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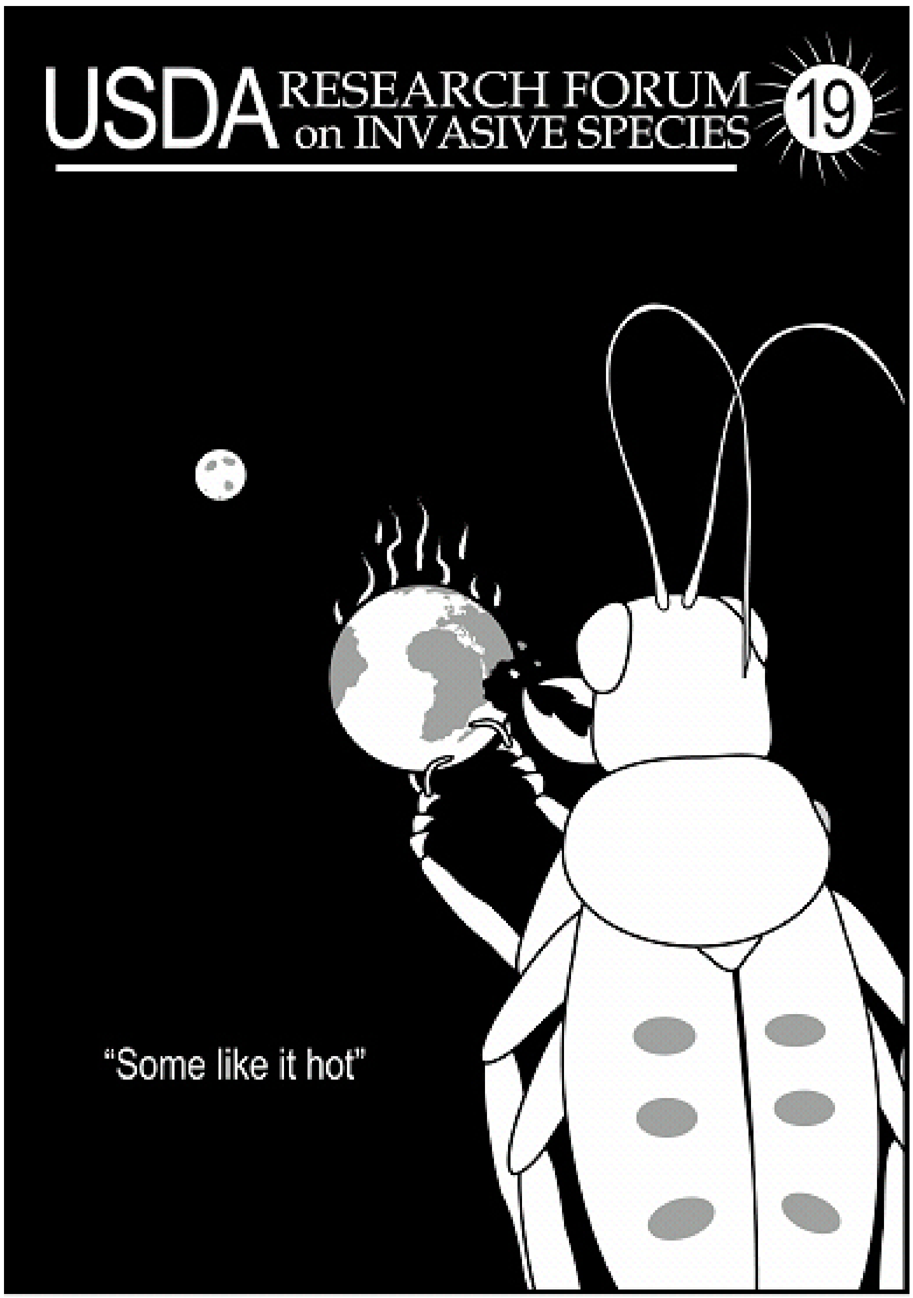

January 8-11, 2008 ○ Annapolis, Maryland

ACKNOWLEDGMENTS

Thanks go to Vincent D'Amico for providing the cover artwork, "Some Like it Hot."

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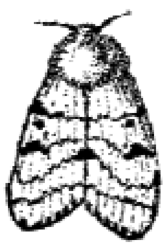
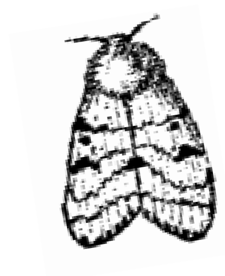


January 8-11, 2008
Loews Annapolis Hotel
Annapolis, Maryland

Edited by
Katherine McManus and
Kurt W. Gottschalk



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CONTENTS

FOREWORD

This meeting was the 19th in a series of annual USDA Interagency Research Forums that are sponsored by the Forest Service, Animal and Plant Health Inspection Service, and Agriculture Research Service. The USDA Interagency Research and Development Coordinating Group's original goal of fostering communication and providing a forum for the overview of ongoing research among the agencies and their cooperators is being realized and facilitated through this meeting.

The proceedings documents the efforts of many individuals: those who organized and sponsored the meeting, those who provided oral and poster presentations, and those who compiled and edited the contributions. This document illustrates the depth and breadth of studies being supported by the agencies and their many cooperators and demonstrates the benefits and accomplishments that can result from the spirit of collaboration.

Acknowledgments

The program committee would like to thank the three USDA agencies, as well as Hercon Environmental, and the Management and Staff of the Loews Annapolis Hotel for their continued support of this meeting.

Program Committee

Michael McManus, Joseph Elkinton, David Lance, Victor Mastro, Therese Poland

Local Arrangements

Katherine McManus

Proceedings Publication

Katherine McManus, Kurt Gottschalk

BEYOND GLOBAL WARMING: ELEVATED CARBON DIOXIDE IS HEATING UP ECOSYSTEM DAMAGE BY INVASIVE INSECTS

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ABSTRACT

Elevated levels of atmospheric carbon dioxide (CO_2), a consequence of anthropogenic global climate change, can have profound effects on the interactions between crop plants and insect pests and may promote yet another form of global change—the rapid establishment of invasive species. Elevated CO_2 increased the susceptibility of soybean plants grown under field conditions to the invasive Japanese beetle (*Popillia japonica*) and to a variant of western corn rootworm (*Diabrotica virgifera virgifera*) resistant to crop rotation by down-regulating gene expression related to defense signaling (lox7, lox8, and acc-s). The down-regulation of these genes in turn reduced the production of cysteine proteinase inhibitors (CystPI), specific deterrents to coleopteran herbivores. Beetle herbivory increased CystPI activity to a greater degree in plants grown under ambient CO_2 than under elevated CO_2. Gut cysteine proteinase activity was higher in beetles consuming foliage of soybeans grown under elevated CO_2 than in beetles consuming soybeans grown in ambient CO_2, consistent with enhanced growth and development of these beetles on plants grown in elevated CO_2. These findings suggest that predicted increases in soybean productivity under projected elevated CO_2 levels may be reduced by increased susceptibility to invasive crop pests.

THEY'RE ALL ALIENS: INTERNATIONAL INITIATIVES TO ADDRESS ALIEN INVASIVE SPECIES

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ABSTRACT

Global forest resources are under attack, not just from native pests, but also increasingly from alien or non-indigenous forest pests that are finding their way to new ecosystems and in some cases causing serious mortality and damage. Examples of these invasions can be found in forests worldwide, and in most cases, the introduction of the pests can be linked to international trade. Many countries have documented the interception of insect pests on imported wood and wood products, and such data indicate that pests are coming from and going to most trading nations. All countries are therefore likely complicit in the international movement of forest pests. As such, it is appropriate and likely most effective if approaches to mitigation of pests are agreed upon and developed at the international level.

Most national and international strategies to address alien invasive species include common elements such as the prevention of harmful intentional and unintentional introductions, the detection and identification of new invaders, and the management of established and spreading invaders through eradication, containment, and control. A number of international groups are active in the research and development of solutions to the spread of alien pests.

One such body is the International Plant Protection Convention (IPPC) Technical Panel on Forest Quarantine (TPFQ). This group is represented by scientists and phytosanitary experts from around the world who review relevant technical and scientific information to provide guidance to the standards committee of the IPPC as requested on development, amendment, and revision of international phytosanitary standards. Such standards encourage contracting parties to the IPPC to "secure common and effective action to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control" and to provide a framework for the development of harmonized national phytosanitary regulations. ISPM 15, the international standard on wood packaging, created before the formation of the TPFQ, was recently revised by the panel. Other tasks include developing criteria for the evaluation of existing and new treatments for inclusion in ISPM 15, and providing advice on the practicality and effectiveness of new treatments. Several new standards are being worked on by the panel: international movement of wood, international movement of forest tree seeds, and forest pest surveys.

Another body that works closely with, but is formally independent of, the IPPC is the International Forest Quarantine Research Group (IFQRG). The IFQRG is an independent science body with an open membership from the science and plant health regulatory communities and industry that carries out analysis and research on international forest quarantine issues. Currently there are about 60 active members from 25 countries. A close relationship has evolved between the TPFQ and IFQRG. As the TPFQ identifies research and scientific analysis gaps through its deliberation of issues, requests are made to the IFQRG. Much of the work of the group has focused on science needs related to the modification and revision of ISPM 15 and to the development of new phytosanitary treatments for wood packaging and other forestry commodities. Current work includes research supporting the development of new treatments of wood packaging and other wood commodities and the development of efficacy testing protocols for use in evaluating existing and new treatments. The IFQRG will continue to respond to the needs of IPPC bodies, providing research supporting the development of new standards.

The North American Plant Protection Organization (NAPPO) is a regional body that coordinates the efforts

among Canada, the United States, and Mexico to protect their plant resources from the entry, establishment, and spread of regulated plant pests, while facilitating intraregional and interregional trade. The NAPPO forestry panel leads the development of regional standards for forest products moving to NAPPO countries, an important mechanism in ensuring an effective perimeter approach to protecting North America. The direct inclusion of Canadian industry in NAPPO forestry discussions ensures that industry concerns are addressed through the development of regional standards. Currently the forestry panel is drafting a standard on Asian gypsy moth, developing a strategy for North American compliance issues regarding ISPM 15, and initiating a standard for the regulatory control of wooden handicrafts.

Finally, there is a relatively new working group within the International Union of Forest Research Organizations (IUFRO): WG 7.03.12, Alien Invasive Species in International Trade. This group examines global forestry issues related to the unwanted international movement of alien invasive species, including fungi, insects, nematodes, and plants. The increasing emphasis on pathways for movement of alien invasive species, including those associated with wood packaging and "plants for planting" provides a broad focus for the work of the group.

Through the combined efforts of these international forest quarantine initiatives, we intend to gain a common recognition of international forest pest issues, foster a cooperative approach to international research, and support the development of internationally harmonized phytosanitary regulations that will result in a reduction in the global movement of forest pests.

GYPSY MOTH SEX IN THE CITY: ESTIMATING COSTS AND LOSSES

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ABSTRACT

Although the gypsy moth (*Lymantria dispar* (L.)), is one of the best studied and best known invasive forest pests, there has been limited research on its impact in urban and suburban environments. This lack of research is surprising because these impacts contribute significantly both to public interest in suppression programs and to economic justification of the Slow the Spread of Gypsy Moth (STS) Project (e.g., more than two-thirds of the benefits in a 1996 cost-benefit analysis). Therefore, we focused on the impacts of gypsy moth in urban and suburban forests, first developing a framework for categorizing and modeling these impacts and then identifying alternative methods for quantifying them.

We developed a three-stage conceptual framework, starting with the first stage, outbreak level (determined by gypsy moth population dynamics, statewide suppression efforts, and conditions for entomopathogens), which in turn led to the second stage, physical impacts, and the third stage, costs and losses imposed on residents. We combined the first and second stages into low and high outbreak scenarios of 3-year duration, with percent defoliation and tree mortality varying by species susceptibility. We can estimate the number of trees in different land uses and size classes that will be defoliated and die under each scenario in specific cities for which UFORE and/or FIA urban data are available (e.g., Baltimore).

The third stage was comprised of (1) out-of-pocket costs and (2) losses associated with reduced utility and increases in other costs. Out-of-pocket costs include averting expenditures for local suppression efforts (e.g., ground spraying of trees), mitigation of nuisance impacts (e.g., treatment of rash, more frequent car washing), and costs of tree removal and replacement. Losses are due to nuisance (e.g., inability to recreate and enjoy the outdoors) and tree defoliation and mortality (e.g., reduced aesthetics, increased energy consumption), conditional on assumptions about tree replacement. Estimates of out-of-pocket costs provide a lower bound for total impacts. Contingent valuation studies that elicit willingness to pay for avoiding outbreaks provide an upper bound. Other methods for estimating the losses specifically from tree defoliation and mortality include appraisal (compensatory value), percentage reductions in urban forest benefits as calculated by UFORE and STRATUM, and hedonic valuation.

PREDICTING DIEBACK IN U.S. FORESTS: CONCEPTS AND APPLICATION OF A FOREST HEALTH DECISION SYSTEM

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ABSTRACT

There are important reasons to predict accurately the onset and progression of forest dieback episodes in the U.S. and elsewhere. These include extensive ongoing dieback and expectations of increased mortality as climate becomes warmer, drier, and more variable. Earlier work showed that dieback episodes in U.S. northern hardwoods are incited by root mortality caused by soil frost; effects of root injury are then exacerbated by drought in the following growing season. A test model is described that uses routinely updated NDVI, snow depth, minimum air temperature, and percent soil moisture to estimate risk of dieback in Maine. A computer animation is made using 10-day updates of these parameters available on the USDA FAS web site (http://www.pecad.fas.usda.gov/cropexplorer) to predict the location and severity of potential episodes in the state. I demonstrate that the changing frequency of winter soil frost and summer drought long term (1920 to 2007) accurately predicts actual dieback levels as reconstructed from field records. Further verification is made using meteorological records from 1991 to 1995 at Portland, ME, to predict a dieback episode there in 1993; both snow cover / minimum air temperature / PDSI and SHAW simulation of soil frost and soil moisture correctly depict the event. I discuss applications of these findings to predict dieback being tracked annually by the U.S. Forest Health Monitoring Program. The goal is to help forest managers identify patterns of risk early to enable timely decisions on intervention and treatment.

ARE ALIEN PLANTS THE ECOLOGICAL EQUIVALENTS OF NATIVES?

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ABSTRACT

Alien plant invasions have been the focus of study for decades, but the impact alien plant invasions have on the insect communities in the ecosystems they invade has not been fully explored. Understanding the relationship between alien plants and native insect herbivores is particularly important because of the essential role insects play in moving energy through trophic levels. This study compared the degree to which alien and native herbaceous plants supported native insect generalists and their natural enemies in a common garden setting. We measured the biomass, abundance, and species richness of insect herbivores, predators, and parasitoids produced on six species of native plants and six species of alien plants over 2 years in Newark, DE. Insects were sampled by collecting whole plants in bags, bringing bagged plant samples into the lab, and removing the insects. Insects were identified to species whenever possible, classified according to feeding guild, dried, and weighed. Leaves were removed from plants, dried, and weighed. Insect community parameters (biomass, species richness, and abundance) were controlled for plant biomass to account for variations in plant biomass. Alien plants consistently produced significantly less insect biomass, abundance, and species richness per gram of plant material than native plants. These results suggest that alien plants do not always perform the same ecological functions as the native plants they replace. Alien plants in this study did not support critical components of terrestrial food webs as well as native plants. Additionally, these results document that generalist insect herbivores are not catholic enough in diet breadth to compensate for the loss of insect specialists in alien plant communities.

PHENYLOXIDASE PRODUCTION BY *AMYLOSTEREUM AREOLATUM* AND ITS ROLE IN PATHOGENESIS IN LOBLOLLY PINE

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ABSTRACT

The woodwasp *Sirex noctilio* and its symbiotic fungus *Amylostereum areolatum* constitute an exotic pathosystem recently introduced into North America. Capable of killing living, healthy trees, *S. noctilio* has ravaged pine plantations of the Southern Hemisphere and poses an immediate threat to the conifer forests of the United States, notably the commercially important loblolly pine (*Pinus taeda* L.) forests of the Southeast.

Our investigations have shown that the fungus involved in the symbiosis, *A. areolatum*, produces enzymes capable of oxidizing the phenoloxidase substrates, ABTS, guaiacol, and syringaldazine, in solid media and ABTS in liquid media. The responsible enzymes are likely laccases, as well as one or more peroxidases. We hypothesize that:

1. *Amylostereum areolatum*, like many other white-rot fungi, produces laccase.

2. This laccase is involved in the pathogenicity of the fungus to loblolly pine.

We have developed and optimized a defined medium for culturing *A. areolatum* in the laboratory and are currently establishing growth curves for the fungus. Conditions have been established to increase dry weight of mycelium, as well as increase phenoloxidase enzyme production. We have also established a bioassay system with *P. taeda* seedlings to demonstrate susceptibility to *A. areolatum* infection.

To more completely investigate the role of specific phenoloxidases in the disease process, we are working to isolate *A. areolatum* mutants that do not express these enzymes. Subsequent work will focus on characterizing the enzymes involved, as well as elucidating the specific role played by these enzymes in the disease process. Having a better understanding of the specific interactions between individual players in this pathosystem will enable us to pursue multiple approaches to subverting key interactions, which should provide a more powerful approach to tree protection.

CHEMICAL ECOLOGY OF *SIREX NOCTILIO*

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ABSTRACT

The woodwasp *Sirex noctilio* Fabricius (Hymenoptera: Siricidae) is native to southern Europe, North Africa, and the Near East. It was detected as a pest at the beginning of the last century in New Zealand and has spread out to Australia, South America, South Africa, and North America since then. *Sirex* was found in New York State in 2004, and it reached Pennsylvania (Tioga County) last year. Three major host species in North America are red pine (*Pinus resinosa*), Scots pine (*P. sylvestris*), and white pine (*P. strobus*). Female wasps attack weak or stressed trees and lay up to 500 eggs 10-12 mm deep into the outer sapwood. Adults typically emerge the following year, but the larvae can spend over 2 or 3 years in the tree making galleries as they move. The fungal symbiont *Amylostereum aerolatum* is introduced into the tree by the female during oviposition and is necessary for larval growth and development. The fungus digests cellulose and lignin, disrupting the vascular system and thus killing the tree. Female wasps also inject mucus, which facilitates the spread of the fungus.

Although Siricids are well known for attacking stressed pine and many of the volatile components of pine resin have been shown to elicit response in the antenna of *S. noctilio* (Madden 1988, Simpson 1976, Simpson and McQuilkin 1976), it is still unclear what compounds attract the wasp to the host. To date, the most efficient way to monitor the spread of the woodwasp has been the use of girdled or herbicide-treated pine as a lure. The composition of the volatile blend emitted by the trunk differs from that emitted by the needles (Manninen et al. 2002), and it is the trunk volatiles that attract the females. Therefore, we have developed a non-destructive volatile collection system that can be used in the field to find the active components. Volatile organic compounds (VOCs) are trapped on a small filter containing a polymer adsorbent and are washed off with a solvent. The solutions are analyzed at the lab using gas chromatography techniques.

Over the last 2 years, we have collected VOCs from trunks and needles of healthy and stressed Scots pine and red pine. Furthermore, volatiles have been collected from trees on which female wasps have oviposited. Compounds have been identified based on their retention index and mass spectrum. Typical compound groups are aromatics, green leaf volatiles (GLVs), monoterpene hydrocarbons, oxygenated monoterpenes, sesquiterpene hydrocarbons, and oxygenated sesquiterpenes. Major monoterpenes in both pine species are α-pinene (40-80% relative amount), β-pinene (1-20% relative amount), and δ-3-carene (1-50% relative amount). Red pine samples contain the oxygenated monoterpenes camphor and 3-pinanone in addition to the usual monoterpene hydrocarbons α-pinene, α-fenchene, camphene, β-pinene, β-myrcene, δ-3-carene, limonene, and β-phellandrene. In Scots pine, we distinguish between two different chemotypes: Δ-3-carene producers and non-producers (Thoss et al. 2007). The most abundant sesquiterpenes were α-longipinene, α-copaene, β-cubebene, α-muurolene, γ-cadinene, and δ-cadinene.

We found that the overall volatile emission of herbicide-treated pines was significantly higher than that of healthy ones. Moreover, the time span between the treatment and the date of volatile collection had an effect on the quantity of VOCs emitted. The samples from 2007 were collected 3-4 weeks after treatment and contained five times as much VOCs as the samples from 2006, collected 7-11 weeks after the treatment. The volatile profile of Scots pine needles is different from that of the trunk. The compounds 2-hexanol, hexanal, (*E*)-2-hexenal, (*Z*)-3-hexenol, eucalyptol, and (*E*)-β-farnesene are needle specific.

When female wasps were caged on Scots pine for 10 days, the volatile emission of the trunk below the caged area

increased within 5 days. After removal of the females, we observed elevated levels of monoterpenes over the previously caged area as well, although it might have been partially due to the resin flow induced by oviposition. Treated pines of the Δ-3-carene producing chemotype emitted increased amounts of α-pinene and Δ-3-carene, whereas the non-producer ones emitted increased amounts of α-pinene and β-pinene. Emission levels gradually decreased over 4 weeks after treatment.

Cuticular hydrocarbons (HCs) of insects are key compounds in nestmate and kin recognition as well as in courtship behavior (Wyatt 2003). Within the order of Hymenoptera, females of Vespid wasps and parasitic wasps have been shown to use contact pheromones on their cuticle (Ayasse et al. 2001). Qualitative and quantitative differences were found in the cuticular hydrocarbons of the female and male woodwasp. Unsaturated hydrocarbons are more abundant in the female body wash, whereas methyl-branched hydrocarbons dominate in the male extract. Behavioral assays show that the mixture of female cuticular hydrocarbons extracted with hexane induces mating behavior of males. It is possible to separate the female cuticular HCs based on the degree of unsaturation and testing these fractions with males.

We have analyzed the volatile profile of herbicide-treated and healthy pines to investigate host location of the woodwasp *Sirex noctilio*. It seems to be primarily the quantity of VOCs emitted that distinguishes a stressed pine from a healthy one. Different doses of the major monoterpenes are being tested in trapping experiments. Moreover, we have behavioral evidence that the female body wash contains substances that act as mating stimulants. The identified active compounds could be used in trapping males, possibly in combination with a volatile lure.

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ECOSYSTEM URBANICITY AS A POTENTIAL FACTOR FOR ALIEN SPECIES INVASIONS

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ABSTRACT

One of the major challenges we face in relation to invasive species is to understand and incorporate the complexity of the human dimension in our preparedness to minimize the risk and impacts of invasions. The challenge is not actually to achieve a high level of understanding, but rather to increase our understanding fast enough so we can help managers in the short term to implement measures that mitigate the potential for invasions or reduce their impacts. To this end we began analyzing past and current human-mediated invasions by alien forest pests. The goal was to detect patterns that would allow us to develop potential indicators of future invasions. We made the assumption that most factors linking humans and invasive species were related to urban areas. After all, urban areas are hubs of acquisition, processing, and distribution of international and domestic goods. In addition, urban areas are the places where most international passengers arrive. Thus, it follows that the intensity of the interactions between forest ecosystems and urban centers would contribute to risk of accidental introductions of alien forest pests. Using this rationale, we developed the concept of "ecosystem urbanicity," which we define as the degree of potential exposure by ecosystems to urban-driven interactions. In developing a quantitative approach to this concept, we considered two factors as the main drivers of ecosystem urbanicity: (a) the proximity of forest ecosystems to urban areas, and (b) the size of the neighboring urban populations.

For this study we assessed the usefulness of the ecosystem urbanicity concept in relation to alien invasive species in forest ecosystems. First, we quantified the ecosystem urbanicity of county-level forest land in the contiguous U.S. Then we analyzed the patterns of ecosystem urbanicity for those counties where selected alien forest pests were reported in recent years. For this study, we focused on four invasive species: the Asian longhorned beetle (*Anoplophora glabripennis* (Motschulsky)), the emerald ash borer (*Agrilus planipennis* Fairmaire), the Sirex woodwasp (*Sirex noctilio* Fabricius), and the sudden oak death pathogen (*Phytophthora ramorum* S. Werres, A.W.A.M. de Cock). The areas considered for the analysis are shown in Figure 1.

