Issue Summary

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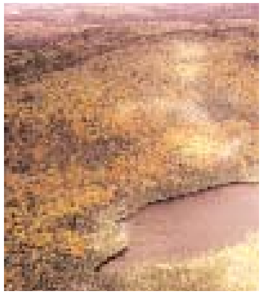
YFF Review



New Threats to North American Forests

A summary of a forum and workshop exploring the impact of Asian Longhorned Beetle and Emerald Ash Borer on forests and forest-based economies

A Yale Forest Forum Event

February 27, 2003

Global Institute of Sustainable Forestry

New Haven, Connecticut

YFF Review

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New Threats to North American Forests

A summary of a forum and workshop exploring the impact of Asian Longhorned Beetle and Emerald Ash Borer on forests and forest-based economies

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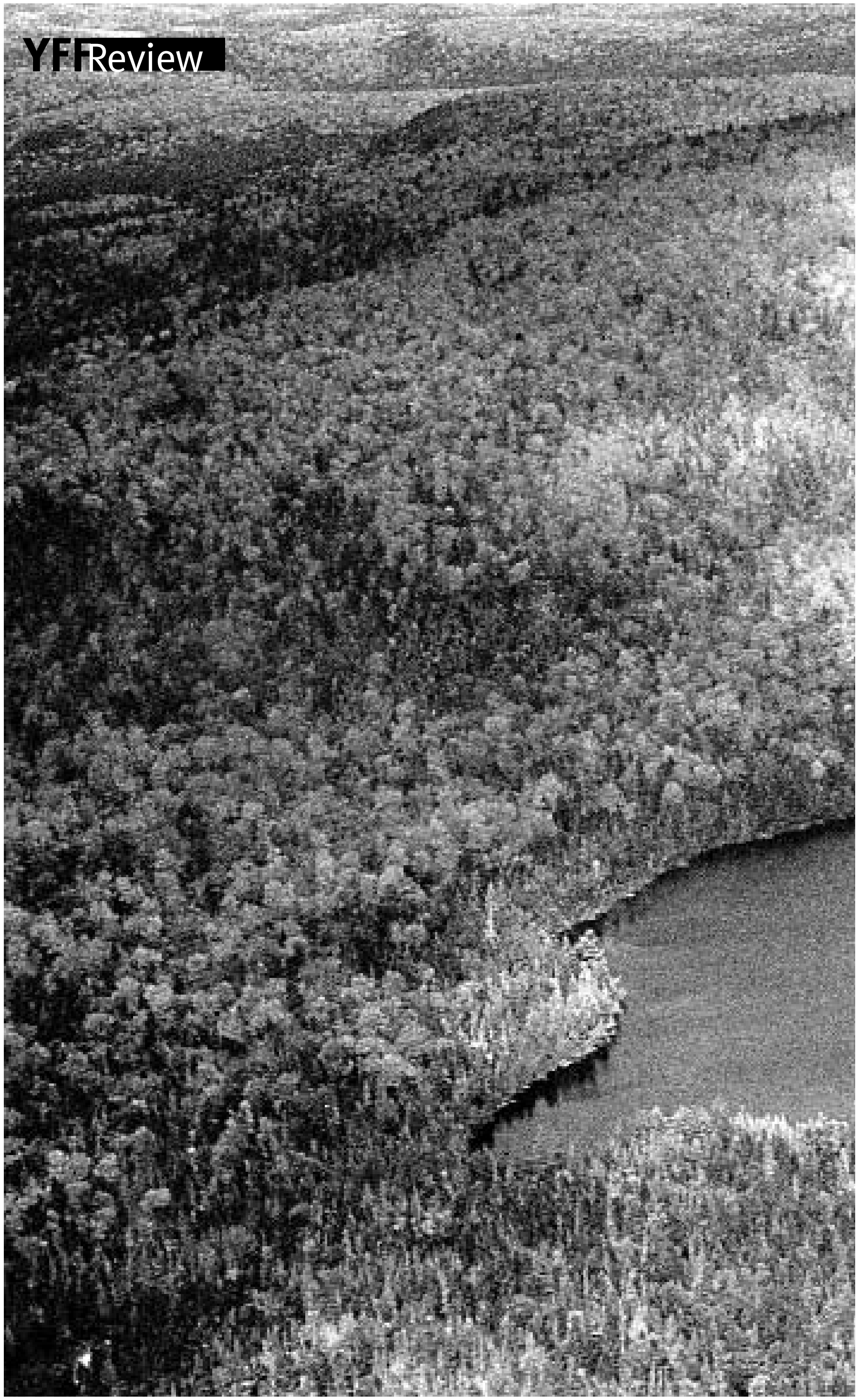

Contents

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Executive Summary

Globalized travel and trade patterns have resulted in the worldwide spread of insect species beyond their indigenous habitats. With increasing frequency, exotic insects and pathogenic organisms are being accidentally released into new ecosystems that lack natural predators or species with evolved host defenses. These introductions carry with them the potential for massive ecological and economic damage.

Examples of recent introductions include the fungus responsible for California's Sudden Oak Death epidemic, believed to have arrived from Europe via contaminated nursery plants; and the Citrus Longhorned Beetle, native to Asia, discovered in the Seattle area on a shipment of bonsai maple trees. North American forests are currently threatened by the introductions of two such exotic pests: the Asian Longhorned Beetle (ALB) and the Emerald Ash Borer (EAB).

The Yale Forest Forum "New Threats to North American Hardwood Forests: The Potential Impact of Exotic Wood-Boring Insects on Forest Ecosystems and Forest-Based Economies," provided an opportunity for a panel of scientific experts on ALB and EAB to share their research and findings with the general public. The panel members also participated in a workshop with landowners, foresters, educators, and government officials to discuss strategies for dealing with the Asian Longhorned Beetle. Dr. Ann Camp, Lecturer in Stand Dynamics and Forest Health at the Yale School of Forestry and Environmental Studies, opened the forum with an introduction of the issue and the scientific panel.

The panelists were: Dr. David W. Williams, a research entomologist with the USDA Forest Service; Dr. David Nowak, an urban forester and project leader from the USDA Forest Service Northeastern Research Station; Dr. Melody Keena, a research entomologist from the USDA Forest Service Northeastern Center for Forest Health Research; Dr. Michael T. Smith, a research entomologist with the USDA Agricultural Research Service Beneficial Insect Introduction Research Unit; Mr. Frank Sapio, a forest entomologist and unit manager from the State of Michigan's Department of Natural Resources; and Dr. Lloyd C. Irland,

the President of The Irland Group, a forestry economics and marketing consulting firm in Winthrop, Maine.

David Williams spoke about his research on differences in the population dynamics of the Chinese and South Korean biotypes of the Asian Longhorned Beetle. The beetle undergoes widespread and frequent outbreaks in China but is comparatively rare on the Korean peninsula, which Dr. Williams attributes to the diverse species composition and good health of South Korean forests. Additionally, the South Korean biotype of ALB has a narrow host range consisting of two species of maple, both of which might have some natural resistance to the pest. Studies of ALB in South Korea suggest it is an edge dweller that might have difficulty penetrating dense, natural forest stands, which could be significant for prevention and containment strategies in North America.

