose.

By 1990, considerable information was accumulating. The acid rain study was repeated and showed the same result. It was noted that the fungus seemed to remain active and grow down the dogwood shoots in the winter. The disease was more common at high elevations and in cool, wet coves was able to spread over large areas very quickly (127 counties now had diseased trees), and the fungus preferred cool temperatures. Pilot-test data showed that the fungicides Benlate and Daconil were providing effective control and that other fungicides showed promise. Fertilization and mulching seemed to improve tree vigor, while not increasing the disease in the field. Other greenhouse and field tests were showing that phosphorus tended to increase and lime tended to decrease disease symptoms.

Early literature reported that there was no resistance in the native flowering dogwood populations, but people were noting some trees in the field that seemed to show resistance. Resistance became a high priority in 1990.

At this time, the University of Tennessee formed a research task force composed of horticulturists, plant pathologists, entomologists, plant physiologists, foresters, and genetists. Their mission was to join forces within and outside the University to solve the dogwood anthracnose problem (Southards 1995).

In the fall of 1990, the Southern Appalachian Man and Biosphere Cooperative, consisting of the U.S. Environmental Protection Agency, USDA Forest Service, Park Service, Southeastern Forest Experiment Station, Fish and Wildlife Service, Department of Energy, Economic Development Administration, and the Tennessee Valley Authority, organized two dogwood anthracnose conferences. One was held in Knoxville, TN and the other was held in Asheville, NC. These conferences consisted of representatives from Federal, State, and private concerns, and featured speakers from a number of these agencies. The program reflected a diversity of views held by various groups throughout the South. These meetings increased the awareness of and understanding of dogwood anthracnose, and helped define specific goals, such as effective information dissemination. A follow-up meeting was held in Roanoke, VA in 1991.

USDA Forest Service, Forest Pest Management, took the lead for maintaining incidence maps. Since there are so many mimicking symptoms, it was decided that for a county to be designated "affected," disease presence had to be confirmed in the laboratory. In 1990, the plot data were added to a Geographic Information System to generate maps displaying both severity and incidence (163 counties now had diseased trees).

In January 1991, another working group meeting was held. Members reported progress in all areas. Five hundred thousand copies of an updated version of "Growing and Maintaining Healthy Dogwoods" including revised control methods were published. This was a model of cooperation where the USDA Forest Service, Carson-Newman College, Champion International Corporation, Georgia Forestry Commission, Izaak Walton League of America, Southern Appalachian Man and the Biosphere, Southern Nurserymen's Association, Tennessee Valley Authority and the University of Georgia collaborated to produce and distribute the copies (Bailey and Brown 1991). Also in 1991, the fungus causing dogwood anthracnose was described as "*Discula Destructiva* sp. Nov." (Redlin 1991) and dogwood resistance screening was developed.

For impact assessment, some 210 permanent 10-tree dogwood plots had been established in North Carolina, South Carolina, Tennessee, Alabama, Virginia, Kentucky, and Georgia by state and federal cooperators. These plots were selected in a random stratified sample on a 15-minute grid. Data showed that the disease increased dramatically (from about ½ million acres in 1988 to 17.3 million acres in 1993), and the severity in the permanent plots had increased.

The working group continues today where state, federal, and other group collaborate on understanding the disease and developing strategies for control.

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HOW *EXOTIC* DOES AN EXOTIC INFORMATION AND EDUCATION INITIATIVE ABOUT THE IMPACT OF NON-INDIGENOUS SPECIES NEED TO BE?

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Providing individuals with effective information, programs, and educational materials about "exotics" or non-indigenous species is generally not a very effective way to get people to act to control, eliminate, and restore damage from exotic species to native ecosystems. Information tends to inform the motivated and educated. Educational research and marketing research agree that information is not enough to motivate most people to action. The key ingredients to engaging people to act are (1) to develop a sensitivity (deep feelings for) to the environment and to the specific problem; (2) to develop knowledge about the environment (ecosystems), the specific problem (invasive exotics), and how people have successfully controlled or eliminated them; (3) to develop a set of skills related to how to take effective action; (4) to develop a sense of "ownership" of the problem (a personal recognition that he/she or their property is being impacted by invasive exotics); (5) to provide an opportunity to act (available resources, time, and support are present); and (6) to nurture a locus of control that is internalized. Research in education, learning, and cognitive science affirms that not all people perceive or process external stimuli in the same way. These unique differences among people may be associated with characteristics labeled as learning styles, brain dominance, cognitive processing, and personality traits. The point being that a single approach to engaging a community of people addresses a diverse audience and is not as likely to succeed as one that is designed and produced in format to reach the community's diverse members or to segment the community into subgroups. The key remains to create a supportive environment in which each person believes he/she can make a difference because he/she internally believes he/she is prepared to act with a reasonable chance for success.

This perspective sets up a dilemma for agencies, such as the USDA Forest Service, the South Florida Water Management District, or any other federal, state, or local agency attempting to enlist citizens and businesses to help address the problem of invasive exotic species. Just telling people there is a problem and even explaining the problem is not enough to make a significant difference on the resource—even though the "telling" is an important element of the larger process that must occur if an effective program is to be established. Research information on this topic is of great importance if it is timely, credible, and in a translated format that the educated public can understand. The research information becomes a critical cornerstone for educators and motivated members of the community to begin to build a solid "exotics" education program or shorter term campaign upon that is grounded in the best science available. Workshops, forums, presentations at garden councils, native plant conventions, horticultural business gatherings, and land management agency and organizational meetings, provide effective access into larger arenas of impact on program implementation.

Once quality information is available in a public form, the strategy for growing the information investment into a full program to address non-indigenous species may take a variety of patterns, depending upon the context of the community in which it is to be applied. The most effective programs I have observed have been those tailor-made to their specific community rather than generic national or state programs designed in a one-size-fits-all approach. The key resources that shape the variables of program implementation are:

- *resources* - people, budget, materials;
- *time* - amount of time it takes to enlist people and to actually implement and complete projects;
- energy - applied to the project in terms of leadership, people, money, and other resources;
- *need* - the degree of perceived impact in the local area on individuals, and public and private land;

and finally what I call. . .

- *focus* - a clear plan of action that is strategically subdivided into attainable objectives and projects leading to the specific goal(s) of the group.

Factors that relate to these program implementation variables are the degree to which "exotics" are viewed as a problem or as an issue in the context that the program is to be implemented. In the environment/education field, we define problems as those situations where there is a discrepancy between what we think conditions should be and what they actually are, based upon available data and information. An issue is defined as a recognized problem upon which people of good intention differ on what they believe the appropriate solution should be. In effect, problems are data based and issues are values based. Thus, additional information from informed sources is usually all that it takes to solve a problem, while an issue is far more complex to address and ultimately find a solution for. Just think about it. People will often tell you non-indigenous species or "exotics" are: aliens, beautiful, a disaster, dancers, invaders, tropical islands, scary, water hogs, costly, useful, natural, wildlife threatening, under/over regulated, a cancer on native communities, part of the pattern of nature, no big thing! There are even individuals who will argue all of these points at a public meeting. How does one proceed?