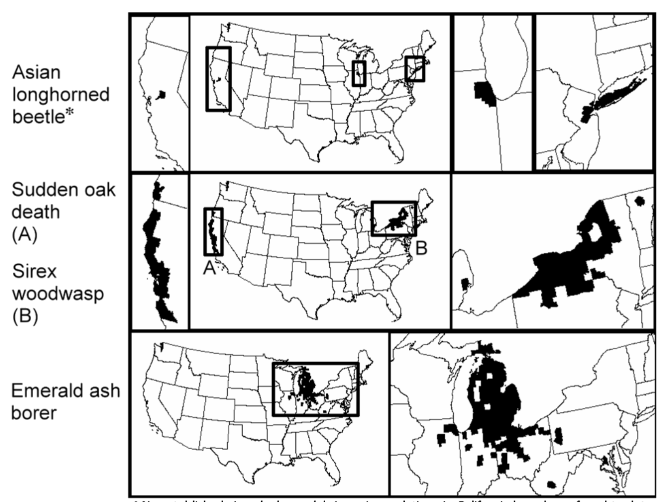

Figure 1.– County detection reports (black) for four invasive species in the contiguous U.S. as of December 2007.

The equation used to quantify ecosystem urbanicity or more specifically forest urbanicity was as follows:

$$FUI_i = \log_{10}\left(1 + k^{-1}\sum_{j=1}^{k}\frac{P_j}{D_j}\right)$$

where FUI_i is an index of forest urbanicity for the i^{th} county, k was the number of urban areas adjacent to the i^{th} county, P_j was the population size in the j^{th} adjacent urban area, and D_j was the shortest distance between the forest centroid in the i^{th} county and the j^{th} adjacent urban area.

The population numbers and locations of urban areas were obtained from the U.S. Census Bureau. Forest ecosystem centroids were determined based on the concentration of forest land within a county. The location of forest land was obtained after combining the deciduous, evergreen, and mixed forest classes of the 2001 National Land Cover Data (Homer et al. 2007).

The resulting ecosystem urbanicity index for forest lands in the contiguous U.S. is shown in Figure 2. The closer their proximity to urban areas and the greater the size of the urban populations, the higher the ecosystem urbanicity values. As expected, large portions of the country exhibited low values (less than 0.5), while the highest values clustered around large population centers. When we analyzed the ecosystem urbanicity values of the counties encompassing the areas highlighted in Figure 1, we found that more than 75 percent of those counties had ecosystem urbanicity values above 0.5 (Fig. 3). Moreover, we found that several of the counties where the four selected pests were detected during the first year after initial discovery had ecosystem urbanicity values greater than 1.

There are many practical implications of these findings. Hypothetically, if we had concentrated our monitoring efforts solely in counties within the top 15 percent of the ecosystem urbanicity scale, we would have detected all four of the selected species. The counties in the upper 15 percent of the ecosystem urbanicity scale represent for the contiguous U.S. approximately 10 percent of the forest land, 45 percent of the nursery/floriculture farms, 20 percent of woodland crop farms, 70 percent of foreign cargo tonnage associated with forest pest interceptions, and 99 percent of the international passengers arriving in the U.S.

Although an ecosystem urbanicity framework may not explain the underlying mechanisms driving human-mediated invasions, this concept appears to capture the influence of those mechanisms. Thus, in the short term, this framework could help managers design and implement monitoring efforts aimed at early detection of invasive forest pests. From a research perspective, this framework facilitates delimitation of geographic areas where human-mediated interactions are occurring (i.e., in areas in close proximity to urban areas). This in turn helps to focus research and enhances our ability to uncover the processes behind human-mediated invasions. More work is underway to refine the measurement of ecosystem urbanicity as used in this paper and to extend its application to invasive species in agricultural and aquatic ecosystems.

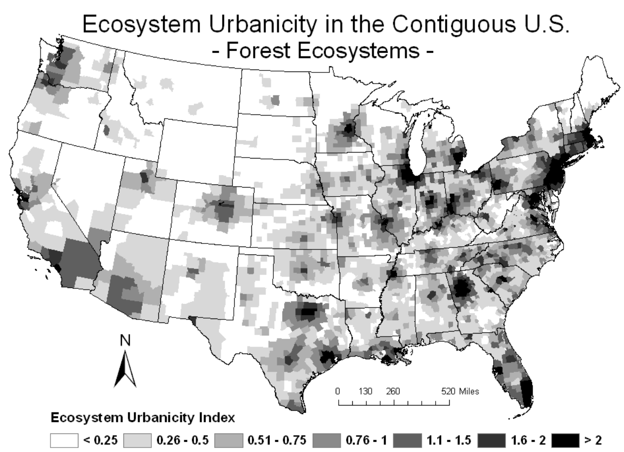

Figure 2.–Ecosystem urbanicity of forest ecosystems in counties within the contiguous United States.

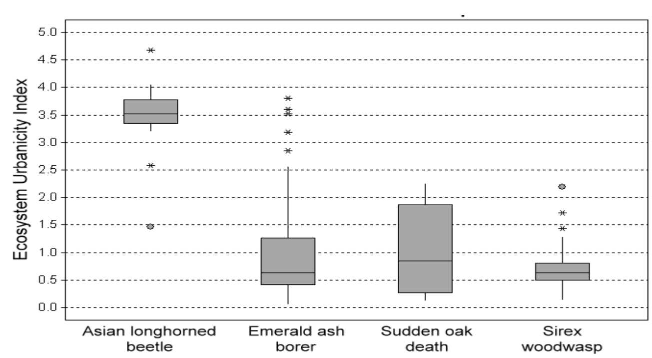

Figure 3.–Box-whisker plots of eocsystem urbancity values for those counties in the contiguous U.S. where four alien invasive species were detected.

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DISPERSAL AND DYNAMICS OF THE WOODWASP *SIREX NOCTILIO* IN ARGENTINA

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ABSTRACT

Sirex noctilio F. (Hymenoptera: Siricidae) is probably the most important pest of softwood plantations in the Southern Hemisphere. Native to Eurasia, this wood-boring, solitary wasp in the last century successfully invaded South Africa, Australia, New Zealand, and South America. More recently, the species has been found along the east coast of North America. Characteristic of the species is the occurrence of severely damaging, pulse-like eruptive population outbreaks.

In Patagonia (Southern Argentina), pine trees (mainly *Pinus ponderosa*) are increasingly being planted in steppe areas. Currently, plantations in this region cover nearly 60,000 ha of which most bear established populations of *S. noctilio*. The first recordings of this pest in the region date back to the early nineties. Since then, woodwasp populations seem to have spread at approximately 9 to 14 km per year, a much slower rate than that observed in Australia and South Africa (J. Corley and A. Liebhold, unpub.data).

To understand local population dynamics and dispersal of wasps, we summarize here our recent study of the spatial redistribution of attacked trees within a *Pinus spp.* plantation. Then, we report on our work on the potential dispersal capacities of *Sirex noctilio* females, and how this is influenced by the introduction of biological control measures. Our emphasis is on summing up recent ecological and behavioral studies of this forest pest carried out in Patagonia. Our aim is to help increase our understanding of wasp spread and improve our abilities to manage expanding populations, especially in more recently invaded areas.

Local spatial dynamics. Spatial dynamics of *S. noctilio* were studied within two independent patches of pine stands, adding up to a total of 70 ha. Invasion by *S. noctilio* had occurred recently at the site, and through a census of all trees in the plantation, we were able to map attacked trees for 3 successive years. Dating of attack was based on tree symptoms (for details on the methods, refer to Corley et al. 2007). Using buffer areas drawn from the oldest attacked trees with GIS tools, we were able to tally and establish the distance at which trees attacked the following season were encountered. The results show that 50 percent of trees attacked in the latest years (years 0 and -1) were found at less than 60 m from the oldest attacked individuals (trees attacked in year -2), and 90 percent were found within a 120-m radius (Fig. 1).

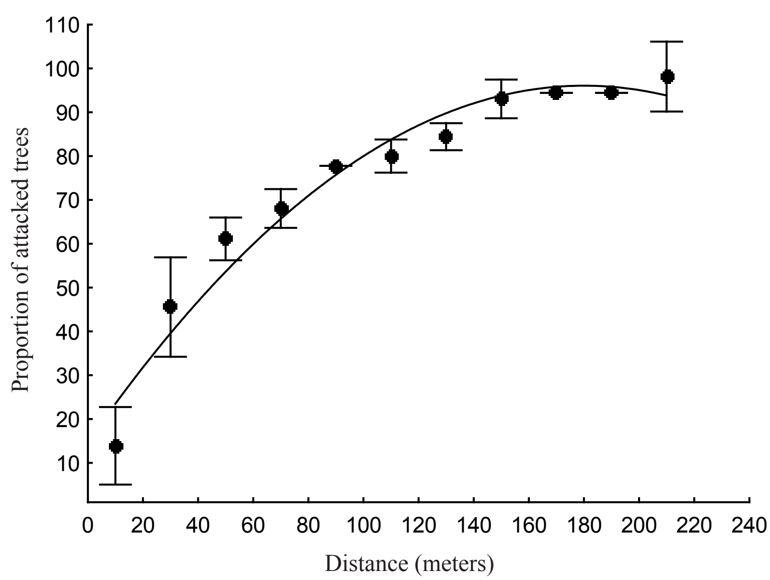

Figure 1.–Proportion of trees attacked by *Sirex noctilio* wasps in recent years (years -1 and 0) with respect to those attacked at a previous time (year -2). Number of attacked trees was estimated through a census of a 70-ha pine plantation in Northwest Patagonia. The figure shows that most new attacks are found close to previous attacks.

Spatial statistics of this database reported elsewhere (Corley et al. 2007) indicate that spatial aggregation of *S. noctilio* infestations during the early stages of pest colonization was strong. Also, the spatial pattern of attacked trees shows a tendency to increase aggregation, together with an increase in the number of attacked trees, throughout the 3 consecutive years studied. The spatial aggregation of woodwasp attacks may relate to the observed population dynamics, as was shown recently through spatially explicit, individual-based models (Aparicio et al., in prep.). Also, reported strong spatial aggregation should be taken into account when designing sampling protocols of damaged trees as well as during the introduction of the nematode *Beddingia* (=*Deladenus*) *siricidicola* (Tylenchida: Neotylenchidae) on the main natural enemies used in wasp bio-control programmes.

Long distance flight potential. Flight potential of *S. noctilio* females was studied on individuals tethered to flight mill devices. Details of the flight mill design and the program designed for collecting the output data are given in Villacide and Corley (in review). Individuals used were recently emerged females, collected from cages holding 1-m-long billets obtained from several *Pinus contorta* var. *latifolia* trees recently attacked by *S. noctilio*, from plantations located in Northwest Patagonia. Before and after flight, each female was weighed (*Scientech SA210*; d: 0.0001 g.). We recorded the accumulated flight distance (in kilometers) and flight speed (in meters/second) during a period of 23 hours for 28 wasps. The effects of infection by the nematode on flight parameters were studied separately by flying 46 (22 infected and 24 uninfected) female wasps. Infection status was determined after flight by dissecting wasps and inspecting their abdomens under a stereo-microscope.

The flight parameters of *S. noctilio* were highly variable between individuals, with some females able to perform long flights. The average distance flown by a wasp during the 1- day-long trial was 17.4 km with a maximum of 49.7 km and a minimum of 1.1 km. The average speed for all wasps was 0.37 m/s, but most of the time individuals remained at rest. In a related paper (Bruzzone et al., in prep.), we show that wasps display different flight patterns that relate closely to initial body size (Fig. 2).

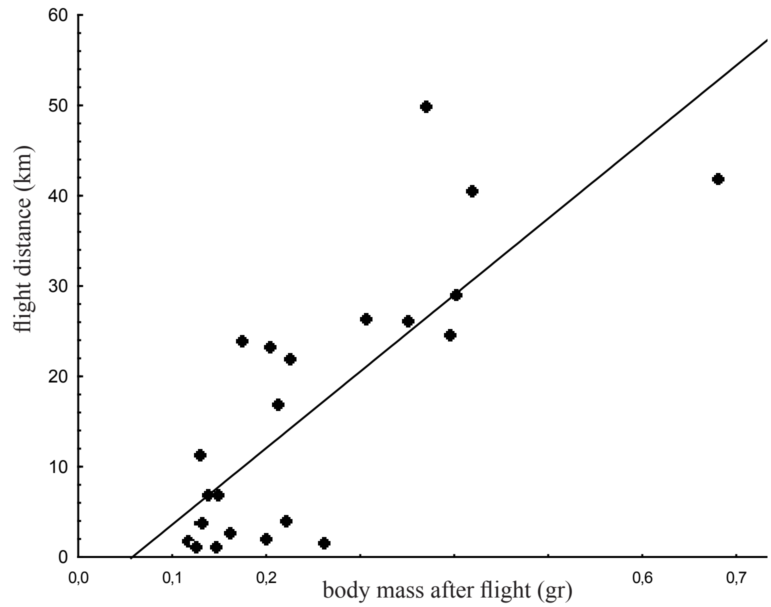

Figure 2.–Distance flown by 28 tethered female *Sirex noctilio* wasps as a function of initial body size ($r^2 = 0.6354$, $p = 0.000003$). Flight was performed in flight mills during a 23-hour-long period. The figure shows that larger wasps are capable of longer flights.

Through a separate set of experiments, we observed that nematode-infected *S. noctilio* females showed reduced flight performances compared to control wasps. The average maximum speed recorded for parasitized individuals was 0.79 m/s, in contrast with the 1.16 m/s observed for uninfected females. Similarly, we observed a marked difference in between infected and uninfected females in the total flight distances displayed (infected wasps flew 16.1 km while uninfected wasps flew 30.5 km), but reduced flight capabilities are probably a consequence of the effects of parasitism on wasp adult size (Villacide and Corley, in review).

Our results show that *S. noctilio* woodwasps have a variable flight behavior, which relates to initial body size. In turn, parasitism by *Beddingia siricidicola* has significant consequences on flight performance of *Sirex noctilio* wasps through its effects on adult body size. Smaller, parasitized females displayed lower flight speeds and shorter flight distances than larger (and healthy) individuals.

In conclusion, while a strong, local demographic aggregation may help explain observed outbreaking population dynamics and successful establishment of *Sirex noctilio* in invaded regions, the contribution of female dispersal potential to wasp geographical spread should not be disregarded. From an applied perspective, we underline the contribution of knowledge on the spatial distribution of attacked trees and wasp flight potential for the designing of sampling protocols and the introduction of natural enemies for the biological control of this important forest pest.

Acknowledgments

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THE EFFECT OF A MUTATION ON FIELD TRANSMISSION OF LDMNPV

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ABSTRACT

Gypchek is a baculovirus-based insecticide produced by the U.S. Forest Service. This biopesticide is species-specific to the gypsy moth and contains as an active ingredient the *Lymantria dispar* nucleopolyhedrovirus, also known as the gypsy moth virus or LdMNPV. Currently, Gypchek is a mixture of many strains of LdMNPV, produced in vivo, and refined into a usable product at our facility in Ansonia, CT. From 2003 to 2006, we conducted a number of field experiments designed to determine if a single strain of LdMNPV might be suitable to use as a replacement for the current mixture. Additionally, research has been conducted in Delaware, OH (J. Slavicek) toward producing the virus in vitro. Central to our testing methodology was the bugs-in-bags experiments in which virus was applied to branches as infected first-instar larvae or as a sprayed product. Branches with approximately 40 leaves were selected on oak trees in the Cedar Swamp State Wildlife Management Area near Smyrna, DE. These branches were then enclosed in mesh bags with 25 third-instar test larvae representing bugs that would be eating contaminated foliage in the field. After 1 week in the field, branches were cut off trees and returned to the lab. Test larvae were removed to individual diet cups where they were reared for 3 weeks and necropsied if they died.

SIREX NOCTILIO IMPACTS ON NATIVE AND EXOTIC PINE STANDS IN THE NORTHEASTERN UNITED STATES

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ABSTRACT

Sirex noctilio F. (Hymenoptera: Siricidae) was detected in North America during a 2004 exotic species survey conducted in New York. *S. noctilio* has also been detected in Michigan, Pennsylvania, and Vermont, and a large portion of southern Ontario is positive for *S. noctilio*. This large geographical area of positive *S. noctilio* detections represents a region where several important native pine species grow including red pine (*Pinus resinosa* Ait.), white pine (*Pinus strobus* L.), and jack pine (*Pinus banksiana* Lamb.). The non-native Scots pine (*Pinus sylvestris* L.) was also planted throughout this area and is still a component of landscapes today.

While *S. noctilio* has been problematic in Southern Hemisphere countries where pines are planted in even-aged pure stands, it is unknown how this insect will behave in North American pine ecosystems. North American pine ecosystems have well-developed invertebrate and fungal communities that will compete, prey upon, and/or parasitize *S. noctilio*. Understanding *S. noctilio* behavior in northeastern U.S. and southern Ontario forests is important in determining the potential economic and ecological impact this insect will have on regional forests.

Forest stand assessments are currently underway in New York and are planned in southern Ontario by the Canadian Forest Service. The objectives of this study are to (1) describe stands attacked by *S. noctilio*, (2) assess the ecological impact of *S. noctilio* on these stands, and (3) describe the growth history of attacked and un-attacked trees in infested stands. Fixed-radius plots were placed throughout infested stands in the Syracuse, NY, area during 2006 and 2007 to describe vegetation (tree spp., d.b.h., live crown ratio, etc.) and *S. noctilio* activity. To determine the presence of *S. noctilio* in a stand, trees were checked for characteristic resin beading and round exit holes that are diagnostic for this insect. Resin beading on red and Scots pine can easily be differentiated from damage caused by native insects, but round exit holes are more problematic. Because of a concern for confusing *S. noctilio* exit holes with those of native insects (e.g., Cerambycidae, native Siricidae), we attributed tree mortality to *S. noctilio* for only a 2-year period. Trees that had fresh resin beading were considered attacked during the current year, while trees that had round exit holes, some crown remaining, and signs of older resin beading were considered attacked the previous year. A subsample of attacked and un-attacked trees was selected and increment cores were removed from breast height. On each of these cored trees, the height of the base of live crown and total tree height were measured and live crown ratios determined.

In general, the data collected and analyzed thus far suggest infestation patterns in red and Scots pine were similar. Stands that had *S. noctilio* attacks were overstocked (33-44 m^2/ha basal area) and generally in poor condition. In these stands, it appears that *S. noctilio* is preferentially attacking trees under 16 cm d.b.h. However, some larger trees (> 26 cm) have also been successfully colonized but much less frequently than smaller trees. Increment cores from one stand indicated that attacked trees were growing at about half the rate of un-attacked trees over the 10-year period before *S. noctilio* colonization. Increment cores from other infested stands are currently being analyzed. Attacked trees also had approximately one-half the live crown ratio of un-attacked trees.

At this point in the invasion, *S. noctilio* is behaving similarly to endemic population patterns documented

in Southern Hemisphere countries where this species is invasive. Suppressed trees in unthrifty stands seem to be the focus of attacks. However, in other countries, epidemic *S. noctilio* populations are reported to move into more vigorous tree classes as populations build in an area. While we have not yet observed this high level of tree mortality documented in other countries, long-term monitoring of infested forests should be conducted to follow population patterns over time.

While *S. noctilio* in the Northeast is behaving like a secondary species at this point, it is unknown how this insect will respond to forest ecosystems in other parts of North America. Forests and landscapes in the known *S. noctilio* positive area are diverse compared to parts of the world where this insect has been problematic. As *S. noctilio* populations spread south and west in North America, larger blocks of contiguous pine forests will be encountered that are more similar to areas where this species has been economically damaging.

HAZARD ASSESSMENT SURFACES FOR *PHYTOPHTHORA ALNI* SUBSP. *ALNI*

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ABSTRACT

Special acknowledgements go to Dr. Thomas Jung for his contributions in assessing the hazard of *Phytophthora alni* in the conterminous United States. His knowledge, expertise, and intelligent reasoning contributed greatly to this project and guided our assumptions in modeling the hazards. We wish to recognize one specific difference in our model assumptions: the hazard from planting alder in the U.S. may be manifested differently than in Europe. It seems more likely that the hazard will come from nurseries receiving infested plants and the delivery of infested plants to the general population, not from direct planting of alder in natural forests.

Phytophthora alni subspecies *alni* (PAA) is currently present throughout Europe and spreading. The potential susceptibility for *P. alni* was mapped for the conterminous United States in 1-km2 units by the U.S. Forest Service, Forest Health Technology Enterprise Team's (FHTET) PAA Invasive Species Steering Committee. The map is intended for use in developing a detection strategy for monitoring PAA.

Assumptions in developing the susceptibility product included the following: (1) *Alnus* species in North America are susceptible to PAA, (2) PAA can be transported into the United States on either host or non-host bare root stock, (3) PAA introduction will most likely occur at nurseries or through horticultural plantings in or near municipalities, (4) *Alnus* species will be highly susceptible to PAA on sites that tend to be wet.

UPDATE ON WINTER MOTH IN NEW ENGLAND

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ABSTRACT

The winter moth *Operophtera brumata*, a leaf-feeding geometrid native to Europe, recently invaded eastern New England and is causing widespread defoliation. Previous invasions by this species in Nova Scotia and British Columbia have been suppressed by the introduction of two parasitoids from Europe, the tachinid *Cyzenis albican* and the ichneumonid *Agrypon flaveolatum*. As a result of these introductions, low-density populations of winter moth now persist indefinitely in these regions similar to those that exist in Europe. Over the past 3 years, we introduced *C. albicans* at three locations in Massachusetts, and in 2007 we recovered the first parasitized larvae at our release site in Falmouth, MA. With the help of colleagues at the USDA APHIS lab at Otis Air Base, we are developing a mass rearing program for this tachinid and its winter moth host on artificial diet so that we can release large numbers of this parasitoid at many locations in the future. We focus our efforts on *C. albicans* because it specializes on winter moth and it is thought to be the agent primarily responsible for the decline of winter moth densities in Canada. We have established long-term monitoring plots where we will quantify densities of winter moth life stages and document parasitism before and after establishment of *C. albicans.* We conducted a survey for winter moth across southern and eastern New England with pheromone-baited sticky traps beginning in November 2005. We expanded this survey in 2006 and 2007 to include the entire Northeast from Pennsylvania to Nova Scotia. The traps attracted both winter moth and the North American congener of winter moth, Bruce spanworm (*Operophtera bruceata)*. We used dissection of male genitalia to distinguish between these two species. In New England, we recovered winter moths at sites that stretched from eastern Long Island, southeastern Connecticut, all of Rhode Island, to eastern Massachusetts, coastal New Hampshire, and southern coastal Maine. We caught winter moths in areas that were at least 100 km from any areas known to be defoliated by winter moths. Traps further west and north and south caught exclusively Bruce spanworm. We confirmed these identifications by sequencing the CO1 mitochondrial gene of specimens of these two species. This technique does not distinguish between possible hybrids of these two species, a matter that will require further analyses. The survey in 2007 showed that winter moth occurs in Nova Scotia but not in interior areas of Maine or New Brunswick. We suspect that winter temperatures may prevent winter moth from invading these regions. Winter temperatures in Nova Scotia are very similar to those in southern New England.

UNITED STATES *SIREX* WOODWASP PROGRAM UPDATE

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ABSTRACT

On February 19, 2005, an exotic woodwasp was found in a sample collected as part of the USDA Animal and Plant Health Inspection Service (APHIS) Cooperative Agricultural Pest Survey (CAPS). The identity of the suspect woodwasp was confirmed by the Systematic Entomology Laboratory in Beltsville, MD, 4 days later as a female *Sirex noctilio* Fabricius. This specimen was originally collected on September 7, 2004, from a Lindgren funnel trap placed among mixed hardwoods and pine just inside a forest edge adjacent to a recreational field located in Fulton, NY (Oswego County).

As a followup to the detection of *S. noctilio*, extensive delimiting surveys were conducted in 2005-2007 in New York, in surrounding Northeastern States, and in nearby Great Lakes States. Additional detection surveys were conducted at U.S. ports-of-entry and in numerous states via CAPS and U.S. Forest Service surveys. To date, *S. noctilio* has been detected in 2 Michigan counties, 29 New York counties, 6 Pennsylvania counties, and 1 Vermont county. In 2008, APHIS plans to continue surveys in high risk areas of the Northeast and in Great Lakes States, as well as throughout the U.S. via cooperative surveys.

Sirex noctilio is a pest of *Pinus* spp. that is of regulatory concern to the U.S. Based on the findings of a Pest Risk Assessment, an economic analysis by the Forest Service, and the recommendations of the USDA *Sirex* Science Panel, APHIS Plant Protection and Quarantine (PPQ) is developing domestic and international regulations to slow the spread of *S. noctilio*. The movement of untreated pine commodities that originate in *S. noctilio*-infested areas will be regulated.

APHIS PPQ is investigating a promising biological control agent, *Beddingia siricidicola*, which is currently used in several other counties for effective control of *S. noctilio.* Three pilot studies using the *Sirex* biocontrol nematode have been conducted in two different states. Until all required environmental documentation is complete, experimental logs inoculated with the biocontrol nematode will be safeguarded and removed from the field before *Sirex* emergence.

