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Hiding in plain sight

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Compiled by:

Katherine A. McManus
USDA Forest Service, Northern Research Station, Hamden, CT

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FOREWORD

This meeting was the 29th in a series of annual USDA Interagency Research Forums that are sponsored by the Forest Service, Animal and Plant Health Inspection Service, National Institute of Food and Agriculture, and Agriculture Research Service. The Group's original goal of fostering communication and providing a forum for the overview of ongoing research among the Agencies and their cooperators continues to be realized and facilitated through this meeting. This 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. The proceedings 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 through the spirit of collaboration.

ACKNOWLEDGMENTS

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Keynote Address

INVASIVE ORGANISMS AND INVASIVE FIRES: RECIPROCAL EFFECTS, MANAGEMENT OPTIONS

Kier D. Klepzig

Joseph W. Jones Ecological Research Center, Newton, GA

ABSTRACT

There is a developing tendency to treat invasive plants with resignation, accept their effects as the new normal, or even greet them as a source of more plant diversity. However, in many cases (cogon grass, spotted knapweed, etc.) their impacts can be devastating to ecosystem function. Management of invasive plants, pests and pathogens is challenging and only grows more complex when fire is used as a tool necessary for maintaining ecosystems. Fire severity is increasing. While invasives impact fire, timber, agriculture and more, the exclusion of fire from ecosystems can result in catastrophic wildfires. Prescribed burning can promote establishment and spread of invasives. Restoration can counter the effects of invasives through returning ecosystems to normal cycles of fire and regeneration and is cheaper than revegetation after invasives control. The USDA Forest Service led National Cohesive Wildland Fire Management Strategy offers one synthetic and rigorous approach to prioritizing fire management, including within the context of interactions with invasive species. The longleaf pine ecosystem (as highlighted in a consideration of the Jones Center at Ichauway) is an example of the effectiveness of active management on preventing deleterious effects of invasives and fire. In summary, interactions between fire and invasives are complex, scale matters, and prescribed fire is an essential tool for managing wildfire severity.

IT'S ABOUT TIME: APPLYING VARIABLE AND CHANGING TEMPERATURES TO THE MANAGEMENT OF TWO NATURALIZED INVASIVE PESTS, OAK WILT FUNGUS AND GYPSY MOTH

Kenneth F. Raffa[1], Michael A. Falk[2], Stephanie M. Jagemann[1], Jennifer Juzwik[3], Ken Keefover-Ring[4], Richard L. Lindroth[1], Patrick C. Tobin[5]

[1] Univ. Wisconsin-Madison, Dept. Entomology
[2] Wisconsin Dept. Agriculture, Trade, and Consumer Protection
[3] USDA FS, Northern Res. Stn
[4] Univ. Wisconsin-Madison, Dept. Botany
[5] Univ. Washington, School of Environ. & Forest Sci.

ABSTRACT

Contending with the threats posed by invasive species requires a mix of preventing new introductions, eradicating new arrivals, delaying the spread of newly established species, and managing populations of long-established species below damaging levels. We discuss management of two long-established exotic species from the standpoint of variable temperatures.

In the first example, building temperature models into existing management strategies can improve their effectiveness and generality, and also help us prepare for changing climate.

In the second example, changing climate can alter the manifold between tree defense and insect phenology.

The causal agent of oak wilt, *Bretziella (Ceratocystis) fagacearum* (DeBeer et al. 2017), was previously viewed as a native species, but is now considered a non-native invasive species (Juzwik et al. 2008). This change is based largely on four lines of evidence: Phylogenetic analyses and genetic structure, its directional spread, the lack of coevolved resistance within some oak species, and its lack of similarity to any North American species (Harrington 2009). Spread occurs between neighboring trees through root grafts, and over longer distance by sap beetle (Coleoptera; Nitidulidae) vectors. Prevention of spread is based primarily on avoiding cutting during periods of vector abundance (Juzwik et al. 2010). However, our knowledge of vector abundance and phoresy rates is limited. Adding to the uncertainty and complexity in contending with the tradeoffs between setting no-cut guidelines too broad or too narrow is that these activity periods are not well quantified. Also, weather varies from year-to-year and over latitudinal gradients, and coupled with rising baseline temperatures due to climate change, adds to this uncertainty.

We quantified the seasonal flight activities of the major vectors of *B. fagacearum*

throughout Wisconsin, quantified their frequencies of association with *B. fagacearum,* and developed degree-day models to increase the generality of results, guide decisions about pruning and silvicultural practices, and anticipate changing climate. We sampled 12 oak sites across a latitudinal gradient over two years using baited traps, and evaluated fungi using a combination of culturing and PCR methods. Emphasis was placed on the earliest and latest occurring nitidulid species, with additional data on 10 other species. Ultimately risk is a product of the number of beetles, the proportion carrying viable fungi, and vector transmission efficiency, each of which varies phonologically (Jagemann 2017, Jagemann et al. In Review). Risk projections were overlaid over current no-cutting early-season and late-season guidelines.

Climate change has been postulated to have multiple potential impacts on plant-insect interaction. These include processes such as alteration of defense chemistry, altered tritrophic interactions, altered tolerance to herbivory, range expansions leading to new host plant associations, and altered phenological synchrony. Our previous work in outdoor mesocosms administered controlled temperature manipulations emulating predicted conditions observed relatively minor changes in foliar chemistry, and relatively minor changes in larval suitability, when foliage age is standardized. Both budbreak and egg hatch developed more quickly as expected, but budbreak advanced more than egg hatch, thereby changing synchrony. Our current study asks, 'How will altered phenological synchrony affect herbivory?'

We qualified how trembling aspen phytochemistry (phenolic glycosides, Nitrogen) changes throughout leaf expansion, how these patterns vary with genotype, and how variation in early-season phytochemical patterns affects phenological relationships between aspen and gypsy moth. Aspen foliar chemicals underwent pronounced changes within short periods after budbreak (Falk 2017, Falk et al. 2018). Foliage had initially high phenolic glycosides, followed by rapid decline, with strong genotypic variation in both magnitude and pattern. Aspen foliage also had initially high Nitrogen, followed by a steep but steady decline, with moderate genotypic variation in magnitude and pattern. Performance of gypsy moth neonates on various aspen genotypes can be explained largely by foliar phenolic glycosides and Nitrogen, but only when timing is included. The relative effects of phenolic glycosides and Nitrogen depends on the timing of egg hatch & budbreak. The effects of climate-induced changes on gypsy moth will vary among host genotypes based on absolute concentrations of foliar chemistry, temporal patterns of foliar chemistry, and budbreak phenology. Hence, some genotypes will become more susceptible to gypsy moth, but others are likely to become less susceptible.

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PRESENTATIONS

Research Reports

IMPACT, SURVEY AND CONTROL OF THE BEECH LEAF MINING WEEVIL, *ORCHESTES FAGI*, AN INVASIVE PEST OF AMERICAN BEECH IN NOVA SCOTIA, CANADA

Jon Sweeney[1], Cory Hughes[1], Joel Goodwin[2], Kirk Hillier[2], Simon Pawlowski[2], Peter Mayo[1], Lucas Roscoe[1], Ed Czerwinski[3], Tarryn Goble[4], Rob Johns[1] and Peter Silk[1]

[1]Natural Resources Canada, Canadian Forest Service, Atlantic Forestry Centre, Fredericton, NB, Canada
[2]Acadia University, Wolfville, Nova Scotia, Canada
[3]ForestTree Care, Fredericton, NB, Canada
[4]BioForest, Sault Ste. Marie, ON, Canada

ABSTRACT

The beech leaf mining weevil, *Orchestes fagi* (Coleoptera: Curculionidae), native to Europe, was discovered infesting American beech in Halifax, Nova Scotia, Canada in 2012, but anecdotal reports of damage to beech foliage suggest it may have established in the area 5–7 years prior to its discovery. Because adults overwinter in crevices and under moss and scales on the trunks of beech and other trees, risk of human-assisted spread of the weevil via transport of logs and firewood is high. We present results of studies to measure the weevil's impact on American beech, and to develop tools for its survey and control. In 2014, fixed radius plots were established in areas of high, moderate, and low–nil weevil populations; plots were monitored each year for infestation levels and beech mortality. Between 2014 and 2017, infestation levels (i.e., mean number of leaves with larval mines) increased by 20% at the low-nil and moderately infested sites and cumulative mortality of beech increased by 10%. However, at the heavily infested site, beech mortality increased from 20% in 2014 to 85% in 2015 and was 90% in 2017; infestation levels dropped to zero in 2016 because there were no beech leaves for the weevil to infest. The number of consecutive years of heavy weevil infestation that the site endured is unknown but was at least 4 years and possibly as many as 10 years. Annual mortality will be monitored in all plots to get a better estimate of mortality rate. We also plan to use tree ring analysis to determine the year when weevil infestation may have started affecting radial growth rate. The most effective trap and lure to date is a bright yellow sticky trap baited with geranyl-p-cymene (a host volatile emitted from beech buds at the time of budburst, when mating and oviposition occurs), and placed in the upper canopy of beech trees. Additional research on the response of *O. fagi* to semiochemical, visual, and auditory stimuli is underway to further increase the efficacy of survey tools and methods. Stem injection of mature beech with TreeAzin™ (produced from azadirachtin extracts from seeds of the neem tree) in fall or early spring significantly reduced *O. fagi* larval survival and damage to foliage. In 2018–2020, we will compare the mortality rate of weevil-infested beech treated with annual *vs* biennial injections of TreeAzin™ or left untreated.