The following discussion and recommendations grow from more than thirty-seven years, both within formal education systems and from the nonformal sector of "slow learning," watching, and participating in public information, and action programs that attempt to enlist citizens to take action on significant public projects. There are a number of key strategies I highly recommend for consideration.

1. The best guiding strategy I know of is the one that is described as the "Monday Group Commandments" used by the Lee County School System (in the 11th and 12th grade environment education seminar classes for the past 26 years). The Monday Group Guidelines have proven very effective at supporting student and adult implementation of action-research programs.

They are:

Take only positive positions—do not just tell people what you do not like or do not want to tell them—tell them what your wish—what you want to see as conditions of the solution;

Do your homework—become an expert. Read at least three papers and interview three experts on the topic and you will know more than most people;

Avoid stereotyping—stereotypes limit possibilities rather than encourage positive engagement;

Analyze the "force field"—seek out supporters, doubters, and opposition, and get to know firsthand what their ideas, thoughts, and perspectives are (they may have a more thoughtful view than your own or, if you differ, you will understand why). This will better inform your position and strategy;

If at first you don't succeed—RECYCLE! The second cycle starts at a much more informed position than the first initiative did—each cycle is built upon the learning reflections of the previous work—and informs it;

Persistence is the key to success—most problems and issues did not develop overnight and usually cannot be solved quickly. Patience, focus, and persistence are the key to success on a significant project.

2. Build a coalition of partners...think diversity! A meaningful partnership is generally strengthened when all participants have a key common interest at stake. Collaboration is the key to optimizing very limited resources experienced by most public agencies and private organizations today. If the USDA Forest Service were to partner with the National Science Teachers Association for distribution of materials and information, the reach of the agency would grow exponentially. The same is true of partnerships with the National Council of State Garden Clubs or groups at the local level. My experience is the more diverse the partnership, the more powerful the potential benefits.

3. Celebrate rather than lament and whine! People respond far more positively to celebration by tending to feel more empowered than they do to predictions and lament of pending disaster from invading exotics which demonstrations often leads to a sense of dread, futility, and hopelessness. The focus of celebration needs to be on the wonders of the native community and its wonderful local/bioregional adaptations, and integrated benefits to the community which is formed from the sensitive balance of local species in a community. The idea that exotics are simply "great" non-indigenous species not adapted to local habitats is a positive way to characterize them. The emphasis should be that these species did not evolve in the local ecological community and, are

thus likely to stimulate change in local conditions for years, and maybe even centuries, before integrating into the local ecosystem, depending on how invasive or benign their specific characteristics express themselves in your local area.

4. Establish projects that clearly succeed and demonstrate how to successfully control or eradicate invasive species. That implies keeping the scale of specific project goals and objectives broken down into manageable project elements so that local people can experience success in completing and seeing a finished product in a reasonable time period. Our local motto, when working with citizens or students clearing areas of exotics by working in ten x ten meter square quadrats or pixels, is work one meter at a time!

5. Document your projects with before- and after-video, photos and slides, then catalog and place them into a safe but accessible archive (library, nature center, or government agency file). It is always amazing how many times the documentation materials will be called into use, sometimes many years later. Take advantage of your documentation resources to inform people in your community of your success and what needs to be done, and how it can best be accomplished. This kind of information tends to encourage locus of control.

6. Celebrate results and invite the media! Spreading the word of success is a critical part of making the management of exotics an integral part of your local culture. The news media usually finds citizens out clearing or controlling exotics good human interests, community improvement projects filled with good photo opportunities. Be prepared with a spokesperson who can succinctly explain the project in front of a live TV camera in the field.

7. Build your next element upon your previous success by always trying to engage new participants to mix with the experienced to address a new area or aspect of the problem on which you are working. Margaret Mead once told us how important and powerful it is when you mix different generations of people on the same project. Experience has affirmed her wisdom. As the learning curve zooms, so does the richness of the experience and pride of accomplishment when people of different ages are voluntarily brought together to work on addressing a common problem.

8. Never, never, never GIVE UP! (Winston Churchill). There are so many examples of successful projects to manage, control, eliminate, and restore the impacts of exotic species management projects, things are really encouraging. The difficulty of living in a semi-tropical region is the continual pressure of new species being introduced, many of which have invasive characteristics and potential, creating a never-ending vigil and effort relative to managing exotics.

One of my earliest encounters with *Melaleuca* trees was with students surveying a newly acquired local nature center site infested with the trees at about a 30% level. Working with a hundred students, we cleared fifteen acres in two days with very little regeneration. The regeneration that did occur was easily controlled over the next year until no trees existed in the work area. We found that even upper elementary students could pull young trees that were up to about a meter and a half tall during the dry season. On this size tree, the tap root is almost as deep as the tree is tall. When the trees reach two to six inches in diameter, the tap root tends to degenerate and typically three or four lateral roots become dominant. We found that high school students with a pointed shovel could pop the lateral roots and push or "ride" the tree down. If they then completely covered the remaining in-ground roots, preventing light access, roots would not sprout. While this is a slow process, it works and it involves students directly in the solution in a way that they get full satisfaction from their sweat while seeing visible results. Students have worked with girdling *Casuarina* on seaturtle nesting beaches, removing Brazilian Pepper (*Shinus*), Air Potato, and Downy Rose Myrtle and many other plants in lesser numbers. They have also worked with reducing populations of non-native animals, especially reptiles and amphibians. Most student field trips into locations with exotics stop and spend time "pulling exotics" and hanging their roots high to dry—the message is this is a never-ending task that takes commitment to succeed.

I am a firm believer in minimal use of chemical treatment for exotics and only as a last resort for critical management. Integrated management techniques are the key to long-term success and public acceptance. A great citizen example of this type of effort is the comprehensive program of the Sanibel Captiva Conservation Foundation's extensive effort to eliminate invasive exotic plants through a control strategy that uses flooding into management impoundments, burning, and both hand and mechanical removal techniques with topical spraying of some stumps where they cannot reasonably be removed. Over the past thirty years, they have changed public attitudes from being very reluctant and opposed to any removal of shade trees or other "pretty" exotics to a very strict adherence to the city's local comprehensive plan that protects native vegetation and requires removal of exotics on the island.

"Pepper Busters" are a volunteer group from the Sanibel Captiva Conservation Foundation that consults with local landowners on how to get rid of exotics and also volunteers to "bust" the Brazilian Pepper infestation on the island, which greatly changes the island's character and impacts wildlife in significant ways.

The local Calusa Nature Center provides the Native Plant Society free meeting space provided they conduct a series of exotic plant removal days during the year—bartering is a nice and effective strategy to engage people.

In California, I have seen middle school students clear a creek of bullfrogs that were displacing native frogs in months when the public agencies had written the prospect off.

There is no end to the stories of success and engagement that can be told about children and adults, in institutional settings and in nonformal settings, making a major impact on the invasive exotics in their community. The message continues to be simple—it happens one plant or animal at a time and one meter at a time secured!