For further information, refer to the APHIS Sirex web page at: http://www.aphis.usda.gov/plant_health/plant_pest_info/sirex/background.shtml

THE EFFECTS OF THINNING AND GYPSY MOTH DEFOLIATION ON WOOD VOLUME GROWTH IN OAKS

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ABSTRACT

Stem dissection and dendroecological methods were used to examine the effects of thinning and defoliation by gypsy moth (*Lymantria dispar* L.) on wood volume increment in oaks (*Quercus rubra* L., *Quercus alba* L., *Quercus prinus* L.). A model was developed to evaluate radial volume increment growth at three time periods: before defoliation, during defoliation, and after defoliation, as a function of species, defoliation intensity, and crown position. Volume increment during these same periods was also compared at different stem locations. Trees were defoliated for 2 consecutive years, and results indicated that volume loss was greater during the second year of defoliation with complete recovery taking 2-3 years after defoliation. Oaks in thinned stands had reductions in annual volume increment during defoliation similar to those in the unthinned stand. Annual volume increment demonstrated a decreasing trend from stump to base of the live crown, and volume increment of the lowest log (from stump height to 1.37 m) was always higher than that of upper log sections, even during defoliation. Both earlywood and latewood increments were reduced during defoliation; however, latewood reductions were distributed along entire stems while earlywood reductions were greater on upper stem sections within the crown.

RIPARIAN CORRIDORS AS POTENTIAL BIODIVERSITY REFUGIA

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ABSTRACT

Forested corridors are used to protect streams from agricultural pollution and runoff. Corridors may also encourage terrestrial and aquatic biodiversity by providing habitat in suburban and agricultural landscapes, increasing connectivity of fragmented patches, and excluding invasive plants. Surprisingly, current guidelines for corridor construction are based on limited quantitative data. The goal of this study was to determine if and how forested buffers can be effectively used to preserve native biodiversity.

In March 2006, we conducted a pilot study of soil chemistry across buffers at twelve 1,000-m transects along forested stream corridors in and near Newark, DE, in agricultural and suburban/urban environments. After this pilot study, we decided to focus on one watershed in hopes of minimizing variance within the study area. In the summer of 2007, we collected soil samples, aquatic macroinvertebrate samples, and invasive plant densities at 36 study sites located on first-order and second-order streams throughout the White Clay Creek watershed.

Analysis of data collected is ongoing, and these measurements will be repeated in the summer of 2008. Preliminary data from the pilot study and supported by initial results from further soil tests suggest that nutrients such as phosphates, nitrates, and ammonium might be filtered effectively by forested riparian corridors. At the same time, no statistically significant correlation between buffer width and aquatic macroinvertebrate community integrity is immediately apparent. Macroinvertebrate identification is incomplete at this time, and ongoing analysis may yet reveal an impact of buffer width on stream biota.

Further analysis of data collected last year and data collected this coming summer is necessary to reach any conclusions about the effectiveness of riparian corridors as refugia for native biodivty.

EMERALD ASH BORER: IS THE CAMPING PUBLIC AWARE OF EMERALD ASH BORER AND ISSUES RELATING TO THE MOVEMENT OF FIREWOOD?

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ABSTRACT

The exotic emerald ash borer (*Agrilus planipennis* Fairmaire) was identified in Michigan in 2002 and has since been found in a number of other states. This insect has killed millions of ash trees (*Fraxinus* spp.) and continues to be found in new locations. A key goal in managing emerald ash borer is to reduce artificial spread through the movement of the insect to new locations in firewood. Inspections of firewood in state and federally operated campgrounds have revealed that ash firewood is still being used and is likely being moved around the state. Public education campaigns have been implemented to inform people about emerald ash borer and associated firewood regulations in Michigan. These educational programs use media that include fliers, billboards, radio and television advertisements, and newspaper articles.

During the summer of 2006, two types of questionnaire-based surveys were conducted at state park campgrounds throughout Michigan to (1) determine public awareness of the regulations associated with the movement of firewood, (2) determine any demographics that influence a patron's knowledge about the firewood regulations, and (3) identify the components of the educational program that are reaching the most campground patrons. The first type of questionnaire was distributed at selected state parks and self administered by campground patrons. The second type of questionnaire was administered by a researcher at selected state parks.

The questionnaires showed that most of the camping public in Michigan does know about the emerald ash borer. More than 90 percent of the participants claimed to know there are firewood regulations, but less than 4 percent of them actually knew what the regulations were. The surveys also showed that about 30 percent of the participants still move firewood, and more than 50 percent of the people moving firewood travel more than 160 km when camping. Therefore, despite having knowledge about firewood regulations, the camping public still has the potential to move emerald ash borer over significant distances. The types of educational outreach that appear to be the most effective are television, billboards, and flyers/posters. These types of outreach material could be useful in clarifying firewood regulations for the camping public.

TAMARIX AND RAPIDLY EVOLVING COLD HARDINESS

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ABSTRACT

To investigate the evolution of inherited latitudinal variation, we compared cold hardiness in the introduced saltcedar (*Tamarix ramosissima*, *T. chinensis,* and hybrids) and the native plains cottonwood (*Populus deltoides* subsp. *monilifera*), two dominant riparian trees in the western Great Plains. In a common garden in Fort Collins, CO (latitude 41ºN), we grew individuals of both species collected along a latitudinal gradient in the central U.S. from 29ºN to 48ºN. Eleven times between August 22, 2006, and May 22, 2007, we exposed twigs from 270 plants to a range of cold temperatures in a programmable freezer, allowed the twigs to stand in water at room temperature for 14 days, and determined survival by direct observation of stem color and formation of roots and leaves.

Both species are easily killed by freezing temperatures during the growing season and are hardier in the winter. Cottonwood, however, hardens off more rapidly and deeply. In midwinter, cottonwood was unharmed by cooling to -70 ºC, while saltcedar was killed at -33 to -47 ºC, which is within the temperature range of the northern Great Plains. Frost sensitivity, therefore, may explain the small size and relative scarcity of saltcedar in the north, and the recent spread of northern saltcedar may be related to increases in winter temperature.

There is inherited latitudinal variation in cold hardiness for both species. Twigs from northern plants survive colder temperatures earlier in the fall than twigs from southern plants. In addition, overwinter mortality of whole saltcedar plants in the common garden was inversely correlated with latitude of origin. Such clinal variation is common in native trees but was unexpected for saltcedar because of the limited time for evolution since its introduction around 1850. Analysis of nine microsatellite DNA loci shows a gradual north-south genetic gradient in saltcedar with no distinct breaks; southern plants are more closely related to *T. chinensis* and northern plants are more closely related to *T. ramosissima,* but most individuals appear to be hybrids. Such hybrids have not been reported in the native Asian range. Hybridization between these two *Tamarix* species may have introduced the genetic variability necessary for rapid evolution of the latitudinal gradient in cold hardiness.

MECHANISMS OF INVASIVE SPECIES SUCCESS ACROSS RESOURCE GRADIENTS

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ABSTRACT

One of the most widely accepted hypotheses explaining the success of invasive plant species is the fluctuating resource hypothesis, which states that invasive species are facilitated by high resource (e.g., light, water, nutrient) availability. While most plant invasive species occur in highly disturbed, resource-rich environments, some invaders exist in lower resource habitats. If they are to succeed in these areas, they must compete with native plants that are adapted to these areas. I examined phenotypic plasticity and resource use efficiency as mechanisms of invasive plant species success in low resource systems. The work was conducted in Hawaii, which harbors a large number of invasive species and contains spectacular gradients of light, nutrient, and water availability, all on the same island. Working with phylogenetically related pairs of invasive and native species, I found no support that invaders are better able to respond to variation in resource availability through phenotypic plasticity, but this result varied across species. I also found that invasive species are as efficient as natives in using limited resources, suggesting that species invading low resource habitats have traits similar to natives. This result contradicts the general paradigm that invasive species are opportunistic and display fast growth, with little resource conservation. My data suggest that resource use traits could be used in risk assessment models to predict which species may become invasive in resource-limited regions. These data also have potentially important implications for restoration and invasive species control programs. Namely, ecosystem manipulations that alter resource availability to favor the growth of native species may not work in some systems because low resource availability may actually favor the growth of invasive species with high resource use efficiency. Knowledge of resource use traits may be used to select native species for ecological restoration that could outcompete resource-efficient invaders.

IS HOUSING A FACTOR OF INVASIVEPLANTS DISTRIBUTION AT COARSE AND FINE SCALES?

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ABSTRACT

Understanding the factors related to exotic species distribution is important for management because biological invasions are detrimental for many ecosystems. Biological invasions are strongly facilitated by human activities. Housing development is particularly important because disturbed habitats are more easily invaded, landscaping introduces exotic plants, and roads are dispersal corridors. Housing growth is widespread across the globe. Between 1950 and 2000, the proportion of urban area in the conterminous U.S. increased from 1 to 2 percent, while rural low-density housing increased from 5 to 25 percent. Rural growth is particularly strong in areas with natural vegetation, resulting in an increase of the area where natural environments and housing meet, i.e., the Wildland Urban Interface (WUI).

Our goal here was to analyze the relationship between housing and distribution of invasive exotic plants in forested areas at coarse and fine scales. Specifically, we tested how important housing is compared to other environmental and human factors in explaining exotic invasive plant distribution and how this relationship changes with the scale of analysis.

At a coarse scale, we conducted our analysis in New England. We used multiple regression analysis to explain the richness of invasive exotic plants with three sets of explanatory variables at the county level: housing, other human influence, and environmental factors. Two methods were applied to measure the importance of each variable in explaining the richness of invasive exotic plants. Hierarchical Partitioning Analysis measures how much variation is explained by each variable when they are simultaneously included in the regression model. Best Subset Analysis counts how many models out of a set of 20 “better” models included each explanatory variable.

Housing variables were strongly and directly related to the distribution of invasive exotic plants richness. Housing was as important as other human influence and environmental variables in determining richness of invasive exotic plants. Interface WUI (areas where urbanization and natural vegetation meet), low intensity residential area (suburban areas), and change of house units between 1940 and 2004 were the variables that explained most variation of invasive exotic plant richness. All three explained more variation than the human-related or environmental variables, none of which explained more than 18 percent of variation (Fig. 1).

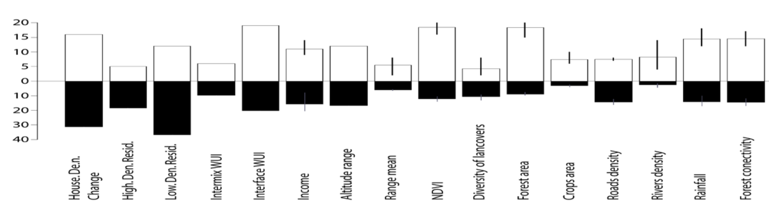

Figure 1.–Summary of multiple regression analysis. White bars represent results of Best Subset Analysis (mean, minimum, and maximum number of times a variable enters 20 models). Black bars represent results of Hierarchical Partitioning Analysis (mean, minimum, and maximum percent of the variability explained by each variable when all variables are included in the model).

Considering the results of Hierarchical Partitioning Analysis and Best Subsets, richness of invasive exotic plants was determined by a positive association with interface WUI, low intensity residential area, change of house units between 1940 and 2000, income, NDVI, rainfall, and altitude and a negative association with forest area and degree of connectivity. Roads were positively related to invasive exotic plant richness but to a lesser extent than the other variables. Area of agricultural land, diversity of landcovers, and density of main rivers were not important variables at the scale of our analysis.

At a fine scale, we conducted the analysis in Baraboo Hills, 30 miles north of Madison, WI. The study area is the largest maple (*Acer* spp.) and oak (*Quercus* spp.) forest remnant in southern Wisconsin, approximately 15 x 30 miles in size. There is a west-east gradient of increasing housing development intensity. We stratified the area according to housing density and set randomly (in numbers proportional to each stratum area) 80 circular sampling plots 20 m in diameter where we recorded presence/absence of eight common invasive exotic plants: garlic mustard (*Alliaria petiolata*), Japanese barberry (*Berberis thunbergii*), autumn olive (*Elaeagnus umbellate*), bell's honeysuckle (*Lonicera x bella*), white mulberry (*Morus alba*), common buckthorn (*Rhamnus cathartica*), multiflora rose (*Rosa multiflora*), and bittersweet nightshade (*Solanum dulcamara*). We also recorded data on native plants cover and forest structure. Using GIS, we recorded for each plot the distance to the nearest house, road, and forest edge, the number of houses in a 1,000-m-wide buffer around each plot, altitude, and slope.

We used Poisson multivariate regressions to explain richness of invasive exotic plants in each plot and Logistic regression to explain presence of individual invasive exotic plants species in each plot. With Best Subset Analysis, we measured the importance of each explanatory variable as the number of times it was included in 20 best models. The set of explanatory variables included all forest structure ones, distances to houses, roads, and forest edges, and topography.

In the Baraboo Hills, richness of invasive exotic plants increases closer to houses, roads, and forest edges, in plots surrounded with a larger number of houses, and at lower altitude and gentle slope (Table 1). Housing variables, roads, edges, and altitude were the most important determinants of invasive exotic plant richness (Fig. 2). Invasive exotic plants showed two different relationships with the explanatory variables. Buckthorn and honeysuckle were more related to landscape human-related variables, while Japanese barberry, multiflora rose, and garlic mustard were more related to stand condition (Table 2).

Table 1.–Variables explaining richness of invasive exotic plants from four multiple regression Poisson models, each one including a human influence variable (distance to edge, etc). Signs indicate variables included in each model and a direct (+) or inverse (-) effect.

Model	Human influence	Altitude	Slope	Native herbs cover	AIC
Distance to edge	-	-			263
Distance to roads	-	-	-		273
Number of houses	+			-	274
Distance to houses	-	-	-		279

Figure 2.–Importance of each significant variable in explaining richness of invasive exotic plants according to Best Subsets Analysis. Bars represent the number of times each variable entered the 20 best possible models.

Table 2.–Variables explaining presence of the five more abundant invasive exoticplants from Logistic regression models. Signs indicate variables included in each model and a direct (+) or inverse (-) effect.

Species/ variables	Dist. to edges	Number houses	Dist. to houses	Dist. to roads	Altitude	Slope	Shrub cover	Logging
Buckthorn	-	+	-	-				
Honeysuckle	-	+	-	-				
Japanese barberry	-				-	-		
Multiflora rose					-			
Garlic mustard	-						-	-

In conclusion, at broad and fine scales we found consistency in the variables related to the distribution of invasive exotic plants (housing, roads, forest cover and fragmentation, topography). More important, housing variables were as important as other human-related or environmental variables in determining the richness of invasive exotic species both at coarse and fine scales. Plant species showed variation in the association with housing and other factors at fine scales; plants heavily used for landscaping (buckthorn and honeysuckle) were more strongly related to housing and human-created landscape features. Our results have clear management and conservation implications. Housing is expected to continue growing, particularly in rural and natural areas. Areas undergoing housing development should not be located in close contact with natural habitat of high conservation value. Also, housing areas should be a main target for monitoring programs for invasive exotic plants. Regulations should be implemented on species that can be used for gardening in houses located in natural areas.

RECOGNITION OF ADULTS OF *SIREX NOCTILIO* AMONG SPECIES OF THE GENUS *SIREX* IN NORTH AMERICA

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ABSTRACT

Among the seven genera of the New World, *Sirex* is the most diverse. Schiff et al. (2006) list 10 species of *Sirex*. Work in progress with D.R. Smith (Washington, DC) and N.M. Schiff (Stoneville, MS) brings several changes among the named species and new species for a total of 11 species.

The family Siricidae and the genus *Sirex* are characterized. Special characters are pointed out to allow for fast field recognition. Then, characters to segregate both sexes of *Sirex noctilio* are shown. Old characters presented in previous papers and new characters found recently are discussed. Segregating characters include puncture development on the dorsal surface of the head and sculpture development around punctures of the mesoscutum in both the female and male, tarsal pad and ovipositor pit development in the female, and hind leg color patterns in the male. With clean and freshly collected or alcohol-preserved specimens, it should be possible to sort out adults of *S. noctilio* in the field anywhere in North America using a 10 to 20 times magnifying lens.

Literature Cited

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REARING *SIREX NOCTILIO* FROM RED PINE IN CENTRAL NEW YORK

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ABSTRACT

Six red pines (*Pinus resinosa* Soland) from central New York State containing *Sirex noctilio* F. were felled and cut into ~50-cm sections. Siricids and their parasitoids were reared from the wood. More than 90.0 percent of *S. noctilio* emerged from wood ranging from 4.5 to18.0 cm in diameter and from 4.8 to16.2 m in height. *S. noctilio* accounted for 94.3 percent of the siricid specimens collected, totaling 1,313 specimens from six trees, with a maximum of 495 *S. noctilio* from one tree; 22.0 ± 5.2 percent (range: 0-34%) of the *S. noctilio* emerging were female. *Sirex noctilio* was recovered from all six trees, but two native siricid species, *S. nigricornis* F. and *S. edwardsii* Bruule, also emerged from three of the same trees as *S. noctilio*. (Note: Species identifications are based on the 2006 guide to North American siricids by Schiff et al.) Three species of siricid parasitoids emerged from rearings: *Ibalia leucospoides* (Hochenwarth), *Rhyssa lineolata* Kirby, *Megarhyssa atrata* (F.). *Ibalia leucospoides* (Family Ibaliidae; Superfamily Cynipoidea) was by far the most abundant (19.9% parasitism, with a total of 286 specimens emerging from one tree).

Within the diameters of wood we evaluated, no strong trend in total *S. noctilio* by tree diameter was found. However, the percentage of females emerging was positively associated with wood diameter: 89.3 percent of female *S. noctilio* emerged from wood between 9.2 and 18.0 cm in diameter and between 3.1 and 9.0 m in height. Percent parasitism was negatively associated with wood diameter.

The principal purpose of this study was to rear S. noctilio to isolate its symbiotic fungus *Amylostereum areolatum*. This fungus is most easily isolated from living females. For this purpose, we needed to learn how to maintain adults in the laboratory after their emergence from wood. We found that adult females tended to survive longer than males and could be maintained at 10 ^{o}C for up to 69 days.

DISPERSAL OF GYPSY MOTH PATHOGENS TO NEWLY ESTABLISHED HOST POPULATIONS

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ABSTRACT

Gypsy moth (*Lymantria dispar*) is constantly spreading to the west and south. As gypsy moth colonizes new areas, the fungal (*Entomophaga maimaiga*) and viral (LdMNPV) pathogens infecting larvae also disperse into new gypsy moth populations. Both of these pathogens have been released to speed their dispersal in areas newly colonized by gypsy moth. Our study addresses spatial and temporal conditions associated with pathogen dispersal to answer questions about predictability of pathogen dispersal. Larval pathogens were sampled in different ways along the edge of gypsy moth spread in central to southwestern Wisconsin in 2005-2007, using 50 sites.

The most sensitive methods for detection of gypsy moth pathogens in low density populations were diagnoses of reared field-collected larvae and field-collected cadavers. For all years, *E. maimaiga* was found at more low density sites than LdMNPV, and *E. maimaiga* infections were more prevalent than viral infections. For sites where *E. maimaiga* was found, there was no association with larval density although data suggest a threshold gypsy moth density; both *E. maimaiga* and LdMNPV were not found at sites where less than 8.6 and 7.3 larvae could be collected per hour, respectively. The number of years that gypsy moth had been present at varying densities at a site was associated with *E. maimaiga* presence. With more years of greater male moth densities, the chance of *E. maimaiga* presence at a site increased.

BIOLOGY AND HOST ASSOCIATIONS OF REDBAY AMBROSIA BEETLE, EXOTIC VECTOR OF LAUREL WILT KILLING REDBAY TREES IN THE SOUTHEASTERN UNITED STATES

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ABSTRACT

The redbay ambrosia beetle (*Xyleborus glabratus* Eichhoff (Coleoptera: Curculionidae: Scolytinae)) and its fungal symbiont (*Raffaelea* sp.), new introductions to the Southeastern United States, are responsible for the wilt of mature redbay (*Persea borbonia* (L.) Spreng.) trees. In 2006 and 2007, we investigated the seasonal flight activity of *X. glabratus*, its host associations, and population levels at eight locations in South Carolina and Georgia where infestations ranged from very recent to at least several years old. Traps on artificially wounded trees showed that redbay ambrosia beetles were active throughout the year, but very few beetles were caught from March to late May 2006 and from mid-November 2006 through March 2007. Peak adult activity occurred in early September. Males are flightless, but a few were found at every sample date from 3 June 2006 to 30 January 2007. Based on these male emergence data, brood development appears to take 50 to 60 days. Uninfested redbay wood remained attractive to *X. glabratus* females for up to 70 days after being cut from live trees. Wood infested with beetles and infected with the *Raffaelea* sp. was similar in attraction to uninfested redbay wood, but uninfested and infested redbay wood were more attractive than a non-host species. Sassafras (*Sassafras albidium* (Nutt.) Nees), another species of the Lauraceae, was not attractive to *X. glabratus,* and very few beetle entrance holes were found in sassafras wood compared to redbay. Conversely, avocado (*Persea americana* Mill.) was as attractive to *X. glabratus* as swampbay (*P. palustris* (Raf.) Sarg.), and both were more attractive than the non-host red maple (*Acer rubrum* L.). However, avocado had relatively few entrance holes in the wood so it is unclear whether it is a good host for brood development. In 2007, we compared *X. glabratus* populations in areas where all mature redbay were dead to areas where infestations were very active and more recent, as well as an area outside the known infestation. Trap catches of *X. glabratus* and numbers of entrance holes in trap bolts of redbay were correlated with the number of dead trees with leaves attached. Areas where mature host trees had been eliminated by the wilt had very low beetle population levels that ranged from 0.04 to 0.12 beetles/trap/day compared to areas with active infestations where catches ranged from 4 to 7 beetles/trap/day. Our results indicate that populations of the beetle drop dramatically after suitable host material is gone, providing hope that management strategies can be developed to restore redbay trees. The lack of attraction of *X. glabratus* to sassafras suggests that spread of *X. glabratus* should slow once it is outside the range of redbay.

FLYING AGM FEMALES: WHEN AND HOW FAR ARE THEY FLYING?

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ABSTRACT

It is well known that females of the Asian gypsy moth (AGM) (*Lymantria dispar* L.) have flying ability, but there are no studies about their flying times and distances. We studied flight frequencies and distances of AGM females in two fields in Japan.

The two fields were in Norikura, Nagano, and in Misawa, Aomori. Norikura was in high mountains (1,300 m above sea level), but Misawa was near sea level. We collected 37 and 31 egg masses at Norikura and Misawa, respectively, and got adults for release. We released 69 virgin females at Norikura between August 9 and 14, 2007, and released 66 virgin females at Misawa between August 22 and 24, 2007. The females were numbered on the forewing by felt pen. At the same time, we released the same number of unmated males as released females at each site. After the releases, we checked mating time and places and oviposition time and places with GARMIN GPSMAP 60CSx. The GPS machine recorded the positions of the checked places on maps and recorded our paths to search for AGM females. We set a thermo recorder in the study field.

We searched for females in a 400 m × 300 m area in a playground at Norikura. At that site 30 of 69 females oviposited at release trees (43%). We were able to check the flight distances for 9 of the 39 females flying away. The distances were between 1 and 38 m. We set a video camera at 6:39 p.m. on August 12, 2007. The sunset was at 6:43 p.m. on that date at Norikura. The true dark began at 7:09 p.m. at a plain at Nagano. We observed a female flying at 7:09 p.m. and another female flying at 7:11 p.m. These females had not mated yet.

At Misawa, we searched for females in a 400 m ×150 m area. At Misawa, 29 of 66 females oviposited at release trees (44%). We were able to check the flight distances for 13 of the 37 females flying away. The distances were between 6 and 36 m.

In conclusion, about a half of AGM females flew to find mating or ovipositing places. AGM females flew both before and after mating. Flight distances were not far from emerging sites and may usually be less than 50 m.