David Nowak detailed how a sampling methodology combining field data and satellite imagery can be used to predict the ecological and economic risks associated with the nationwide spread of Asian Longhorned Beetle and Emerald Ash Borer. Dr. Nowak estimated that approximately 71 billion trees nationwide are at risk to ALB, with compensatory values alone totaling $2.5 trillion. The Emerald Ash Borer, in comparison, threatens a total of 8 billion trees, which have a compensatory value of $300 billion. This predictive methodology is a powerful tool that could be used to assist in the management of nearly any biotic or abiotic threat to forest health.

Melody Keena's presentation described a series of experiments conducted at the Asian Longhorned Beetle quarantine lab in Ansonia, Connecticut. Her research examined the effects of temperature changes on beetle behavior and biology, and found that reproductive potential, larval development and survival, and flight activity decreased when temperatures strayed too far above or below an ideal range between 20 and 25 degrees Celsius. The results of the experiments help explain why ALB has successfully colonized New York and Chicago, since both regions feature climates in which optimal temperatures for beetle growth coincide with seasonal beetle emergence. Dr. Keena's findings also suggest that, based on temperature, ALB has the biological ability to colonize nearly the entire continental United States.

Michael Smith described his research on the Asian Longhorned Beetle in mainland China. Dr. Smith studied the influence of biotic and abiotic factors on ALB behavior and characterized the dispersal patterns of the beetles in terms of flight propensity and capacity, tendency to colonize a new host tree or re-colonize an existing one, and their long- and close-range host orientation. A comprehensive understanding of ALB behavior and population movement can be used to optimize monitoring strategies and increase the probability of detecting the beetle in North America.

Frank Sapio gave an account of the history and development of the Emerald Ash Borer outbreak near Detroit, which as of February 2003 encompassed 2,400 square miles and threatens the health of 700 million ash trees throughout Michigan. Mr. Sapio related how EAB was discovered and identified, and how a pre-existing contingency plan for exotic pests was rapidly implemented. He also described how the Animal and Plant Health Inspection Service (APHIS) recommendations served as the foundation for the current long-term, multi-tiered management strategy designed to contain and eradicate this pest.

Lloyd Irland provided a socioeconomic perspective on managing forests against the threat of Asian Longhorned Beetle and Emerald Ash Borer, and illustrated how attitudes and responses to these pests might vary with different forest management objectives. Dr. Irland described the role of socioeconomic analysis in assessing the willingness of industry, landowners, and consumers to pay for ALB and EAB prevention programs, and stressed the importance of education in ensuring that foresters employ long-term, pro-active management practices.

Issue Introduction

A native of Asia, Asian Longhorned Beetle (ALB, *Anoplophora glabripennis*) is considered to be a serious and widespread pest throughout China, particularly in plantations. In August 1996, it was discovered inflicting fatal damage to trees in Brooklyn, New York. Although its exact means of entry into the United States is not know, it is widely suspected that ALB arrived via imported Chinese heavy material, most likely in the poplar timber used for crating. Infestation was initially localized to Brooklyn, and another outbreak was reported in Chicago less than two years later. Both the beetle's own destructive activity and efforts to eradicate it have had profound impacts on the urban landscape of both cities. Currently there are five known infested sites in Chicago, five in New York, including Central Park and midtown Manhattan, one in New Jersey, and the latest near Toronto, Canada was discovered in September 2003. This beetle has devastated urban forests, resulting in the removal of over 8,000 trees in New York and Chicago at a cost of over $2.4 billion.

The Emerald Ash Borer (EAB, *Agrilus planipennis*) is also a native of Asia, where it is a major cause of mortality in ash (*Fraxinus*) trees. This beetle was discovered in Southeast Michigan in July 2002, and has since been identified in Ontario, Canada and most recently in Maryland. It is unknown how or when it arrived in North America, though a substantial ash die-off was observed in Southeast Michigan beginning in the summer of 2000. Scientists suspect that the area of EAB infestation covers more than 2,000 square miles of natural and urban forests in Michigan and Ontario. So far the pest has successfully infected every species of ash it has encountered, and it is estimated that EAB is in the process of killing millions of trees in Michigan alone.

These two wood-boring beetles have similar life cycles. Larvae emerge from eggs laid by adult beetles in bark crevices, or oviposition pits, then move into the cambium to feed on the phloem and outer sapwood. While EAB larvae feed and eventually pupate exclusively in the sapwood, ALB larvae also move into the xylem and heartwood to feed and pupate. The larvae of both species overwinter inside host trees, and adult beetles emerge from the pupal phase by boring to the surface to feed, mate, and lay eggs. Infested trees die from the destruction of vascular tissue by feeding larvae, and, in the case of ALB, infested trees often fall apart because the structural integrity of their heartwood has been compromised.

To date, these are the only known populations of ALB and EAB infesting live trees, however, these populations have not yet been fully contained, and in some instances are actually spreading. The latest ALB outbreak, in Toronto, was discovered in September 2003. Experts estimate that the original New York and Chicago infestations were 10 years old at the time of detection, and suspect that the New Jersey infestation is several years old as well. Because of the lag time between the arrival and detection of these pests, it is not unreasonable to assume that their spread might be more extensive than currently estimated.

It is feared that both of these pests will spread beyond their current outbreak zones and into the suburban and rural forests of North America where they could wreak havoc on regional biodiversity. If either pest moves into natural forests and kills or weakens a significant component of species, it will drastically change the structure, composition and diversity of the hardwood forests of the United States and Canada. Many of these forests are already under the combined stresses of air pollution, acid rain, periodic drought, insect outbreaks, and disease, which will likely reduce their resistance to attack.

Forest-based economies are also at risk. It is estimated that the Asian Longhorned Beetle alone could cause up to $138 billion in damage to the U.S. timber industry, with additional losses expected in the agricultural and tourism industries. Private property values would also suffer from the beetle's spread.

In order to explore the potential ecological and economic impacts posed by these two exotic insect species, and the extent to which North American hardwood forests might be threatened, the Program on Private Forests at the Yale School of Forestry and Environmental Studies hosted a scientific panel discussion and workshop titled, "New Threats to North American Hardwood Forests: The Potential Impact of Exotic Wood-Boring Insects on Forest Ecosystems and Forest-Based Economies," on February 27^{th} and 28^{th}, 2003, in New Haven, Connecticut, USA.

Asian Longhorned Beetle

***Acer mono*, host species of Asian Longhorned Beetle in South Korea**

Emerald Ash Borer

***Fraxinus* spp., host of Emerald Ash Borer**

Presenter Summaries

"The apparent distribution bias in South Korea of the Asian Longhorned Beetle towards isolated, potentially stressed trees in riparian habitats suggests that it is an edge dweller."

— Dave Williams

David Williams
Research Entomologist, USDA Forest Service

The Asian Longhorned Beetle (ALB) is found across East Asia, from north-central China to the coast, and from Manchuria south towards Vietnam and Cambodia. It is also found on the Korean peninsula. The population dynamics of the beetle are quite different, however, between South Korea and the Chinese mainland.

The beetle has been an incredible pest in China for many years, undergoing repeated and extensive outbreaks, especially in plantation forests. The problem has been exacerbated by a reforestation program that began in the 1950s, in which 67,000 square kilometers of poplar monocultures were planted in northern plantation forests. Not being well suited to the climate of the region in which they were planted, many of these planted poplars became stressed from the outset. The creation of vast plantations of stressed trees set the stage for the massive ALB outbreaks that have taken place since the 1980s. Millions of trees have been destroyed. The beetles also infest windbreaks, planted between highways or agricultural fields, and urban street trees. The species composition of these plantings is predominantly willow, elm, and maple.