The South Florida Water Management District has one of the most extensive invasive exotic plant control and eradication programs in scope and intensity of funding of any regional agency in the world. They sponsor an extensive aquatic weed control program, using mechanical, chemical, and biological controls on thousands of miles of canals, lake shores, and wetland areas. Their *Melaleuca* removal project covers almost all of the Everglades. They cooperate with federal and other state agencies for exotic removal throughout their extensive landholdings in all or part of 16 counties in South Florida. This is a massive effort and requires a great deal of public education and information to sustain public support for the effort and for the very significant funding this program requires.

This is a time when the public is growing more conscious and concerned with the application of chemicals and their impacts on the environment, themselves, and family; while they also gain more concern about the impact of control burns on air quality and public health. This clearly means professional managers of lands containing invasive exotic species face even more difficult management challenges.

In South Florida, just as in so many other areas of the nation and planet, we see local native communities being converted into lake and golf course frontage, residential development, creating stressed habitats in the surrounding areas that are ripe for exotic invasions. The usual fix is to go to the cheapest chemical methods to control the problem and bring the waters to aquarium clarity devoid of the aquarium life. The challenge and task will accelerate and grow rather than decline in the future as exotics travel via modern technology, transported by commuters and goods traversing the "global village."

As we examine the elements of an effective information and education program about acting to minimize the impact of exotic or non-indigenous species, the basic lesson is to follow Nature's lead. The most effective programs are not the exotic-glitzy media campaigns and slick materials produced by public relations firms that are served up in a blitz campaign that raises public awareness for a time—although they may serve in a useful narrow niche. The successful programs are those built upon sound research and information that take the time to integrate themselves into their community structure. They, in fact, become a part of the community's accepted culture. This takes time, but gets consistent results, as opposed to quick impact programs that do not establish long-term maintenance, sustainability, and acceptance. A successful program has a greater chance of success if it avoids or minimizes the "exotic" and follows the longer, more stable, path of natural models.

The fundamental rule is **Nature Knows Best—and always bats last!**

MONITORING CHANGES IN EXOTIC VEGETATION

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Ecological monitoring provides critical information for management decisions by measuring changes in managed and unmanaged populations, communities and ecological systems. It integrates ecology, goal and objective setting, sampling design, sampling methods, and statistical analysis. It is a topic that I, with a team of Nature Conservancy ecologists, teach in a six day workshop as part of the USFS Continuing Education Program. It is attended by land managers from public agencies and The Nature Conservancy. Here I will provide an overview of the most important monitoring issues, modified to address the management of exotics. I have subtitled the presentation **The 7 Habits of Highly Effective Eliminators of Exotic Vegetation,** borrowing from the title of Stephen Covey's (1989) bestseller.

1. Choose Your Battles Wisely. Exotics make up a large percentage of the species diversity in each state (Rejmanek and Randall 1994) and most land managers manage sites that have numerous exotic species. It would be overwhelming and impossible to attempt to eliminate or control all exotic species at a site—there is not enough funding, expert personnel, and time. This requires that exotic species be prioritized for control and subsequent monitoring.

Prioritizing control effort involves examining the biology and distribution of exotics to identify criteria that reflect their invasiveness. A ranking system that uses an analytical approach has been developed by Hiebert and Stubbendieck (1993). Invasive species:

1) alter ecosystem functions. Examples include species that either reduce or increase fire likelihood or intensity or that alter the water table or hydrologic regime;

2) become established in undisturbed natural communities;

3) outcompete native species after natural disturbance; and

4) prevent or depress the regeneration of native species.

Species that have low invasiveness, and thus low priority for management and monitoring, are those: 1) whose numbers are stable or decreasing, 2) that colonize only disturbed areas and do not move into undisturbed habitats, and 3) that will be controlled or eliminated with natural succession or re-establishment of natural processes (especially restoration of fire or hydrologic regime).

The assessment of exotics needs to be framed within the context of the ecological communities they have invaded. Higher priorities should be given to exotics which occur in rare or relatively undisturbed ecological communities.

The feasibility of controlling or eliminating exotics also needs to be factored in before management actions are initiated.

2. Follow the Latest Paradigm. The word paradigm is being overused in the ecological literature. The concept of the word, however, is very important. It means the assumptions one uses when viewing, explaining, and understanding the world. It is our current frame of reference. The current ecological paradigms greatly influence the way we approach the management of natural resources.

This current ecological paradigm includes the following concepts:

- **Biological Diversity** - the concern of conservationists is shifting away from an emphasis on single species management to one of managing ecological communities to protect all native species. For exotic management this means equal concern should be given to restoration of native diversity as to the removal of the nonnatives.
- **Natural Processes** - the role of natural disturbance regimes has been recognized as one of the most important determinants of species composition and community structure, with the role of management to mimic these natural processes. For exotic management, the native natural processes should be assessed in the management of exotics. Using natural processes to control exotics assists in the restoration of the ecological community (Pollak and Kan, in prep). Management regimes using natural processes may also be the most resource efficient.
- **Spatial Scale** - the role of spatial scale is important in understanding the dynamics of populations (metapopulations, dispersal, viability), the patterns of species richness and the dynamics and patterning of natural processes.
- **Temporal Scale** - the role of temporal scale is important in understanding population dynamics and natural processes. This has resulted in longer time-frames to explain population and community changes and a shift to longer-term management and monitoring.
- **Interconnectedness/Interrelationships** - a greater awareness that there are more connections out there than you can guess and that management should consider trophic relationships, predator-prey relationships, soil fertility, hydrologic regimes in watersheds, acid deposition, etc.
- **Low Predictability** - the complexity of natural systems makes it difficult to predict future events or conditions. This is why adaptive management is so important, that we monitor our management rather than relying on ecological assumptions.
- **Human Impact** - is more insidious than we have previously thought, impacting natural communities at many temporal and spatial scales through direct and indirect means. Managers of exotics already know this.
- **Humility** - that nature and the management of any site is more complex than we currently understand. Humility is the primary value behind adaptive management.

3. Begin with the End in Mind. What are your expectations for management and how you define success? For the control of exotic species, as it should be with any adaptive management project, it can be summarized in two questions: What is your management objective? and What is your monitoring objective?

Management Objective: What is your vision of what you want the site to look like after management? Is the exotic species eliminated? Are all exotic species eliminated? What does a controlled population of an exotic species looks like? The answers to these questions are determined by the biology of the exotic species, the resources available to the land managing agency, and characteristics of the ecological community.

Monitoring Objectives are specific and quantifiable. They address what is measured (what species, group of species, communities, environmental parameters), where it is measured (defines the sampling universe, are the measurement going to take place throughout the whole Smoky Mountain National Park or just within the Little River drainage?), what methods will be used (point intercept for cover, photopoints), the frequency of measurements, and the precision of your measurements.

The concept of precision in monitoring deserves additional discussion. Precision is the closeness of samples to one another. (Accuracy, on the other hand, is the closeness of samples to the true value, a value we rarely know.) Estimates of precision are communicated by confidence intervals or a measure of variability, such as the standard deviation.

Two examples of monitoring objectives with their stated precision:

For estimating a population parameter: The monitoring design will be able to detect a 20% change in the population density of exotic species *X* in a specific natural area between 1997 and 1999 with 90% confidence.