COMMON MISCONCEPTIONS ABOUT FOREST TREE BREEDING, A VALUABLE TOOL FOR ADDRESSING FOREST HEALTH ISSUES

Jennifer L. Koch

USDA Forest Service, Northern Research Station, 359 Main Rd., Delaware, OH 43015

ABSTRACT

Breeding programs are an important tool for managing invasive insects and diseases causing high mortality rates and even threatening extinction of some of our forest tree species. The emerald ash borer (EAB) invasion of North America, as one example, has resulted in five North American ash species being listed as "critically endangered" on the IUCN red list (IUCNredlist.org). Impacts from such significant losses are far-reaching. Wildlife species that depend on threatened tree species can also be at risk of extinction, Mortality of riparian tree species such as Eastern hemlock, currently under attack by the hemlock woolly adelgid, can impact water quality. Economic impacts can be far-reaching, and include the costs of removing and replacing trees, and the loss of valuable income sources. This income loss is especially pertinent to rural communities reliant on both traditional – such as lumber, pulp, paper, and fiber -- and non-traditional forest products – ginseng, morels, and goldenseal. Additionally integral to rural economies are recreational opportunities provided by healthy forests, such as camping, hiking, canoeing, kayaking, hunting and fishing. In Hocking County, Ohio, for example, recreational tourism supports one out of every seven jobs and generates more than 115 million dollars annually (Apsley et al. 2014). Hemlock trees are cornerstone species in these recreation areas and their loss due to hemlock Wooly Adelgid (HWA) pose a serious threat to local communities.

Once an invasive insect or disease has become established, it is difficult, if not impossible, to remove. Breeding programs develop seed sources with appropriate levels of resistance for restoration, and are sometimes are the only available option for managing forest health issues. Tree breeding is a repetitive process of selection, mating and testing trees with the goal of producing improved populations of parent trees to produce genetically diverse, adapted seed. Each generation of breeding will produce seed lots with an increased proportion of resistant individuals and the average level of resistance of the population will be higher. The goal is to incorporate many different types (genes, gene variants) of resistance and preserve genetic diversity so that resistance cannot easily be overcome and the population maintains the ability to adapt to future threats and changing environmental conditions. Not every seedling will be resistant, but improved seed lots that have undergone rigorous testing, give forest managers an idea of what rate of mortality can be expected, and they can adapt their planting plans accordingly. However, programs to breed for improved host-resistance are often not pursued, or are only considered once all other options have failed, costing valuable time. Misconceptions about forest tree breeding programs may contribute to hesitation on the part of managers to pursue them as a forest health priority. These misconceptions will be discussed below, to offer clarification of both the potential and the limitations of breeding programs.

Myth: a resistant tree must be completely "bulletproof." When an invasive pest is introduced, the popula-

tion of host trees have not been previously exposed, so they have not been able to develop resistance over a long period of co-evolution. This does not mean that the population is completely devoid of resistant trees. Each tree is a unique individual with its own set of unique traits. Within genetically diverse populations, individual trees can have a wide range of responses, or phenotypes, to the invasive threat. The naturally occurring high levels of genetic diversity found in most forest tree species provides one of the most valuable tools for addressing forest health issues. Although trees that are highly susceptible to the insect or disease are likely to be most common, because there has been no selective advantage to such traits prior to introduction of the invasive pest or pathogen, there may be some infrequently occurring individuals with certain combinations of genes or gene variants that confer a variety of resistance traits, ranging from partial resistance or tolerance to high levels of resistance. Trees with partial resistance may only be able to live a few years longer than susceptible trees, but this does not mean that they are not "resistant" enough to provide a solution. When two partially resistant parent trees are bred, they may produce some progeny that get the best genes from each parent, and as a result are more resistant than both parents. For example, "lingering ash" trees that have survived long term EAB infestation when all surrounding ash trees have died, have been shown to have increased measurable mechanisms that allow them to mount a defense against EAB (Koch et al. 2015). Preliminary results indicate that breeding two lingering ash trees does produce some progeny with even greater defenses against EAB than either parent.

Myth: breeding takes too long, is too expensive and isn't successful. Although every program may not be successful, there are many examples of programs that have achieved success, and some that have done so in relatively short periods of time (Sniezko and Koch 2017). For example, the first Port-orford cedar seed lot having increased resistance to the root rot pathogen, *Phytophthora lateralis*, was released within five years after the start of the resistance program at the Forest Service's Dorena Genetic Resource Center. Resistant seedlots were available for seven out of thirteen breeding zones of Port-Orford cedar within fourteen years (Sniezko et al. 2012). This rapid success contributed, in part, to Port-Orford cedar being downgraded from being listed as a "vulnerable" species on the IUCN red list in 2011, to "near threatened" in 2013 and is anticipated to be considered a species of "least concern" within 10 years (Farjon 2013). Another example is the U.S. Forest Service Northern Research Station's program breeding for American beech with resistance to beech bark disease, which deployed its first resistant seedlings within ten years of the start of the program and currently has nine regional seed orchards in seven states in various stages of development (Koch and Heyd 2013).

The length of time it takes for a breeding program to achieve successful deployment of seed with improved resistance is dependent on many different factors. For example, the genetic complexity of resistance and the ease or difficulty in being able to identify appropriate trees can influence timelines. The more genetically complex resistance is, the more difficult it may be to breed for, leading to potentially longer time periods (more generations of breeding) until appropriate levels of resistance can be deployed. However, if substantial resistance (frequently occurring and high level of resistance) can be identified in existing natural populations, this can reduce the amount of time to produce improved seedlots. Developing methods to identify resistance in seedlings and parent trees plays an important role in breeding programs. Protocols that allow efficient high-throughput screening to select resistant material can reduce both the time and cost involved in a successful breeding program. The biology of the tree species can also impact the length of time a breeding program requires. For example, the time it takes for a tree to reach sexual maturity and produce seeds can range from less than ten years up to several decades. Hormone treatments and various lighting and cultural regimes are commonly used in some tree species to induce flowering as early as one to three years of age. Another important factor is continuous support of the breeding program; programs that go through rounds of starting and stopping, typically tied to success or failure of obtaining sources of "soft" funding, are much less efficient than those that have continuously

committed resources.

Nevertheless, the time frame of these examples and many other breeding programs is consistent with the length of time and resources dedicated to alternative management strategies, such as the development of biocontrol. Despite significant resources being committed to the development of EAB and HWA biocontrol programs over a period of more than 15 years, and significant progress being made, there is yet to be definitive evidence of biocontrol leading to improved tree health. Combining both biocontrol and improved host resistance through breeding programs may be the best strategy for retaining the tree species these invaders are currently threatening (Duan et al. 2015).

Myth: genomics and biotechnology alone can solve the problem. The advent of molecular biology and the age of genomics, has created much enthusiasm about the use of genomics and genetic modification to accelerate the production of resistant trees. The use of genomics to develop methods such as marker assisted selection (MAS) or genomic selection (GS), can streamline the breeding process by using markers to select seedlings or parent trees that are resistant. However, the development of such strategies depends on resources produced by breeding programs – large numbers of trees or seedling with known parentage and phenotypes (resistant or susceptible). Similarly, genetic modification through transgenic or gene-editing technologies, cannot replace a breeding program. These techniques may be able to create a single resistant tree (genotype) that will require costly regulatory authorization to plant in natural forests. For successful landscape scale restoration, the genetically modified tree will need to be integrated with a traditional breeding program to incorporate genetic diversity and maintain adequate adaptive capacity to multiple stresses and environments. Although genomic tools and genetic modification techniques can play an important role in understanding the underlying mechanisms of resistance and have the potential to enhance breeding programs, investing in such research alone will not produce resistant tree. An active breeding program is a prerequisite for the successful development and implementation of such tools, but does not require such tools to be successful. Most, if not all, operational breeding programs do not utilize such tools, often due to high cost of implementation. Careful cost-benefit analysis should be considered prior to pursuing the development of such tools to augment breeding efforts.

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DO WOOD BORERS IN CUBAN FORESTS AND GROVES POSE A THREAT TO THE UNITED STATES?

Demian F. Gomez[1], Paloma Carton De Grammont[1], Damian C. Adams[1], Jiri Hulcr[1]

[1] School of Forest Resources and Conservation, University of Florida,
136 Newins-Ziegler Hall, Gainesville, FL 32611

ABSTRACT

Introductions of invasive pests are largely a consequence increase of global trade, increasing during the past 50 years due to globalization. Existing phytosanitary and biosecurity procedures are developing but are not yet sufficient to protect the US from new invasive pests. Hence, post-border surveillance, such as early detection and rapid response procedures for exotic species are a critical task.

Bark and ambrosia beetles (Coleoptera: Scolytinae) are important disturbance agents in conifer and broadleaf forests. The vast majority breed in dead or dying tissues and do not cause economic impact. However, some species attack living trees, seedlings or seeds of commercial importance and cause severe damage. Beetle outbreaks are among the largest forest disturbances. In the United States, bark beetle outbreaks affect an average of 20,400,000 ha per year with annual average costs above US$2 billion. The costs involve timber losses, diminished ecosystem services, major carbon release pulses, and changes in the landscape aesthetic value.

To prevent future epidemics driven by invasive wood borers or tree pathogens, United States regulatory agencies need an evidence-based decision support system to accurately identify high priority pests, monitor and mitigate these pests offshore, manage pathways of introduction, and establish early detection and eradication programs if needed. The Caribbean is one of the most biologically diverse regions. This, along with its geographic proximity and ecological similarities to the United States, make the region a key pathway for potentially harmful exotic pests. Cuba is the closest large land mass to Florida, and little is known about pests of concern in Cuba.

Most Caribbean countries lack adequate information on invasive species, and the poor relationship between the United States and Cuba has resulted in the absence of information on pests in Cuba. For instance, several authors list no more than 85 species of bark and ambrosia beetles (Scolytinae). Yet Cuban diversity is probably much greater than that, considering that even in Florida, over 160 species are known. Despite some recent research on Cuban scolytine beetles, literature on this topic is scarce. Most specimens were identified abroad, and national collections are poorly represented in terms of number of species.