USE OF SSR-PRIMERS FOR PROGENY SELECTION IN A CHESTNUT BREEDING PROGRAM

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ABSTRACT

The introduction of the fungus *Cryphonectria parasitica* into North America at the beginning of the 20th century almost eliminated the once dominant forest tree, the American chestnut. However, the Chinese chestnut, its Asian counterpart, has remained resistant to the fungus. A breeding program began almost two decades ago to develop a blight-resistant variety of the American chestnut for restoring it to eastern U.S. forests. The Chinese chestnut, although it has resistance to the fungus, lacks the desirable superior timber qualities of the American variety. The hybrids that have resistance are being backcrossed to the American parent to develop a true American variety that has resistance and all the superior timber traits. The American Chestnut Foundation, which initiated the backcrossing program, has been using traditional techniques to determine the resistance and growth characteristics of a mature tree to screen the progeny. These methods are not precise and require long times for identifying the desired progeny. Molecular techniques to ascertain true resistance and presence of desirable traits will speed the project to develop a resistant American chestnut variety for restoration efforts. In the past, we have used PCR and RAPD primers to screen progeny for desirable traits. We have now included short sequence repeat (SSR) primers as selection tools.

Genomes of plants contain high levels of length polymorphism in dinucleotide and trinucleotide tandem repeat sequences. Such repeat sequences, known as SSRs, are abundant, uniformly distributed, hypervariable, codominant, and highly reproducible. A linkage map has been generated for the Chinese and American chestnut trees based on these SSRs. We are using this information to screen for the presence or absence of specific alleles in the progeny of American chestnut backcross breeding program.

SSR screening helps identify progeny that are truly resistant and have desirable traits of the American chestnut. Through every backcross, progeny are screened for those having more American alleles and fewer Chinese alleles. Some of those having resistance to the blight will be selected for further analysis. This technique of screening progeny would be a valuable addition to the breeding program and will greatly contribute to its success.

STATUS OF MICROWAVES AND RADIOFREQUENCY AS ALTERNATIVE TREATMENTS FOR SOLID WOOD PACKING MATERIALS

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ABSTRACT

Microwave (MW) and radiofrequency (RF) irradiation are forms of dielectric heating; both heat by waves that penetrate throughout the profile of wood, which heats the water in the wood and organisms in the wood simultaneously, in contrast to conventional heating, which depends on radiant heating from the outside to the inside of the wood. For example, after approximately 3 minutes of MW exposure of red pine logs *(Pinus resinosa* Ait.*),* temperatures measured in the log with fiber optic probes showed 62 °C in the core, 60 °C in the cambium, and 53 °C at the surface, indicating that the core and the cambium heat up rapidly with dielectric heating. For several years, we have been testing microwave energy (MW) as an alternative method for destruction of wood-boring insects and pinewood nematode in wood used for international shipping as part of a formal NPPO submission of MW as an alternative method of phytosanitation under ISPM-28 (alternative treatments to conventional heat and methyl bromide). This submission is currently before the Technical Panel on Phytosanitary Treatments (TPPT) for review and is expected to move forward to country consultation and approval by the International Plant Protection Convention (IPPC).

MW kills 100 percent of adults, larvae, and pupae of a number of insect species and pinewood nematodes through short irradiation treatment times. To date, we have shown that microwaves kill several species of cerambycids including *Anoplophora glabripennis* (Motschulsky), pinewood nematode (*Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle), bark beetles (*Ips* spp.), and white pine weevil (*Pissodes nemorensis* Germar) in wood of various species, sizes, and moisture contents. Most recently, we tested MW treatment of fresh red pine bolts naturally infested with bark beetles (*Ips pini* (Say)). All life stages were successfully eradicated with MW irradiation. Temperatures of 55 º to 60 ºC measured in the cambium with exposure times of 2:40 ± 10 (min:sec) at 3.2 kW killed 100 percent of all life stages. Also, we examined the relationship between temperatures reached simultaneously at the bark surface vs. the cambium or the core. Regression analysis showed that the temperature at the bark surface could be used to accurately predict the temperature in the cambium ($R^2 = 0.77$, $p = 0.022$) and the core ($R^2 = 0.70$, $p = 0.013$) to ensure that lethal temperatures are reached in all regions of the log. Interestingly, the cambium and the core are always hotter than the outer surface of the wood (due to convection cooling from the surface). This is important because it is more practical for operators to monitor surface temperature during treatment.

Our experiments on dielectric irradiation of wood samples infested with insect pests have mostly been done using MW because we have had limited access to RF equipment for long-term studies, so we cannot make direct comparisons to our results from microwaves trials. However, of the insects we tested with RF, cerambycid larvae required slightly lower levels of RF irradiation to achieve the same level of efficacy compared with microwaves. Also, RF is very effective against sapstain and wood decay fungi. Moreover, RF has some important advantages over MW because it is less sensitive to volume effects when heating wood to reach a critical lethal temperature, and this could be important when scaling up to treat larger volumes of firewood or larger log sections, particularly for treatment of valuable saw logs.

Future research includes collaborations with USDA personnel on MW and RF testing of wood infested with emerald ash borer (*Agrilus planipennis* F.) and *Sirex noctilio* F. Equipment that can operate by batch or pass-through (conveyance) processing is commercially available, but design types are currently limited. As cost-benefit analyses are conducted to demonstrate the efficacy and cost-effectiveness of dielectric methods compared with conventional heating, we anticipate a considerable effort by companies to produce the necessary equipment.

PHENOLOGY OF THE ASIAN LONGHORNED BEETLE UNDER SIMULATED ANNUAL ENVIRONMENTAL FLUCTUATIONS

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ABSTRACT

The Asian longhorned beetle (ALB) (*Anoplophora glabripennis* Motschulsky [Coleoptera: Cerambycidae]) is an introduced insect with the potential to devastate urban hardwood forests, especially maple species (*Acer* spp.) commonly found in North America. Consequently, there is a critical need for biological information that can be used for phenological models that will enable the development of exclusion and eradication methodologies. In China, ALB completes development in 1 or 2 years. Later, emerging adults lay eggs that may not hatch until the following spring, and some full-size larvae require cold temperatures before they pupate. In this paper, I document the phenology of this beetle in the laboratory over a 3-year period using simulated seasonal variations.

Thirty-one pairs of laboratory-reared adults from the Chicago, IL, strain (emerged end of June to middle of August) were used to initiate this study. Forty-year (1961-2000) weekly average temperature, humidity, and day length for Central Park in New York City were used as climatic variables. A total of 1,989 eggs were laid by the original 31 adult females; 1,193 of these hatched and we followed the development of 406 larvae placed on artificial diet. The first egg was laid on June 28 and the last on October 30 when the temperature was 12 °C during the first year of the study. Egg hatch continued until the temperature went down to 6 °C and resumed the following year when temperatures reached 12 °C. The last larval molt in the first year occurred at 13 °C on October 19, and the first molt the next year occurred on May 8 at 16 °C. Larvae continued to molt through the year until temperatures dropped below 5 °C. During the first simulated winter, eggs and larvae through the 7th instar overwintered, and during the second winter, 6th through 13th instars overwintered. At the onset of the simulated winter, larvae that pupated during the second year weighed 0.568 + 0.037 g and those that pupated during the third year weighed 1.883 + 0.022 g. Pupation of 6th through 13th instars occurred from July 3 to August 29 in the second year and from June 3 to August 6 in the third year. Adults emerged from July 22 to September 24 during the second year and from June 27 to August 26 during the third year. ALB phenology allows the species to easily adapt to ambient environmental conditions. Larvae that have not reached the critical weight for pupation, either by the beginning of winter or when they resume feeding in the spring (before temperatures approach 25 °C), will not proceed to pupation but instead will continue to grow and molt until they reach their maximal weight or temperatures drop below about 15 °C. This can force part or all the individuals in a population into a 2-year life cycle, especially larvae that hatch too late to grow large enough the first year or where the growing season is short. ALB eggs and larvae of all sizes overwinter and can survive low temperatures of at least 0 °C for 3 weeks, thus enhancing the ability of this insect to adapt. This dataset will be used to validate a phenology model developed using previously collected data on the effects of temperature on the development of all the life stages.

INSECT REARING – A TOOL FOR DETECTING NON-INDIGENOUS WOOD BORING INSECTS

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ABSTRACT

Since 1998, the Canadian Food Inspection Agency (CFIA) has been using Lindgren funnel traps baited with the exotic bark beetle lure, ultra high release (UHR) ethanol, and UHR ethanol/UHR alpha-pinene to detect non-indigenous wood boring insects. However, several insects either do not respond to the lures used in this survey or do not rely on long-range chemicals to locate mates or host trees. Although effective at detecting some target species, this type of survey limits the spectrum of potentially detectable insects.

Rearing insects from infested logs is a more generalized approach to detection because it does not exclude insects that do not respond to specific lures. As long as brood production of a given species occurs under the bark or within the wood of any tree, this survey has the capability to detect that insect.

The CFIA, in partnership with the Canadian Forest Service, City of Surrey, City of Toronto, City of Montréal, Halifax Regional Municipality, and Vancouver Parks Board, is rearing infested logs as a tool for detecting established populations of non-indigenous wood boring insects.

Steel marine transport containers (40 feet long) were modified into climate-controlled rearing facilities and placed in pre-selected locations in each of the cities (Surrey, Toronto, Montréal, Dartmouth). Logs that meet specific criteria (e.g., proximity to high risk sites, state of decline, signs of insect activity, etc.) are obtained through a city's hazard tree removal program. Logs are placed in sleeve cages suspended from an overhead racking system or placed in modified sonotubes/building forms and held for insect emergence.

To date, ambrosia beetles, weevils, bark beetles, longhorn beetles, and metallic wood borers have been reared from a variety of softwood and hardwood species. Although a few naturalized non-indigenous species have been collected, most of the reared insects are native. To date, there have not been any new records of introduced species.

COMPETITION BETWEEN FUNGI ASSOCIATED WITH *SIREX* WOODWASP AND SOUTHERN PINE BEETLE

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ABSTRACT

The mutualistic symbiotic fungus of the invasive woodwasp *Sirex noctilio* is *Amylostereum areolatum*, a wood rotting fungus. Wood rotted by *A. areolatum* is fed upon by developing woodwasp larvae. The fungus itself serves as the food source for *Deladenus siricidicola*, a nematode that also parasitizes Sirex larvae. The resulting sterilization of adult woodwasps serves as the basis for biological control programs worldwide. Biological control of *S. noctilio* is achieved via the use of trap logs, colonized by nematodes feeding upon *A. areolatum*. Any interference with these linked life cycles may disrupt the biological control system and corresponding reductions in *S. noctilio* populations.

We tested competitive interactions between *A. areolatum* and the southern pine beetle (SPB) fungal associates it may interact with if it becomes established in the U.S. South. *Amylostereum areolatum* (from South Africa), *Ophiostoma minus*, *Ceratocystiopsis ranaculosus*, and *Entomocorticium sp. A* (all from SPB in the U.S.) were pitted against one another on malt agar. The area colonized by each competing fungus was measured as an indicator of its ability to colonize (and defend) substrate. The primary phoretic associate of SPB was able to competitively exclude the mutualistic fungus of the *Sirex* woodwasp and vice versa. The success of SPB or *Sirex* associated fungi will thus likely depend upon order of arrival. The likely influences on success of *Sirex* biocontrol efforts may then include the following:

1. Timing of inoculation/ placement of trap trees —*A. areolatum* will need to be well established before exposure to insects vectoring stain fungi.

2. Variability within strains of *A. areolatum* and parasitic nematodes—Substantial variation exists in competitiveness of *A. areolatum* strains and in their compatibility with biocontrol nematodes.

3. Abundance of, and pressure from, indigenous pine colonizing beetles and their associated fungi—Seasonal and dynamical factors may influence pressure from competitors for log substrates.

ASIAN ASH SPECIES AS A SOURCE OF RESISTANCE TO EAB: DEVELOPMENT AND CHARACTERIZATION OF NOVEL ASH SPECIES

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ABSTRACT

No resistance has yet been identified in native North American ash species to the emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire). In contrast to the situation in North America, outbreaks of EAB in Asia appear to be isolated responses to stress and do not devastate the ash population. Our work is based on the hypothesis that the Asian species of ash have evolved resistance genes and mechanisms that allow trees to coexist with the EAB. The long-term goal of our research is to introgress these resistance genes into the native North American ash species through the development of novel ash hybrids and then to perform subsequent rounds of backcrossing to recover all of the characteristics of the native North American species while maintaining EAB resistance.

Over the past 3 years, 31 different ash species combinations have been used to perform controlled cross-pollinations and 1,619 seeds were produced. Only four different species combinations resulted in viable seedlings, producing just 44 hybrid seedlings. Molecular markers, such as AFLPs and SSRs, are being used to confirm the hybrid parentage of these seedlings. At this time, we have confirmed the hybrid parentage of two seedlings (ChiAm1, ChiAm 2) from a cross between a female *Fraxinus chinensis* and a male *Fraxinus americana*. We are continuing to assess the remaining seedlings.

Comparisons between the ChiAm hybrids and their parent species showed no significant differences in the amount of foliage consumed by EAB over a 48-hour period. In contrast, significantly more EAB landings were observed on ChiAm2 than on *F. chinensis* over the same period of time, but no such differences existed in comparing ChiAm1 and *F. chinensis*. Profiles of antennally active leaf volatiles from aerated ChiAm hybrids were different from both of the parent species, *F. chinensis* and *F. americana*. The significance of these differences is being investigated.

SPATIO-TEMPORAL ANALYSIS OF REDBAY AMBROSIA BEETLE INVASION IN THE SOUTHEASTERN U.S.

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ABSTRACT

The redbay ambrosia beetle (*Xyleborus glabratus* Eichhoff), native to eastern Asia, was first detected in the U.S. in 2002 near Savannah, GA. Widespread mortality of redbay (*Persea borbonia*) trees on Hilton Head Island, SC, in 2004 has been attributed to the beetle; the trees were actually killed by an associated fungus (*Raffaelea* sp.). This fungal disease, referred to as laurel wilt, has since caused mortality of redbay and, in some cases, sassafras (*Sassafras albidum*) trees in coastal Florida, Georgia, and South Carolina. A number of other species from the Lauraceae family, including the commercially planted avocado (*Persea americana*), appear to be susceptible. While there are ongoing efforts to address unknowns regarding the biology and behavior of the beetle and fungus, policymakers also need information from broad scales when deciding how to manage this invasion. We completed a broad-scale assessment by exploiting relevant, available spatio-temporal data. First, we interpolated redbay and sassafras density maps from Forest Inventory and Analysis (FIA) Phase 2 plot data. Second, we performed climate matching with the beetle's native range in Asia to delineate potential U.S. geographic limits for the beetle. Third, we used county infestation data to estimate the beetle's rate of spread and then modeled spread through time, incorporating host density as a weighting factor.

Our results reveal that the invasion has developed over a region of the Southeast with numerous hotspots of moderate to high redbay density. High-density areas of redbay just beyond the currently invaded extent suggest spread will continue to be rapid in the short term. Lower densities elsewhere may translate to slower spread in the long term, although it is unlikely to be stopped completely due to the possibility of long-distance dispersal. Notably, there is no evidence that sassafras attracts the beetle as redbay does, so spread deep into eastern U.S. forests seems unlikely; our climate match also suggests the beetle will be constrained to the southeastern U.S coast. Nevertheless, if unchecked, the beetle may spread throughout the range of redbay in less than 40 years. The greatest potential economic impact may come if the redbay ambrosia beetle invades the avocado growing region in south Florida, although avocado appears to be somewhat resistant to the laurel wilt fungus. Disruption of anthropogenic, long-distance dispersal may be the most immediately effective measure for slowing the spread of both beetle and fungus.

ARTIFICIAL EGGING SUBSTRATE FOR REARING ASIAN LONGHORNED BEETLE

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ABSTRACT

Artificial diets are available for rearing larvae of Asian longhorned beetles (*Anoplophora glabripenni*s Motschulsky), but recently harvested plant material is still used for adult feeding (maple twigs) and oviposition (maple logs). Obtaining these materials on a regular basis can pose logistical problems, and field-collected materials can inadvertently introduce pathogens, mites, or other undesirable organisms into areas where colonies are maintained. In addition, peeling logs to remove eggs is time consuming and exposes workers to potential injury. Over several years, we tried a variety of alternative oviposition substrates with little success.

In tests last year, we offered female *A. glabripennis* artificial oviposition substrates consisting of pieces of florist's foam or rolls of corrugated cardboard (ca. 15 cm long by 15 cm in circumference) wrapped in several layers of cotton cheesecloth. In some cases, a wrap of synthetic cheesecloth was used beneath the cotton. Unlike the previous artificial substrates we had tried, females accepted the cheesecloth-covered materials for oviposition. In fact, numbers of eggs per female with either artificial substrate were comparable to numbers deposited on our standard oviposition substrate, a bolt of striped maple (*Acer pensylvanicum* L). In contrast (and perhaps surprisingly), the mean percentage of eggs that hatched was significantly lower for females with maple bolts (~50%) than with artificial substrates (~70% with either substrate; $F = 16.4$; d.f. = 2, 32; $P < 0.001$; Tukey's HSD test). Reasons for the higher hatch rates with the artificial substrates are not clear. Oviposition substrate had no apparent effect on survival of larvae after hatch.

Although our results have to be viewed as preliminary at this point, we believe that cheesecloth-wrapped foam or cardboard provides a potentially useful alternative to logs as an egging substrate for laboratory colonies of *A. glabripennis.*

TREND OF TWO INVASIVES: THE BANDED AND EUROPEAN ELM BARK BEETLES

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ABSTRACT

The banded elm bark beetle (BEBB) (*Scolytus schevyrewi*) is an invasive beetle from Asia that attacks elm (*Ulmus* spp.) trees and may vector the fungal pathogen causing Dutch elm disease, *Ophiostoma ulmi*. BEBB shares a similar biology to an established invasive, the European elm bark beetle (EEBB) (*Scolytus multistriatus*). However, BEBB seems to attack standing trees more aggressively and appears now more abundant than EEBB in the Rocky Mountain region, suggesting that BEBB may have displaced EEBB and/or is better able to colonize regions beyond EEBB's range. Our objectives were to determine the relative abundance of BEBB and EEBB in seven states and compare how each species locates host elms for attack.

To monitor abundance, a trap Siberian elm log, baited funnel trap, and passive plexiglass trap were set up at four sites in each state and checked from April/May to September. BEBB was less common than EEBB in California (13%), BEBB increased in abundance in Nevada (68%) and Utah (65%), and it was highest in Colorado (89%) and Wyoming (83%). BEBB populations were minor moving east to Kansas (3.3%) and Missouri (2.7%). This survey suggests that BEBB may be displacing EEBB because EEBB is no longer commonly found in Colorado where it was often found in the past.

Flight toward uninfested and variously infested elm logs was monitored for BEBB in Colorado and Wyoming and for EEBB in California. BEBB responded strongly to elm odors and showed no preference for elm infested with females or males. EEBB responded somewhat to elm odors but more so to pheromones from an elm that was infested by EEBB females for 48 to 96 hours. Colonizing female EEBB required a few days to produce an attractive pheromone. In Nevada, BEBB responded indiscriminately to all elm logs regardless of whether the log was infested with BEBB, EEBB, or both. Thus, when a new elm is available, BEBB may have a competitive advantage attacking first, whereas EEBB may attack in greater numbers later, following pheromone production from the initial attacks of EEBB females

EMERALD ASH BORER: CHEMICAL ECOLOGY AND VISUAL TRAPPING

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ABSTRACT

The emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae)) is a serious invasive pest in North America. Previous work by our laboratory group showed that feral EAB males are attracted to potential mates by using visual cues once on a host ash tree. This attraction is not likely to be mediated by volatile compounds, because these feral male EAB will approach and attempt to copulate with dead EAB of both sexes. However, once they have landed on another EAB, males can clearly discriminate between the sexes, spending far more time attempting to mate with females than with males. Washing the dead EAB used as lures for this behavior results in a lowered, intermediate time period of investigation when compared to unwashed female beetles. Investigation of such washed lure EAB of either sex is greater than investigation of unwashed male lure EAB. This evidence suggests the use of a contact chemical cue by feral male EAB to discriminate between male and female conspecifics.

We have undertaken Solid Phase Micro-Extraction (SPME) collections from the cuticle of male and female, freshly eclosed and sexually mature EAB to determine the differences in cuticular chemistry between the sexes. We also performed collections of cuticular compounds by dipping whole adult beetles in solvent and analyzing these solvent washes for the chemicals present. With specific attention to differences in quantity or quality of cuticular compounds between mature males and females and between mature and immature females, we have identified and isolated several compounds of interest from the cuticle of female EAB. These compounds are sex-specific, and in at least one case, show an increase in concentration as the beetle matures.

After synthesizing samples of one of these compounds, we undertook field testing by applying the compound to the cuticle of dead female beetles that had previously been solvent-washed to remove cuticular compounds. We used three concentrations: one representing the approximate of a beetle-equivalent of the compound, another that is one-third of a beetle-equivalent, and a high dose of three beetle equivalents. As controls, both unwashed female beetles and female beetles washed in solvent with only hexane reapplied were tested simultaneously as elicitors of male behavior in the field. Investigation time of unwashed female EAB was high, while female EAB washed only in solvent elicited very short time periods of investigation. The high-dose treatment of three beetle-equivalents elicited time periods of investigation significantly higher than the washed-only control, but significantly lower than unwashed female EAB. Both one beetle-equivalent and one-third beetle-equivalent doses were indistinguishable from washed-only controls in terms of male investigation time; however, all treatments elicited statistically equivalent frequency of male landing behavior, reinforcing the idea that vision dominates long-range mate location in this species.

This work should have great importance in motivating future studies on luring and trapping this beetle using visual and perhaps contact chemical cues. Thus far, a species-specific lure has eluded the EAB research program, and here we report a significant step toward the establishment of a more specific lure for this pest. We have also shown that it is possible to trap emerald ash borers using pinned conspecifics as a lure. It is hoped that combining very high doses of cuticular compounds with the visual lure of dead EAB on a trap may help increase trap efficacy, especially in low density EAB population areas. A prototype trap under development that uses both visual and chemical cues will be tested during the 2008 EAB flight season.

COMPARING EMERALD ASH BORER DETECTION TOOLS: ARE BIGGER TRAP TREES BETTER?

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ABSTRACT

Since its discovery in southeastern Michigan in 2002, emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) has spread into neighboring states and provinces. Detecting EAB at early stages of invasion may provide the opportunity for early implementation of forest management, which may limit the potential of further spread. A field experiment was established in the Lower Peninsula of Michigan, northeastern Indiana, and northwestern Ohio to test the capture rates and effectiveness of eight different trap types for the detection of EAB. Traps included a current-year girdled ash trap tree, a previous-year girdled ash trap tree, a non-girdled ash trap tree, a current-year girdled ash trap tree with purple Tanglefoot®, a current-year girdled ash trap tree at 3 m above the ground, a non-ash trap tree, a current-year girdled ash trap tree with a d.b.h. of at least 30 cm, and a purple, prism trap hung 3 m above the ground in an ash tree. The previous-year girdled trap tree occurred at only 25 sites, and the large girdled trap tree did not occur at 6 sites.

The detection of EAB was independent of the ash species selected for the traps used in this study. At low density sites, where < 200 EAB adults were captured (n=42), large girdled trap trees had the significantly highest mean capture rate per day of adult EAB. When standardized for the surface area of the traps, the large girdle, current-year girdle, and high-girdle trap trees had the highest capture rates of adult EAB. In terms of detection, for current-year and large girdled trap trees, with each increase in diameter of 1 cm greater than 25 cm d.b.h., there was an increase of approximately 9 percent in the odds of detecting EAB. Also, the large girdled trap trees had the only increase in the odds of detecting EAB as ash basal area and total forest basal area increased.

Because the detection of EAB was independent of the species of ash tree used for trapping, the selection of trap trees does not need to be species-specific. As forest and ash basal area increase at a detection site, the large ash trees remain a considerable proportion of the resources available to EAB. The use of the large girdled trap tree may provide more effective detection of EAB at low density.

PUTTING THE PIECES TOGETHER: CAN WE SOLVE THE EMERALD ASH BORER MANAGEMENT PUZZLE?

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ABSTRACT

Emerald ash borer (*Agrilus planipennis* Fairmaire), a phloem-feeding buprestid native to Asia, has become one of the most devastating forest pests in the U.S. More than 25 million ash trees (*Fraxinus* spp.) have been killed by emerald ash borer (EAB) in southeast Michigan alone. Well-established populations are present across much of lower Michigan and areas of Ohio, Indiana, and Ontario. Localized outlier populations, most of which were established at least 4 to 6 years before they were detected, have been found in four other states. Data collected from more than 30 forested sites show that virtually all ash trees > 1 inch in diameter are killed once EAB moves into a stand. At least 15 native ash species across the U.S. are threatened by this invasive pest. Efforts to eradicate EAB in localized outlier populations are expensive and unpopular, and most have not been successful. As populations of EAB expand and more outliers are discovered, it is becoming clear that alternative strategies for EAB management are needed.