For detecting change over time: The monitoring design will be able to detect a 20% decline in the density of exotic species *X* in a specific natural area between 1997 and 1999, with 90% certainty that the change will be detected if it occurs (power) and a 10% chance of concluding a change took place when it did not (false-change error or Type I error rate).

4. Design For Precision. Monitoring does not always involve sampling. In many cases one can count or measure all the individuals within a population of interest. When your population of interest is too large to measure everything, then one needs to sample. Sampling is the process of selecting a part of something with the intent of showing the quality, style, or nature of the whole. The role of sampling is to provide information about the population in such a way that inferences about the total population can be made. This inference is the process of generalizing to the population from the sample, usually with some measure of how good the generalization is (its precision).

The precision of sampling is determined by the sampling design. Sampling design is the selection and spatial arrangement of sample units used to measure specific variables in a population, community, or ecosystem. The sampling design used in a monitoring study should maximize the ability to distinguish real changes, trends, or differences from random variation. Many sampling design decisions appear to be made arbitrarily, uncritically, or by following general sampling procedures. These decisions should be made with the precision of the data in mind.

There are six major sampling design decisions one makes when developing a monitoring study (Sutter 1996). These decisions involve determining:

- the sampling universe: the population, community, or area of biological interest to which inferences are to be made;
- the placement of sample units (plots, lines, individuals) within the sampling universe, randomly of course;
- the selection of sampling units, either individuals, points, lines, plots;
- the selection of permanent or temporary sampling units;
- the sampling frequency; and
- the number of samples that need to be collected.

The following equation illustrates the relationship among sampling components that influence the level of precision.

$$\mathbf{Power = f(a, ES, n, o^2)}$$

where: Power, the certainty of detecting real change, is a function of alpha, effect size (your desired precision as minimal detectable change), sample size, and the variance.

What can you control as you design your monitoring study? You can control the number of samples and the effect size you would accept, and you have some control over variability in the way you define your sampling universe and with the placement, permanency, and shape and size of the sampling unit.

5. Use Methods to Avoid Madness. There are numerous sampling methods one can use to monitor changes in exotic populations. One can ask several questions to help determine which methods to use.

1. Which level of monitoring is appropriate?

- Qualitative or Semi-quantitative Monitoring: quick, inexpensive monitoring that has a significant subjective component, is observer-dependent, provides data that can not be statistically analyzed, and can only detect changes that are dramatic. Includes the following methods: mapping of populations, presence/absence of population or plants, estimates of individuals, estimates of cover, and photomonitoring.
- Quantitative Monitoring: repeatable, analyzable, but usually does not address changes in individuals, and is time-consuming and expensive. Includes measures of individuals, cover, or frequency in sampling units.
- Quantitative Age or Stage Class Monitoring: or demographic monitoring, the strengths of quantitative monitoring with more data on individuals and the biology of the species, greater predictability, but very time consuming and expensive. Includes following individuals over time to assess their life history characteristics and obtain demographic parameters (survival, mortality, fecundity) of the population.

In reality, one mixes methods from two or more of these monitoring levels. One can map the location of an exotic species at a site, establish permanent photopoints, and quantitatively measure cover in permanent plots. See Menges and Gordon (1996) for more information on levels of monitoring.

2. What specific parameters are best to be monitored?

- Abundance Parameters: numbers, density, cover, frequency.
- Condition Parameters: measures of vigor, performance, fecundity.
- Structure Parameters: size or age class information.

The parameters one chooses is determined by the biology of the species and the management objective. Exotics that occur as discreet individuals can be counted, while rhizomotous species are best measured by cover. Frequency measures are probably the least useful for exotics, since complete elimination is difficult. Measures of condition are important when the process controlling an exotic species will take a long time and benchmarks are needed for short-term assessments (vigor measurements such as for plant height or reproduction).

6. Adapt Accordingly. Any management action is an experiment. We rarely know the exact results from managing natural resources. This uncertainty and the complexity of natural systems requires an adaptive management approach. Manage, and then monitor and evaluate the results. If the results are not meeting the management objectives, adapt the management or alter your management objectives.

7. Patience. The Zen of exotics management: controlling exotics is like planting a tree, it may take several generations for it to bear fruit. So in the mean time, do effective management and good monitoring. Do what you can so that fruit is born, or maybe better said, fruit will not be born for future generations.

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EXOTIC INSECTS IN NORTH AMERICAN FORESTS: ECOLOGICAL SYSTEMS FOREVER ALTERED

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ABSTRACT. More than 400 species of exotic phytophagous insects have become established on native and introduced woody plants in North America. About 5 percent of these invasives have well-recognized, severe ecological impacts on the trees and ecosystems that they occupy. For the others, very little is known about their influence on natural processes. However, evidence suggests that all may irrevocably change their respective, invaded ecosystems. In the worst cases, the exotics insects have become the "final straw" causing their adopted host plants to fall into perennial decline-death spirals.

EXOTIC FOREST INSECTS: PILING STONES UPON A SAGGING BACK

In North America, there are currently at least 400 species of exotic insects which have become naturalized on native and introduced woody plants in forests, parks, and urban landscapes (Mattson et al. 1994, Niemelä and Mattson 1996). Many of these invaders, such as the gypsy moth, *Lymantria dispar*, the balsam woolly adelgid, *Adelges piceae*, and the beech bark scale, *Cryptococcus fagisuga*, have precipitated serious ecological and economic consequences, the full magnitudes of which are not yet fully appreciated (Liebhold et al 1995, Wallner 1996, see also Wallner this volume). In fact, Liebhold et al (1995) and Wallner (1996) astutely observed that biological invasions, i.e., the wanton spread and establishment of alien organisms in native ecological systems, can have local ecological consequences as important as those resulting from rising levels of pollution and global climate change. Yet, the number of exotics continue to rise along with international trade, and travel (Liebhold et al. 1995, Wallner 1996).

In trying to simply comprehend the general physiological and ecological effects of exotic insects and pathogens upon their newly adopted host trees and forests in North America, it is instructive to invoke the metaphor of loading stones upon the back of an already laden beast of burden. The metaphor, though imperfect, is apt because it emphasizes that the trees which serve as new hosts for the alien herbivores are already carrying a significant burden of native herbivores, most of which have long been associated with the particular trees--for at least hundreds of thousands if not millions of years (Tahvanainen and Niemela 1987, Labandeira et al. 1994). The effects of loading yet another one, two, or even more new species of insects on top of a typical, already in-place load of about 50 species (Strong et al. 1984, Niemelä and Mattson 1996) are not simply linear, but are decidedly nonlinear. In other words, the impacts of the new, additional species are often vastly out of proportion to their number. Why? For one, the host tree has no evolutionary history with the new consumer and thus (a) may have minimal defenses (including damage repair, recovery) with which to respond to it, or even worse, (b) the tree may over react (in terms of a rapid inducible resistance) and in the process kill itself, such as in auto-immune disorders in humans. Moreover, the exotics are invariably lacking in natural enemies and hence can cause vastly more feeding damage than the natives. The net result is that exotics, when coupled to the natives, and the normal, abiotic stresses and strains, may induce total herbivory to overshoot the "load bearing" limit, the resilient capacity of the tree, causing it to become physiologically depressed and ecologically disadvantaged. In fact, this is the thesis of the paper. Moreover, I propose that the host tree and its ecosystem is forever altered as the result of the invasion of the exotics.