In order to detect potential new invasive species, the project "Potential tree pest invasions from Cuba: Pest diversity, economic assessment of threat, and Cuban policy analysis" was carried out as part of the USDA-APHIS Farm Bill Section 10007 2016 and 2017 spending plan. The goals of the projects have been to review the Cuban State plant protection system, to improve identification capacity, to build an up-to-date database of wood borers in the country as well to define high-risk potential pests for the U.S., and to produce an economic analysis of the cost of a potential new invader from Cuba. The solid organizational structure of the Cuban border protection system and collaboration instances were identified as a strength

in the system. The current status of the entomological collections present in the country, together with the scarce reference material and the identification capacity are discussed as shortcomings of the plant protection system. Our collaborative US-Cuban team have documented many known and newly discovered bark beetle species, so far none is showing the potential for impact in the US. However, the lack of access to information about new invasive species in Cuba arriving on imports to Cuba is identified as one of the blind spots in the US safeguarding systems.

URGENT NEED FOR UPDATED RESEARCH ON INFESTATION RATES OF TREATED WOOD PACKAGING MATERIAL (WPM)

Faith T. Campbell[1] and Robert A. Haack[2]

[1]Center for Invasive Species Prevention, 8208 Dabney Avenue, Springfield, VA 22152[2]USDA Forest Service, Northern Research Station, 3101 Technology Blvd., Suite F Lansing, MI 48910 (emeritus)

ABSTRACT

Although the International Standards on Phytosanitary Measures (ISPM) No. 15 was fully implemented by the United States in 2006, live pests of quarantine significance continue to be detected in wood packaging material (WPM) entering the United States. Inspections by the Department of Homeland Security Bureau of Customs and Border Protection (DHS CBP) have found that a high proportion of infested WPM bears the stamp indicating that the wood had been treated in accordance with ISPM#15 requirements and therefore should be free of live wood pests. A European study has found a similar level of infested wood that is marked as having been treated (Eyre et al. 2018).

Current estimates of the approach rate of live quarantine pests to the United States in WPM (0.1% of shipments with infested WPM) are based on USDA APHIS "Agriculture Quarantine Inspection Monitoring" (AQIM) data from 2006 through 2009 (Haack et al. 2014). Eight years have elapsed since these data were evaluated. During this interval, the requirements of ISPM#15 have been changed several times and in 2017, CBP began penalizing importers when their WPM does not comply with ISPM#15 requirements.

To understand the current approach rate and associated risk, we strongly urge that the original study be updated. The new research must utilize AQIM data because those data are statistically based on random sampling, unlike other interception databases maintained by USDA APHIS (PestID) and CBP.

The large volume of imports with associated WPM that could be transporting quarantine pests necessitates development of an updated assessment of the pest approach rate. The United States imports more than 27 million shipping containers each year. According to one recent estimate (Meissner et al. 2009), 75 per cent of maritime containers arriving at US ports include WPM. Applying the estimated 0.1% approach rate from Haack et al. (2014) with the above figures would suggest that approximately 20,000 containers enter the United States each year that are transporting WPM with live quarantine pests.

A second issue deserving research is the question of what explains the high proportion of infested WPM that is marked as having been treated according to ISPM#15. Is this evidence of inefficacy of some prescribed treatment, of misapplication of treatments that are effective when properly applied, or of fraud? Determining which steps to take to reduce the associated pest risk with WPM depends on a better understanding of the underlying causes.

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SIREX NOCTILIO POPULATION BIOLOGY IN THE USA AND SPAIN

Flora E. Krivak-Tetley[1], María J. Lombardero[2], Matthew P. Ayres[1]

[1]Dartmouth College, 78 College Street, Life Sciences Center, Hanover, NH 03768
[2]Universidade de Santiago de Compostela, Departamento de Producción Vegetal, 27002 Lugo Galicia, Spain

ABSTRACT

Sirex noctilio Fabricius (Hymenoptera:Siricidae) (the Sirex woodwasp) is a widespread pest of pines in the southern hemisphere, and was recently introduced to North America, where it has slowly colonized pines in southern Ontario and eight New England states. While tree mortality due to *S. noctilio* has been high in some southern hemisphere locations, damage in North America has so far been minimal. Here, we report on the abundance, basic biology, parasitism, sex ratios, host use patterns and natural enemies of *S. noctilio* in the northeastern United States and compare these findings with data from Galicia, Spain, in the native range.

Adult *S. noctilio* mating and host selection occurring during the summer months (in North America, typically July-October). Females preferentially oviposit in suppressed or stressed trees, depositing a phytotoxic venom and their symbiotic fungi *Amylostereum areolatum* along with eggs. The parasitoid *Ibalia leucospoides* lays its eggs inside *S. noctilio* oviposition sites following woodwasp oviposition, while *Rhyssa spp.* locates developing larvae and oviposits on the them at later developmental stages. *S. noctilio* are also colonized at times by the nematode *Deladenus siricidicola*, which survives free-living in wood feeding on *A. areolatum*, but enters *S. noctilio* larvae for dispersal, sometimes sterilizing them by colonizing the eggs. This nematode has been used extensively as a biocontrol agent in the southern hemisphere and, when sterilization is high, has the capacity to control *S. noctilio* populations.

From 2013-2015, we collected *S. noctilio*-attacked trees from Galicia, Spain, and from New York, Pennsylvania and Vermont just prior to the start of the emergence season. After felling, trees were cut into one-meter bolts and brought back to laboratory facilities in Lugo, Galicia and Hanover, NH. They were placed in emergence barrels and emerging insects were collected throughout the emergence season. *S. noctilio* (and their native congener *S. nigricornis* in the USA) were measured and dissected to check for nematode parasitism. Emerging parasitoids were collected and counted. After emergence, bark was removed from bolts, and the phloem was shaved down to expose oviposition sites, which were counted. The number of individual drillings per attack site was noted and used to estimate the number of eggs laid in each bolt. We used this information, combined with emergence hole data, to estimate reproductive success.

In the USA, as in Spain, we found that many trees colonized by *S. noctilio* failed to produce offspring, with 5 of 38 trees (13%) producing 64% of the total insects. In both countries, >75% of the insects emerged from <20% of trees. *S. noctilio* required 1 or 2 years to develop in the USA, compared to 1-3 in Spain. Sex ratios were male biased, 1:2.89 female:male in Spain and 1:2.98 in the USA. Body size and fecundity were highly variable and positively correlated. The average female in Spain was 20 mm long and had 88 eggs; in the USA the average female was similar, with a length of 19.67 mm and 82 eggs. In

Spain, 20% of S. noctilio were parasitized by *I. leucospoides* and *R. spp*., with 21% parasitism by these hymenopterans in the USA. 39% of Spanish wasps were parasitized by the nematode *D. siricidicola*, and ~90% of their eggs contained nematodes. In contrast, 56% of *S. noctilio* were parasitized in the USA, but no nematodes entered eggs. Within-tree survival (from egg to adult) was estimated at 0.13 emergences/egg in Spain and 0.28 emergences/egg in the USA.

Combining these demographic factors, preliminary life table calculations allowed us to estimate the maximum possible production of females per female =2.38 for Spain and 4.53 for the USA. Most demographic factors were strikingly similar between the USA and Spain, with the main exception being the absence of sterilization by nematodes in the USA. These findings suggest that population growth has the potential to be moderately higher in USA than in the native range, but the factors controlling these populations are otherwise similar. Comparing these results with data from the southern hemisphere will be useful to further elucidate why *S. noctilio* is, so far, more of a pest outside of North America and Europe, and to make predictions about the potential impacts of this insect when and if it arrives in the southern pine-growing regions of the USA.

THE IMPACT OF *SIREX NOCTILIO* IN ONTARIO PINE FORESTS

Laurel J. Haavik[1,2] , Kevin J. Dodds[3], and Jeremy D. Allison[1]

[1]Canadian Forest Service, Great Lakes Forestry Centre, 1219 Queen St. E., Sault Ste. Marie, ON P6A 2E5
[2]Present address: USDA Forest Service, Forest Health Protection, 1992 Folwell Ave., St. Paul, MN 55108
[3]USDA Forest Service, Forest Health Protection, 271 Mast Rd., Durham, NH 03284

ABSTRACT

More than a decade after its discovery in North America, the European woodwasp (*Sirex noctilio* F.), has not been an aggressive tree killer in northeastern pine forests. Concern that *S. noctilio* has potential to become a more aggressive pest as it spreads south, or as environmental conditions change, is warranted, because it has caused extensive pine losses on other continents that it has invaded. To better understand and predict impacts of *S. noctilio* in North America, we (1) tested the relative suitability of four common *Pinus* species in the northeast (*P. sylvestris*, *P. resinosa*, *P. banksiana*, and *P. strobus*) as hosts for *S. noctilio* in a controlled, but in situ experiment; (2) observed *S. noctilio* impact and attack behavior in eight pine stands annually for a five-year period (2012 – 2016); and (3) investigated whether existing natural enemies or the availability of susceptible and suitable pine limited *S. noctilio*.

(1) *P. sylvestris* and *P. resinosa* were optimal hosts for *S. noctilio*. *P. strobus* was a suitable larval host, but was not perceived as such by females, as evidenced by lower oviposition. *P. banksiana* was perceived as a suitable host by females, but was the least suitable larval host.

(2) *S. noctilio* impact was variable in unmanaged pine forests; it killed 3 – 48% of pine stems, and 3 – 36% of pine basal area. Most *S. noctilio*-caused mortality was limited to suppressed and intermediate trees. Of the 17% of 493 pines that were affected by *S. noctilio*, many (44%) were attacked in multiple years. Depending on the year, between 46 and 79% of trees remained alive in the year immediately after attack, which suggests that many study trees were at least initially resistant to attack by *S. noctilio*.