In contrast, ALB is very rare in South Korea. There, many entomologists are unaware of its existence or are familiar with it only through museum specimens. The Korean scientific community is more familiar with the Citrus Longhorned Beetle (*Anoplophora chinensis*), a congenic insect pest, which is much more prevalent on the Korean peninsula. The relative scarcity of the ALB in South Korea might be due to the fact that the beetle uses only two maple species as its primary native hosts, while in China its host range is wider. Surveys of the trees that are typically host species in China, such as birches and willows, have revealed virtually no beetles dwelling on these species in Korea. Instead, the beetle is found mostly on *Acer mono* and *Acer truncatum*, two closely related maple species.

Acer mono is a common tree in South Korea, distributed fairly evenly throughout the country in natural stands and plantings. In South Korea it is referred to as Korosei namu and is often tapped in the early spring, much like North American sugar maples. Its raw sap is used as a health drink. The trees are typically found between 650 to 800 meters in elevation, often in riparian habitats growing alongside the stream banks and up the surrounding slopes. It also grows quite densely in rocky mountain ravines.

In the summer of 2001, surveys were conducted to determine the distribution and local abundance of ALB populations in the natural Acer mono forests of South Korea. Beetles were discovered at four sites in the region between Mount Songni National Park, in the central part of South Korea, and Mount Sorak National Park near the North Korean frontier. At two other sites in this area, beetle damage was discovered, but there was no conclusive evidence that the ALB was the culprit. Intensive surveys were conducted at these sites in which individual trees were counted, tagged, mapped with a GPS unit, and then measured and examined for live beetles.

The overwhelming observation from these local surveys was that the majority of trees were not infested. Of the 112 trees surveyed at the Oknyo Tang study site, only six showed beetle damage sustained in 2001 and only six other trees showed damage from previous years. During three days of surveying, only three adult beetles were observed. Clearly, even in the most favorable locations, the beetles are quite rare in South Korea and large populations are essentially nonexistent. When beetles were found, they were usually on single, open-grown trees in riparian habitats. Apparently, such trees are more vulnerable to attack.

Why doesn't ALB have outbreaks in South Korea, and what makes the forests apparently resistant to the beetle? One factor may be that the tree species diversity in these natural forests hampers beetle reproduction, given that the South Korean biotype has a relatively narrow host range.

There is also the possibility of genetic resistance in the primary host tree, *Acer mono*. Population levels of the ALB might also be controlled by natural enemies, like wasps and woodpeckers that attack the eggs and larvae deposited in trees. Most importantly, though, is the notion that healthy trees generally have a higher resistance to infestation, so maintaining healthy forests is vitally important to preventing outbreaks.

This last hypothesis was tested using water stress experiments conducted in the summer of 2002. The basic hypothesis was that a female will lay more eggs in a water-stressed tree than one that is healthy and unstressed; experimental results bore this out: trees in which water stress was induced by trunk girdling received roughly twice as many oviposition attacks as healthy trees.

The apparent distribution bias of the Asian Longhorned Beetle in South Korea towards isolated, potentially stressed trees in edge environments and riparian habitats suggests that it is an "edge dweller"—well-adapted for man-made habitats like windbreaks and street tree environments, but poorly-suited for penetrating dense natural stands. The confirmation of this hypothesis could serve as the key to developing successful management strategies for this pest in the United States.

Mount Sorak National Park, South Korea

David Nowak
Project Leader, USDA Forest Service Northeastern Research Station

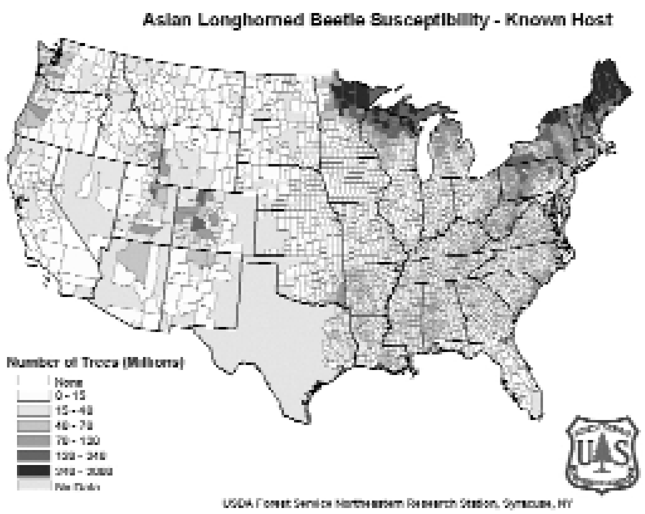
"A quarter of the forest is at risk nationally to the Asian Longhorned Beetle, and about three percent to the Emerald Ash Borer"

— David Nowak

A key component of urban forestry is statistical sampling and data collection on the vegetation located within cities, towns, and suburbs. Random sampling, stratified by land use type—urban areas, street trees, backyards, and parks—provides fundamental data about the forest composition that can be used to gather information on urban forestry concerns like air and water pollution or disease spread. This type of data also lends itself to making predictions about the potential damage that could be caused by insect pests like the Asian Longhorned Beetle (ALB) and Emerald Ash Borer (EAB).

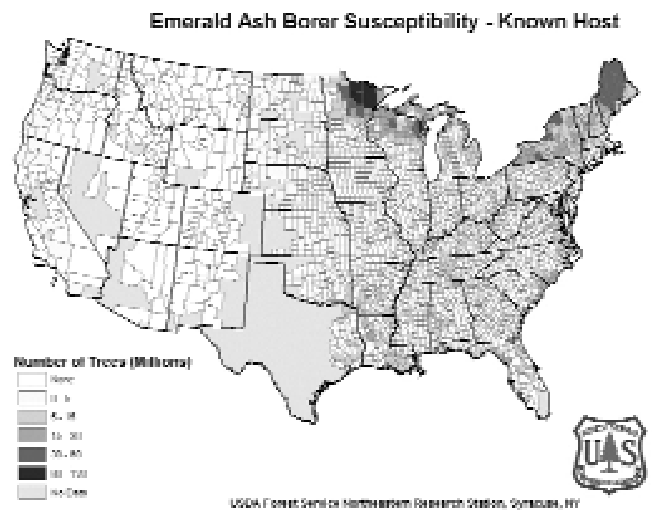
The Animal and Plant Health Inspection Service (APHIS) approached the U.S. Forest Service Northeastern Research Station about making those types of assessments for the areas where ALB occurs in the United States. Fortunately, forest composition data for New York, Chicago, and Newark had already been compiled: the number of trees, species composition, leaf area, tree size, tree health, tree cover, tree density, and their locations relative to buildings and backyards. Therefore, the risks associated with the urban forests in these regions could be readily estimated. The next level of investigation was to examine the risk posed by the beetle moving outside the urban areas and into forest stands—if the beetle escaped in the United States and had preferences to certain tree populations, what could it kill? Moreover, if a forest were lost to ALB, what would be the value or compensation to landowners or homeowners?

In order to answer these questions, the existing regional field data was extrapolated to a cover basis and compared to a high-resolution satellite map of national cover type in order to derive risk estimates for forests across the United States. The combination of local field data and satellite data provided a one kilometer resolution of tree cover in urban areas across the United States, which yielded the risk per unit of cover. The



economic impact, in terms of compensatory value, was calculated in part by using tree and landscaper appraisal tables that described the cost of tree replacement. By plugging in variables like species, location, condition, and trunk area, the table could provide the replacement cost for small trees. For larger trees that were presumably more valuable, trunk area and species value adjustments to the replacement cost generated a compensatory value that was prorated according to tree age.