THE DEATH, DECLINE SPIRAL: EXOTICS AS INCITING FACTORS

When subjected to numerous simultaneous stresses or debilitating experiences, trees and even whole ecosystems may end up slipping from their normal growth and development trajectories onto the slippery slopes of a death-decline (D/D) spiral from which recovery is difficult because of many reinforcing feedback loops that inexorably push (ratchet) toward further plant/system dysfunction, weakness, and ultimately death (Fig. 1, Manion 1981). Manion (1981) classifies the many interacting factors surrounding the D/D spiral into predisposing, inciting, and contributing factors. Predisposing factors are usually the background abiotic components of a particular environment, and the unique properties of the trees therein (e.g. their genetics, age, etc.). On the other hand, the inciting and contributing factors are mainly the background of biotic stressing agents. However, severe, episodic "acts of god" such as frost, drought, or human-caused stresses are also included among the inciting factors. Using this framework, I would argue that exotic insects and diseases often behave as severe, inciting stress factors during their "initial" contacts with new host populations. In a particular landscape, this "early" period of intense and severe (inciting) impact of invasive insects on hosts may play out for many decades or even centuries before the interactions "evolve" to become less intense and less severe owing to critical changes in the gene pools of hosts and invasive insects, and heightened deleterious impacts of natural enemies upon the invasive insects as more and more native predators and parasites eventually adopt the exotic as host and food. Over the long-haul, as the exotics spread everywhere, and the systems adjust ecologically and evolutionarily, the invasive exotic may eventually change into the role of a contributing factor. When this happens, probably no less than a hundred years from its first contact with any particular local landscape, no one will remember and few people will understand how the system has been changed as the result of the invader(s). Just as we accept the presence of dandelions, *Taraxacum officianale*, without thinking about their exotic origins and ecological impacts, we now also indifferently accept the absence of American elms, *Ulmus americana*, or only a small fraction of the number that used to occur in urban, rural and forest landscapes before the spread of dutch elm disease by introduced and native species of bark beetles. Few ask what, if anything, was lost when so many elms disappeared? Is it possible that the American elms will ever recover their former prominence? Not likely—at least within any time frame meaningful to *Homo sapiens*.

TREES PUSHED TO THE EDGE

Fortunately, not all of the 400 or so exotics insects which are now naturalized and living on woody plants in North America have become the final "straw" leading to the general breakdown and collapse of the plants they attack. In fact, most exotic species, though common and widespread, seem to have only very localized severe effects, i.e. their severe impacts are limited to very few, and particular trees. One such exotic is the eastern spruce gall aphid, *Adelges abietis*, which forms small pineapple-like galls on the tips of elongating white spruce, *Picea glauca*, shoots. Although most trees are infested to some extent, only few trees are so heavily attacked that they are rendered incapable of competing with their neighbors (Mattson et al. 1996). However, the impacts of most species are not known but suspect. For example, there are 20 plus species of introduced, root-feeding weevils (e.g. *Otiorynchus, Polydrusus, Phyllolobius* spp) which are incredibly abundant in forests. Their huge numbers suggest that they must be taking a toll, although it has yet to be determined. In addition, their serious impacts on woody ornamentals in nurseries and in urban settings also imply that these inconspicuous, unstudied immigrants may be having important, though unappreciated, ecological impacts (Drooz 1985).

On the other hand, about 20 species of exotics typically have frequent and extensive, severe effects on their host plants. These are the subject of the following discussion. Insects in this category seem to be either (a) the definitive "final straw," or (b) the conditional "final straw." The mere presence of the former type seems to start the unraveling of the system, whereas the second type precipitates an unraveling usually only under conditions of concomitant abiotic stresses. The "overloading" of trees with exotic insects and pathogens can easily render them ecologically "incompetent" in their natural ecosystems and hence lead to their ultimate displacement by other species. And, it can also render them economically unsuitable for use in commercial forestry applications owing to their diminished growth rates, and high probability of failure before harvestable products are produced.

EXOTICS AS THE DEFINITIVE "FINAL STRAW" SOME EXAMPLES

Beech: One of the premiere examples of an exotic insect precipitating serious and widespread debilitation of its newly adopted host plant is the case of the European beech bark scale on North American beech, *Fagus grandifolia* (Houston 1994, also Houston this volume). The scale's feeding stylet penetrates and alters the bark such that formerly innocuous, native *Nectria* spp fungi can also enter the bark and trunks and trigger rapid decline and death of the trees.

Elm: A similar example of an exotic insect and pathogens in tandem pushing a tree species to an ecological precipice is the well-known case of the European elm bark beetle, *Scolytus multistriatus*, vectoring the deadly Eurasian fungus, *Ceratocystis ulmi*, along with three other exotic bark and several American bark beetles. Although most of the American elms in urban and rural landscapes of eastern North America have long since been killed and removed, and out of public attention, elms are still dying in great numbers in the forests at the western edge of the advancing infestation wave. For example, between 1980 and 1993 in the Upper Peninsula of Michigan, the number of elms declined by 65%, from 66.1 to 22.9 million, and growing stock volumes dropped 75%, from 189.5 to 47.3 million ft^3 (Spencer 1982, Leatherberry 1994, Schmidt 1993).

Firs: Another exotic insect renown for its high damage potential is the balsam woolly adelgid, (BWA) which feeds by means of its hair-like stylet, on the boles, twigs and buds of Fraser fir, *Abies fraseri*, and bracted fir, *A. balsamea* var. *pheneroleopis,* in the southern Appalachians. Although some may argue that acidic deposition and drought were also involved, the BWA appears to be the most parsimonious explanation for the rapid death and decline of 80-95% of mature firs in several locations, but especially at Mt. Mitchell, North Carolina (Witter and Ragenovich 1986).

Hemlock: Three species of exotic sucking insects could ultimately prove to be important inciting factors in the death and decline of eastern hemlock, *Tsuga canadensis*. The hemlock woolly adelgid, *Adelges tsugae*, which is currently confined to a handful of mostly eastern seaboard states, and two exotic scales (*Fiorinia fioriniae*, and *Fiorinia externa)* need to be vigilantly monitored for their expanding impacts along with natives such as the ever-devastating hemlock looper, *Lamdina fiscellaria*, and the hemlock borer, *Melanophila fulvoguttata* to guard against escalating hemlock losses.

White Pine: Two exotic defoliators, the introduced pine sawfly, *Diprion similis*, and the pine falsewebworm, *Acanthodyla erythrocephala*, coupled to the lethal, Eurasian-origin, white pine blister rust, *Cronartium ribicola*, and the native white pine weevil, *Pissodes strobi*, have caused many to question white pine's, *Pinus strobus*, utility as a commercial tree species, not to mention its capacity for long-term survivability and regeneration in the wild. Besides these concerns, white pine is also noted for its high susceptibility to damage by tropospheric ozone which is rising in the United States.