The Slow the Spread of Gypsy Moth Project (STS) has demonstrated that many economic and ecological benefits can be accrued by slowing the rate at which gypsy moth populations build and spread. Presumably, a similar approach applied to EAB could yield even greater benefits. Gypsy moth, however, has been studied and managed in the U.S. for almost 150 years; EAB was not discovered until 2002. Nevertheless, in the past 5 years, scientists have learned much about EAB. A multi-year, integrated effort to slow the spread and delay the onset of widespread ash mortality may now be feasible for EAB.

Many of the components of an integrated EAB management program would likely parallel similar components of the STS project. For example, host range and preference of EAB have been evaluated in several studies (Anulewicz et al. 2007, 2008a, 2008b; Eyles et al. 2007; Rebek et al. 2008). In general, these studies have shown that EAB appears to successfully develop only in *Fraxinus* species. EAB host preference or host susceptibility differs among North American ash species. Green ash and black ash, for example, appear to be highly preferred and very susceptible to EAB. Asian ash species are generally more resistant or less preferred hosts when compared with North American ash species.

Much research has been directed at finding effective methods to detect relatively new or low-density EAB outlier populations. Detection of EAB is especially difficult because newly infested trees have virtually no external symptoms. Many larvae in healthy trees with low EAB densities will require 2 years for development (Tluczek et al. 2008). This means that a tree can be infested for at least 2 years before even a D-shaped exit hole is present. Detection trees—girdled ash trees that are debarked in winter to find larval galleries—remain the most effective method to detect low-density EAB infestations. Establishing girdled trees, however, is expensive and labor-intensive, and it can be difficult to locate suitable trees. Research on traps and lures for EAB is progressing. In 2008, USDA APHIS plans to establish a 2- to 3-mile-wide band of traps set on a 1.5 by 1.5 mile grid. The traps will consist of purple panels that use EAB beetles' response to color. Traps will be baited with Manuka oil lures. Manuka oil is chemically similar to volatiles associated with ash wood and bark. Research will also continue to determine if additional colors, variations in trap design, or improved lures can increase the effectiveness and efficiency of the traps.

Biological control for EAB is another option that has been aggressively pursued by scientists. Researchers from the U.S. Forest Service and APHIS, along with Chinese scientists, have conducted a substantial amount

of research on EAB parasitoids native to China (Bauer et al. 2005). Two larval parasitoids and one egg parasitoid appear to hold promise for biological control of EAB. Work included determining the biology of each species, developing rearing methods, and conducting studies with potential non-target species. In 2007, the three Asian parasitoids were released in sites in southeast Michigan (USDA 2007). Followup studies to evaluate establishment and impacts of the parasitoids on EAB populations are planned. In addition, we found a braconid parasitoid, identified as *Atanycolus* sp., associated with late instar EAB larvae in at least two sites near Fenton, MI (Cappaert and McCullough 2008). Subsequent surveys indicated that parasitism rates at the primary site reached 70 to 80 percent in some trees. Further studies to identify this parasitoid and assess its potential for augmentative biocontrol are planned.

Substantial progress has been made in developing methods for using insecticides to protect valuable landscape ash trees. Systemic neo-nicotinoid products, applied to the soil, injected into the trunk, or applied as non-invasive trunk sprays, are often successful, especially if treatments are initiated before EAB larvae damage the vascular tissue. Efficacy can vary, however, depending on the size and vigor of the tree, the beetle pressure (e.g., density of EAB in the area), and the application methods and products. In 2007, we evaluated a new product, emamectin benzoate. Results were striking. Overall, the emamectin benzoate provided > 99 percent control of EAB when the treated trees were compared to untreated trees (McCullough et al. 2008). We have never observed this level of control with any of the other systemic products we have tested. A special registration for emamectin benzoate will be requested in Michigan and probably other affected states.

Additional research efforts that are underway will provide information that can be incorporated into an integrated EAB management strategy. We developed models that can be used to predict the phloem area and the potential number of EAB adults that can be produced based on the d.b.h. of a tree (McCullough and Siegert 2007). If ash inventory data are available for a site, therefore, it is relatively simple to estimate how many EAB can be produced in the site if no action is taken. Using ash inventory data collected from two outlier sites, for example, we determined that roughly 80 percent of the ash trees at both sites were less than 4 inches in diameter. Only 5 to 6 percent of the ash at the sites were merchantable—e.g., > 9 inches in diameter. The merchantable trees, however, would have eventually produced 55 to 65 percent of the EAB at each site. Therefore, harvesting only those large ash trees could considerably reduce the overall EAB density in the sites.

An extensive dendrochronological reconstruction of the progression of ash mortality across southeast Michigan was recently completed (Siegert et al. 2007) and has provided us with insight into the rate and patterns of EAB spread. A model of EAB population growth and spread is currently being developed, using empirical data from this and other EAB studies. We are also determining whether girdled ash trees can be used to suppress EAB population growth. Data from pairs of girdled and control trees at an outlier site showed that at low EAB densities, girdled trees were highly attractive to ovipositing EAB females (McCullough et al. 2007). Removing these "sink" trees before larvae complete development eliminates a portion of the EAB population. As EAB density builds, however, all trees become stressed and girdled trees will no longer function as sinks. Whether sink trees can be used operationally to slow EAB growth and spread will be determined in a large-scale experiment initiated in 2007.

The research summarized here, as well as other studies that are underway, is providing tools and options for EAB detection, survey, and control. Other components of an EAB-STS type program are, however, still lacking. A thorough economic evaluation is needed to assess the costs of EAB impacts in urban and forested settings and to compare costs and benefits of alternative management options. A consistent, transparent, and accessible database is still needed to support EAB survey and mitigation efforts. A more formal link between Federal regulatory agencies and the scientists working on EAB research would facilitate the transfer of new technology and research to operational programs. Funding, particularly for a multi-year, integrated approach to EAB management, remains problematic. If these issues, which are largely administrative, can be addressed, we can make considerable progress in slowing EAB and ash mortality.

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WHAT ARE WE FACING IN THE SOUTHERN REGION? THE BIGGER INVASION OF PLANTS, INSECTS, DISEASES, AND MORE

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ABSTRACT

A multitude of non-native organisms have been invading eastern U.S. forests since Europeans and Africans began arriving there in the 16th century. Over the ensuing 500 years, human populations have gone from an estimated 30 to 80 million Native Americans, whose population drastically declined due to the introduction on non-native diseases, to more than 500 million people in the Americas by 2005. In the U.S. alone, an estimated 50,000 species from all life forms have been introduced. Some introductions have been deemed essential, like crops, livestock and their forages, and others used in food processing, while many others have less tangible values, like ornamental plants and pets. About 4,000 introduced species have become invasive pests that are causing mounting economic and ecological harm and harm to human and animal health, as well as added expenditures for their control. The total costs of damage and control was estimated at $138 billion in 1999. The U.S. Forest Service is charged with managing and mitigating the negative impacts of non-native forest invasive pests on national forests and other lands through State and Private Forest Health and Research. The Forest Service in the Southern Region is working to be more effective at that mission.

A priority action item in the Forest Service Southern Regional Framework for Non-native Invasive Species (NNIS) is to prioritize NNIS posing the highest threats. The Southern Region Task Force for NNIS Assessment to Identify Priority Species (referred to as the task force) was assembled in August 2006 to address this action item and is composed of expert staff and scientists from all branches of the Forest Service. The regional framework, also known as the regional NNIS strategic plan, states that invasive species extend across the landscape unbounded by ownership, which requires a regional strategy that can be applied at the local level.

The objective of the process is to compile a list of the most severe and potentially damaging invasive species in the region for use in focusing programs and management, using the best science available, and recognizing that a multitude of invasive organisms are present and invading the Southern Region. The assessment process should also identify components of a strategy for management, education, and research for each priority species. All invasive taxa are to be considered for the Candidate Priority Species List including those that occur widely, those with restricted occurrence, and those that are in the eastern U.S. and poised to enter the Southern Region. Those currently in tropical Florida are not included unless they are thought to have potential for northern spread. Only species recognized to represent or pose the most threat of damage to forest ecosystems (plants-soil-water systems), their sustainability and diversity, ecosystem services, and multiple amenities are included.

During 2006 and 2007, the task force:

- Developed a candidate list and database for assessment to identify priority high risk NNIS of southern forest ecosystems. The candidate list was compiled through study of existing invasive species databases (e.g., Global Invasive Species Program, PLANTS Database, USGS Nonindigenous Aquatic Species List, The University of Georgia's Bugwood Network databases, etc.); existing NNIS assessments (e.g., NatureServe, USDA ExFor, University of Florida's Institute for Food and Agricultural Sciences, etc.); the existing R8 Regional Forester's List and Ranking Structure of Invasive Exotic Plant Species of Management Concern; and from recommendations and reviews of draft lists by Forest Service scientists, staff officers, managers, botanists, and national forest NNIS coordinators. Input from experts at universities was requested and incorporated when

Forest Service expertise was lacking (e.g., amphibians and reptiles). After study of existing assessment protocols, the task force decided to use NatureServe and ExFor assessments schemes with possible modifications of these national assessments for the Southern Region and a similar approach for other taxa. The candidate list contains 118 taxa (Table 1).

• Developed a Priority Early Detection (ED) NNIS List and Database for the region of species that are not yet known to be in the forests of the South but poised to enter from surrounding regions. The sources of information were the same as above with inclusion of federally listed noxious weeds that inhabit forests and foreign ExFor listed insects and diseases. There are currently 19 priority early detection species.

• Initiated the compilation of a complete list of NNIS invading southern forest ecosystems that currently contains 563 species with an additional 92 species that currently are known to occur only in south Florida. All the above databases and inputs were used with the University of Florida's Institute for Food and Agriculture's Assessment of the Status of Invasive Plants in Florida's Natural Areas to determine whether a species is only in south Florida or occurs in north Florida and has potential for northern spread.

• Developed a complete early detection NNIS list of 58 species including those on the priority early detection NNIS list and other recognized invasives not within the U.S. that are listed on the Global Invasive Species Program List. This listing will direct early detection and rapid response activities on national forests and identify species for Research and Development.

Table 1.–The number of taxa by subphyla identified in the Candidate List, Complete List, and Complete Early Detection (ED) List

Subphyla	Candidate	Complete	ED
Plants			
Terrestrial	65	410	34
Aquatic	10	50	12
Pathogens (mainly fungi)	6	21	1
Insects	10	64	6
Crustaceans	1	6	2
Mollusks	2	7	1
Jellyfish	1	1	0
Earthworms	2	12	0
Tapeworms	1	1	0
Mammals	7	8	0
Birds	5	5	0
Fish	8	22	0
Reptiles, amphibians, and lizards	0	45	2
Total	118	655	58

Conceived and defined categories of non-native invasive species that can support programs at the forest level and aid in directing strategies at the state and regional levels. Each national forest and all forest districts are faced with a specific suite of priority invasives at varying levels of entry and establishment as well as a variety of habitats under threat. Also, they are often unaware of imminent advancing fronts of regional scale invasions, often with outlier populations with long-range dispersal. This categorization scheme integrates knowledge at several scales for the district, and when combined, can provide Forest Supervisors and Regional staff opportunities to strategically direct efforts toward the priority species identified in the assessment.

Categories of Non-native Invasive Species

1. Early Detection and Rapid Response (EDRR) Species—those poised to enter the region or a specific national forest that require high priority surveillance, inventory, and eradication with monitoring when detected.

a. Federal Listed Plant Species or Forest Health Alert Species

b. Non-Federal listed Species recognized as high risk species

2. Outliers of Advancing Fronts—high risk priority species arriving by long-range vectors requiring surveillance of potential entry sites, inventory of occurrence, treatment and re-treatment with monitoring and rehabilitation to eradicate infestations and contain the spread.

3. Leading Edge of Advancing Fronts or Scattered Entrenched Infestations—surveillance of potential entry sites, inventory of occurrence, treatment and re-treatment with monitoring and rehabilitation to eradicate infestations and contain the spread.

4. Widespread, Extensive, and Abundant Species—management focused on surveying and treating those infestations that threaten special habitats, recreation areas, and scenic resources.

a. Abundant and spreading at a constant rate into forests with canopies.

b. Spreading along rights-of-way or edges into forests with disturbance.

5. Isolated Severe Infestations of Non-priority Species—those that threaten special habitats, recreation areas, and scenic resources.

6. Naturalized with Little Impact—no control treatments needed except in rare circumstances.

Finally, the Southern Region Task Force compiled a list of what is currently considered the worst invasive species of the Southern Region (Table 2). This short list is used for communications with partners, customers, and staff on high threat species that span the region and life forms, those that pose severe threats in specific areas (like zebra mussels along the Mississippi and Tennessee Rivers), and those poised to enter the region's forests (Table 3). This list can also be used to convey to stakeholders and citizens the sense of urgency to act, support programs, and prevent spread.

The assessment process is continuing at this time as well as the vigil for listing new or potential invasive entries or preexisting populations. Copies of lists and materials can be obtained from James Miller, Task Force Coordinator, jmiller01@fs.fed.us. Southern Research Station, 520 DeVall Dr., Auburn, AL 36849.

Table 2.—U.S. Forest Service Southern Region's worst invasive species

Type	Scientific name	Common name
tree	*Triadica sebifera*	Chinese tallowtree
tree	*Ailanthus altissima*	tree-of-heaven, *ailanthus*
shrub	*Ligustrum sp.*	non-native privets
vine	*Pueraria montana var. lobata*	kudzu
grass	*Imperata cylindrica*	cogongrass
grass	*Microstegium vimineum*	Nepalese browntop, Japanese stiltgrass, microstegium
aquatic	*Myriophyllum spicatum*	European waterfoil
aquatic	*Hydrilla verticillata*	hydrilla, waterthyme
pathogen	*Discula destructiva*	dogwood anthracnose
pathogen	*Raffaelea (Ophiostoma) sp.*	aurel wilt
insect	*Xyleborus glabratus*	redbay ambrosia beetle (laurel wilt vector)
insect	*Adelges piceae*	balsam woolly adelgid
insect	*Adelges tsugae*	hemlock woolly adelgid
insect	*Lymantria dispar*	gypsy moth
mammal	*Sus scrofa*	feral hog, European wild boar
bird	*Sturnus vulgarus*	starling
fish	*Channa sp.*	snakehead fish
mollusk	*Dreissena polymorpha*	zebra mussel
earthworm	*Lumbricus terrestris*	Canadian nightcrawler

Table 3.—Invasive species of imminent threat poised to enter the region's forest ecosystems

Type	Scientific name	Common name
pathogen	*Phytophthora ramorum*	sudden oak death
insect	*Agrilus planipennis*	emerald ash borer
insect	*Sirex noctilio*	*sirex* woodwasp
aquatic	*Didymosphenia geminata* (alga)	didymo (near dams in VA and KY)

RESEARCH AND DEVELOPMENT PROGRAM ON HOST PLANT RESISTANCE TO HEMLOCK WOOLLY ADELGID

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ABSTRACT

Adelges tsugae Annand, the hemlock woolly adelgid (HWA), is a serious pest of hemlocks in the eastern United States. Hemlocks native to western North America and Asia are not damaged by this sucking insect. Recent phylogenetic research (Havill et al. 2006) determined that HWA is native to western North America and Asia and that the population in the eastern U.S. is non-native and came from Japan. It is hypothesized that in the areas where HWA is native, a combination of host resistance and natural enemies maintains HWA populations below damaging levels.

For more than a decade, the Forest Service has aggressively supported a program to obtain natural enemies from areas where HWA is endemic for establishment as biological controls for HWA in the eastern U. S. This initial emphasis on establishing biological controls was based on the premise that biological control could be achieved more rapidly than increasing host resistance or tolerance to HWA. Recently, the quest for management options has been more balanced and the availability of special funding in 2005-2007 permitted acceleration of research on biological controls, chemical insecticides, and host resistance. Requests for proposals (RFP) issued these 3 years funded 11 proposals on host resistance research totaling $624,493.

These extramurally funded proposals cover a wide range of topics, including host chemistry and physiology, feeding behavior, tree breeding, tree ring analysis, and field evaluation of tree resistance, and illustrate the need for a multidisciplinary approach to development of host resistance. Projects funded were (1) Evaluating phytochemicals (terpenoids) in hemlock species and cultivars in relation to host resistance (Villanova University), (2) Single cell EST sequencing to define molecular responses associated with resistance (FS Southern Research Station), (3) Feeding behavior of HWA in relation to host suitability (North Carolina State University), (4) Field evaluations of non-indigenous and local hemlock species (Cornell University), (5) Evaluating hemlock species for resistance, hardiness, and cultural suitability (Pennsylvania State University), (6) Role of twig morphology in resistance (Oregon State University), (7) Production and evaluation of eastern hemlocks with putative resistance (University of Rhode Island), (8) Evaluation of inter-specific hybrids and development of new hybrids (ARS National Arboretum), (9) Dendrochronological analyses for resistance and changes in soil and foliar nutrients in relation to HWA attack (West Virginia University). Most of these studies are still in progress, but below are brief accounts of some research on HWA initiated before 2006.

The volatile chemistry of hemlocks has been examined by Anthony Lagalante of Villanova University, who developed a sampling method to determine the relative content of volatile terpenoids in the needles of seven hemlock species. For all species, 51 terpenoids were identified, with 2 of these—isobornyl acetate and α-pinene, the most abundant terpenoids—accounting for 90 percent of the total variance in a principal component analysis on untransformed data. Except for *T. metensiana*, which is in a separate phylogenic group from the other species, the grouping of the hemlocks along both axes of the PCA corresponded to their east-to-west geographic locations. When PCA is run on log-transformed data to minimize the influence of the mean size of the variable, *T. caroliniana* is grouped with the Asian species and *T. canadensis* is considerably distant from the other species.

This grouping corresponds to the phylogeny of *Tsuga* species. It is suggested that the high level of isobornyl acetate in the eastern North American hemlocks reflects evolutionary pressure from defoliators in the absence of pressure from sucking insects.

Controlled pollinations by Susan Bentz of the National Arboretum, USDA ARS, resulted in authentic hybrids between *T. caroliniana* and *T. chinensis*. These hybrids are now of sufficient size in a field nursery that their resistance can be evaluated using artificial inoculations of HWA. Preliminary results indicate that the hybrids have resistance to HWA that is intermediate to that of their parents.

Recent understanding of the genetics of worldwide HWA populations and observations on the biology of these populations has made it clear that populations of HWA in the eastern U.S. cannot be assumed to have the same relationships with hemlock species as populations in other regions. *Tsuga chinensis* generally has light—but sometimes dense—populations of HWA in China but is virtually immune to HWA when grown in the eastern U.S. Similarly, *T. heterophylla*, in western North America, often has dense HWA, but this species seldom is observed with dense populations of the adelgid when growing in eastern U.S. Conversely, *T. canadensis* growing in arboreta in western North America seems to be more resistant than the native, western hemlock growing beside it. Greater abundance of natural enemies of HWA in Asia and Western North America has been a suggested explanation for both native and exotic hemlocks being less damaged in these areas; however, the different genotypes of HWA in these areas may cause less damage to hosts on which they have coevolved. Although the relative resistance of the hemlock species remains unclear, care should be taken to avoid additional introductions of HWA from Asia or western North America because these may differ in biology from the genotype now present in the eastern U.S.

Other researchers are looking for putative heritable resistance among eastern and Carolina hemlocks that have escaped damage from HWA. Another tactic is to identify the role of environment on susceptibility of hemlock to HWA, including silvicultural prescriptions to increase tolerance to HWA.

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EXCLUDING INVASIVE PLANTS WITH RIPARIAN CORRIDORS

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ABSTRACT

Riparian corridors are strips of forest between a stream and human-impacted land. This area is thought to provide protection for the stream against the harmful effects of surrounding human activities. This buffering effect may include the exclusion of invasive plants, considered a threat to native biodiversity, from the streambank. By sampling multiple riparian corridors of varied widths and surveying the progression of invasive plant density into the corridor, as well as the basal area and the canopy density, we were able to determine the relationship between the width of a buffer and its ability to exclude invasive plants. Our results suggest that invasive plants at the streambank are greatly reduced by a 50-m buffer and are sufficiently excluded by a 100-m buffer.

FIELD BIOASSAYS ON THE ASIAN LONGHORNED BEETLE MALE-PRODUCED PHEROMONE

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ABSTRACT

The Asian longhorned beetle (ALB) (*Anoplophora glabripennis* [Coleoptera: Cerambycidae]) is a high risk, exotic species in the U.S. In 2002, two male-produced volatiles were isolated from ALB that stimulated antennae of both sexes of ALB. The components were synthesized and consisted of an aldehyde (4-(n-heptyloxy) butanal) and an alcohol (4-(n-heptyloxy) butan-1-ol).

Behavioral tests conducted in the laboratory in 2006 showed a significant attraction of virgin female ALB toward the alcohol ($P<0.05$). In July 2007, field trapping experiments using ALB male-produced pheromone were performed in Ningxia province in China. A pheromone blend of 1:1 (v:v) of the alcohol and the aldehyde was compared to each component alone and to the blend added to linalool and pinocarveol, two plant volatiles found in maple. Controls consisted of empty traps and traps with caged live insects, males or females separately. All treatments were replicated seven times over space. Trapping was conducted for 3 weeks. New IPM intercept PT traps were used for all treatments. Traps were checked daily, and the sex and number of beetles caught in each trap were recorded.

Results showed a significantly higher total trap catch in the pheromone blend-baited traps, followed by traps baited with the pheromone blend + plant volatiles ($P_{(MPvs.MPPL)}=0.04$). Alcohol-baited traps caught only females, supporting previous lab results. Coupling plant volatiles with the male pheromone appeared to increase the attractiveness of females to the traps. Future research will investigate the effect of different plant volatiles on the attractiveness of the male-produced pheromone.

SITUATION WITH *ANOPLOPHORA* SPECIES AND OTHER INVASIVE FOREST PESTS IN THE EPPO REGION

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ABSTRACT

The European and Mediterranean Plant Protection Organization (EPPO) is an intergovernmental organization that was created in 1951 by 15 countries. It currently has 49 member countries. Its aim is international cooperation in plant protection (plant quarantine and plant protection products). Its missions are to prevent entry and spread of harmful organisms; identify potential risks (by PRA); give recommendations on pests that should be regulated as quarantine pests (EPPO A1 and A2 Lists) and on phytosanitary measures; and provide information to EPPO members.

Anoplophora chinensis Forster was added to the EPPO A1 List (of pests recommended for regulation) in 1994 following European interceptions of infested bonsais from Japan. *Anoplophora glabripennis* Motschulsky was added to the EPPO A1 List in 1999 following the introduction of the pest (in 1996) into North America. Before this, it had been added to the EPPO Alert List, and then PRA was performed by the EPPO Panel on Phytosanitary Measures. *A. chinensis* was first (for Europe) reported in Italy in 2000, in the Netherlands and in France in 2003 (officially declared eradicated in 2006 in both countries), and then in Switzerland in 2006 (situation unclear). *A. glabripennis* was first (for Europe) reported in Austria in 2001 (eradication efforts continue), in France in 2003 (eradication is still considered feasible), in Germany and Poland in 2004 (in Poland the current situation is unclear), and in Italy in 2007. Interceptions of both pests in Europe continue, but *A. chinensis* is most often detected in bonsais and other plants for planting whereas *A. glabripennis* is most often detected in wood packaging. Both pests are intercepted in consignments originating in China, Japan, and Korea.

The EPPO Project on Quarantine Pests for Forestry was conducted in 2000-2005 to analyze potential risks of introduction of forest pests from the territory of the former USSR to the western part of the EPPO region. The outcomes of the project are published in the EPPO Bulletin. During this project, the EPPO Panel on Quarantine Pests for Forestry performed PRA for 45 forest pests, 19 of which have been included in the EPPO A1 and A2 lists. At present, the panel continues its activities, mainly concentrating on development of EPPO commodity-specific standards on Coniferae, *Castanea, Quercus*, and other forest trees.

The most important recent news is the first introduction of *Agrilus planipennis* Fairmaire into Europe. The pest was detected in Moscow and has already spread at least 30 km around the city. Eradication does not seem feasible.