(3) We found correlative evidence that the availability of suitable hosts has limited the *S. noctilio* population. *S. noctilio* killed more pine when more pine was available, especially suppressed (highly suitable) pine. More co-dominant (healthy) pines were attacked but not killed by *S. noctilio* at sites with more *S. noctilio* activity (defined as number of attacked and killed trees), indicating that higher densities of *S. noctilio* were needed to overwhelm healthy pines. The role of parasitoids was less clear. Parasitism did not vary consistently with the amount of *S. noctilio* activity at sites.

Though the impact of *S. noctilio* appears to be limited in most Ontario forests for now, we recommend that observations continue in future years.

ECOLOGICAL IMPACTS OF LAUREL WILT DISEASE

John J. Riggins[1], Frank H. Koch[2], Jason A. Smith[3], John P. Formby[1], Marc Hughes[3], Natraj Krishnan[1], Richard Brown[1], Adam Chupp[4], Natalie Dearing[1], Hannah Bares[1], Kelly Oten[5], and Don Duerr[6]

[1] Mississippi State University; [2] USDA Forest Service, SRS; [3] University of Florida; [4] University of South Alabama, Mobile; [5] North Carolina Forest Service ;[6] USDA Forest Service, FHP

ABSTRACT

Laurel wilt is an invasive non-native tree disease in the southeastern United States that involves naïve hosts in the family Lauraceae, an introduced insect vector (*Xyleborus glabratus*), and a pathogenic fungal symbiont (*Raffaelea lauricola*). All native North American shrub and tree species in the Lauraceae family that has been tested thus far are susceptible. Genetic markers were used to test the hypothesis that the vector and pathogen entered North America as a single introduction. With a portion of the cytochrome oxidase I gene, a single *X. glabratus* haplotype was detected among specimens sampled from throughout their range in the USA. Similarly, amplified fragment length polymorphisms indicated that 54 of 57 examined *R. lauricola* isolates were of a single clonal genotype; only minor variation was detected in three polymorphic isolates. Therefore, it is likely that a single founding event is responsible for the laurel wilt epidemic in the United States, which may threaten an entire native plant family. If the mass die off of trees in the Lauraceae continues, obligate specialists of laurel wilt susceptible hosts such as the palamedes swallowtail (*Papilio palamedes* Drury) may be at risk.

Exhaustive literature searches yielded a catalogue of native arthropods reported to have associations with Lauraceae species. Arthropods were assigned an endangerment risk rating based on the extent of their specialization on susceptible hosts. Overall, >150 native arthropod species from 7 orders were catalogued as herbivores that could be impacted by declines of their Lauraceous host plants. More than 20 insect species were identified as obligate specialists of Lauraceae. In a field trial, the mean number of palamedes swallowtails encountered in transects through laurel wilt infested stands was significantly lower than in uninfested stands. This suggests dire consequences for the palamedes swallowtail, and warrants concern for other native arthropods that are obligate specialists of laurel wilt susceptible host plants.

AFTER EXTENSIVE REDBAY MORTALITY DUE TO LAUREL WILT, IS SASSAFRAS NEXT?

Frank H. Koch[1], John J. Riggins[2], and John P. Formby[2*]

[1]USDA Forest Service, Southern Research Station, 3041 E. Cornwallis Rd., Research Triangle Park, NC 27709
[2]Mississippi State University, Biochemistry, Molecular Biology, Entomology, & Plant Pathology, Box 9655, Mississippi State, MS 39762 *Current address: New Mexico State Forestry Division, 1220 S. St. Francis Dr., Santa Fe, NM 87505

ABSTRACT

Laurel wilt is caused by a fungal symbiont (*Raffaelea lauricola* sp. nov. T.C. Harr. Fraedrich & Aghayeva) of the redbay ambrosia beetle (*Xyleborus glabratus* Eichhoff), an Asian species that was discovered near Savannah, Georgia in 2002. The disease affects several native trees and shrubs from the Lauraceae family that serve as hosts for the beetle, including sassafras (*Sassafras albidum* (Nutt.) Nees). However, it has been particularly devastating to redbay (*Persea borbonia* (L.) Spreng.), which is widely distributed in coastal forests of the southeastern United States. Since its introduction, laurel wilt has spread throughout a large portion of the redbay range. In a recent analysis, we used data from the USDA Forest Service's Forest Inventory and Analysis (FIA) program to estimate that approximately 330.9 million redbay trees have been killed by laurel wilt. This represents 31.2% of the redbay trees that were growing in the region prior to the disease's introduction. So far, Georgia (67.1%), South Carolina (46.1%), and Florida (44.5%) have experienced the most mortality, which is consistent with the documented pattern of laurel wilt expansion through time across the region. Overall, the data show that redbay loss due to laurel wilt has been extensive and rapid, altering the composition of many coastal forest stands substantially.

Initially, sassafras was believed to be just a host of opportunity for the redbay ambrosia beetle, but this was refuted by subsequent beetle detections in forested areas with sassafras but without any nearby redbay. These detections also raised concerns that the beetle might be sufficiently cold-tolerant to survive in much of the sassafras range, which extends across the eastern United States and into Canada. Subsequent experiments suggested that some beetles could survive at minimum temperatures above -10°C, especially given the additional protection afforded to the beetles by living inside sassafras trees; based on field measurements, we estimated the buffering capacity of this microhabitat to be ≈1.2°C. We constructed potential distribution models for the redbay ambrosia beetle that incorporated sassafras distribution data, the lower lethal temperature thresholds we derived experimentally, and climate data corrected for the buffering capacity of sassafras heartwood. According to our models, just 0.1% of the current US sassafras range has sufficiently harsh winters to preclude the beetle's establishment, and 48% of the current range is unlikely to experience winter temperatures cold enough to impede establishment significantly. Furthermore, under a relatively modest climate change scenario (RCP 4.5, +1.4°C by 2050), 91% of the current sassafras range is projected to have winter minimum temperatures that are unlikely to cause any beetle mortality. Thus, concerns about the possible impact of a broader move by the beetle and disease into sassafras appear to be justified.

AMBROSIA BEETLES IN THE *EUWALLACEA FORNICATUS* SPECIES COMPLEX

Miriam F. Cooperband[1], Richard Stouthamer[2], Akif Eskalen[3], Allard Cossé[1], Daniel Carrillo[4], Tappey Jones[5]

[1]Otis Laboratory, USDA APHIS PPQ S&T, 1398 W. Truck Rd., Buzzards Bay, MA 02542
[2]Department of Entomology, University of California, Riverside, Riverside, CA 92521
[3]Department of Plant Pathology, University of California, Davis, CA 95616
[4]Tropical Research and Education Center, University of Florida, Homestead, FL 33031
[5]Department of Chemistry, Virginia Military Institute, Lexington, VA 24450

ABSTRACT

Three species in the *Euwallacea fornicatus* species complex are invasive in the United States. These have not been named scientifically yet, but are referred to as the polyphagous shot hole borer (PSHB), Kuroshio shot hole borer (KSHB), and tea shot hole borer (TSHB) and their invasive populations are centered in Los Angeles, San Diego, and Miami, respectively. They are thought to be native to Vietnam/Taiwan, Taiwan/Okinawa, and Thailand, respectively (Stouthamer et al. 2017). With populations that multiply every five to six weeks, we now know that in California the PSHB can reproduce in over 60 hosts, 19 of which are native to California (Eskalen et al. 2013, Cooperband et al. 2016). The PSHB and KSHB populations have expanded and now overlap in some areas, and they have caused extensive damage, killing large numbers of native trees in riparian areas, commercial avocado trees, as well as trees that make up the urban forest such as street trees, parks, campuses, and residential yards in California. In Florida, the TSHB population has been increasing in commercial avocado groves and surrounding areas (Carrillo et al. 2016). They each carry their own species of *Fusarium* symbionts on which they feed inside their galleries in trees. The *Fusarium* interferes with the flow of xylem and causes wilt and dieback of trees, and in mass attacks, can kill a tree (Eskalen and Stouthamer 2012).

Here we reviewed recent research that has taken place in our group. In particular, the discovery of quercivorol, (1*S*,4*R*)-*p*-menth-2-en-1-ol, as a fungal kairomone attractive to all three species (Cooperband et al. 2017a, Cossé et al. 2017). The kairomone, quercivorol, has four enantiomers which we synthesized and tested for antennal response and behavior, and we found that two are attractive (1S,4R and 1R,4S) and two are repellent (1R,4R and 1S,4S) (Cooperband et al. 2017b). From this understanding, we recommended optimal enantiomeric ratios in commercial lures which are now used widely in detection programs (Dodge et al. 2017).

In addition, we identified two pheromone components, 2-heneicosanone and 2-tricosanaone, that are used by all three species but in three unique ratios. This pheromone is likely used for communication between nest mates within the galleries (Cooperband et al. 2017c).

Field studies were conducted in California to test the pheromone and quercivorol lures in combination to evaluate whether the pheromone could improve trap capture, with the pheromone deployed in either bubblecaps or flexlures, however there were no differences between treatments and the quercivorol controls. Additional field studies were conducted on quercivorol in conjunction with alpha-copaene, ethanol, verbenone, and pipertone, and those results were discussed. Dose response to quercivorol, and longevity of quercivorol

lures in the field were also evaluated.