Red Pine: Two exotic defoliators, the European pine sawfly, *Neodiprion sertifer*, and the pine falsewebworm, coupled to two rather recently introduced sucking insects, the red pine adelgid, *Pineus boerneri*, and the red pine scale, *Matsucoccus resinosae*, and European scleroderris canker, *Gremmeniella abietina*, may eventually threaten the usually high commercial potential of *Pinus resinosa*. Red pine is not known for its high genetic variability and hence may have limited genetic resources to call upon for surviving the onslaughts of devastating exotics.

EXOTICS AS A CONDITIONAL "FINAL STRAW" SOME EXAMPLES

Paper birch: Four species of sawfly leafminers from Europe, especially *Fensusa pusilla*, are well known for their chronic and heavy defoliation of paper birches in North America. These insects, when coupled to several native defoliators, aphids, and especially to drought, and then to the very lethal bronze birch borer, *Agrilus anxius*, can wreak havoc on urban and forest-growing birches. The one-two punch of drought and bronze birch borer are bad enough, but to further debilitate the trees through heavy defoliation virtually guarantees that birch growth rates, and life expectancy will be significantly diminished. For example, following a series of dry summers, there was a 400% rise in birch mortality in Minnesota in the years 1990-92, translating to over 105 million dead trees (Twardus and Mielke 1995). At the same time, about 75% of the birches in Wisconsin had at least low levels of crown die back.

Sugar Maple: The exotic pear thrips, *Taeinothrips inconsequens*, a cell-sap feeder, when coupled to several native defoliators like the forest tent caterpillar, *Malacosoma disstria*, the bruce spanworm, *Opheropthera bruceata*, the maple leafcutter, *Paraclemsia acerifoliella*, and root pathogens may together be important inciting factors in the decline and death of sugar maple, *Acer* *saccharum* (Parker et al. 1991). However, abiotic factors like drought, acidic deposition, and stress-induced flowering are also likely to be crucial contributing factors.

Oaks: The European gypsy moth has caused cyclical and heightened defoliation of eastern North American oaks for over 100 years. They, along with several native defoliators like the forest tent caterpillar, and random weather stresses (e.g. severe spring frosts and drought) and follow-up attacks by the two-lined chestnut borer, *Agrilus bilineatus*, on weakened trees, are undoubtedly changing the structure of mixed oaks forests (Wallner 1996). For example, in the state of Michigan, this very combination of factors has precipitated the death (varying from 10-100%) of northern pin oak, *Quercus ellipsoidalis*, on about 387,000 acres (Twardus and Mielke 1995).

Spruces: The European aphid, *Elatobium abietinum*, has sporadically caused severe outbreaks on western spruces, *Picea* spp, precipitating the extensive decline and death of trees both in urban and forested environments along the west coast (Furniss and Carolin 1977). During 1995-96, in the Rocky Mountain region of the United States more than 10,000 acres of blue spruce, *P. pungens*, forests were severely defoliated and may very likely succumb to attacks by bark beetles. Nothing is known about the particular circumstances leading to the severe outbreaks, but it is likely that unusually favorable weather for aphid survival and reproduction is part of the story.

IS THERE A SOLUTION?

Given that there are no less than 400 exotic insects, and 20 or so exotic pathogens now naturalized in the forests, parks, and urban landscapes of North America (Liebhold et al 1995, Niemela and Mattson 1996), is there anyway to minimize the potentially negative impacts of these biological pollutants?

First thought. We must minimize the spread of exotics. Therefore, we need to aggressively plug the leaky "dikes"at crucial environmental boundaries, staunching the influx of new invasive organisms. This is an absolute given. The same should apply to the movement of already existing exotics in North America.

Second thought. We must find inexpensive and ecologically tenable ways to limit population growth of the exotics species. This will be possible through several avenues: (1) enhance the build-up of natural enemies of the exotic pest by facilitating the transfer of natives to it, and by importing natural enemies from the exotic's ancestral environment, (2) facilitate the development of natural plant defenses (including tolerance) that are efficacious against the exotics by employing classical and novel genetic engineering methodologies, (3) discover, create, and restore ecological, environmental conditions that are inimical to the exotics through special forest management, silvicultural approaches, (4) invent and employ special methods to lower the effective breeding stock of the pest, such as the "sterile male," trapping out, and pheromone bewilderment methods, and most importantly, (5) brainstorm entirely novel approaches.

All of the potential solutions will have substantial costs, and none is likely to yield overwhelming results in the short run (10 years). In fact, it is unrealistic to expect significant break-throughs until 2 decades of effort have been invested. Fortunately, there have been some remarkable success stories that justify the substantive investments. For example, the outbreaks of at least three very damaging exotic defoliators (*Coleophora laricella, Gilpinia hercyniae, Pristiphora erichsonii*) and one shoot borer (*Rhyacionia buoliana*) have been essentially eliminated following the establishment of parasites and pathogens from the ancestral home of the exotics. In other words, though still present in North America, their numbers have been brought down to tolerable levels and hopefully so have their ecological and economic impacts.

Of course, such timetables for attaining success are dependent to a degree on the amount of effort and money expended. In any case, developing methods for stopping and managing exotics is a trench war that will never be won with weak resolve and capricious support. However, it's not the only problem begging for attention. Because the world is now changing at a record pace owing to the huge (6 billion) population and its unprecedented impacts on fundamental life support systems, incredible numbers of critical issues need to be addressed simulataneously. It provokes one to ask whether there is enough money to go around.