This methodology produced an estimate that almost 35 percent of the urban forest canopy in the United States is at risk to ALB. That amounts to 1.2 billion urban trees, with a compensatory value of almost $670 billion. This is a worst-case estimate in the sense that it assumes the beetle can attack anywhere in the lower 48 states, with no temperature or physiographic limits, because data does not yet exist for predicting if ALB can attack in a given location. For EAB, only about 1-2 percent of the urban canopy is at risk because there aren't as many ash trees.



Sampling for ash trees is problematic because they tend to be in local populations with wide geographic variations—around Chicago and Michigan, ash comprises around 10-15% of the urban tree population, whereas in New Jersey it's nonexistent—and it is difficult to extrapolate such a small range of a large population.

Forest inventory analysis data was used to estimate the percent of the population at risk to ALB in non-urban environments across the country. In terms of the percentage of the tree population and basal area, the area of greatest risk stretches from Minnesota to Maine, and as far south as St. Louis, Missouri. Here, the population and basal area percentages at risk vary from twenty to sixty percent. In some of the Midwestern states, more than 60 percent of the tree population and basal area is at risk to the beetle, but the reason for this pattern might be because there are so few tree species in these Midwestern ecosystems, and the ones that exist tend to be susceptible hardwoods growing along riparian zones. The greatest total numbers of susceptible trees are found not in the Midwest, but in the Great Lakes and Northeastern states, which serves to strengthen this hypothesis. In those areas, 240 million to 2 billion trees per county are at risk, totaling somewhere between $16 billion to $160 billion in compensatory value. A similar distribution pattern of ecological susceptibility and economic impact has emerged with EAB.

However, there is a vast difference in the threats posed by the two beetles—nationally, about 71 billion forest trees are at risk to ALB versus about 8 billion trees for EAB. In other words, a quarter of the forest is at risk nationally to ALB and about 3 percent to EAB. Similarly, about 19 percent of the national basal area is at risk to ALB, but only about 3 percent to EAB. In terms of compensatory value, about $2.5 trillion is at risk to ALB and about $300 billion to EAB.

This methodology can be applied to generate estimates for a variety of pests, such as the pathogen responsible for Sudden Oak Death, and other exotics that are putting forests at risk. Inventory and sampling data can now be used to produce estimates about what poses the biggest risk to the forest. For instance, a given forest or urban setting without any elms is not at risk to Dutch Elm Disease, but one with a lot of maples might be at risk to the Asian Longhorned Beetle. This methodology is a managerial tool that can help calculate the risk posed by a variety of threats to forest health.

Melody Keena
Research Entomologist, USDA Forest Service Northeastern Center for Forest Health Research

"The bottom line is that the Asian Longhorned Beetle is probably capable of growing and developing in most of the United States."

— Melody Keena

An important aspect of predicting the spread of the Asian Longhorned Beetle (ALB) is an understanding of how the beetle will respond to the different climates it is likely to encounter throughout North America. The United States Forest Service Northeastern Center for Forest Health Research has conducted a series of experiments at its ALB quarantine facility, which have demonstrated that the beetle exhibits rather plastic behavioral and biological responses to changes in temperature.

Reproductive experiments indicate that Asian Longhorned Beetle seems best able to oviposit at 25 degrees Celsius. Below that temperature threshold the beetles often lived longer but there were fewer eggs laid, and above 25 degrees Celsius there were fewer eggs laid and the beetles actually lived for a shorter period of time. One particularly notable result of these experiments is that at 35 degrees Celsius—around 95 degrees Fahrenheit—there were no eggs laid. Moreover, a female beetle that was already laying eggs at 25 degrees could be moved to 35 degrees and she would stop laying eggs, but she would resume laying when returned to 25 degrees. So, higher temperatures did not make ALB infertile, but they did inhibit them from laying eggs. Another key finding was that beetle eggs would not hatch at 10 degrees Celsius, but would remain viable for long periods of time and hatch when warmer temperatures returned. The time to hatch size decreased between the 10 and 30 degrees in a roughly linear fashion.

Additional experiments measured the effects of temperature on larval mortality, the time spent developing in each instar, and the length of larval life period. Optimal temperatures for development were around 20 and 25 degrees Celsius, with reductions in larval weight gain observed both above and below this range. The actual lower and upper temperature limits of larval development were essentially 10 degrees and 40 degrees Celsius, respectively. The lower threshold for larval

Asian Longhorned Beetle

development was estimated to be slightly less than 10 degrees Celsius. Larvae were capable of surviving even cooler temperatures, although their development was essentially halted and after prolonged exposure they would gradually begin to suffer significant mortality.

In contrast, ALB larvae could survive only for a short period of time at the upper limit of larval development, around 40 degrees Celsius. The take-home management lesson from this observation is that if there were a really hot summer and it were over 100 degrees Fahrenheit all day and night for a sustained period, all the newly-hatched larvae could be killed—none would develop through the first instar.

Laboratory experiments also demonstrated that temperature affected the ability of larvae to complete their development. The only constant temperatures at which ALB was able to proceed all the way to the pupation phase were 15, 20, and 25 degrees Celsius. At 20 degrees, the larvae pupated between six and nine instars, with more pupation in the lower end of this range. A chill period introduced at the ninth instar—which was probably not the natural number of instars that the larvae would undergo in the wild—did assist ALB development by generating some pupation at higher temperatures. In other words, the larvae waited until they received a chill period and then went through one or more instars before pupation.

Pupation was not very high at 30 degrees Celsius even when a chill period was imposed, and there was no pupation observed above that temperature. Essentially, larvae could not complete development at constant temperatures at or above 30 degrees, nor could they develop to completion at or below 10 degrees. As one approaches the 10 degree threshold, the number of days required for ALB pupation increases astronomically. At 15 degrees, it took about two years to complete pupation, and above 25 degrees pupation was essentially nonexistent.

What this means in the field is that the larvae probably pupate in the spring to early summer, when the temperatures are cooler, and do most of their larval growing during the higher temperatures of the summer. Likewise, mean adult weight decreases at lower temperatures and at temperatures above 30 degrees. A smaller female will produce fewer eggs, so at the optimal temperatures for adult ALB body weight, there are larger numbers of eggs per hatch.

Additional experiments examined the effects of temperature on ALB flight behavior. At 15 degrees Celsius, neither sex initiated flight. As temperatures rose towards 30 degrees Celsius, more of the beetles flew: males tended to fly more often than females and the newly emerged beetles tended to fly less often than the recently mated ones. The general trend was that flight propensity tended to increase with temperature, and recently mated adults were more likely to fly than newly emerged ones.

In the areas where the beetle exists in the United States—New York and Chicago—growing conditions are optimal, with long periods of ideal temperatures for development and maturation. But what about a place like Vermont or Florida? In Vermont, there is still a growing period that's probably sufficient in length, but there's also a longer chill period. In Florida, the only question is if there is enough of a cooling period to create conditions necessary for pupation. However, the bottom line is that the Asian Longhorned Beetle is probably capable of growing and developing in most of the United States.

"Because Asian Longhorned Beetle exhibits different behaviors at different times of the year, there is a strong seasonal component to monitoring strategies."