A review of efforts to control the invasive ambrosia beetles in California using natural enemies was discussed. Several trips to southeast Asia were taken by RS to collect natural enemies in sentinel logs infested with shot hole borers. This resulted in the discovery of a number potential parasitoids emerging from the infested wood: Bethylidae, Braconidae, Encyrtidae, Megaspilidae, Pteromalidae, Eulophidae, Eupelmidae, and Eurytomidae. The Stouthamer lab has been able to rear multiple generations of the braconid, bethylid, and eulophid species on *E. fornicatus* reared in the laboratory. This work is ongoing. Also in California, the Eskalen laboratory has been investigating endophytes in trees that may interfere with *Fusarium* growth. When beetles attack trees protected with such endophytes, they prevent *Fusarium* growth thus blocking successful establishment by the beetles. So far, five bacterial isolates were found that interfered with *Fusarium* establishment in trees.

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UPDATE ON SPOTTED LANTERNFLY IN PENNSYLVANIA

Sven-Erik Spichiger

Pennsylvania Department of Agriculture, Room 111 - Division of Entomology,
2301 North Cameron Street, Harrisburg, PA 17110 - 9408

ABSTRACT

An update on new pest to North America, Spotted lanternfly (HEMIPTERA: FULGORIDAE: *Lycorma delicatula* (WHITE)) and the response program implemented in Pennsylvania by the Pennsylvania Department of Agriculture is presented. Biology and distribution of the pest are summarized. New feeding and swarming behaviors are highlighted including video of activity on apple trees and grape vines. Control measures are explained and tallies are updated. Tree removal and trap tree establishment are taking place at high pathway risk and leading edge properties. Though not yet quantified, visual evidence indicates that spotted lanternfly mortality is extremely high on treated properties. A non-target impact of trap trees study and a method using e-DNA for detection are discussed. A paid Facebook advertising campaign which increased public reporting to an overwhelming extent is highlighted.

Despite aggressive mitigation attempts and highly cooperative community engagement, in the three seasons since its detection, the pest has shown an alarming ability to reproduce and is expanding its range in North America significantly. As communities and growers struggle to deal with its impacts, new research is needed to assist with monitoring, regulatory compliance, and suppression.

SPOTTED LANTERNFLY: HOSTS, ATTRACTANTS, AND DISPERSAL

Miriam F. Cooperband[1], Jacob Wickham[2], Nathan Derstine[1,3], Isaiah Canlas[1,3], Kelley Murman[4], Matthew Wallace[4], Sven-Erik Spichiger[5], John Baker[5], Daniel Carrillo[3]

[1]Otis Laboratory, USDA APHIS PPQ S&T, 1398 W. Truck Rd., Buzzards Bay, MA 02542
[2]Chinese Academy of Sciences, 1 Beichen West Rd., Beijing, China 100101
[3]Tropical Research and Education Center, University of Florida, Homestead, FL 33031
[4]Department of Biological Sciences, East Stroudsburg University, East Stroudsburg, PA 18301
[5]Pennsylvania Department of Agriculture, 2301 North Cameron Street, Harrisburg, PA 17110

ABSTRACT

Spotted lanternfly (SLF), *Lycorma delicatula* (Fulgoridae) were evaluated for their ability to develop and survive on various host plants and their attraction to host plant odors. Improved sticky bands were tested for trapping, and lures were developed and tested. Sticky bands were tested, allowing us to fine an improved product for capturing SLF. A dose response to methyl salicylate was demonstrated in the field using several lures with different release rates. A high release methyl salicylate lure was developed which caught more SLF than methyl salicylate lures with lower release rates. Host suitability testing revealed three host plants in addition to their preferred host, *Ailanthus altissima*, on which SLF can fully develop from first instar to adult: hops *Humulus lupus*, black walnut *Juglans nigra*, and chinaberry *Melia azedarach*.

Background

An invasive population of spotted lanternfly (SLF), *Lycorma delicatula* (Fulgoridae), was first discovered in 2014 in Burks County, Pennsylvania. Since then, we have been conducting studies to identify attractants that could be utilized in the development of detection tools such as traps and lures. SLF are known to be highly polyphagous phloem feeders, with over 70 known host trees and woody plants. They cause damage by feeding in large numbers, reducing host plant vigor, or even killing the plant. Their preferred host is the invasive tree of heaven *Ailanthus altissima*, but they also feed heavily on grape and a number of other economically important species woody plants. Due to their strong preference for *A. altissima* it is suspected that *A. altissima* may be a required host for SLF to complete their development. Based on that notion, Pennsylvania Department of Agriculture (PDA) developed a tool for use in eradication efforts that involves turning their preferred host, *A. altissima*, into trap trees, which are trees treated with systemic insecticide. SLF are attracted to and feed on these trees, ingesting a lethal dose of insecticide. To enhance the effect of trap trees, PDA accompanies trap trees with the removal of surrounding *A. altissima* trees, thus removing alternative feeding choices.

Since the trap tree approach as an eradication tool hinges on the reliance of SLF on *A. altissima* for completing development, we conducted host suitability studies on a number of other host plants on which SLF has been observed to feed or cause damage. The goal was to determine if there are any alternative hosts on which SLF can develop in the absence of *A. altissima*.

In addition to developing eradication tools, we must develop tools for surveying and delineating the popula-

tion in order to contain and treat all infested areas. We have been conducting chemical ecology research in search of attractive host plant volatiles (kairomones), identifying and testing active compounds, and developing them into lures. With that comes a need for improved trap technology, so we conducted studies in search of a better trap. We also compared attraction of *Ailanthus* volatiles with those from other host plants.

Finally, the use of traps, lures, and trap trees all requires a better understanding of the natural movements of SLF. We conducted a field study to evaluate the distance that SLF travel at each stage in a forest setting dominated by *A. altissima* using capture-mark-release-recapture techniques.

MATERIALS AND METHODS

Host suitability. In the field in Burks County, PA, we placed sleeves on 11 suspected host plant species and placed 10 first instar nymphs (or youngest instar available) in each sleeve. The same methodology was used with first instar nymphs on two of the host plant species in the field in Anhui, China. In the Otis Laboratory insect containment facility (ICF), we placed plant cuttings in water tubes, or whole potted plants, inside cages with 5 or 10 SLF nymphs, respectively. Cuttings were refreshed three days per week. Some species were tested in both the laboratory and field, for a total of 15 host plant species tested. SLF were monitored weekly for survival and development.

Trap and lure development. In 2015 we conducted volatile collections, dual choice bioassays, and field studies testing traps and lures. These were previously reported, and the results were the discovery of three kairomones: methyl salicylate, (*E,E*)-α-farnesene, and (*Z*)-3-hexenol. In 2016 and 2017, efforts were focused on developing and optimizing lures using one or more of these compounds, as well as improving trap technology. In 2016, lure development began, and methyl salicylate started to emerge as the best choice between the three compounds. In addition, in 2016, we discovered Web-Cote sticky bands performed 30 times as well as the brown sticky bands (Korean Beneficial Insect Laboratory KBIL, Korea) (KBIL) at catching adults. So in the summer of 2017, we tested the Web-Cote bands against KBIL for first and second instars. We also compared several newly developed lure formulations for the three compounds in field tests in China (provided by several companies), but most studies were focused on methyl salicylate lures. Prior to testing lures in the field, they were evaluated in the laboratory for release rate and longevity.

Exploration for additional kairomones. We conducted volatile collections on several host plants, both with and without SLF, including black walnut, hops, and *Ailanthus.* We also developed GC-EAD capabilities for SLF and analyzed the different volatile collections for antennal activity. Behavioral function was evaluated using dual choice olfactometers. In this way, we tested SLF attraction to odors from leaves, volatile collections, essential oils, and individual or blends of compounds.

Dispersal. To describe the natural movement of SLF in the field, a study was conducted in a forest composed of *A. altissima* and other tree species near the outbreak zone in Burks County, PA. Three arrays of 10 banded *A. altissima* trees around a banded central release tree were established near each other. For each array, SLF were captured and marked with a different color dye, then released on the central tree above the band (SLF only walk up, and are always captured at the bottom margin of sticky bands). Distances from release trees to array trees ranged between 5 and 70 m.

RESULTS

Host suitability. Of the 15 species we tested for host suitability, we found that SLF were able to develop from first instar to adult on *A. altissima* (tree of heaven), *Melia azedarach* (chinaberry), *Juglans nigra* (black walnut), and *Humulus lupulus* (hops), but not on *Vitis vinifera,* (grape), *Acer saccharinum* (silver maple), *Betula nigra* (black birch), *Salix babylonica* (weeping willow), *Parthenocissus quinquefolia* (Virginia creeper), Spicebush *Lindera benzoin*, or blueberry *Vaccinium angustifolium*; although the grape, willow, maple, and Virginia creeper all supported more than one stage advancement. Chinaberry is not present in PA, so it was tested in China and in our ICF at the Otis Laboratory. Other species were tested with later instars and require further testing.

Trap and lure development. In 2015 we identified three host-associated compounds that were attractive to SLF: methyl salicylate, (*E,E*)-α-farnesene, and (*Z*)-3-hexenol. They were field tested in 2015, 2016, and 2017. Methyl salicylate was found to be the most successful as a single-component lure and produced a dose response in the field. The highest release rate tested, approximately 50 mg/d, caught the most SLF. The sticky bands initially used (KBIL) had difficulty catching adult SLF, so we sought alternatives. An alternative sticky band, Web-Cote, caught 30 times more adults and twice as many nymphs as the KBIL bands.

Exploration for additional kairomones. Antennae responded to 39 unique compounds in volatile collections, and 19 of those have been chemically identified so far. Behavioral bioassays were conducted on a number of these new compounds, demonstration attraction. We compared blends containing methyl salicylate blended with other compounds against methyl salicylate alone in the dual choice olfactometer and found that some blends were significantly more attractive, even when we increased the amount of methyl salicylate. Light was very attractive in bioassays. Although when compared against blank controls volatiles from other host plants were attractive, volatiles released from *A. altissima* were more attractive when compared to volatiles from other host plants we tested.