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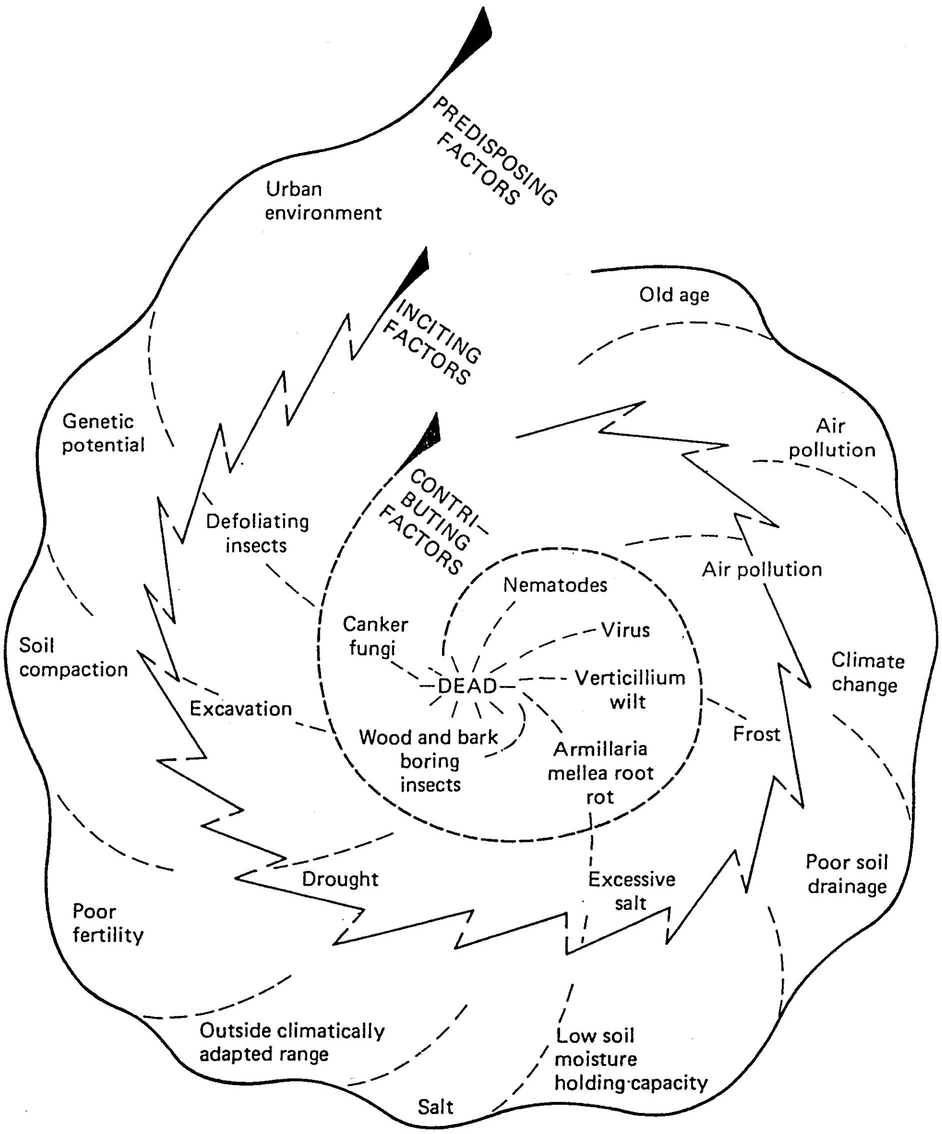
Figure 1. The decline-death spiral showing the many interacting factors, from Manion (1981), printed with permission of Prentice-Hall, Inc.



MANGROVE FORESTS: A TOUGH SYSTEM TO INVADE

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INTRODUCTION

Tropical forests are the most species-rich forests in the world. As many as 225 tree species per hectare have been reported in these ecosystems, values that are equivalent to almost finding a different tree species every other tree encountered in the forest. Under some conditions, tree species richness decreases in tropical forests. For example, Hart et al. (1989) reported that forests in Africa that were dominated by a single species had on average 18 tree species per 0.5 ha. Fewer species still are normally found in freshwater forested wetlands. Values in these systems range from 1 to 23 species per hectare, with averages at 8.3 and 6 species per hectare for riverine and basin freshwater wetlands, respectively (Lugo et al. 1988). Mangrove forests are even more species-poor, and, in fact, are among the most species-poor forest ecosystems in the tropics (Lugo et al. 1988). Mangrove stands can be found where the plant species list is only one tree species. In fact, Jansen (1985) asked: "where is the mangrove understory?" after he observed that mangrove forests contain no understory plants. Several articles were written trying to answer the questions raised by Jansen (Corlett 1986, Lugo 1986).

Environmental conditions within mangrove forests make it extremely difficult for plants to grow and reproduce. These include flooding, prolonged hydroperiods, anoxic conditions, and salinity. Salinity is the major obstacle to species invasion to mangrove forests because in order to survive in a saline environment, plants must possess highly specialized metabolism and mechanisms to either exclude salt or mitigate its effects on living cells. Worldwide, only 34 tree species have been identified as possessing these adaptations (true mangroves *sensu* Tomlinson 1986), 20 other species tolerate some salinity and are considered minor elements of mangroves, and an additional 60 species are considered mangrove associates (Tomlinson 1986).

Only a small fraction of the world's flora are halophytes (plants that tolerate salinity) and those taxa with halophytic species have a lower mean number of genera per family and a lower mean number of species per genera than non-halophytic taxa (Waisel 1972). This means that when considering the subject of mangrove invasions by exotic species, one has to realize that the species pool available to invade these ecosystems is limited on a global scale. If a tree was to be able to grow under the saline and hydrologic conditions of mangroves, it would by definition be a mangrove tree species, and should it be an exotic to Florida, it would not be an exotic to the mangrove environment. So, the first question one asks when finding an exotic tree species or any kind of exotic plant species growing inside a mangrove forest is: **is it a halophyte**?

I have witnessed non-halophytes (other than epiphytes) inside mangrove forests in Florida. For example, floating acquatic plants like the water hyacinth invade mangrove forests. However, their incursions into mangroves is short-lived and depend on one of two conditions: (1) how quickly the plant dies if it floated into saline water, or (2) how long the freshwater on which it floats lasts as freshwater inside the mangrove. Freshwater lenses occur in mangroves during periods of high rainfall or runoff, and it is possible for acquatic plants to occupy that space and survive as long as the freshwater lens maintains its integrity. Once the saline conditions is re-established, these invaders are doomed. So, the second question one must ask when finding a species invasion in the mangroves is: **what conditions of the environment is it occupying and how long will those conditions last?**

Mangrove forests usually have sharp ecotones with adjacent ecosystems because the saline condition of the mangroves is tidally and topographically determined. Wherever the tide transports saltwater, the mangroves will follow. But changes in elevation, even if on the order of centimeters, can create a sharp ecotone where the mangrove conditions end. Usually, these conditions either do not have salinity, do not flood, flood without salinity, or have salinity without floods. Depending on them, the adjacent ecosystem can be a freshwater wetland, a saline flat, a terrestrial ecosystem, or any combination of these. The transition from mangrove to nonmangrove conditions can be shaper as indicated or gradual, where mangroves become less and less important as the conditions change away from those that delimit the mangrove habitat.

In Florida, I have witnessed exotic plant pecies, including trees, invading the ecotones of mangroves. These trees can be observed growing quite successfully, but failing to penetrate the mangrove environment. Examples of these are the *Melaleuca quinquenervia, Casuarina equisetifolia,* and *Schinus terebinthifolius*. Loope et al. (1994) discusses these and other examples. These trees form dense and vigorous stands at mangrove ecotones, but fail to invade the saline soils of mangroves because they are not halophytes. Therefore, a third question one needs to ask when considering the invasion of exotic species into mangroves is: **What is the geographic location of the invasion, is it only at the ecotone or does it penetrate the forest?**

There is a quick action mechanism that promotes species invasions into forest ecosystems. That mechanism is disturbance. Disturbance events disrupt ecosystem structure and functioning, and can create conditions for the invasion of species. There are two ways in which disturbances can create conditions for species invasions. First, the disturbance alters microsite conditions on a temporal basis. For example, after a canopy opening, light energy and air temperatures increase in the resulting gap. Through succession, the gap is repaired and original stand conditions return. Invading species have a window of opportunity to enter the system during the time its repair and succession are taking place. The invasion after a frost of frost-intolerant mangroves by first tolerant *Spartina* marshes, is an example of how a disturbance can determine the dominance of species at a site (Lugo and Patterson Zucca 1977, Kangas and Lugo 1990).