— Michael Smith

Michael T. Smith
Research Entomologist, USDA Agricultural Research Service Beneficial Insect Introduction Research Unit

The Beneficial Insects Introduction Research Unit has conducted extensive research in Northern China on the life history and behavioral aspects of Asian Longhorned Beetle (ALB). The goal of this research is to identify the main factors that influence ALB populations and to develop models for predicting their spread, which in turn can help forest managers formulate strategies for dealing with the beetle in ecosystems like the North American hardwood forests.

Successful development of predictive models requires an understanding of the influence that biotic and abiotic factors have on behavioral and population parameter characteristics. In the case of ALB, the biotic factors pertained to the beetle itself—insect age, gender, size, and egg load—in addition to its preferred hosts—tree species, health, size, and branching and canopy structure. Abiotic factors included temperature, relative humidity, wind speed and direction, cloud cover, time of day, precipitation, and landscape features.

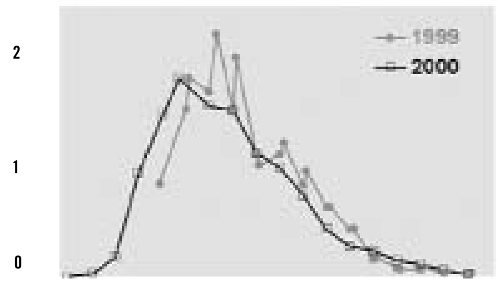
Adult beetle behavior can be broken down into at least six different categories: emergence, when the adult beetle makes its way towards the surface of a tree and chews a sub-surface gallery as it matures; feeding, when the beetle exits the tree and feeds on exterior plant tissues; mating, when beetles—particularly males—seek, guard, and often steal mating partners; oviposition, when female beetles chew holes in the bark of host trees and lay a single egg in each hole; resting, which in part is a behavioral manifestation of thermoregulation; and colonization/re-colonization, when beetles either remain on their current host tree or seek a new host, depending on host quality and population density. The nutritional differences between various host tree species may affect some of these behaviors. For instance, female beetles lay more eggs and live longer when feeding on Norway maple compared to red maple or black willow, and ALB larvae experience the most weight gain when feeding on Norway maple. Therefore, the tissues on which ALB feed may influence their reproductive potential and behavior.

Complementary field experiments were used to assess the dispersal potential of ALB, including measures of both flight propensity (the tendency to take flight) and flight capacity (flight distance). First, mass-mark recapture studies examined population spread over the course of an entire season and on a large spatial scale. Then tracking studies examined individual beetle movement on a daily basis and on a smaller spatial scale. These were followed by flight studies which were used to assess the flight capacity of individual beetles that were released from captivity. Lastly, two year-long resident density and emergence studies measured the resident time of beetles emerging from a given tree and their propensity to remain or depart for a new host.

These studies provided a comprehensive picture of the characteristics of ALB movement. Flight patterns differed by gender, with females traveling an average of 27.5 meters per day and males 32.4 meters per day, although the beetles did demonstrate the ability to move over a kilometer in a day depending on landscape and time of year. The average dispersal over an entire season was approximately 223 meters, with a maximum season-long movement of 2.4 and 2.6 kilometers for males and gravid females, respectively. During epidemic conditions of high population density, flight propensity from a given host tree was 81 percent, most likely resulting from diminished host tree quality. Therefore, flight propensity is directly proportional to population density and inversely proportional to host quality.

In-flight orientation studies provided a more detailed portrait of ALB flight behavior. In initial studies where beetles were released from captivity, beetles demonstrated a clear preference for landing on trees rather than other landscape features, and for shaded rather than sunlit areas. While these beetles showed no preference for landing on host trees versus non-host trees, it was clear that their long-range host orientation is based, at least in part, on visually tracking trees. In subsequent studies where the relative attraction of different tree species were evaluated by placing them adjacent to naturally infested poplar trees, it was demonstrated that ALB can differentiate tree species at close-range, as well as trees under differing levels of stress. It was also demonstrated that close-range orientation is influenced by abiotic factors such as time of day and wind speed: about three times as many beetles made directed flights and landings on sentinel trees in the late afternoon than in the early morning, and their ability to orient, take flight, and land on trees became greatly diminished once wind speeds exceeded eight miles per hour.

While there are many different tree species in China, relatively few of them are actually attacked and infested by ALB. This is true even within tree genera known to contain species commonly attacked by ALB, suggesting that some tree species are resistant to ALB. For instance, while the primary host trees attacked by ALB in China are in the genus Populus, some Populus species are not attacked. In other Populus species into which ALB oviposit, ALB eggs and early instar larvae are reported to be killed as a result of water pressure. Similarly, while Ulmus species are another common host for ALB, female beetles are reported to chew ovipositional pits in some Ulmus species but fail to lay eggs. Finally, within some Tilia species, ALB eggs are laid and larvae hatch, but larvae die before reaching the sapwood.



Seasonality of Asian Longhorned Beetle in China.
Average number of beetles per tree from May 30 to September 27.

Monitoring strategies for ALB should be optimized based on what is known about beetle behavior. Visual indicators of the presence of ALB include: (1) dime-sized circular exit holes and oval to round egg sites which may be present along the trunk and branches; (2) adult feeding damage in which: (a) the outer bark/tissue layer is eaten off of twigs and leaf petioles, (b) the main leaf veins or inter-vein leaf tissues are consumed, thereby leaving irregular shaped holes in leaves, and (c) leaves fall prematurely as a result of feeding on leaf petioles; (3) frass accumulated in branch crotches or at the base of trees; and (4) sap bleeding from oviposition sites and larval galleries. It is important to note that exit holes and oviposition sites may occur from the base of trees to high in the canopy depending, in part, upon bark thickness. For example, young thin barked trees may have signs of attack at or near ground level along the trunk, while such signs are more typically higher along the trunk and branches in more mature or thick barked trees.

Because ALB exhibits different behaviors at different times of the year, there is a strong seasonal component to monitoring strategies. As such, monitoring for adult beetles, feeding damage, and oozing sap should be concentrated during July and August, the peak period of adult abundance. More specifically, recent studies have shown that peak population abundance occurs 800 to 900 degree days (base threshold = 10 ºC) from the first of January. Monitoring for exit holes and oviposition sites should occur after leaf fall, since these signs are more visible at that time. Spatial studies of ALB behavior and population abundance suggest that monitoring efforts should be concentrated on preferred host trees, particularly solitary individuals, and along edges in plantations, forests, windbreaks and urban landscapes. These guidelines should assist in optimizing monitoring efforts to alert managers to the presence of an infestation.

Ultimately, an understanding of species richness, diversity, host quality and health will be the basis for predicting how Asian Longhorned Beetle might spread in North America.

"Fortunately, the Michigan state government had developed a working plan for handling an exotic insect outbreak, and it paid immediate dividends."

— Frank Sapio

Frank Sapio
Forest Entomologist and Unit Manager, Michigan Department of Natural Resources

In the early 1990s, an ash decline began in the Detroit area. This was not a unique problem—ash declines periodically occur everywhere in the country, usually as a result of local environmental conditions and poor planting practices. Often, the agents of mortality are native borers of ash that attack trees already weakened by other pests or diseases. Ash yellows, a lethal disease cause by a phytoplasma, is also evident in the greater Detroit area, though in smaller amounts. The ash decline problem grew in magnitude throughout the 1990s and yet no one primary causal agent could be positively identified. Finally, during the summer of 2002, scientists from the Michigan State University extension service and the Michigan Department of Natural Resources (DNR) discovered a non-native, exotic insect in the ash, an *Agrilus* beetle that was feeding on the boles of the trees and killing them.