Dispersal. A total of 43,027 SLF were captured on all bands, including 342 of the 6,077 that were marked. First, second, third, fourth, and adult instars were recaptured at 10.3, 9.3, 1.6, 1.6, and 1.8%, respectively. The majority of those were recaptured on their release tree, indicated that 82, 91, 83, 57, and 46% of respective SLF stages stayed on the *A. altissima* tree where they started. In the 24 hour period after release, we recaptured 3.8, 6.7, 1.1, 1.1, and 0.8% of marked SLF for each respective stage. These numbers allow the estimation of the total SLF population in trees by dividing the number captured that was not marked by the percent that was marked and recaptured for each stage in 24 h. At best, as with second instars, trap capture after 24 h represents 6.7% of the total SLF in the tree. Third, fourth, and adults were recaptured at much lower rates around 1-2%, reflecting that sticky bands are not as effective against those stages. The few SLF that were captured on trees away from their origin were captured as far as 25 m away, and the percent venturing farther away increased with age. Based on 24 h recaptures of first instars, the rate of movement was at least 25 m/d.

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PRESENTATIONS

Cerambycid Pheromones

NEW PHEROMONES FOR INVASIVE CERAMBYCIDS: FROM THE BENCH TO THE FIELD

Jocelyn G. Millar[1] and Lawrence M. Hanks[2]

[1]Department of Entomology, University of California, Riverside CA, 92521
[2]Department of Entomology, University of Illinois, Urbana IL, 61601

ABSTRACT

Cerambycid beetles perform crucial ecosystem services by beginning the degradation and recycling of woody biomass. Conversely, they can also become devastating pests, particularly as invasive species which are freed from the constraints of their coevolved natural enemies, and with novel hosts which have no coevolved natural resistance to them. Surveillance of invasive cerambycids is hampered by the lack of effective detection tools. To address this problem, we summarize progress over the last 15 years on the development of effective pheromone-based lures for cerambycids, and concurrently, the optimization of trapping methods. In particular, recent research has shown that some pheromone components are highly conserved across genera and tribes, whereas others are used by only a few species, or may even be species-specific. The implications of this range of pheromones from "generic" to species-specific is discussed in the context of monitoring cerambycids with pheromone-based methods.

Cerambycid beetles are one of the groups of insects that are most easily transported between countries and continents by international commerce, with their long-lived larvae hidden within dunnage, palettes, and other wooden materials. They are of major importance as potential invasive species, particularly because they can be so difficult to detect until the adults emerge. Thus, attractant-baited traps deployed around ports and shipping facilities may form the first line of defense for detection of new invasions, and for delineating the range of a new infestation should a particular species become established. However, this strategy is obviously contingent upon having effective and relatively specific attractants available as trap baits.

For many years, forestry personnel and natural historians collecting cerambycids have used host plant volatiles such as turpentine, a-pinene, and ethanol as attractants for cerambycids. These materials are cheap and readily available, but for most species, they are only weakly attractive or not attractive at all, so they cannot be relied upon as a sensitive detection system. In addition, until about 2005, the general consensus was that cerambycids were not likely to use attractant pheromones to any great extent; up to that point, attractant pheromones had been identified from fewer than 10 species, and preliminary trials had suggested that the pheromones might be only weakly attractive. However, since 2005, our hypotheses about pheromone use by cerambycids have radically changed, based on the identification and demonstrated effectiveness of pheromones for ~several hundred species, including important pest and invasive species. Furthermore, pheromones for additional species are being identified on a continuing basis. Thus, it appears likely that pheromones can indeed be used as powerful tools for surveillance and quarantine efforts aimed at detection and exclusion of potentially invasive species.

So why is it that it took so long to recognize that cerambycids were indeed using attractant pheromones extensively in their reproductive interactions, analogous to many other insect families? There are a number of possible reasons, any one or any subset of which may have resulted in erroneous conclusions about pheromone use. These include:

1. In several of the major subfamilies, including the Cerambycinae, Lamiinae, and Spondylidinae, the attractant pheromones are produced by males and not females. Because the natural indication is to assume that females are the attractive sex, this may have misled some of the early researchers.

2. Attraction of beetles of both sexes to the male-produced aggregation pheromones may be less obvious than, for example, a male moth responding to a female moth's sex pheromone, where the male will literally damage or kill himself trying to get to the female. In contrast, cerambycid responses to the male-produced aggregation pheromones may be more subtle. Nevertheless, over the course of a day, tens or even hundreds of beetles can be attracted to pheromone-baited traps.

3. Another consequence of the male-produced aggregation pheromones is that they are produced in much larger amounts (ranging up to ~100 micrograms or more per hour) than female-produced sex pheromones, which typically have release rates which are orders of magnitude lower than this. A major consequence of the high rate of production and release of the male-produced pheromones is that trap lures have to approximately match or exceed this rate to be effective. This means that lures have to release at least several milligrams of pheromone per day, so that field lures intended to last for a week or more will need to be loaded with 50-100 milligrams of pheromone, or more. In contrast, early researchers generally used much lower lure loading rates, which likely contributed to the relatively weak attraction that they observed.

5. The problem is further compounded because cerambycids do not produce pheromone continuously. Instead, the evidence suggests that pheromone is released during species-specific time windows of a couple of hours a day. Thus, it would be easy to miss the calling period, and to be bioassaying insects outside their normal activity period.

4. Some cerambycid species have to undergo a sexual maturation period and/or they may need to feed as adults before they begin to produce or respond to pheromones. Thus, beetles used in bioassays may not have been in the appropriate physiological states.

5. In some cases, such as for *Monochamus* species, pheromones are very strongly synergized by plant volatiles, to the extent that either plant volatiles or pheromones are minimally attractive alone, but combined, attraction increases by an order of magnitude or more.

6. There is increasing evidence that cerambycids may occupy specific strata in the forest canopy, with a number of examples known in which pheromone-baited traps placed high in the canopy caught large numbers of beetles, whereas the same traps caught little or nothing when deployed at ground level. Conversely, a subset of species were found only in traps at ground level, with none caught in traps deployed high in the canopy. This obviously has important implications for detection and surveillance efforts.

7. Finally, several research groups have now independently shown that effective trap design is crucially important for trapping cerambycids, and for retaining them in traps once they have been caught. Thus, vertically oriented cross-vane intercept traps or multifunnel Lingren traps seem to be the design of choice. One of the single most crucial design features is to coat the trap surfaces and collection jars of all traps with a Teflon dispersion called Fluon, which renders the trap surfaces extremely slippery. Thus, any beetle that lands on the trap will not be able to hang on to the trap surface and will drop down into

the collection bucket. The importance of the fluon coating cannot be over-emphasized: field trials have shown that Fluon treatment can increase trap catch and retention more than ten-fold.

In hindsight, because of this plethora of factors, it is easy to understand how the extensive use of pheromones within the Cerambycidae was missed for so long. However, the situation started to change around 2005, when pheromones for a number of cerambycids were identified in rapid succession, initially as the result of large-scale screening trials of the few pheromones which had been identified up until that time, along with several possible analogs. These trials showed beyond a doubt that many cerambycids were using attractant pheromones. Subsequent collection of volatiles produced by both sexes then showed that the pheromones produced by species in the subfamilies Cerambycinae, Lamiinae, and Spondylidinae were all produced by males, but attracted both sexes, making them formally aggregation pheromones according to the historical definition of these types of pheromones. However, because their main function is probably to bring the sexes together for mating, this definition has been recently modified to "aggregation-sex pheromones", which more accurately describes their function.

A second outcome of the large-scale screening trials with the handful of pheromones or likely pheromones that were known around 2005 was that this small group of 10 or so compounds was shown to attract >100 species, suggesting that pheromone structures were highly conserved, with species within the same genus, tribe, or even subfamily using exactly the same pheromone components. Furthermore, this conservation reached across continents (and hence millions of years of evolutionary time); for example, it is now known that one of the most common compounds, 3-hydroxyhexan-2-one, is a known or likely pheromone for cerambycid species from all 6 habitable continents. Similar results have been found with a number of other cerambycid pheromones, including fuscumol, fuscumol acetate, monochamol, 2-methybutanol, and isomers of 2,3-hexanediol, with each one of these compounds being shown to be a pheromone component for a number of closely, and even more distantly related species. This led us to hypothesize that cerambycid pheromones, on the whole, were likely to be highly conserved, with related species using the same or similar pheromones.

However, results from the past couple of years have suggested that the situation is likely to be much more nuanced than that. In particular, over the space of several years, intensive and repeated use of pheromone-baited traps to survey local populations of cerambycid beetles began to show that there were a number of species which were known to be present from historical records, but which were rarely or never caught in the pheromone-baited traps, suggesting that they might be using some other, hitherto unknown, types of pheromone compounds. Ongoing efforts to identify pheromones from these species has shown that this is indeed the case, with a steady stream of new and entirely unexpected structures being identified. Furthermore, these new structures are sometimes being found in species in genera from which entirely different pheromones had previously been identified. That is, we are finding that in some cases, even congeneric species are producing pheromones with entirely different structures. Thus, our revised working hypothesis is that pheromone use within the cerambycids follows a continuum; at one end of the spectrum, some compounds are highly conserved and are shared among many species, whereas at the other end of the spectrum some pheromone components may be shared by only a few species, or may even be species specific. There are now numerous examples of both classes of pheromones/species, and of others somewhere in the middle of the continuum.