A second way in which a disturbance can affect site conditions is through a radical modification of the environment such that succession is not likely to return to original conditions. Instead, succession may proceed through an alternative pathway into a different ecosystem state. An example would be if a disturbance changes the course of a river, or impounds a mangrove, or removes the mangrove substrate, i.e., the peat. Succession after these changes is likely to proceed to different states because hydrological, edaphic, topographic, or even salinity conditions have been modified. Invading species have an opportunity toexploit the new environment and gain an advantage over the original species composition at the site. Species invasion of mangroves after a disturbance raise a fourth and fifth question. **Is the invasion a shortterm response to changes in microsite conditions?** or **Is the invasion the result of a longterm shift in the mangrove habitat?"**

My experience in Florida and elsewhere, suggests that exotic species fail to invade mangrove forests after disturbances, such as hurricanes, as long as the hurricane fails to change salinity and hydrological conditions. However, it is conceivable that native or exotic species could invade mangrove habitats in locations where the disturbance has changed the salinity and the hydroperiod of the stand. Smith et al. (1994) reported both native and exotic grasses and sedges growing on the tip-up mounds inside mangroves in the moths after passage of a hurricane. These elevated mounds lose their soil salt by leaching and become a different environment than the soil below.

Human activities such as the construction of canals, diversion of water flows, construction of roads, dredging, and filling, greatly modify mangrove wetland conditions, and could facilitate the introduction of native or exotics species into impacted mangrove habitats. In these instances, it is necessary to carefully access the environmental change, the nature of the species, and the spatial and temporal distribution of the species before one can conclude that a mangrove habitat is being invaded.

The observations of Pimm et al. (1994), Loope et al. (1994), and Smith et al.(1994) after Hurricane Andrew, impacted south Florida mangroves are consitent with the discussion above. The description by Loope et al. (1994) of the invasion of *Schinus* into "higher (less wet and less saline) areas within the mangrove zone" deserves further analysis and an ecophysiological determination on whether this species is a halophyte or not. Pimm et al. (1994) suggest that *Schinus* can outgrow mangroves in open areas, but this broad generalization is not supported by the description of the phenomena in Smith et al. (1994). Smith et al. (1994) qualify their observation to "along the upstream mangrove marsh interface" from the Shark River to the Chatham River where *Schinus* leafed out faster than the surviving mangroves. Clearly, the "invasion" of *Schinus* is at the ecotone and it is not clear if this species has the capacity to invade mangrove forests.

SUMMARY

Mangrove forests are a tough ecosystem to invade because there is a small species pool that can survive its salinity, hydroperiod, and anaerobic soil conditions. Even species that survive one of the conditions may not be able to survive all three. For example, *Conocarpus erectus*, listed erroneously as a mangrove, can tolerate salt but not flooding. The same is true of *Casuarina,* while *Melaleuca* tolerates flooding, but not salinity. Before one can conclude that a species has invaded a mangrove forest, one has to answer five questions that lead one to rule out the following: if the species has adaptation to salinity or not, if the species is just taking advantage of a temporary environmental condition, if the species is located at a particular geographic zone avoiding the stressors of the mangrove environment, if the species is temporarily taking advantage of a disruption of the forest by a disturbance, or if the disturbance has sochanged the habitat that it is no longer a mangrove environment. Reports of mangrove invasions by exotic species in south Florida may be premature.

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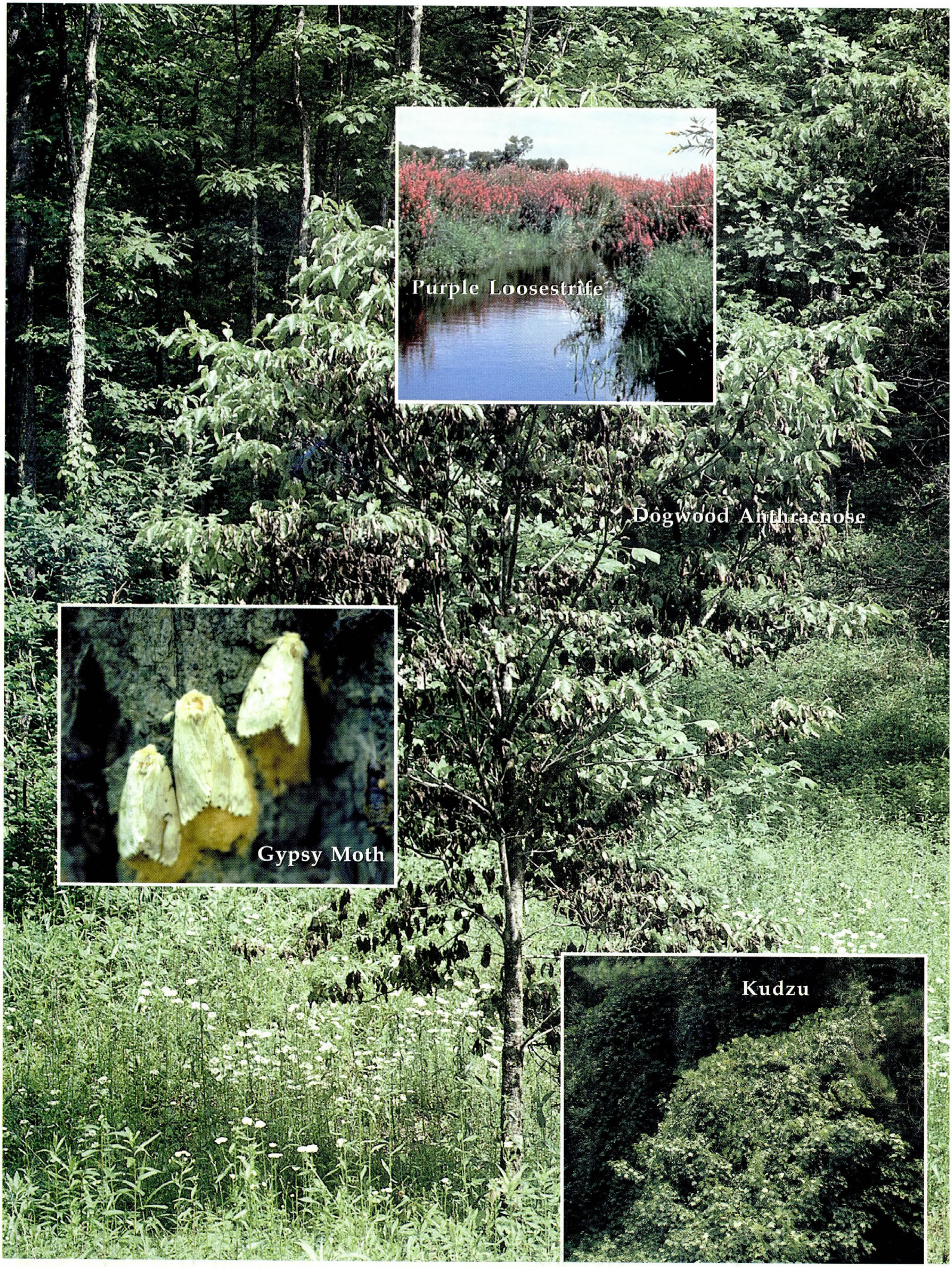
Purple Loosestrife
Dogwood Anthracnose
Gypsy Moth
Kudzu