Fortunately, the Michigan state government had developed a working plan for handling an exotic insect outbreak in response to the recent introduction of the Asian Longhorned Beetle in Chicago. The plan was formed through the cooperation of state and federal agencies—the Michigan Department of Agriculture, the U.S. Forest Service, the Animal and Plant Health Inspection Service (APHIS), the Michigan DNR, and Michigan State University—and it paid immediate dividends. Within a week of discovering the exotic *Agrilus*, the Michigan Department of Agriculture had deployed field survey teams; within three weeks, a group of cooperating scientists in the Czech Republic had identified the beetle as *Agrilus planipennis*, which Deborah McCullough at Michigan State University named the Emerald Ash Borer (EAB).

The initial focus was on insect surveys, conducted by ground and air, to determine the extent of infestation. A damage survey was also conducted, using aerial photography and ground truthing, to determine the impact of infestation. The combined goal was to determine the magnitude of the problem in order to secure adequate funding for pest management. Both surveys were made possible by volunteer assistance from around the nation.

Based on the February 2003 survey data, the infested area is roughly 2,400 square miles, extending through parts of Michigan and into Ontario, Canada. However, because outward signs of infestation are already a year old, the actual area of infestation might be larger. Six counties in Michigan are under quarantine. Fifty percent of the ash in this area are either declining or dead, which amounts to roughly 6 million trees. Slightly less than half of the area's 650,000 landscape trees are in decline. The Emerald Ash Borer is certainly no longer just an urban pest, and, because it has entered the natural forests of Michigan, all of the state's 700 million ash trees are at risk. Computer modeling based on ash cover type suggests that the insect will spread west and north.

The survey data also suggests a possible origin of the EAB outbreak: there is a focus of beetle activity near the Detroit Metro Airport, specifically, next to the freight area. This could be coincidental, but given how the Asian Longhorned Beetle came to this country, it is highly possible that EAB arrived in Michigan via infested freight.

Current management of the beetle emphasizes containment and eradication, and is based on a four-tiered strategy developed by an APHIS scientific panel. The first management zone is the infested core area, the boundaries of which are defined by a collection of three mile buffer zones around the infested sites. Within the core, the strategy is to let EAB eat all of the host and let the infestation burn out, so there are no management practices employed. Wood chipping is used to prevent the spread of infested material outside the core.

The surrounding area is a suppression zone, acting as a sort of sponge. The idea is to allow the beetle move into this area so it can be killed. Management here is insect-directed instead of emphasizing host removal. The next zone is the firebreak zone, which probably holds the most promise for successful management of the beetle. Much like with forest fire management, here the reliance is on an area of minimal "fuel" to stop the movement of the insect—by reducing the available amount of host, EAB will not be able to survive in the firebreak zone. The firebreak zone is a maximum of three miles wide, and its delineation is based on a combination of ash density and pre-existing administrative or municipal boundaries.

The fourth zone is the survey and detection zone. Because this area is vital to keeping management efforts one step ahead of the beetle's spread, some extremely intensive surveying occurs here—the specificity of survey mandates the detection of ninety-five percent of all infestations greater than twenty trees in magnitude. As beetles are located and management efforts proceed, these zone boundaries will change.

The Emerald Ash Borer has been successful in the Detroit area largely because of the previous twenty years of ash decline; the poor health of these trees set the stage for infestation by the beetle. Because ash decline occurs across the continent, the beetle has the potential to be a widespread problem. Unfortunately, there are limited data available on the condition of the ash resource nationwide. For the moment, the best method is to identify areas of ash decline based on crown data from the National Forest Health Monitoring Program and to deploy survey teams accordingly. However, the crown data are only applicable in natural forests, and as of yet there is no similar mechanism for detection in urban environments.

Scientists have recently discovered EAB in Toledo, Ohio, so the true range of the outbreak is still being determined. The most pressing question now is how far the beetle can spread before it is detected.

Addendum
As of September 2003, the Emerald Ash Borer quarantine has spread to a total of 13 counties in Michigan, and it has been discovered infesting ash trees in Maryland.

LLOYD C. IRLAND
President, The Irland Group

"Nobody is interested in living with Asian Longhorned Beetle and Emerald Ash Borer, or trying to figure out which stands should or should not be treated. There must be an actual eradication objective."

— Lloyd Irland

Responses to outbreaks of exotic insects like the Asian Longhorned Beetle (ALB) and Emerald Ash Borer (EAB) are too often characterized by battles between Dr. Pangloss and Chicken Little. The eternal optimist of Voltaire's Candide maintains that everything is fine and nature will sort itself out without human intervention, while Chicken Little argues that the sky is falling and immediate action is required to prevent a catastrophe. Unfortunately, these debates are not always informed by any real facts.

Socioeconomic analysis of pest management focuses on resource owner, resource user, and agency behavior in relation to pest programs. There are four objectives when analyzing pest management: to develop cost effective and implementable strategies for predicting and managing impact; to help decision-makers clarify, measure or rank values at stake, especially related to opportunity cost; to give insight into the effects of incentives in the various programs and markets; and to help evaluate programs in a systematic way—is a program working or is it not, and what can be learned?

Pest management analysis must examine the full spectrum of affected environments. In wilderness areas and national parks, there is a strong working bias for letting nature take its course. However, parks have boundaries and neighbors have different ideas about management, which lead to containment or safety questions. The Department of the Interior and the U.S. Forest Service manage most wilderness and national parkland, and so management can be fairly straightforward. The number of people involved is fairly small, and the commodity values of the resources in question are often zero.

In national forests, the number of actors remains small but there is usually an objective requiring the protection of management or ecological values. Timber production is not always the highest priority, so it is sometimes recognized that "pests" are part of nature and they might have a desirable impact. Pest-mediated disturbances can nudge forests along successional pathways, and the resulting snags and coarse woody debris can be a boon to wildlife. Ironically, ecosystem management prescriptions usually urge forest managers to grow trees on longer rotations, because the landscape is depleted of more mature age classes. Unfortunately, those are the very age classes that are most vulnerable to pests.