In the course of trying to identify pheromones for new species, and in particular, of major target species deemed to have both a high probability of invading North America, and of causing substantial damage if they did invade and become established, our Asian colleagues were having trouble collecting some of the target species for conducting pheromone analyses. Thus, as an alternative, we wondered if it might be possible to take advantage of the highly conserved nature of at least some of the cerambycid phero-

mones by using a "pheromone identification by proxy" strategy. That is, we reasoned that if we could identify the pheromones of some readily available North American species that were closely related to the Asian target species, we could then test the pheromones with the Asian species to see whether they might respond. In particular, our Asian targets were species in the genera *Callidiellum* and *Semanotus*, and our proxy species were Californian species in the genera *Callidium* and *Semanotus*. This proxy strategy turned out to be highly successful. Thus, we found that two *Callidium* species and three *Semanotus* species native to California all had male-produced pheromones consisting of a novel pyrrole compound, which we gave the common name semanopyrrole, alone or in combination with the very common component 3-hydroxyhexan-2-one. Collaborators in Japan and China tested semanopyrrole and 3-hydroxyhexan-2-one in field bioassays, and found that the blend of the two compounds was highly attractive to *Callidiellum rufipenne*, which has invaded the northeastern US, and *Callidiellum villosulum*, which has been intercepted in shipments entering Maryland, but which apparently has not yet successfully invaded and become established. There were also several added bonuses, because further field trials revealed that semanopyrrole is also a crucial pheromone component of the North American species *Dryobius sexnotatus*, as well as several South American species. Thus, it seems likely that semanopyrrole will turn out to be another of the "generic" type cerambycid pheromones that is widely shared by a number of related species.

In contrast to this widely shared pheromone, research on a number of other species has suggested that their pheromones may attract only a few species, or may even be species specific. For example, as described in detail in the following article by Steve Teale, with a team of collaborators in China and Japan, we identified a novel epoxy-aldehyde compound from the highly invasive species *Aromia bungii*, which has recently invaded Japan and several countries in Europe, where it is already causing substantial damage. To date, in field bioassays in Japan, China, and Slovenia, there has been no indication that any other cerambycid species are attracted by this compound, indicating that it might be species specific. In another example, described in detail in the article by Ann Ray, the invasive species *Trichoferus campestris*, which has become established in several US states, produces another novel structure, given the common name trichoferone. In extensive trials in the US, where there are no other native *Trichoferus* species, no other species have been caught, but collaborator Alain Roques has found that several European Trichoferus species appear to be attracted to this compound, suggesting that it is likely to be a component of their pheromones as well. In ongoing work with our Brazilian collaborators Weliton Silva and Mauricio Bento, we have discovered that South American species are producing a wide variety of unexpectedly diverse pheromone structures, including a straight-chain hydrocarbon, sesquiterpene hydrocarbons, straight- and branched-chain aldehydes and alcohols, an alkylated tetrahydrofuran, and even a sulfur-containing compound. Not surprisingly, given that pheromone structures are often conserved, we are starting to find at least some of these structures being produced by species native to other continents as well. Very importantly, the structures of most of these pheromones are simple enough that it should be economically feasible to develop them as commercially available lures for surveillance and monitoring programs. Thus, in the space of less than 15 years, we have gone from having no effective monitoring tools available for any cerambycids, to the situation now, where there are a number of highly attractive pheromones available, with many more on the way.

A comprehensive overview of cerambycid beetle biology and the use of pheromones and related semiochemicals by cerambycids can be found in the recently published "**Cerambycidae of the World: Biology and Pest Management**" (ed. Q. Wang), CRC Press/Taylor & Francis. The reader is also referred to a recent review article, L. M. Hanks and J. G. Millar (2016) Sex and aggregation-sex pheromones of cerambycid beetles: Basic science and practical applications. Journal of Chemical Ecology 42:631-656.

ACKNOWLEDGMENTS

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IMPROVED TRAPPING TOOLS FOR SURVEILLANCE OF BEETLES MOVED IN SOLID WOOD PACKAGING

Jon Sweeney[1], Peter Silk[1], Peter Mayo[1], Dan Miller[2], Cory Hughes[1], Jerzy M. Gutowski[3], Tomasz Mokrzycki[4], Qingfan Meng [5], Yan Li[5], Joe Francese[6], and Davide Rassati[7]

[1]Natural Resources Canada, Canadian Forest Service, *Atlantic Forestry Centre, 1350 Regent Street, Fredericton, New Brunswick E3B 5P7*
[2]Southern Research Station, USDA Forest Service, 320 Green St., Athens, GA, 30602
[3]Forest Research Institute, Białowieża, Poland
[4]Warsaw University of Life Science, Warsaw, Poland
[5]Forestry College of Beihua University, 3999 Binjiangdong Road Jilin, Jilin Province, The P.R. China, 132013
[6]USDA APHIS PPQ, Otis Laboratory, 1398 West Truck Road, Buzzards Bay, MA 02542
[7]University of Padua-DAFNAE, Padua, Italy

ABSTRACT

The objective of this research is to increase the efficacy of trapping surveys for early detection of non-native and potentially invasive bark- and wood boring beetles moved incidentally among continents via global trade. We present results from field experiments that tested the effects of trap color, trap height, and lure on the abundance and diversity of Cerambycidae, Buprestidae and Scolytinae detected in Lindgren 12-funnel traps. The first was a 2 x 3 factorial experiment with two trap heights (canopy, understory) and three trap colors (black, green, purple), all baited with the same multicomponent lure consisting of five longhorn beetle pheromones (racemic 3-hydroxyhexan-2-one, racemic 3-hydroxyoctan-2-one, *syn*-2,3-hexanediols, *E/Z*-fuscumol, and *E/Z*-fuscumol acetate) plus an ultra high release rate (UHR) ethanol lure. This experiment was replicated 8X in randomized complete blocks at each of four sites in 2015: New Brunswick, Canada; Białowieża, Poland; Georgia, USA; and Jilin, China. The second was a 2 x 2 x 2 factorial experiment testing trap height (canopy, understory), trap color (green, purple) and trap lure (same multi-component lure described above *vs* UHR ethanol alone) replicated 17X in randomized blocks, each block located at a separate site in Northeastern Italy in 2016.

Trap height, color and lure significantly affected the species composition, richness and abundance of target taxa in traps. In the first experiment, buprestid species richness was greatest in green canopy traps and least in black understory traps; results were intermediate for purple traps. Several *Agrilus* species were captured only in green canopy traps. There was no effect of trap height or color on longhorn beetle species richness but species composition differed among trap colours and heights, i.e., some cerambycid species were captured mainly in green canopy traps whereas others were captured mainly in black or purple understory traps. Understory traps caught significantly more Scolytinae species than did canopy traps but some individual species, e.g., *Xyleborinus saxesenii,* were detected more frequently in canopy traps. There was a common trend at four sites, i.e., using more than one trap color and placing traps in both the canopy and understory increased the total number of target taxa detected. However, the trap color-height

combination that detected the most target spp. was not consistent among sites. For example, in Poland, black funnel traps in the understory (the standard protocol used in early detection surveys in the US and Canada) detected the fewest species and green canopy traps detected the most, whereas in Georgia, green understory traps detected the most species and black canopy traps the fewest.

Results on the effect of trap color and trap height were similar in the second experiment but with some differences. Buprestid species richness was greater in green than purple traps, greater in canopy traps than in understory traps, and was unaffected by lure treatment. Cerambycid species richness was greater in traps baited with the multi-component lure than in ethanol-baited traps, and greater in the canopy than the understory. Trap color did not affect overall longhorn beetle species richness but there were differences among subfamilies. More species of Cerambycinae were caught in purple traps than green traps whereas the opposite was true for Lamiinae and Lepturinae. Green traps baited with the multi-component lure and placed in the canopy detected the most species of target taxa per trapping effort in Italy (Cerambycidae and Buprestidae only; Scolytinae not yet tallied in this experiment).

Our summary and take home message is that the efficacy of detecting bark and wood boring beetles in trapping surveys is usually increased by diversifying the trapping methods, i.e., use pheromone-enhanced multi-component lures rather than UHR ethanol alone, place traps in both the canopy and understory, and use more than one trap color.

ON THE HORIZON: RED-NECK LONGHORN BEETLE, *AROMIA BUNGII* (CERAMBYCIDAE: CERAMBYCINAE)

Stephen Teale

Department of Environmental and Forest Biology, College of Environmental Science and Forestry, State University of New York, Syracuse, NY 13210

ABSTRACT

Aromia bungii Faldermann is known as the red necked longicorn, the peach red necked longhorn, the plum and peach longhorn, the peach musk beetle, and variations thereof. As these names suggest, it is a common pest of peach and plums as well as apricot and several species of cherry including ornamentals. It is oligophagous on the genus *Prunus*. It is native to eastern Asia including China, Mongolia, Korea, Taiwan and Vietnam. It became established in both Japan and Italy in 2012, and in Germany in 2011. It was intercepted in the U.K. and the U.S. (Seattle) in 2008. In its native and invaded ranges, *A. bungii* is known to be established in plant hardiness zones 4 through 11 which includes all of the contiguous 48 states. It is among the most destructive longhorn beetles on fruit trees in China where it causes substantial economic loss. Its feeding habits are typical of wood-boring longhorn beetles. Larval tunneling impairs vascular function, causes structural weakening and breakage, creates infection courts resulting in stem decay, and reduced fruit yields.

A male-produced sex-aggregation pheromone has been identified from *A. bungii* (Sci. Rep. 7: 7330; DOI:10.1038/s41598-017-07520-1). It is the first pheromone reported from the tribe Callichromatini. The structure of the pheromone [(*E*)-2-*cis*-6,7-epoxynonenal] is new for the Cerambycidae many of which share the same pheromone compounds or at least follow a pattern of structural similarity. Field tests of the synthetic pheromone in both Japan and China demonstrated that it is very attractive though additional work on lure optimization is currently underway. These lures present new management options in the native and invaded ranges of *A. bungii* and can be used as a sensitive detection tool in regions with the potential for invasion.