ELECTROPHYSIOLOGICAL AND BEHAVIORAL RESPONSES OF CITRUS ROOT WEEVIL

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ABSTRACT

The tropical root weevil *Diaprepes abbreviatus* (L. 1758) (Coleoptera:Curculionidae) is a polyphagous insect from the Caribbean Islands and an invasive insect in the southern U.S. where it is a pest of citrus crops and ornamental trees. Adults feed upon foliage where aggregation, mating, and oviposition take place. Here, the headspace volatiles from *Citrus macrophylla* Wester (Rutaceae), a host plant of *D. abbreviatus*, and adults feeding on this plant, were collected by aeration and solid-phase microextraction (SPME) and then analyzed by gas chromatography-linked mass spectrometry (GC-MS). Electrophysiological responses of weevil antennal receptors to volatile headspace extracts and synthetic compounds were recorded by gas chromatography-linkedelectroantennographic detection (GC-EAD) and electroantennograms (EAGs). Separation of volatiles using GC revealed a preponderance of monoterpenes in the headspace of citrus leaves and adults feeding on the leaves. Antennal responses were recorded to (R)-(-)-linalool, citronellal, nerol, citral, and carvacrol. When comparing EAGs between (+/-)-linalool and (R)-(-)-linalool, no significant difference was found; responses to (R)-(+)-citronellal were larger than for (S)-(-)-citronellal. An open T-track dual choice olfactometer measured behavioral responses to electrophysiologically active compounds and several blends. Among the individual compounds and blends tested, only the blend of (+/-)-linalool, cis-3-hexen-1-ol, and carvacrol (source dose 25:25:2.5 µg) elicited significant attraction. The biologically active compounds found here likely play a role in host finding by *D. abbreviatus* and other interactions of the insect with its host plant.

EFFECT OF WINTER TEMPERATURES ON THE SURVIVAL OF HEMLOCK WOOLLY ADELGID AND THE POTENTIAL IMPACT OF GLOBAL WARMING ON ITS FUTURE RANGE IN EASTERN NORTH AMERICA

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ABSTRACT

Global climate change has already affected the abundances, range limits, and interactions of many species. The hemlock woolly adelgid (*Adelges tsugae*), an invasive insect introduced to eastern North America from Japan, has decimated stands of eastern hemlock (*Tsuga canadensis*) and Carolina hemlock (*T. caroliniana*) from Georgia to Connecticut. However, its spread across central and northern New England has been slowed substantially by its inability to tolerate cold winter temperatures. Using data from previous lab and field studies including adelgid cold shock experiments and overwintering mortality, we first characterize the temperature conditions that may limit adelgid spread. We then show how rising winter temperatures due to climate change are likely to remove the conditions currently limiting adelgid spread and facilitate the northward expansion of adelgid as more suitable habitat becomes available. The potential range of adelgid is estimated under high and low emissions scenarios as defined by the Intergovernmental Panel on Climate Change (IPCC) through the year 2100.

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PLANT INVASIONS INTO MOUNTAINS

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ABSTRACT

Across North America and around the globe, mountain ecosystems are increasingly threatened by invasive plants and research is urgently needed to understand this problem. In 2005, an international research network was established to address the issues of plant invasions into mountains. The Mountain Invasions Research Network (MIREN) addresses the problem of plant invasions in mountain regions, using mountains as model study systems for research into the mechanisms of plant invasions, particularly under the conditions of global climate change. MIREN aims to respond to management needs to conserve the unique ecosystems of high mountains as well as to general research needs to understand the mechanisms behind plant invasions. High mountains vary greatly in structure, climate, and vegetation although all show strong environmental gradients that affect plant invasions. MIREN analyzes the changing patterns and processes along these gradients to gain a deeper understanding of plant invasions. Six core mountain regions, including two locations in North America, are currently participating in standardized baseline screening and monitoring and in standardized comparative experiments. These core mountain regions cover the major climatic zones and include island and continental systems. MIREN is responding to the increasing needs for managing plant invasions into mountains by

- Developing mechanistic understanding for efficient control
- Providing reference databases on mountain plant invasions
- Facilitating exchange of expertise
- Providing specific management guidelines

Preliminary results of the standardized baseline screening have found more than 400 species of non- native plants in core regions. Eighty species were found in more than one region. Monitoring efforts that are underway may help gauge the relations of climate change in mountain ecosystems. Global warming is expected to weaken the abiotic resistance of mountain ecosystems to plant invasions. Generally, an increase in temperature and growing season and correspondingly a decrease in frost and snow cover frequency and duration are predicted for mountains around the world. These conditions will favor native and non-native lowland plants and threaten native high elevation mountain plant communities. For more information on non-native plant invasions into mountains, see the Mountain Invasions Research Network http://www.miren, ethz.ch.

SYMBIONTS OF INVASIVE INSECTS: CHARACTERIZATION, ECOLOGICAL ROLES, AND RELATION TO INVASIVE POTENTIAL AND MANAGEMENT STRATEGIES

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ABSTRACT

Most, and perhaps all, multicellular organisms house symbiotic microorganisms. Recent research identified a number of ways in which symbionts are critical to the success of various insects, yet we know very little about the symbiotic associations of the major invasive species. The information we do have is largely limited to two specific types of relationships, insect vectors of plant pathogens and entomopathogens. Yet these reflect only a subset of the most prevalent types of symbioses. This presentation makes four main points:

1. Invasive insects are really invasive species complexes.
2. Symbionts can enhance the invasive potential of introduced species.
3. Understanding insect-symbiont interactions can improve management.
4. Insect microbial communities provide useful models for testing general theories of biological invasions.

Few invasive tree-feeding insects have been evaluated for their major symbiotic associates. Among those species that have been considered, evaluations of gypsy moth (*Lymantria dispar* (L)) (Broderick et al. 2004), Subterranean Formosan termite (Adams and Boopathy 2005), Asian longhorned beetle (*Anoplophora glabripennis* (Motschulsky)) (Schloss et al. 2006), and emerald ash borer (*Agrilus planipennis* Fairmaire) (Vasanthakumar et al., in review) have revealed a high diversity of gut bacteria. Thus, these pests should not be viewed as single-species entities, but rather as species associations. The numbers of morphospecies and Operational Taxonomic Units vary among groups, and different symbionts show varying degrees of association with their hosts. These communities show structure, with different members dominating different life stages and sections of the gut. They are also responsive to the plant species on which the insect feeds. Many of these symbionts are culturable, but some can be detected only by using molecular methods.

These symbionts perform a number of functions that can benefit the insect, particularly in their abilities to exploit host plants (e.g., Dillon and Dillon 2004, Moran 2007). Some of these functions include: (1) Digestion, including cellulose metabolism, nutrient concentration, and nitrogen fixation; (2) Detoxification of plant defense compounds; (3) Pheromone production; (4) Protection from environmental extremes; (5) Defense against natural enemies. Almost all aspects of insect biology are facilitated by symbionts (Moran 2007). These functions relate to specific life histories of the herbivore. For example, we have observed celluloytic activity in cerambycids and buprestids but not in bark beetles. Likewise, we have observed use of symbiotic bacteria to inhibit gallery-invading fungi and thus protect brood in a number of bark beetle species (Cardoza et al. 2006).

An understanding of the identities, ecological functions, and community structures of symbionts can improve our ability to manage invasive species. These opportunities include improved treatments and improved monitoring and detection. For example, enteric gut bacteria play a crucial role in the toxicity of Bt to gypsy moth, as demonstrated by assays involving both Dipel and insecticidal crystal toxin administered through engineered *E. coli* (Broderick et al. 2006a). Similar results have been obtained with four other species of Lepidoptera, for a total of representatives from five families (Broderick et al. 2006b). Altering the gut microflora may provide opportunities for synergizing Bt activity. Likewise, some natural enemies of insect herbivores that feed below bark locate their cryptic prey

by cueing on volatiles produced by their microbial symbionts. This has been demonstrated, for example, with parasites of both the woodwasp *Sirex noctilio* F. (Madden 1968, Martines et al. 2006) and the bark beetles *Ips pini* Say and *Dendroctonus ponderosae* Hopkins (Adams and Six 2008, Boone et al. 2008). This can provide opportunities for discovering, synthesizing, and deploying attractants for both the pest and its natural enemies. In other cases, the boring insects themselves are attracted to volatiles produced by microorganisms with which they are commonly associated, through either direct or plant-mediated relationships. We are currently testing this approach for developing detection methods for emerald ash borer and its parasitoids.

Finally, insect microbial communities can provide useful models for testing general theories of biological invasions. Biological invasions are ultimately landscape-scale processes. As such, they do not lend themselves to controlled manipulations. Such manipulations would be both unethical and impossible to replicate. Because each insect contains a community, it provides an independent experimental unit. These units can be manipulated by administering antibiotics, introducing knockout phage, feeding various plant species and allelochemicals, exposing them to external factors such as temperature and crowding, and subjecting them to transplant experiments. They can be used to address some overarching questions such as:

1. What makes some species more likely to be invasive?
2. What makes some ecosystems more likely to be invaded?
3. What intervention tactics are most likely to succeed at various stages of invasion?
4. What are the roles of specific processes such as Allee effects, competitive displacement?

As with all models, insect symbiont communities have both practical and conceptual limitations, but they can be added to our overall toolbox of approaches.

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MOUNTAIN PINE BEETLE AND CLIMATE CHANGE

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ABSTRACT

The mountain pine beetle (MPB) (*Dendroctonus ponderosae*) is a native insect of pine forests in western North America. While it has a broad geographical distribution, it has been historically confined to the western side of the continent, in the U.S. by the distribution of its pine hosts and in the northern half of British Columbia in western Canada by the geoclimatic barrier of the Rockies. Since the early to mid-1990s, an outbreak of MPB has reached unprecedented levels in terms of acreages and numbers of pine trees, in particular lodgepole pine, killed throughout its range, most notably in Colorado and British Columbia. The MPB is also causing very high mortality among whitebark and limber pines at high elevations. Historical records from the past 100 years suggest these ecosystems have had pulses of MPB-caused mortality but not at levels currently being observed. Since 2006, MPB has extended its range into the Peace River area of north-central Alberta. Climate change may well be involved in this recent northeastward and upward range expansion. There is ample and mounting evidence of similar latitudinal and altitudinal shifts in insect distributions throughout the world, many convincingly linked to climate change. The main concern at this time is the likelihood that this insect will continue spreading east into the pines of Canada's boreal forest, eventually reaching the eastern provinces and threatening the pines growing on the Atlantic side of the continent all the way into the Southern U.S. Because of this recent incursion at the gates of the Canadian boreal forest, MPB is being viewed as a potential invading species in eastern pine ecosystems. It could be viewed as an invader into the high-elevation whitebark pine ecosystems as well.

There are three well-understood links between climate and MPB that form the basis for our belief that changing climate (temperature and precipitation) has had (and will have) a role to play in the recent outbreaks and range expansion of this insect. A well-synchronized adult emergence pattern is a prerequisite for successful mass attack of healthy pine trees by MPB. Such highly synchronized emergence is most likely to occur where (and when) the insect has a strictly univoltine life cycle. For more than 20 years, process-based models describing MPB responses to temperature have been under development and analysis (Bentz et al. 1991, Bentz and Mullins 1999, Logan and Bentz 1999, Powell and Logan 2005). In addition to the synchrony issue, a hemivoltine life cycle (one generation every 2 years) leads to lower population performance mainly because it implies that the MPB is exposed to two winters. We know that cold winter temperature is the major mortality factor in MPB ecology (Amman and Cole 1983). A third weather factor is drought, because it affects the ability of pine trees to defend themselves against MPB attack (Safranyik et al 1975). We thus have three model components available to study the impact of weather on MPB populations. A phenology model predicts life stage-specific developmental timing (Gilbert et al. 2004). A cold tolerance model predicts probability of MPB larval mortality due to cold temperature (Régnière and Bentz 2007). And a drought-stress model can be extracted from the climatic suitability index of Safranyik et al (1975) and predicts fluctuations of tree susceptibility. All three models have been implemented within BioSim (Régnière and St. Amant 2007) to make landscape-scale predictions of MPB performance under climate change scenarios.

The phenology model is very good at predicting the portions of the continent where the insect has a high likelihood of being univoltine. This model predicts the northward and upward shift of MPB. Under a conservative climate change scenario, it also predicts that by the end of the 21st century, the area at risk of univoltine MPB will

shift considerably north, to a point that the insect may be misadapted over much of its current distributional range. The cold tolerance model suggests that winter survival is very low and will remain so in the foreseeable future throughout the boreal pine forests of the Canadian central provinces from Alberta to Ontario. While drought stress is and will be more common in that same area, there is not a very large change in this risk factor predicted in the near future. Thus, with our current understanding of the insect's physiology and host plant interactions, the risk of seeing the MPB roll across the northern forests of Canada into the eastern pine forests seems rather low. This, of course, is contingent upon the insect not adapting (evolving) to change its thermal responses and upon the distribution of pines not changing appreciably over the time range under consideration.

These models currently must be run separately, and it will be difficult to really integrate the development and survival processes until the two models are truly integrated. Temperature regimes that are favorable for adaptive developmental timing may not necessarily be favorable for survival and vice versa. Predicting outbreak risk also depends on an understanding and incorporation of population growth rates through time. Thus, one of our main objectives is to integrate these models, a task that will require a different modeling approach, probably using an individual-based framework, coupled with a distributed-computing system, to deal with the very high CPU demands of such a model.

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POTENTIAL NORTHERN DISTRIBUTION OF ASIAN LONGHORNED BEETLE IN NORTH AMERICA

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ABSTRACT

The Asian longhorned beetle (ALB) (*Anoplophora glabripennis*) is endemic to the Oriental and eastern Paleartic regions. The insect was recently introduced into North America and now infests the urban forests of Long Island, Chicago, New Jersey, and Toronto. Most North American insects from this family (Cerambycidae) normally infest dead and dying material and usually are considered beneficial because they hasten the breakdown of dead trees by opening up the wood to wood rotting fungi. However, members of the Lamiinae subfamily, genus *Anoplophora,* also infest healthy hardwood trees. In its native environment, this insect feeds on more than 24 species of living hardwoods (Yang et al. 1995). In China, its preferred tree species are *Salix* and *Populus* (Li and Wu 1993) whereas in North America *Acer* species are most commonly attacked (Haack et al. 1997, 2006).

Objective

The supercooling point of insects has been used to predict the potential northern distribution of insects susceptible to freezing (Sullivan and Wallace 1972, Roden 1981). So far, the supercooling point has provided a reasonably accurate prediction of the northern distribution of the gypsy moth (*Lymantria dispar*) and the smaller European elm bark beetle (*Scolytus multistriatus*) in North America. While there is no guarantee this is an accurate assumption for all insects because of insect physiological and behavioral adaptations that may differ between species, the determination of an insect's supercooling point provides a useful tool for resource managers unless that species is freeze-tolerant.

The objective of this study was to determine the supercooling temperature of ALB larvae and how this temperature compares to the range and overwintering supercooling point of larvae from a native cerambycid from the same subfamily, the whitespotted sawyer beetle (WSB) (*Monochamus scutellatus)*.

Material and Methods

The ALB larvae used in this experiment were obtained from infested Norway maple (*Acer plantanoides*) collected from Massapequa, NY (40.68N. 73.46W.) on February 27, 2002. Larvae of the WSB were obtained from white spruce (*Picea glauca*), collected near Wharncliffe, ON (46.25N. 83.22W.) on October 18, 2001. The WSB collection material was stored outside at the Great Lakes Forestry Centre in Sault Ste. Marie until the ALB material from Massapequa arrived. Wood containing the two species was moved indoors on March 4, 2002, where it was held at –2 ˚C for 4 weeks before larvae were randomly removed for testing.

Results and Discussion

The mean supercooling points (^{o}C ± S.E.) for ALB and WSB larvae were 25.8 ± 1.1 ^{o}C (n=17) and –35.6 ± 1.9

°C (n=20), respectively. The mean weights (g ± S.E.) for larvae of ALB and WSB removed from the wood were 1.52 ± 0.29g and 0.12 ± .03g, respectively. There was no correlation between larval weight and freezing point for either species as has been suggested by other studies (Johnston and Lee 1990). The correlation coefficients for ALB and WSB were 0.16 and 0.23, respectively. Two female ALB larvae survived freezing and successfully completed development on artificial diet. One of these copulated successfully with an untreated male and laid several eggs.

Eighteen of the WSB larvae survived freezing; most of these actively tunneled in artificial diet for several weeks. However, only one successfully completed development but did not live long enough to mate.

Because two ALB larvae survived freezing and completed development, further studies were initiated to investigate the possibility that ALB may be freeze tolerant. In subsequent studies, larvae were held for 24 hours at -25, -30, -35, and -40 °C. It was anticipated that larvae held at temperatures lower than their supercooling point (-25.8 °C) would either die or emerge from eclosion badly deformed. However, a high percentage of the larvae from each of the different treatments survived freezing; the percentages were: 92, 97, 95, and 95 percent, respectively. The percentages of adults that completed development and mated to produce an F_1 generation successfully in each of these treatments were 33, 46, 27, and 24 percent, respectively.

These results suggest ALB is freeze tolerant. This assumption also is supported by the shape of the freezing curves from our studies, which were classic for freeze-tolerant species (Humble and Ring 1985). In other words, the northern distribution of ALB will not be limited by cold temperature but by host availability. Consequently, ALB may be able to infest its preferred Asian hosts wherever they are present in North America. Survival for the WSB at temperatures below the supercooling point was less than 5 percent—too low to test for an F_1 generation. However, the WSB supercooling point of -35.6 °C was very similar to its northern North American range (Linsley and Chemsak 1985), the distribution of its hosts, and the -35 °C North American isotherm.

Additional Research

Because ALB larval survival is also time dependent, further tests of survival at 2 and 4 weeks at these temperatures are required before it can be ascertained whether these larvae can withstand freezing for longer periods. A 90-plus percent survival rate for 24 hours below the species' supercooling point certainly suggests they can withstand exposure to lethal cold temperatures for short periods. Normally researchers could scan collection records for an indication of an insect's presence and successful development. However, Chinese collection records are often incomplete and difficult to obtain.

Current preliminary studies at the Turkey Lakes Watershed (47.02 N. 84.23 W.) near Sault Ste. Marie, ON, suggest the range and survival of ALB also will be affected by tree diameter. These studies suggest external air temperature may be buffered by as much as 10 °C in large diameter sugar maple. Another year of winter weather data is required to complete this aspect of the study.

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SPATIAL DYNAMICS OF THE ASIAN LONGHORNED BEETLE: CARTERET, NJ, TO STATEN ISLAND, NY, IN NINE YEARS?

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ABSTRACT

The exotic Asian longhorned beetle (ALB) (*Anoplophora glabripennis* [Motschulsky] [Coleoptera: Cerambycidae]), was first discovered on this continent in Brooklyn, NY, in 1996. Other infestations were later found in Chicago (1998), Toronto (2003), and Carteret, NJ (2004). DNA evidence suggests that these represent independent introductions from China. Between August 2004 and March 2007, several sites in Middlesex and Union Counties, NJ, and Richmond County, NY (Prall's Island and Staten Island) were found to be infested with the ALB. We conducted field studies and population analyses that now allow us to reconstruct the history of these infestations and draw conclusions about the relationships among them and about the population biology of this invasive species. Our work provides evidence that the oldest infestation, established in Carteret in 1997, was unrelated to those occurring later in Linden (east of the New Jersey Turnpike) and on Prall's and Staten Islands. East Linden appears to have experienced a separate colonization event in 2000. The infestation on Prall's Island, located in the Arthur Kill (river) between New Jersey and New York, most likely originated in east Linden in 2002 and then served as the source of beetles invading Staten Island in 2006. We believe the open landscape in this area, offering few impediments to dispersal (or reasons to remain in place) facilitated population spread across open marshes, fields, and industrial wasteland to distant and widely scattered host trees. If the infested sites are related as described, then the Carteret population dispersed (considering only natural, not human-assisted, movement) 1.4 mi (2.25 km) in 7 years, the east Linden population spread the same distance in 5 years, and the population established on Prall's Island spread 1.0 mi (1.6 km) to Staten Island in 4 years. We anticipate that DNA analyses, still pending, will shed additional light on this. Our studies also highlight the fact that when suitable host trees are abundant (as in Carteret), a population of ALB can remain highly localized for years, reproducing on relatively few trees in a limited area (a few hundred meters in radius). We hypothesize that eventually, and rather suddenly, declining food resources or negative interactions among adults lead beetles to disperse more widely.
One additional finding is that a severe infestation, with hundreds of exit holes on trees plainly visible from the ground, can go unnoticed—or at least unreported—by the general public for years. The infestation in Carteret, in a busy commercial and residential district, apparently went undiscovered for 7 years.

UPDATE ON *SIREX NOCTILIO* IN CANADA

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ABSTRACT

In 2007, surveys for the *Sirex* woodwasp (*Sirex noctilio*) were conducted in the provinces of Ontario, Quebec, Nova Scotia, and New Brunswick. To date, the *Sirex* woodwasp has not been found in Quebec, Nova Scotia, or New Brunswick. However, in Ontario, there are now 25 counties/districts where *S. noctilio* is known to occur. It is generally associated with Scots pine and present within the Great Lakes/St. Lawrence forest region.

It is unclear whether *S. noctilio* poses a serious threat to pine in Canada. Scientists in Canada are studying the ecology of *Sirex* within pine ecosystems. Studies include the investigation of the spatial distribution of all insects and parasites associated with *S. noctilio*. Fungal interactions between *Amylosterum areolatum* and the fungal species vectored by pine bark beetles are also being studied.

The nematode *B. siricidicola*, a proven biocontrol agent in managing populations of *S. noctilio* in the Southern Hemisphere, was confirmed in Canada during the summer of 2007. Further research is required to confirm if these nematode populations are effective in managing *S. noctilio*.

A second round of consultation meetings is being organized with various industry groups in Canada in an effort to provide information on the biology of *Sirex* woodwasp and its current known range in Canada and to seek stakeholder input into future mitigation options and regulations that will reduce the spread of *S. noctilio*.

RECONSTRUCTION OF THE ESTABLISHMENT AND SPREAD OF EMERALD ASH BORER THROUGH DENDROCHRONOLOGICAL ANALYSIS

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ABSTRACT

Emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire [Coleoptera: Buprestidae]), a phloem-feeding beetle native to Asia, was identified in 2002 as the cause of widespread ash (*Fraxinus* spp.) mortality in southeastern Michigan and Windsor, Ontario. We used dendrochronological analyses to reconstruct where EAB originally became established and how it spread throughout southeastern Michigan. The area we sampled was greater than 15,000 km2 in size and encompassed the original six-county EAB quarantine established in 2002. Increment cores from EAB-killed green ash were preferentially collected over declining or non-stressed ash trees on at least a 4.8 × 4.8 km sampling grid. Cores were dried, mounted, and surfaced prior to measuring ring widths to the nearest 0.01 mm using a Velmex measuring system. Skeleton-plots depicting annual relative growth rates were generated and used to visually crossdate cores to a known master chronology compiled from ash trees surrounding the study area.

Preliminary crossdating analyses suggest that EAB initially became established and began to kill trees in the Westland-Garden City vicinity by 1997-1998. Related research has shown that an area is typically infested for 3 to 4 years before tree mortality occurs, suggesting that EAB was introduced and became established in southeastern Michigan in the early to mid-1990s. Preliminary measurements of the reconstructed spread of EAB indicate that the EAB population exhibited a biphasic expansion following an initial establishment phase. This type of expansion pattern is characteristic of invasive species in which nearby expanding satellite colonies coalesce with their primary core infestation over time. The core EAB infestation initially radiated from the epicenter by about 6.5 km each year and then increased to 30 km per year as nearby satellite EAB colonies started to coalesce. Jump distances of new satellite colonies of EAB averaged 20 km from the nearest edge of the core infestation (95% C.I. = 15 to 24 km). In 5 years (1998 to 2003), the area occupied by the core EAB infestation increased 170-fold.

BALANCING THE COSTS AND BENEFITS OF SLOWING THE SPREAD OF GYPSY MOTH

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ABSTRACT

The Slow the Spread of Gypsy Moth Project (STS) has successfully reduced the rate of spread of the gypsy moth (*Lymantria dispar* (L.)), by detecting and eradicating isolated populations that establish outside of the infected zone. The costs of slowing the spread have averaged $11.2 million per year since 2000 (deflated to 2000). Do the benefits of the program justify this cost? The objectives of this study are (1) to estimate the incremental benefits of reducing the rate of spread during the full operational phase of STS, 2000–2006, and (2) to project and compare the benefits and costs of STS for the next 20 years, 2007–2026. Here, we focus on the categories and methods for quantifying the benefits, both ex post and ex ante.

The primary benefits of slowing the spread of gypsy moth accrue to areas immediately outside of the currently infested zone. The government and the private sector benefit from delay of (a) expenditures on aerial suppression, (b) imposition of the quarantine, and (c) costs associated with outbreaks. This benefit of delay is quantified by summing the discounted future costs under different scenarios for spread of gypsy moth and then comparing the present value of costs under spread scenarios with and without STS. Thus, the spread scenarios are critical to the assessment.