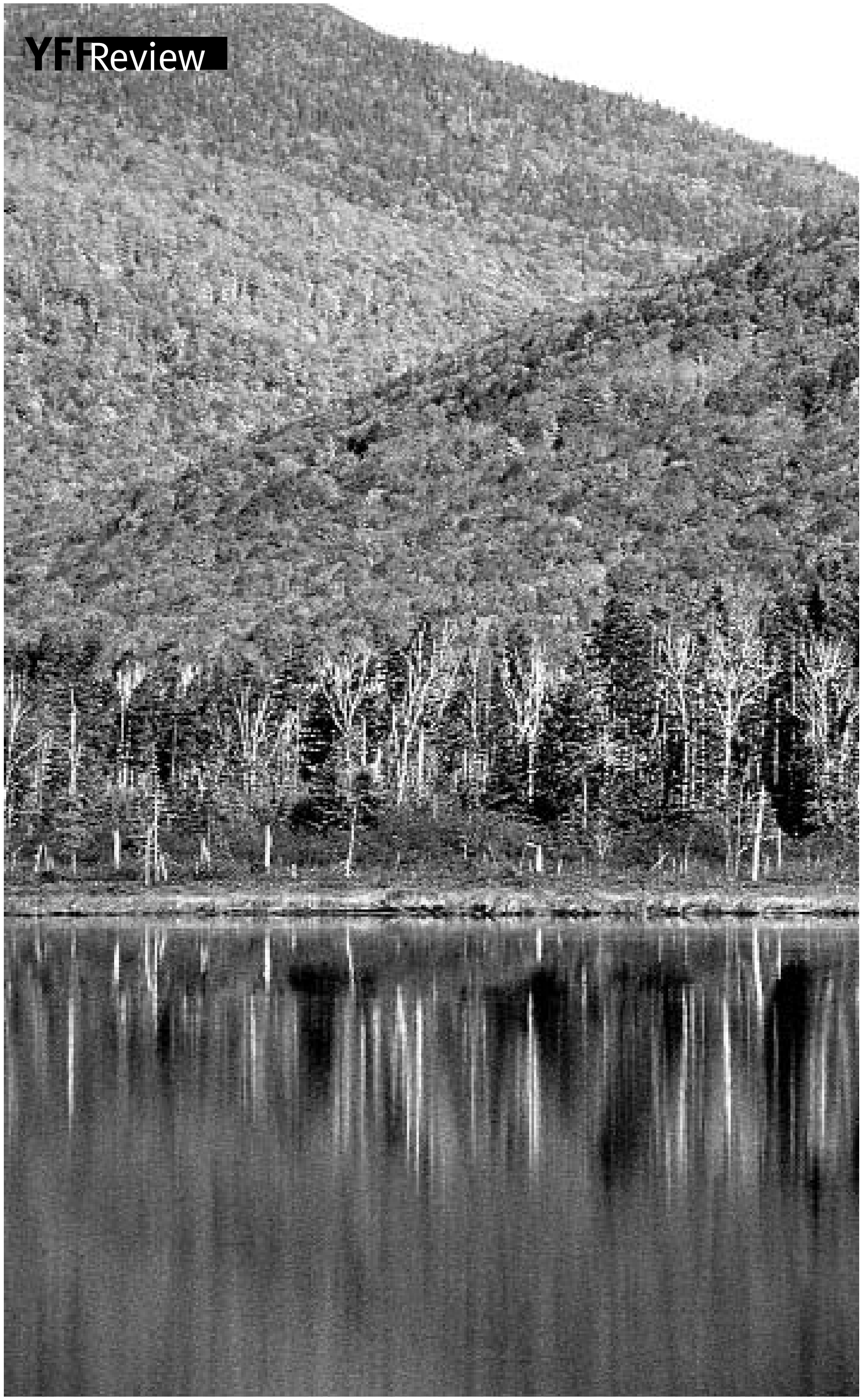
Managed timberland is more complex because of production goals, income objectives, and increasing numbers of actors. One approach is to risk-rate production stands and decide which need treatment based solely on economic investments and returns. Unfortunately, the "brown needle syndrome" often guides timberland pest management—if the trees aren't brown and dying, there is no concern about insect pests. Socioeconomists must be vigilant about dispelling this mentality, and fortunately pro-active management does exist. Managers strive to avoid the problems created in China when they planted, at great effort and expense, massive quantities of preferred host species for ALB. For instance, a lot of foresters balk at planting Eastern White Pine because that will create habitat for White Pine Blister Rust—their hope is to avoid making that pest problem any worse.

Urban forests are the most complicated because of the enormous amount of people who must act against and be made aware of pest threats. In the city, resource values are higher and the environment weakens trees. Their roots have been paved around, the soil is compacted, and the air is polluted. Moreover, urban forests are often single species monocultures that have heightened susceptibilities to exotic pests. For example, Norway maple is highly preferred by ALB and is planted in large, continuous tracts throughout Eastern cities. These factors maximize the risks to urban forests to the extent that their commodity values are negative, because of the costs of removing the damaged and dead trees.

Asian Longhorned Beetle and Emerald Ash Borer are vastly different from native pests like the Western Spruce Budworm and Mountain Pine Beetle because of the unique economic questions they pose. No manager is interested in living with ALB and EAB, finding a loss threshold, and figuring out which stands to treat — there must be an actual eradication objective. That's terrifying to most pest managers because these pests have no known natural enemies in North America and there are no real control technologies.

About 50 million acres of maple-beech-birch forest in the northeastern and north-central United States could be lost to ALB. The inventory of just the hard maple in those regions is about 50 billion board feet, totaling nearly $10 billion. Lumber production from both hard and soft maple in the United States is 800 million board feet per year, worth around $400 million a year. Maple also has significant value as a non-timber forest product and real estate asset. How much would landowners, mills, and consumers pay to fund protection programs for at-risk trees and forests? The role of socioeconomists is to help federal, state and private organizations answer this question by scrutinizing assumptions about host control effectiveness, environmental impacts, resource values, and resource owner behavior.

Education will play a huge role in the struggle against insect pests. Something is amiss if practicing foresters suffer from the "brown needle syndrome." The educational focus must be revamped to emphasize a pro-active approach, because the learning curve is too steep, the resource too valuable, and the stakes too high for foresters to learn on the job. Until the system is fixed and people are better prepared, pest management will remain at the mercy of debates between Dr. Pangloss and Chicken Little.



Discussion Summary

Following is a brief summary of the panel's response to issues raised by the audience.

Preventing the spread of contaminated timber and firewood

Frank Sapio
Quarantines are in place for both for the Asian Longhorned Beetle and Emerald Ash Borer that limit the movement of any wood products that might harbor the insects. In the case of ALB, it's a national quarantine governed by the Animal and Plant Health Inspection Service (APHIS). The Emerald Ash Borer quarantine is currently at the state level, but now that the beetle has turned up in Toledo, Ohio, it's become a multi-state issue and APHIS is also developing a quarantine. While the Michigan quarantine for EAB prohibits the movement of any ash materials out of state, the national quarantine for ALB limits the size of the woody material that can be transported across state lines. The rationale behind the national quarantine is that when material is sufficiently small, the risk of transporting the pest is greatly diminished. Therefore, intact boles and branches would not be permissible, but wood chips smaller than one inch would be.

Vigorous, fast-growing tree species as a tool for preventing beetle infestations by improving forest health and reducing overall tree stress

Michael Smith
In China, the trees that are the preferred hosts for ALB are stressed poplars and willows, which are fast-growing species. Unfortunately, the exact cause of the stress is unknown—it could be drought, air pollution, soil compaction, or something else. These problems are difficult enough to manage for by themselves. Fast-growing trees that rapidly reach the maximum basal area capacity might not be the answer. If they're within the host range of the beetle, landowners just might not want them at all.

David Nowak
Both these beetles validate the classical silvicultural wisdom of maintaining species diversity in forest stands. In northeastern stands, maples are very fast-growing and aggressive, and tend to take over if left to themselves. This tendency is worth fighting, but it's also wise to maintain stand vigor. In a typical New England hardwood management situation, the difference in growth rates between species is not going to be as dramatic as in China. However, faster growth and greater vigor do provide more options for management. Fortunately, sensible silvicultural practices and the natural mixed-species composition of northeastern forests are both beneficial.