In the most recent period without any barrier zone policies, the gypsy moth spread at an average rate of 20.8 km/ year, although the spread has been much faster (up to 45 km/ year) in the northernmost portion of the range. This faster rate of spread is expected in the Upper Peninsula of Michigan, Wisconsin, and Minnesota east of the prairies. Under STS, the gypsy moth has been spreading at an average of 6 km/ year. If the STS project were suddenly cancelled, there would probably be a transition period, during which the rate of spread would slowly increase. Based on these considerations, we developed two types of spread scenarios without STS: a flat spread of 20.8 km/ year and a dynamic spread increasing from actual to an expected maximum (20.8 or 45 km./ year) over a 7-year period. To project spread of gypsy moth under STS forward for the next 20 years, we considered spread rates of both 6 km/ year and 10 km/ year (the original goal of STS). See Figure 1 for an example of the additional area that would become infested with gypsy moth under a spread scenario without STS compared to spread at 6 km/ year with STS.

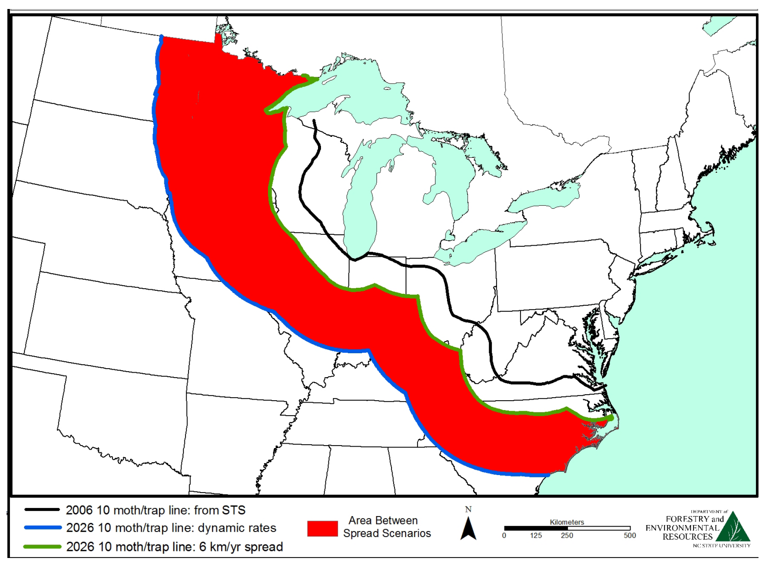

Figure 1.—Projected Spread of Gypsy Moth with STS (6 km/yr) and without STS (Dynamic Rates).

Preliminary estimates of the postponed costs include only expenditures on aerial suppression, and the nuisance, defoliation, and tree mortality impacts in residential zones, all discounted at a 4-percent rate. Quarantine costs have not yet been quantified, and the costs in rural forest zones (e.g., loss of timber and recreation) are much more difficult to predict due to greater substitution possibilities (e.g., mortality of some trees benefits growth of remaining trees; recreationists can visit unaffected sites). All costs are projected based on the number of "susceptible hectares," which are forested acres with more than 20 percent of basal area in species preferred by gypsy moth. Specific cost estimates are as follows:

Aerial suppression costs are $1.80 per susceptible hectare, including:

- Cost share suppression costs $86/ ha, plus 15 percent indirect costs for administration and outreach, applied to 1.6 percent of susceptible hectares
- Private suppression costs $84/ ha, applied to 0.26 percent of susceptible hectares

Nuisance, defoliation, and tree mortality impacts in residential zones:

- $955 ($563) per urban (small town and rural) household occupying single family or duplex home in year facing 40 percent defoliation; 25 percent less for households facing 25 percent defoliation based on 1991 contingent valuation study by Paul Jakus
- Long-term average defoliation of 6 percent of susceptible hectares is assumed to be half 40-percent defoliation and half 25-percent defoliation

When these cost estimates are applied to reasonable combinations of spread scenarios for the next 20 years, the present value of the costs postponed by STS are roughly $490 million. This compares favorably with a present value of estimated total program costs of $195 million (all in 2007 dollars). Because this calculation relies heavily on a methodologically sound but 15-year old study of willingness to pay to avoid gypsy moth outbreaks, ongoing work is focusing on triangulation with alternative methods.

INFORMATION SYNTHESIS FOR PREDICTING CLIMATE CHANGE IMPACTS ON INVASIVE SPECIES

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ABSTRACT

The objective of this work is to develop strategies to incorporate aspects of climate change into analytical tools and products, so that they can be used for longer term planning and management decisions. Issues to consider include the direct change in insect and pathogen biology, the direct changes in host plant biology, the changes in agent-host interactions, and the changes in interactions with other disturbance agents (fire, storms, etc). Issues specific to invasive species include impacts on the speed of spread, the biological range of habitats, and the eventual geographic extent of the invader.

The institutional tools and products we want to make "climate smart" include operational risk and hazard models and rating systems; the strategic National Insect and Disease Risk Map (NIDRM); species-specific non-native invasive risk analyses; and insect and pathogen management impact models for the Forest Vegetation Simulator (FVS). Various analytical relationships are used in existing tools and products. Existing models of relationships range from simple correlations to complex process models; the simple ones often reflect our incomplete state of knowledge and understanding of these biological systems. When climate relationships are represented by correlated, non-climatic variables, direct modeling of future climate scenarios is not possible. For non-native organisms, "incomplete knowledge" is usually a gross understatement.

Modeled descriptions of risk relationships between agents and hosts may use physiographic site descriptors, climate, or calculated variables such as moisture stress, which represent biological processes. In a changing climate, correlates and indices of climate (elevation, latitude, and site index) are not stable, requiring further analysis. Our analytical process considers the following questions: what are the known agent/host/climate relationships; how might climate change modify these relationships; how might climate change create new problems; and where, when, and how much might these changes impact forest resources. Our specific projects include construction of a Risk and Hazard Rating System Database; a Pest and Host Range Mapping System; and a Pest, Host, and Climate mechanism publication summary.

The Risk and Hazard Rating System Database was developed as a Microsoft Access database. It includes details on about 520 citations, about 190 available within the product as PDFs or online with URL links. Entries include agent and host, independent and dependent variables, model type, geographic range, and bibliographic citations. The assembled variables found to be significant in risk assessments and empirical evaluations will help indicate how projected climate change for an area may modify risk conditions. Even through direct climate information may not have been included in the original studies or models, correlates such as aspect, elevation, habitat type, site index, and latitude should be useful in projecting at least the impact of changes in temperature and precipitation.

Our Pest and Host Range Mapping system links an Access database and an ArcGIS geographic database to store information about host-pest relationships and spatial information for host and pest distributions and observed and predicted damage locations. We currently have entries for about 800 tree species and 3,500 pest species. This system has the potential to extract climatic and related physiographic factors limiting host and pest range and for use with climate scenario vegetation range change projections.

We are also reviewing climate change literature to assemble a comprehensive list of climate factors that have been documented as mechanisms impacting pest biology, host biology, or pest x host interactions. This information is being summarized in a simple database linking mechanisms, pest groups, and citations.

The National Insect and Disease Risk Map is a national Forest Service product to project potential future forest damage. FHTET has been asked to build functionality into the NIDRM, which could include longer term climate change impacts. We are currently building procedures to integrate external research results on the impact of climate change scenarios on forest stresses and species distributions, modifications of existing risk models, and the other broad, potential impacts of climate change on forest health not at issue under current conditions.

At the fine spatial scale project level, we are investigating the use of our FVS-BGC model as a practical means not only for incorporating climate change scenarios into growth and yield models, but also for estimating stress and other forest health-related hazards to potential insect and disease risks.

MICROSPORIDIAN PATHOGENS IN COLEOPTERAN PREDATORS OF HEMLOCK WOOLLY ADELGID

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ABSTRACT

Although quarantine regulations and practices are in place in the U.S. to avoid releasing natural enemies of non-native biological control agents, latent or cryptic pathogens such as submicroscopic viruses, microsporidia, and protozoans may be undetected in a host species during the quarantine period. After release from quarantine, problems may not be observed until establishment of colonies for one or more generations. These “creeping” diseases can build from low to very high prevalence, resulting in destruction of a colony for which large amounts of time and funding have been expended and compromising field releases. Two microsporidian species have been recovered from two coleopteran predators of the hemlock woolly adelgid, the Asian import *Sasajiscymnus tsugae*, and *Laricobius nigrinus* collected from the western U.S. (Table 1). Screening for one microsporidian species in a laboratory colony of *S. tsugae* over several years showed a strong increase in prevalence in the colony and strong winter mortality among infected beetles. The several predatory beetle species being reared and released for control of HWA are relatively host specific, increasing the risk that in the field, infected beetles will inoculate the feeding niche of the adelgids, thereby exposing conspecific individuals and other predatory species to the pathogens. We currently do not know if the microsporidia are specific to the hosts from which they were recovered, but one infected *Scymnus sinuanodulus* individual from a facility where infected *S. tsugae* were reared suggests that other coccinellid species may be susceptible to this pathogen. We are currently working to produce phylogenetic information about the microsporidia and plan to study cross-infectivity among predatory beetles being reared for HWA biological control.

Table 1.—Microsporidia in hemlock woolly adelgid predators, 2002-2007

Host species	Year and colony location	Percent infection in colony
Sasijiscymnus tsugae	2002 NJDA	12
	2003 NJDA	50
	2004-2005 NJDA	5
	2006 NJDA	3
Scymnus sinuanodulus	2003-2006 NJDA	0
	2004-2005 CT Ag	0
	2006 NJDA	1
Laricobius nigrinus 2005	Washington, Pt. Defiance	20
	2006 OR & WA sites	0
	2007 Washington, Pt Defiance	0

MAPPING HISTORIC GYPSY MOTH DEFOLIATION WITH MODIS SATELLITE DATA: IMPLICATIONS FOR FOREST THREAT EARLY WARNING SYSTEM

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ABSTRACT

A case study was conducted to assess the potential of MODIS (Moderate Resolution Imaging Spectroradiometer) data for monitoring non-native gypsy moth (*Lymantria dispar*) defoliation of forests. Gypsy moth defoliation of broadleaved forests in the United States is specifically listed as a threat in the Healthy Forest Restoration Act (HFRA) of 2003. The HFRA mandates development of a national forest threat EWS (Early Warning System). The U.S. Forest Service Eastern and Western Forest Threat Assessment Centers are designing and building this system. NASA is helping the Forest Service to integrate needed satellite data products into the EWS. This activity includes the evaluation of MODIS data sources for supplying EWS forest disturbance monitoring products. This case study focuses on one facet of the EWS: the need for monitoring forest disturbance due to exotic insect defoliation.

Our presentation discusses results of the case study compared to EWS needs, such as producing early indications of forest defoliation using historic and current temporal composites of MODIS data. This study employed MODIS data collected over a 15.5 million-acre mid-Appalachian Highland region during the annual expected defoliation timeframe of mid-June through July in 2000–2006. The study focused on 2001 defoliation because of available reference data during that year. Analysts computed and validated 2001 regional wall-to-wall defoliation maps from multiple MODIS products. We determined that MODIS time series data can accurately map regional historic gypsy moth defoliation (providing that temporal data processing was applied to data from the defoliation period). We used MODIS time series data to compute baseline NDVI (Normalized Difference Vegetation Index) levels of non-defoliated forests during the targeted timeframe. The latter can be compared to current conditions of the same timeframe to detect anomalous drops in NDVI due to defoliation. Temporal processing of MODIS NDVI data from the defoliation period proved effective even though clouds covered the study area about 80 percent of the targeted time. MODIS defoliation maps may aid airborne sketch map defoliation surveys, either in the planning stage or after the fact in terms of adjusting estimates of total defoliated area. More work is being done on other geographic regions and other years to further assess this promising application.

THE HISTORY OF EMERALD ASH BORER DISCOVERIES IN THE UPPER PENINSULA OF MICHIGAN FROM 2005 TO 2007

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ABSTRACT

Extensive emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) detection surveys using girdled trap trees have been performed throughout the Upper Peninsula of Michigan by Michigan Technological University (MTU) and the Michigan Department of Agriculture (MDA) since 2004. In 2005, the first find of EAB in the Upper Peninsula of Michigan occurred at Brimley State Park in Chippewa County. EAB exit holes were discovered on a single ash tree in July 2005. This tree was removed, peeled, and burned, but no life stages were found. In October 2005, more than 50 trees were felled and peeled. Eleven of these trees had EAB exit holes and/or larvae. EAB had likely been introduced to the campground at Brimley State Park through the movement of firewood, with the first adults emerging in 2003. Eradication efforts at Brimley State Park are thought to have been effective.

In 2006, there were no new detections of EAB in the Upper Peninsula. In 2007, trees infested by EAB were identified near Moran and in Straits State Park, both in Mackinac County, approximately 15 km apart. During September 2007, EAB was initially detected in a single trap tree in Brevort Township near Moran. Through a grid survey of the surrounding forest areas in November 2007, 14 other positive trees were located and EAB larvae, galleries, and exit holes were identified. While no exit holes were found on the original detection tree, several individuals in different larval stages were found. One positive tree that was fully peeled did have exit holes and these were dated to 2005. A girdled trap tree established in 2005 at Straits State Park was identified as having exit holes, larvae, and pre-pupae in October 2007. Peeling of 21 other trap trees within the park did not result in any additional infested trees. This included trap trees set in 2005-2007 in both the lower and upper campgrounds within the park. A small firewood pile (1-10 pieces, 50% ash) was recorded in close proximity to the infested tree in June 2006 and may have provided a source of EAB for this infested tree. It is likely that eggs were laid in 2006, with a few individuals completing a 1-year life cycle and most individuals completing a 2-year life cycle, first as pre-pupae during 2007 and then emerging in 2008.

FIELD RELEASE OF SPATHIUS AGRILI YANG (BRACONIDAE): MONITORING NON-TARGET WOOD BORERS

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ABSTRACT

Before the identification of emerald ash borer (EAB) (*Agrilis planipennis* [Coleoptera: Buprestidae]) in Michigan in 2002, *Spathius agrili* Yang (Hymenoptera: Braconidae) was discovered attacking this buprestid in its native range in China. Subsequent laboratory host specificity testing with North American wood borers and olfactometer testing of various tree volatiles, including those from ash, suggest that *S. agrili* will not have a significant impact on native North American wood borer fauna.

To determine the ability of *S. agrili* to establish in Michigan and to monitor non-target impacts, field releases were made at three sites in Michigan in late summer 2007. Three wood borers native to North America are being monitored: the redheaded ash borer (*Neoclytus acuminatus* [Say]), the twolined chestnut borer (*Agrilus bilineatus* [Weber]), and the bronze birch borer (*Agrilus anxius* Gory).

Redheaded ash borers were brought to the release sites as larvae feeding in 1-m-long ash logs. Three logs were brought to each release site as well as three ash logs infested with EAB larvae. Pairs of redheaded ash borer- and EAB-infested logs were strapped 1 m above ground to the trunks of EAB-infested trees in the immediate area of the planned *S. agrili* release sites. In late winter 2008, the ash logs will be placed in individual rearing tubes and monitored for *Spathius* emergence.

Host trees (d.b.h. ~ 15 cm) for the non-target *Agrilus* species were moved to the release sites during early summer 2007: pin oak (*Quercus palustris*) for the twolined chestnut borer and European paper birch (*Betula pendula*) for the bronze birch borer. In the laboratory, bolts of host trees infested with these species were placed in rearing tubes and adults were collected upon emergence. Adults were held for 10 days, fed with foliage and honey: water, and then released into containment cages around the trunks of the oak and birch trees, where it was anticipated that they would lay eggs. The cages also included a sapling of the host tree with foliage and small twigs of foliage with their stems in a moist bag. Cages were removed 2 weeks after the beetles were confined. The trees will be cut into sections in early 2008 after a sufficient cold period. A subset of the wood will be debarked to confirm the presence of nontarget *Agrilus* species and any possible parasitism. The remaining logs will be placed in tubes, and emerging beetles and parasitoids will be collected and identified.

IMPROVING SEMIOCHEMICAL DEPLOYMENT THROUGH THE EVALUATION AND DEVELOPMENT OF RELEASERS

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ABSTRACT

Release devices for semiochemicals remain relatively rudimentary, primarily due to constraints of cost and fragility. Passive releasers emit semiochemicals through a membrane or wick and are significantly affected by meteorological conditions, making the amount of semiochemical dispensed variable. This variation promotes inconsistencies and inefficiencies in field applications, which confound already complex interactions between semiochemical applications and insect behavior. Insect monitoring and detection programs, such as Early Detection Rapid Response (US FS, FHP), have little or no elution data to guide decisions on lure selection and deployment. Our project was implemented to meet the following objectives: to develop more consistent semiochemical releasers, to improve the utility of elution data through increased field-testing and standardization, and to increase the availability of elution data.

Active releasers offer hope for making semiochemical release more consistent—more independent from climatic conditions and longer lasting—and with reduced semiochemical waste. Puffer and pump technologies provide alternatives to the more frequently used passive devices but are more costly and complex. Standardizing field evaluation protocols and collecting meteorological and elution data simultaneously are integral to explaining release rates and improving their predictability. We evaluated field elution dynamics of more than 30 devices, based upon customer input and needs, at three locations during 2007 (Pineville, LA; Missoula, MT; and Susanville, CA). A web site, hosted by the U.S. Forest Service, Forest Health Technology Enterprise Team, is being developed to serve as a clearinghouse for data that describe release of semiochemicals from these and other commonly used devices. Content has been posted and continues to increase. The web address is http://www.fs.fed.us/foresthealth/technology/elutionrate.

EFFECT OF PHEROMONE STEREOCHEMISTRY ON ATTRACTION OF *TETROPIUM FUSCUM* (FABR.), *T. CINNAMOPTERUM* KIRBY, AND *T. CASTANEUM* (L.)

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ABSTRACT

Silk et al. (2007) found that *Tetropium fuscum* (Fabr.) (Coleoptera: Cerambycidae) males emit a homoterpenoid alcohol (termed "fuscumol") and that a racemic mix (50/50) of *S*- and *R*-stereoisomers of fuscumol synergized attraction of both sexes to spruce host volatiles, i.e., acted as an aggregation pheromone. Because *T. fuscum* males produced mainly *S*-fuscumol, we hypothesized that S-fuscumol would be more attractive than *R*-fuscumol or the racemic blend and would be a better lure for detection surveys of *T. fuscum*. We tested the attraction of *T. fuscum* and other *Tetropium* species to pure *S*-, pure *R*-, and racemic fuscumol, alone and in combination with host volatile lures, in trapping bioassays in Halifax, NS, and Białowieża, Poland in 2007.

Attraction of *T. fuscum* and related species was significantly affected by fuscumol chirality and the presence of host volatile lures. Addition of *S*-fuscumol or racemic fuscumol to traps baited with host volatile lures synergized attraction of both sexes of *T. fuscum* as well as *T. cinnamopterum* Kirby (a nearctic wood borer of spruce and pine) and *T. castaneum* (L.) (a palearctic species not known to be established in North America). *R*-fuscumol did not synergize attraction of any Tetropium spp., but its presence in the racemic blend did not deter attraction to *S*-fuscumol. Without host volatiles, fuscumol was not very attractive; only *S*-fuscumol attracted significantly more *T. fuscum* and *T. castaneum* than unbaited traps, and only in Poland. Similar responses of three different *Tetropium* species to fuscumol suggest these species use species-specific contact pheromones for mate recognition and reproductive isolation. Racemic fuscumol is easier to synthesize than pure *S*-fuscumol, so it will be much cheaper to use in operational surveys. In conclusion, *S*-fuscumol, in pure form or racemic blend, synergized attraction of *T. fuscum*, *T. cinnamopterum*, and *T. castaneum* to spruce host volatiles. Traps baited with the combination of racemic fuscumol and host volatile lures will be useful tools for early detection and survey of these species in areas of high risk of introduction.

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SPACE-TIME INTERACTIONS BETWEEN GYPSY MOTH AND ASSOCIATED ENTOMOPATHOGENS IN NEWLY ESTABLISHED POPULATIONS

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ABSTRACT

Two major pathogens infect gypsy moth (*Lymantria dispar* (L.) [Lepidoptera: Lymantriidae]) in North America: the gypsy moth nucleopolyhedrovirus (LdMNPV) and the fungal pathogen *Entomophaga maimaiga*. Both pathogens can regulate gypsy moth populations, minimize the duration and intensity of gypsy moth outbreaks, and thus be important biological control agents. However, limited empirical studies exist on how long it takes these pathogens to follow gypsy moth invasions. This issue is of particular importance for areas newly colonized by the gypsy moth and has broader implications in the context of natural enemy-victim interactions. We conducted field studies in Wisconsin in 2005, 2006, and 2007 along the leading edge of the gypsy moth population front to quantify the temporal and spatial lag between newly established gypsy moth populations and presence of *E. maimaiga* and LdMNPV. Prior-year gypsy moth density was a significant predictor of *E. maimaiga* ($P<0.01$) and LdMNPV ($P=0.04$) presence, and fungal and viral presence was more likely than not found at moth densities that were more than 68 and more than 252 males/trap in the prior year, respectively. Also, pathogen presence, based upon the prior year's population threshold boundaries, tended to be behind the boundary at which 30 moths or less per trap are captured but generally ahead of the 300 moths/trap boundary. In the case of *E. maimaiga*, only the distance from the 100 moths/trap threshold was a significant predictor of its presence ($P=0.03$), while for LdMNPV, only the distance from the 300 moths/trap threshold was significant ($P=0.04$). Our future work will attempt to develop a spatially and temporally explicit model of the dynamics between gypsy moth and associated entomopathogens as the gypsy moth invades new areas. With renewed interest in classical biological control for managing biological invasions (i.e., emerald ash borer, *Sirex* woodwasp), there is a consequential need to improve our understanding of the space-time relationship between natural enemies and their target victims, and the gypsy moth-pathogen system provides an ideal model system for which field data exist.

ASSESSING ASSUMPTIONS ABOUT ADELGID ATTRIBUTES: LANDSCAPE PATTERNS OF AN INVASIVE INSECT

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ABSTRACT

The hemlock woolly adelgid (HWA) (*Adelges tsugae*) is a small aphid like insect native to Asia and eastern North America. In 1951, this insect was detected on ornamental hemlocks in Richmond, VA, and in the 1980s spread outward into natural stands of eastern and Carolina hemlock (*Tsuga canadensis* and *T. caroliniana*). Infestation by the HWA results in increased rates of tree mortality, and populations of HWA are known to be in at least 17 states in the eastern United States. At the present time, control of the insect is limited to individual-tree applications of insecticides, and although biological control efforts are underway, landscape-scale control of this insect is driven by its ecological tolerances. One of the major factors that may limit the ultimate spread of the HWA is winter temperature. Previous laboratory work has shown that this insect has a limited tolerance for low temperatures. Using recent surveys of *A. tsugae* mortality across the latitudinal gradient occupied by the adelgid in the eastern United States, we show that there is a significant positive correlation between minimum winter temperatures and winter survival at the landscape scale; the strength of this relationship, however, varies through time. In spring 2004, minimum temperatures explained nearly 50 percent of the tree-level variance, but only 7 percent of the variance in 2003. Previous studies have suggested adelgid survival may be density dependent, a pattern that may complicate the detection of environment-insect interactions. Although these data do show a statistically significant relationship between these two variables, the relative contribution of the current year's density to changes in survivorship is small, suggesting other, as yet unidentified, factors play a major role in reducing populations of HWA. Using landscape estimates of minimum winter temperature based on more than 1,200 weather stations, we also show three methods of estimating landscape-level adelgid survival rates as a means to estimate the potential maximum geographic range of this invasive species. All three methods suggest that much of the distribution of *T. canadensis* in the United States, and likely all of *T. caroliniana*, fall within areas in which climate will not impose critical limits on populations of *A. tsugae*.

BACILLUS THURINGIENSIS INSECTICIDAL TOXINS INDUCE SHEDDING OF GPI-ANCHORED APN BY ACTIVATION OF PHOSPHATIDYLINOSITOL-SPECIFIC PHOSPHOLIPASE C

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ABSTRACT

Bacillus thuringiensis (Bt) is an aerobic, gram-positive bacterium that is used as a biopesticide. Many Bt strains produce parasporal proteinaceous crystals containing one or more insecticidal crystal proteins referred to as Cry toxins. The Cry toxins bind to the midgut brush border membrane and cause extensive damage to the midgut epithelial cells of susceptible insect larvae. Until recently, it was generally accepted that the pore-forming Cry toxins caused toxic osmotic lysis of the midgut cells by permeabilizing epithelial membranes. However, now it has been proposed that the toxicity of Bt has to do with its perturbation of intracellular signaling pathways.