Influence of globalized trade on the spread of exotic insect species

Michael Smith
In the last twenty years, there has been a great ballooning in the amount of trade with China. While they've sent some pests to North America, they've received some North American pests as well. As a result, in the last five years the Chinese have gained three notable species: the fall budworm, the western pine beetle, and the pinewood nematode. All three are currently in the top ten lists of Chinese forest pests.

David Nowak
The United States has not seen the last of this problem. Last year, the trade deficit was $400 billion, and this won't change in the near future. In today's world, goods are moving around rapidly and a great deal of them are packed in wood. Globalized trade has not brought the last bad news to the shores of this continent.

Workshop Summary

On February 28, 2003, the members of the previous day's scientific panel met with area landowners, foresters, scientists, educators, and government officials to discuss strategies for dealing with the Asian Longhorned Beetle. The workshop addressed three areas of concern.

Likelihood and timing of a "rural invasion" of the Asian Longhorned Beetle

Currently, the Asian Longhorned Beetle is an urban pest concentrated in Chicago and New York City. While the beetle seems to be contained in Chicago, its range is still expanding in the New York area, where it crossed the Hudson River and was discovered infesting trees in Jersey City, New Jersey in October 2002. Most recently it has been found near Toronto, Canada. Therefore, it seems likely that some magnitude of ALB infestation will eventually occur in the natural forest stands of the Northeast.

The workshop participants decided that wind dispersal and the transport of woody materials were the two most probable mechanisms of long-distance movement of ALB into rural areas. Strong winds, particularly hurricane-force gales that coincided with adult beetle emergence in the early summer, have the potential to move beetles over distances as large as the width of Long Island Sound. The transport of infested firewood by private individuals from urban parks and courtyards into rural homesteads and campsites also poses a serious risk.

While quarantines aimed to prevent the spread of ALB have been implemented, the goal of full compliance has yet to be realized and there is a need for more thorough monitoring of unquarantined areas by professionals or volunteers trained in "forensic entomology," who can identify both the beetle and probable signs of infestation.

Recommendations

Provide landowners with a monetary incentive for allowing inspections or bringing in infested trees. Currently, landowners might be hesitant to do either because an ALB infestation might have an adverse effect on their property values.

Educate urban children about nature, ecosystem health, and the threat posed by ALB, since they are often in a unique position to notice imbalances in ecosytems. Additionally, enlist the assistance of sociologists and anthropologists to create education and awareness programs targeted at specific audiences.

Promote public education and awareness via the mass media, such as newspapers, radio, and television. Creating political awareness of the ALB threat is vital to the implementation of effective prevention and eradication strategies. This was a key to the successful management of ALB in Chicago, where the mayor put his support behind awareness programs.

Address the tension between property rights and prevention and eradication efforts via public events, agricultural and forestry extension programs, and person-to-person dialogues between government officials and landowners. Enlisting the compliance and support of landowners is critical in this process.

Appropriate strategies for suburban and rural monitoring and detection

Effective management strategies for ALB are predicated on successful detection, but significant roadblocks stand in the way of implementing monitoring programs. As discussed previously, concerns over property rights and values often make it difficult for inspectors to gain access to private land in order to survey for the beetle. Interest groups acting on behalf of the horticulture, agriculture, and landscape industries can stymie efforts to regulate and control the importation and distribution of plant species that act as vectors for exotic invasive pests. Garnering

public support and awareness of ALB control programs is also difficult because the threat posed by the beetle can be drowned out by a chorus of warnings about other pests such as the Hemlock Woolly Adelgid and Emerald Ash Borer.

Recommendations

Adopt techniques used by public health campaigns—against lead and carbon monoxide poisoning, for example—to recruit rural and suburban landowners, communities, clubs, and organizations via intensive public outreach programs.

Instead of focusing on specific pests, outreach and education efforts should emphasize forest health as a whole. The most effective monitoring programs might be those that draw attention to signs of poor forest health—crown dieback, exit holes, frass piles, and tree scars—rather than individual pest species.

Redirect federal money to state, county, and local governments for the design and implementation of monitoring programs. This would allow communities to customize programs according to local needs, ecosystems, and knowledge. “Tree City” programs could serve as models for detection, tree removal, and incentive initiatives.

Establish port of entry or primary risk sites using Forest Inventory Analysis data, and implement inspection programs in these regions. Also, focus monitoring efforts on areas that could serve as conduits for ALB spread, like the Bronx River or the Metro North commuter rail right-of-way.

Fund monitoring and detection campaigns using a variety of sources such as local “cost of doing business” tariffs or noncompliance fine, from selling infested firewood or harboring infested trees, for instance.

Providing forest landowners and forest managers with information

The most effective means of combating the spread of ALB is to foster awareness of the threat within both the forestry community and general public. The Asian Longhorned Beetle threatens the livelihood of foresters, loggers, and other forest-based industries. Landowners and rural residents have economic, aesthetic, and quality-of-life interests. Therefore, outreach efforts are likely to have a receptive audience, but care must be taken in order to avoid inappropriate, reactionary responses.

The message that should be delivered to the community is one that combines vigilance and patience. Healthy ecosystems and exotic, invasive pests can be viewed as national security concerns, and preventive measures should reflect the serious nature of the threat. Management practices should take a long-term view that focuses on forest health and biodiversity. Because Northeastern forests are approaching maturity in many areas, regenerative silvicultural treatments might be an ideal way to minimize future economic risk while promoting the growth of vigorous, younger stands of mixed species composition. All-aged forests of balanced age class distributions will have reduced susceptibility to invasive pests.

Recommendations

Provide the general public with a clear avenue for contacting professionals via telephone hotlines or the internet. The flow of information should be a two-way street so that the lay public can both provide information and receive assistance and expertise.

Enlist the assistance of groups outside the forestry community—bird watchers, fishermen, hunters, and hikers—who might recognize changes in forest health conditions.

Encourage forestry professionals to be educators, not merely handing out brochures, but also informing the public about what to do and motivating them to take the initiative in prevention efforts.

Resources for More Information

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The Yale Forest Forum (YFF) was established in 1994 by a diverse group of leaders in forestry to focus national attention on forest policy and management in the United States. The group convened the Seventh American Forest Congress (SAFC) to collaboratively develop and articulate a common vision of forest management to diverse stakeholders.

For over 100 years, the Yale School of Forestry and Environmental Studies (FES) has had a rich history in the pursuit of sustainable forestry. From the establishment of the School in 1901 Yale has played an integral role in the development of leaders who are prepared to confront the environmental challenges of the day.

Marsh Hall, home of GISF, on the Yale University campus

The School's Global Institute of Sustainable Forestry (GISF), housed in historic Marsh Hall, continues this rich tradition. Established by the Dean and a group of FES faculty members in 2000, GISF has launched new, innovative initiatives while coalescing and coordinating the many activities related to sustainable forest management at the School, including the School Forests and the Yale Forest Forum. The Institute was created to address the management and conservation of both domestic and international forestlands in a holistic and comprehensive fashion. In pursuit of these ideals, GISF has developed several formal programs including the Program on Private Forests, the Program on Forest Certification, The Forests Dialogue, the Program on Forest Physiology and Biotechnology, the Program on Landscape Management, and the Program in Tropical Forestry.

The Yale Forest Forum is now the convening body of the Global Institute of Sustainable Forestry. Through YFF, GISF often holds multiple events each week at the Yale School of Forestry and Environmental Studies, and hosts workshops and seminars held outside the School, involving stakeholders from all sectors.

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