Previously, we reported that Bt Cry toxins induce massive shedding of a membrane-anchored aminopeptidase N (APN) from midgut epithelial cells into the luminal fluid. In this study, we found that the toxin-induced shedding of APN was inhibited by cyclic AMP and MAPK kinase (MEK) inhibitors PD98059 and U0126, indicating that signal transduction in the MEK/ERK pathway is involved in the regulation of the shedding process. Furthermore, APN released from epithelial cells appears to be generated by the action of a phosphatidylinositol-specific phospholipase C cleavage of the GPI anchor of the membrane-bound APN based upon detection of a cross-reacting determinant (CRD) on the protein shed into the luminal fluid. Because shedding of various cell surface proteins induced by bacterial pathogens has been implicated in promoting their virulence, shedding of APN may promote the cytocidal action of Bt insecticidal proteins

INCREASING EARLY DETECTION OF INVASIVE SPECIES THROUGH TARGETED OUTREACH

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ABSTRACT

Recent introductions of invasive wood boring insects such as the emerald ash borer and the Asian longhorned beetle in solid wood packing material cost the public hundreds of millions of dollars in Federal funding to manage and control. Our project is designed to increase early detection of invasive forest pests arriving in North America. We will accomplish this by training pest management professionals to search for signs of exotic insects in solid wood packaging in warehouses and how to respond if they find something suspicious. After surveying pest management professionals, we determined that a simple modification of existing practices would significantly increase early detection of invasive species. We have developed an online course (http://www.continuinged.purdue.edu/media/pest/ invasive/) to certify pest management professionals for handling exotic pests. We also are executing a public campaign to create a demand for these services. Our hope is that widespread adoption of our procedures will increase the likelihood of detecting newly arrived exotic forest pests before they can escape into the environment.

EVALUATION OF *BEDDINGIA SIRICIDICOLA* AS A BIOLOGICAL CONTROL AGENT OF *SIREX NOCTILIO* IN NORTH AMERICA

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ABSTRACT

Sirex noctilio F. was identified in 2005 from bark beetle trap collections in Oswego County, NY, the previous autumn. This exotic invader does not seem to be under natural control, is already distributed over a wide area in the United States and Canada, and poses a serious threat to pine forests and plantations in North America if it is not controlled. Its most effective natural enemy, the entomopathogenic nematode (*Beddingia (Deladenus) siricidicola* (Bedding)), has been used very successfully as a biological control agent in management programs in the Southern Hemisphere. *Sirex* nematode's remarkable biology facilitates its use as a management tool. It can occur in two forms: a mycetophagous form that feeds on the *Sirex* symbiotic fungus, *Amylostereum areolatum* (Fries) Boidin, as it builds populations inside a tree and an entomopathogenic form that attacks *S. noctilio* larvae and ultimately sterilizes the woodwasp adults. We report on our recent activities to use the nematode in a developing biological control program, including consideration of some ecological challenges and issues in adapting the system for use in North America.

Australian scientists have investigated the biology of *Sirex* nematode during the past 30 years and developed technology for delivering it as an effective biological control agent. The Australian biocontrol program schedules activities through three seasons. In the spring, trap trees are created. Plots of 10 suppressed pine trees at the edge of a plantation are treated with an herbicide. The trees die slowly and attract *S. noctilio* females to attack them in their stressed state. In the summer, the nematodes are mass reared by Ecogrow Ltd., the licensed commercial nematode producer in Australia. Nematodes are delivered in lots of one million, which are sufficient to treat 10 trees. In the fall, the trap trees are felled and inoculated with nematodes. A special hammer is used to punch holes into the xylem; nematodes are then injected into the holes mixed in a polyacrylamide gel and they swim into the cut tracheid fibers of a tree.

Given the environmental differences between Australia and North America, transferring the biological control technology poses some ecological challenges. Two broad areas for discussion are (1) the ecological factors that affect nematode establishment and spread in North America and (2) the possible effects of nematode releases on non-target native species, especially other siricid woodwasps. Within-tree competition is one important ecological factor. *Pinus* species are exotic in Australia, and native pine feeding organisms are non-existent. By contrast, pine trees in North America contain numerous indigenous species, including borer competitors for *S. noctilio*, fungus competitors for *A.areolatum*, and nematode competitors for *B. siricidicola*. Climate is another factor affecting nematode growth and reproduction. Overall, the area into which the nematode will be introduced—currently New York and Pennsylvania—is much colder and wetter than Australia. Multiple strains of *A. areolatum* from different areas of origin and with varying growth rates also pose a challenge. The North American fungus strain isolated from *S. noctilio* in New York State grows at approximately one-third the rate of the strain used for mass rearing in Australia. This difference in growth of the fungus resource also affects the growth rate of nematodes and results in lower yields, by a factor of about four, in our mass rearing process. Another important factor in nematode ecology is tree species. North America has many native and exotic pine species with individual physiological characteristics that may affect nematode growth, development, and reproduction differently.

The possible effect of the nematode biological control program on non-target native species, especially siricids, is an issue of concern to the ecological community. North America contains 17 species of siricid woodwasps that use *Pinus* spp. as a resource, as well as their parasitoids and other borer species. A review of the literature suggests that the only taxa that may possibly be at risk are species of the pine-feeding Siricinae, most of which are associated with the fungal symbiont *Amylostereum chailletii* (Pers. ex Fries) Boidin. Because *B. siricidicola* lives only on *A. areolatum*, siricids using *A. chailletii* have a refuge from nematode parasitism. Of primary non-target concern among the North American siricids are three *Xeris* species, which do not have a fungal symbiont and may feed on either *A. areolatum* or *A. chailletii*. The effects of nematode parasitism on those species are unknown currently.

We have made much progress in transferring biological control technology for *S. noctilio* to North America in the short time since the pest was first detected. During 2006, we set up a lab for rearing nematodes. We received fungus and nematode cultures from Australia in December 2006 and have maintained them for over a year, mass rearing them in summer 2007.

We carried out a controlled release experiment during 2006-2007. The goals of the study were to test the Australian inoculation methodology, assess the establishment of Australian nematodes in American *Pinus* species, and evaluate overwintering survival of the exotic nematodes under New York winter conditions. The release was "controlled" in that trees were inoculated in the fall 2006, but samples were taken in spring 2007 and remaining tree materials were destroyed before insect emergence. A controlled release was necessary for several reasons. Primarily, the environmental assessment from APHIS Environmental Services that was needed for a full release was not finished by the desired release date in early November. In addition, we did not want nematodes and fungus to escape because of lingering non-target concerns and because of the aggressive growth characteristics of the Australian fungus, respectively. In all, 73 Scots pines (*P. sylvestris*) and 22 red pines (*P. resinosa*) were inoculated at five sites in Oswego, Onondaga, and Madison Counties, New York. Naturally struck trees that were heavily attacked by *S. noctilio* were selected. Three 60-cm sample billets were removed from each tree in March and reared in screened barrels. Almost 2,700 *S. noctilio* adults emerged in summer 2007, and their dissection to determine the nematode parasitism rate is still in progress. Additional controlled releases were made in October 2007 at five sites in New York and Michigan. All nematodes for those releases were mass reared on the North American isolate of *A. areolatum.*

SIMULATING IMPACTS OF INVASIVE PLANTS IN SOUTHERN APPALACHIAN LANDSCAPES USING LANDIS

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ABSTRACT

Landscape simulation models are a useful tool for exploring the reciprocal interactions between forest structure and a variety of natural disturbance agents including wildland fires, windstorms, pests, and disease characteristic of a landscape or a geographical area. These models have also been used to simulate the effects of a variety of human-made disturbances such as harvesting, thinning, and planting. However, the utility of this approach for examining the impact of exotic species invasion is still unclear, particularly in the southern Appalachians, where species diversity is high and the forests are often under multiple environmental threats.

We provide a conceptual framework for using a landscape simulation model to evaluate impacts of invasive species, and we present an experimental study using this approach to explore the impacts of invasive trees on forest composition and structure in the southern Appalachians. Three invasive trees—tree-of-heaven (*Ailanthus altissima*), mimosa (*Albizia julibrissin*), and princess tree (*Paulownia tomentosa*)—were simulated in hypothetical landscapes using LANDIS-II, a spatial explicit forest succession simulation model under no fires and with fires scenarios over a 500-year period. A gap model of forest growth and nutrient dynamics was used to parameterize tree establishment probabilities.

Our results indicate that establishment probabilities of the invasive trees differ among species across the landscape, controlled largely by a combination of temperature, precipitation, soil conditions, and tree life-history traits. At the landscape scale, fire regimes affect the number of invasive trees over time. The seed dispersal trait of the invasive trees is a significant biotic factor to influence invasion success. Our study suggests that using landscape models to investigate the interactions between long-term forest succession and invasion patterns may provide a promising opportunity for planning and evaluating management strategies in forest areas damaged by invasive species and other forest environmental threats.

AN ASSESSMENT OF SIREX NOCTILIO SPREAD AND POTENTIAL IMPACTS ON PINE WOOD SUPPLY AND HARVESTS IN EASTERN CANADA

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ABSTRACT

This study focuses on an emerging threat, *Sirex noctilio* Fabricius, a pine woodwasp recently detected in the United States and Canada and considered a high risk species to pine forests in North America. Our main objective is to estimate possible physical and economic impacts of a *S. noctilio* outbreak on standing pine biomass in eastern Canada. We develop a stochastic spread model to generate several invasion scenarios based on current expert knowledge about *S. noctilio* behavior in Canadian landscapes. The model links the spread patterns with the pine volume map and current regional harvest targets. Projections of killed pine volume range between 25.8 and 115 million m3 over 20 to 28 years depending on the spread model assumptions. Ontario shows the highest and most immediate losses (78% of total losses across eastern Canada over 20 years), and Quebec shares the rest (21.9% over 20 years). Short- and medium-term losses reach $86.3-254.1 million per year after 20 years and are split almost equally between Ontario and Quebec. The net present value of total harvest losses over 28 years is between $0.7 billion and $2.1 billion depending on model assumptions. Adaptation policies decrease short-term losses by 46 to 55 percent and potentially delay larger harvest failures by 9 to 11 years, perhaps buying time for knowledge gains and technical solutions.

Model

We use the Canadian Forest Service Forest Bioeconomic Model (CFS-FBM). The CFS-FBM biophysical component simulates the spread of invading organism, forest biomass growth, timber yields, and basic forest management activities (e.g., planting, thinnings, and harvest). The cost-benefit module uses the biophysical outputs and prices (such as silvicultural costs and forest product prices) to calculate the net revenues and timber supply costs from forestry activities. Data have been developed and the model applied to simulate *Sirex* spread scenarios across all of eastern Canada.

We use a modification of the traveling wave metapopulation model of Sharov and Liebhold (1998) to simulate the spread of *S .noctilio* as a discrete colonization process in a two-dimensional landscape. Based on expert judgments, the maximum annual rate of spread was assumed to be 50 km/year. Because *S. noctilio* does not have a history of observations in Canada, we provide the range of estimates about *S. noctilio* based on different infestation potential. To simulate the pine mortality, we use a ratio that denotes the per capita volume of pine mortality and limits the rate of pine mortality by the maximum limit. Based on observations from the outbreaks in Australian conditions, we assumed the range of maximum mortality rates for Canadian boreal landscapes to be between 4.4 and 16.7 m^3/ha/year or lower for 100-percent pine stands (or 0.8-3 m^3/ha/year when normalized for an average pine proportion in Canadian forests). The susceptibility of pine species was portrayed as a species- and age-dependent probability-density function. The maximum value of this function was based on the U.S. Forest Service FTHET pine susceptibility ratings.

Data and Scenarios

The map of standing pine volume was composed from Canada's National Forest Inventory (CanFI) and included Ontario, Quebec, New Brunswick, and Nova Scotia. The starting point for initial infestations was based on the detection survey conducted in Canada in 2005-2006 and assumes that positive findings would indicate the presence of the *S. noctilio* population in at least 25 percent of nearby pine forests.

We applied a heuristic harvest allocation model to project basic forest management activities in the study areas. Given the coarse scale of the study and the stochastic nature of the data used in the model, the preference has been given to the scoring techniques to calculate harvest allocations. Harvest has been allocated within the Annual Allowable Cut limits for the forest management regions identifying the major wood supply areas around big mills and wood processing facilities. The scoring used three criteria: (1) the present value of net fibre revenues, (2) the inverse distance to a nearest infestation front, and (3) a spatially uniform random error that represents other harvest considerations. To estimate pine AACs, we used existing softwood mills loads and capacities. We divided eastern Canada into the Areas of Primary Harvest (APH) centered on large wood processing facilities and groups of mills with total capacities of 105 m^3/year or more and used the annual mill volume consumption of softwoods to define AACs for each APH. APHs have been delineated based on the existing map of pine volume, assuming an annual growth rate for conifers of 1.8 m^3/ha/year and an average 100-year rotation. The AAC for pine wood was assumed to be proportional to the pine fraction of the total standing volume of coniferous species in the APH.

The present value of net fibre revenues included the costs of silviculture, harvest, transportation, and mandatory post-harvest treatments. Average transportation costs were calculated using a Forest Engineering Research Institute of Canada model. The average per unit per kilometer costs were set to \$0.12/m^3/km. Harvest costs were set to \$20/m^3, post-harvest mandatory treatment costs to \$400/ha, wood price at the mill gate to \$35/m^3, and the discount rate to 4 percent.

The study assesses economic impact of *S. noctilio* from the perspective of forest industry, as the changes in wood supply values delivered to the mill gate. The assessment of potential impacts includes two scenario runs–simulating harvests with and without *S. noctilio* invasion. The impacts are then calculated as a difference between the two scenarios. We explore three basic harvest strategies. The "No Adaptation" scenario applies the exact harvest configuration from the "no-invasion" scenario and hence simulates the economic impacts without any alterations of harvest patterns. The "Value Adaptation" scenario uses cost minimization strategies to adapt the harvest in response to the invasion. The "Value + Salvage" scenario is also driven by cost-minimization but reallocates the harvest closer to the infested area, hence representing a more proactive attempt at salvaging wood supply seemingly doomed to be killed by invasion.

Results

Sirex noctilio is a new species to North America with a short detection history, which dictated using a fairly simple spread model, a broad range of biophysical assumptions, and representing the results in a form of "what-if" scenarios. Overall, the projections show the total killed volume over 20 and 28 years as 25.8 to 43.7 and 79 to 115 million m3, respectively. Provincial totals follow the same tendency except the impacts are spread over time. The harvest allocation approach has relatively little impact on killed volume projections but drastically changes the economic impacts on harvest. For example, annual losses in the "Value Adaptation" scenarios were 1.7 to 2.5 times lower than in the "No Adaptation" scenarios, e.g., \$86.3-112.8 million per year vs. \$212-254 million per year at year 20. Total losses show a similar tendency. Depending on the harvest policy, the total net present value of the losses over 28 years is within \$1.5-2.1 billion in the "No Adaptation" scenario, \$0.7-1.1 billion in the "Value Adaptation" scenario, and \$1.2-1.9 billion in the "Value + Salvage" scenario. Total lump sum savings from using harvest adjustments in response to invasion reach \$0.84-1.0 billion over 28 years.

While harvest adaptation policies cannot slow the spread of invasion, they do help reduce short-term losses from the outbreak invasion by 46 to 55 percent. In general, harvest reallocations tend to avoid heavily infested sites with declining quality of standing wood. The results also suggest that given the long flying range of *S. noctilio*, the "Value + Salvage" scenario may not be an effective cost-saving option, especially when implemented within the existing Annual Allowable Cut limits.

We did not find a specific minimum loss of usable volume that causes large-scale wood supply shortages. "No Adaptation" scenarios show this threshold is between 43 and 111 M m^3 of killed biomass over 20 years. The "Value Adaptation" and "Value + Salvage" scenarios usually show higher levels starting from 230 M m3. Overall, without harvest adaptation, failures to maintain Annual Allowable Cut levels start to occur after 20 years when total area infested could exceed 15 million ha.

Conclusions

Incorporating harvest allocation models into the risk assessments of exotic pest invasions can better connect risk assessments to forest management. The results suggest that adaptation policies could decrease near-term losses by half and delay large harvest failures by 9 to 11 years. The results also suggest that for this species a preventive practice of moving the harvest closer to an infested area may not have an economic advantage or reduce physical losses of pine biomass from invasion. Existing AAC limits are simply too small to create a quarantine corridor comparable with the known flying range of *S. noctilio*.

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AN INTEGRATED EAB DATA MANAGEMENT FRAMEWORK: A PIECE OF THE PUZZLE?

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ABSTRACT

The Slow the Spread of the Gypsy Moth Project (STS) is a USDA strategy that seeks to mitigate the effects of the European gypsy moth (*Lymantria dispar* L.) in the United States. The STS project has developed a proven infrastructure to meet the operational monitoring, data management, risk assessment, and management needs of this national pest mitigation effort over the last 15 years. With an ever increasing threat of invasive species due to globalization, there is a need for greater emphasis on the development of data life cycle (collection, quality control, management) and risk assessment/management (decision support system) strategies during the early stages of emergency program development and deployment. The implementation of a well thought out data life cycle and decision support framework will allow quality data to feed the decisionmaking and planning processes of an emergency program increasing its effectiveness.

Emerald ash borer (EAB) (*Agrilus planipennis*) has rapidly become one of the most important invasive forest pests since it was first identified in the U.S. in 2002. To date, survey methods for EAB have varied substantially among cooperating states and agencies. Methods may include regulatory trace-backs of infested ash trees or logs, visual surveys for symptomatic trees, and girdled trap trees. Even in states where trap trees are the primary survey tool, implementation methods differ and data collected from the trap trees are not consistent. If EAB is to be effectively managed, survey methods and data management must advance. Delays in developing and implementing a proven data management strategy will only hinder the effective management of EAB. This will be particularly important given the potential for increased trap efficacy and greater systematic trapping. The STS framework encompasses a range of applications that not only could be applied to additional managed pest surveys (e.g., EAB and *Sirex* woodwasp), but also could strengthen future detection surveys.

POSTERS

Ambrose, M; Bigsby, K; Bauch, S; Wu, Y; Sills, E; Tobin, P: **Gypsy moth sex and the city: estimating costs and losses**

Auclair, A: **Predicting dieback in us forests: concepts and application of a forest health decision system**

Ballard, M; Hough-Goldstein, J; Tallamy, D: **Are alien plants the ecological equivalents of natives**

Bordeaux, JM, Dean, FD: **Phenyloxidase production by *Amylostereum areolatum* and its role in pathogenesis in loblolly pine (*Pinus taeda* L.)**

D'Amico, V; Slavicek, J; Podgwaite, J; Fuester, R; Peiffer, R; Webb, R: **Consequences of mutation for virus transmission in the field**

Downing, M; Borchert, D; Britton, K; Koch, F; Krist, F; Sapio, F; Smith, B; Tkacz, B: **Hazard assessment surfaces for *Phytophthora alni***

Fajvan, M: **The role of silvicultural thinning in eastern forests threatened by hemlock woolly adelgid (*Adelges tsugae*)**

Ferris, G; Morgan, J; Williams, C; D'Amico, V: **Riparian corridors as potential biodiversity refugia**

Francese, J; Crook, D; Fraser, I; Lance, D; Sawyer, A; Zylstra, K; Mastro, V: **Developing survey techniques for the emerald ash borer: the influence of placement, color and host-produced volatiles on trap capture**

Frederick, J; Storer, A: **Evaluation of public awareness of the risk of moving emerald ash borer in firewood**

Hajek, A; Long, S; Zylstra, K; Williams, D: **Rearing *Sirex noctilio* from Central New York**

Hajek, A; Tobin, P; Hannam, J; Nielsen, C; Diss-Torrance, A; Raffa, K: **Dispersal of gypsy moth (*Lymantria dispar*) pathogens to newly established host populations**

Hanula, J; Sullivan, B: **Manuka oil and phoebe oil are attractive baits for the exotic redbay ambrosia beetle, *Xyleborus glabratus* (Coleoptera: Scolytinae), vector of laurel wilt**

Higashiura, Y: **Flying AGM females: when and how far is she flying?**

Hiremath, S; Lehtoma, K; Hebard, F: **Use of SSR-Primers for progeny selection in a chestnut breeding program**

Keena, M: ***Anoplophora glabripennis* (Coleoptera: Cerambycidae) phenology under simulated annual fluctuations in environmental conditions**

Klepzig, K; Wingfield, M; Slippers, B: **Competition between fungi associated with *Sirex* woodwasp and southern pine beetle**

Koch, J; Mason, M; Pureswaran, D; Poland, T: **Asian ash species as a source of EAB resistance: Development and characterization of novel ash hybrids**

Koch, F; Smith, W: **Spatio-temporal analysis of redbay ambrosia beetle invasion in the southeastern U.S.**

Lance, D; Holske, B; Zylstra, K: **Artificial egging substrate for rearing *Anoplophora glabripennis***

Lee, J; Aguayo, I; Aslin, R; Durham, G; Hamund, **S;** Moltzan, B; Munson, S; Negron, J: **Trend of two invasives: the banded and European elm bark beetles**

Marshall, J; Storer, A; Fraser, I; Beachy, J; Mastro, V: **Comparing emerald ash borer detection tools: Are bigger trap trees better?**

Mausel, D; Elkinton, J; Van Dreische, R: **A *Laricobius nigrinus* (Coleoptera: Derodontidae) race from northern Idaho for hemlock woolly adelgid biological control in New England**

Morgan, J; Ferris, G; Williams, C; D'Amico, V: **Excluding invasive plants with riparian corridors**

Nehme, M; Keena, M; Zhang, A; Hoover, K: **Male-produced pheromone of Asian longhorned beetles**

Otálora-Luna, F; Hammock, J; Alessandro, R; Lapointe, Steve; Dickens, J: **Electrophysiological and behavioral responses of citrus root weevil, *Diaprepes abbreviatus***

Sawyer, A; Panagakos, W: **Spatial dynamics of the Asian longhorned beetle: from Carteret, NJ to Staten Island, NY in nine years**

Schiff, N; Haywood, J; Meeker, J; Johnson, W; **Wilson,** D; Wilkins, C; Ross, W: **Trap trees for *Sirex* in the South: practical considerations**

Siegert, N; McCullough, D; Liebhold, A; Telewski, F: **Reconstruction of the establishment and spread of emerald ash borer through dendrochronological analyses**

Solter, L.F.; Onken, B: **Microsporidian pathogens in Coleopteran predators of hemlock woolly adelgid**

Storer, A; Heyd, R; Katovich, S; Hyslop, M; McNee, W: **A risk based survey for emerald ash borer utilizing trap trees, firewood surveys and visual survey in Michigan and Wisconsin 2004-2007**

Storer, A; Marshall, J; Philip, M; McCullough, D; Siegert, N: **The history of emerald ash borer discoveries in the Upper Peninsula of Michigan from 2005-2007**

Strazanac, J; Gould, J; Haack, R; Fraser, I: **Field release of *Spathius agrili* Yang (Braconidae): monitoring nontarget woodborers**

Strom, B; Karsky, R; Smith, S; Shea, P; Adams, J: **Improving semiochemical deployment through the evaluation and development of releasers**

Sweeney, J; Silk, P; Gutowski, J; Kettela, E; Wu, J; Price, J: **Effect of pheromone chirality on attraction of *Tetropium fuscum* (Fabr.), *T. cinnamopterum* Kirby and *T. castaneum* L. (Coleoptera: Cerambycidae)**

Tobin, P; Hajek, A; Blackburn, L; Hannam, J; **Diss-**Torrance, A; Raffa, K; Nielsen, C: **Space-time interactions between gypsy moth (***Lymantria dispar***) and associated entomopathogens in newly-established populations**

Trotter, R. T.; Shields, K.S: **Assessing assumption about adelgid attributes: Landscape patterns of an invasive insect**

Valaitis, A: ***Bacillus thuringiensis* Insecticidal Toxins induce shedding of GPI-anchored APN by activation of Phosphatidylinositol-specific Phospholipase C**

Xi, W; Lafon, C; Cairns, D; Waldron, J; Tchakerian, M; Klepzig, K; Coulson, R: **Simulating impacts of invasive plants in Southern Appalachian landscapes using LANDIS**

Yemshanov, D; McKenney, D; de Groot, P; Haugen, D; Sidders, D; Joss, B: **An assessment of *Sirex noctilio* spread and potential impacts on pine wood supply and harvests in eastern Canada**

Ziegler, A; Leonard, D; Roberts, E: **An integrated EAB data management framework: a piece of the puzzle**

ATTENDEES

19th USDA INTERAGENCY RESEARCH FORUM ON INVASIVE SPECIES

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