DETECTION OF VELVET LONGHORNED BEETLE POPULATIONS USING ATTRACTANT BAITED TRAPS

Ann M. Ray[1], Joseph A. Francese[2], Yunfan Zou[3], Kristopher Watson[4], Damon J. Crook[2], and Jocelyn G. Millar[3]

[1]Department of Biology, Xavier University, 104 Albers Hall, 3800 Victory Pkwy., Cincinnati, OH 45207-1035
[2] USDA-APHIS-PPQ-CPHST Otis Laboratory, 1398 W. Truck Rd., Buzzards Bay, MA 02542-5008
[3]Department of Entomology, University of California, 900 University Avenue, Riverside CA 92521
[4]Utah Department of Agriculture and Food, 350 North Redwood Road, PO Box 146500, Salt Lake City, Utah 84114-6500

ABSTRACT

The velvet longhorned beetle, *Trichoferus campestris* (Faldermann)(VLB; Cerambycidae: Cerambycinae: Hesperophanini), is native to east Asia where it feeds on a wide range of tree species, including orchard and timber trees. Larvae of VLB can be transported in wood packing material, and individuals are frequently intercepted in quarantine facilities. Populations of VLB have established outside of the native range of the species, including near Salt Lake City, UT USA. Adults are nondescript and nocturnal, and monitoring and control efforts have been hindered by a lack of attractant lures. We recently isolated and identified a novel variant of the conserved 2,3-alkanediol/ hydroxyketone chemical structure from headspace volatiles of males but not females. In field bioassays, this compound attracted significantly more adult beetles than did commercially available high-release ethanol lures or solvent control. We here describe results of subsequent bioassays evaluating the effects of trap design, trap color, and trap height on numbers of beetles captured. We also describe the results of a dose-response bioassay, and results to detect VLB populations in areas where the beetle is not known to occur. The results of our work will assist state and U.S. federal personnel and land managers in developing monitoring surveys for VLB.

PRESENTATIONS

Evolution & Invasive Species

PREDICTING THE IMPACT OF NON-NATIVE SPECIALIST INSECTS

Angela M. Mech[1], Daniel A. Herms[2], Travis D. Marsico[3], Kathryn A. Thomas[4], and Patrick C. Tobin[5]

[1] Western Carolina University, Department of Geosciences and Natural Resources, Cullowhee, NC, 28723
[2] The Davey Tree Expert Company, Kent, OH, 44240
[3] Arkansas State University, Department of Biological Sciences, Jonesboro, AR, 72401
[4] US Geological Survey, Southwest Biological Science Center, Tucson, AZ, 85719
[5] University of Washington, School of Environmental and Forest Sciences, Seattle, WA, 98195

ABSTRACT

A small proportion of non-native insects cause widespread ecological and economic damage on a global scale, but the ability to predict their level of damage has eluded scientists for decades. Advancements in the study of invasion biology and fields such as computational phylogenetics provide tools that could help to quantify the drivers that influence the eventual impact of a non-native insect. Understanding these drivers informs management decisions including risk assessments for insects not yet established in North America but have a high likelihood of introduction given global trade pathways. Our working group, sponsored by the US Geological Survey's John Wesley Powell Center for Analysis and Synthesis, used established literature and databases to quantify the contribution of multiple invasion components: 1) insect traits (e.g., feeding guild, voltinism, reproductive strategy), 2) phylogenetic distance between the insect's native and North American host plants, 3) host plant traits (e.g., shade tolerance, growth rate, wood density), and 4) evolutionary history between the non-native insect and its closest relative native to North America that shares the same host. We contend that by quantifying the relative combined contributions of these drivers to the magnitude of impact, we can develop a framework to predict the rare but ecologically and economically important high-impact conifer pests that can be extended globally.

As a proof-of-concept, we focused on the non-native insects considered to be conifer specialists – those that feed only on species of Pinaceae, Cupressaceae, and/or Taxaceae; 58 insects met our criteria. Non-native conifer specialists were categorized as being high impact if they caused mortality of host trees at the population or regional level. Our results reveal that a number of factors contribute to a non-native conifer specialist's impact, suggesting a model involving multiple components would be optimal for prediction. For example, we found a greater probability of the insect being high impact if the North American host had a slow growth rate (possible lack of bottom-up effects), the insect's native and North American hosts diverged from their most recent common ancestor within a particular timeframe, and there were no congeners with which the North American host had coevolved. Our future work will extend this framework to specialist herbivores of angiosperm trees, and potentially all non-native herbivorous insects in North America.

PRESENTATIONS

Managing Invasive Forest Pests with Biological Control

BIOLOGICAL CONTROL OF EMERALD ASH BORER: CAN IT HELP ASH RECOVERY IN THE AFTERMATH OF INVASION?

Jian J. Duan[1], Leah S. Bauer[2], Roy G. Van Driesche[3], Therese M. Poland[2], Joseph S. Elkinton[3], Juli R. Gould[4], Benjamin H. Slager[5], and Claire E. Rutledge[6]

[1]USDA Agricultural Research Service, Beneficial Insects Introduction Research Unit, Newark, DE 19713
[2]USDA, Forest Service, Northern Research Station, Lansing, MI 48910
[3]Department of Environment & Conservation, University of Massachusetts, Amherst, MA 01003
[4]USDA Animal & Plant Health Inspection Service, Plant Protection & Quarantine, Buzzards Bay, MA 02542
[5]USDA Animal & Plant Health Inspection Service, Plant Protection & Quarantine, Brighton, MI 48116
[6]Connecticut Agricultural Experiment Station, New Haven, CT 06504

ABSTRACT

Ash trees (*Fraxinus* spp.) were abundant in North America when the emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) arrived unexpectedly from Asia in the 1990s. This phloem-feeding beetle was identified in 2002 as the cause of ash decline and mortality in southeast Michigan and nearby Ontario. Despite early efforts by U.S. and Canadian regulatory agencies to contain and eradicate EAB, it is now known in 33 U.S. states, District of Columbia, and 3 Canadian provinces and has killed hundreds of millions of ash trees in the natural and urban forests of North America. Although systemic insecticides are now available to control EAB in ash trees, these insecticides are used primarily via tree injections to protect high-value landscape trees in urban forests. For long-term and sustained management of EAB in natural forests, researchers and land managers in North America are evaluating the use of biological control via the introduction and establishment of natural enemies that co-evolved with EAB in Asia.

Biological control of EAB in North America began in 2007 in southern Michigan after USDA- APHIS issued environmental release permits in the U.S. for three EAB parasitoid species from northeast China: the egg parasitoid *Oobius agrili* Zhang & Huang (Encyrtidae), the larval endoparasitoid *Tetrastichus planipennisi* Yang (Eulophidae), and the larval ectoparasitoid *Spathius agrili* Yang (Braconidae). Following regulatory approval for environmental releases of these parasitoids and initial successes in establishing some of these parasitoids in Michigan, USDA started the EAB Biocontrol Rearing Facility in Brighton, MI, a geospatial database to track parasitoid releases and recoveries in North America (mapbicontrol.org 2018), and continues to provide updated information on EAB biocontrol (USDA–APHIS/ARS/FS 2017; Duan et al. 2017a). Since 2010, the Brighton rearing facility has greatly increased the availability and numbers of the EAB parasitoids for both researchers and cooperators in the U.S. and Canada. In 2015, USDA-APHIS issued permits for the release of a fourth EAB biocontrol agent in the U.S.: *Spathius galinae* Belokobylskij (Braconidae), an EAB larval ectoparasitoid from the Russian Far East. Canada approved releases of *T. planipennisi* and *S. agrili* in 2013, *O. agrili* in 2015, and *S. galinae* in 2017. However, *S. agrili* has not been released in Canada due to lack of confirmed establishment in the northern U.S. To date, at least one biocontrol agent has been released in EAB infestations in 25 states, District of Columbia, and in Ontario and Quebec in Canada (Duan et al. 2018b).

To assess reproduction, overwintering, and establishment of the introduced parasitoids at field sites, various sampling methods have been developed for recovery of these biocontrol agents (USDA–APHIS/ARS/FS 2017). However, to reliably confirm parasitoid establishment, cooperators are requested to wait at least one year after all releases are complete before sampling the release plot and to sample the area for at least two years. Since EAB biocontrol releases began, *T. planipennisi* has been recovered from field sites in Colorado, Connecticut, Illinois, Indiana, Kentucky, Maryland, Michigan, Minnesota, Missouri, New Hampshire, New York, Ohio, Ontario, Quebec, Tennessee, Virginia, and Wisconsin. In addition, *Oobius agrili* has been recovered in Colorado, Connecticut, Indiana, Maryland, Michigan, Minnesota, New Hampshire, New York, Ohio, Ontario, Quebec, and Pennsylvania; and, *S. agrili* in Maryland (see Duan et al. 2018 for parasitoid-release and recovery maps).

We summarized the results of 8-years of published research on EAB population dynamics from six EAB-biocontrol study sites in southern Lower Michigan, where the EAB biocontrol agents were release from 2007-2010 (see Duan et al. 2018 for recent review). Overall, we are finding that the prevalence of *O. agrili* and *T. planipennisi* varies between years and the geographic distribution of both parasitoids has expanded from the initial points of release. We found that while the role of *O. agrili* in reducing EAB population growth requires further evaluation, the larval parasitoid *T. planipennisi* plays a significant role in suppressing EAB larval densities in ash saplings, basal sprouts, and young trees up to ~16-cm DBH (Duan et al. 2017a,b). We also found that innate tree resistance in young or healthy trees, as well as woodpecker predation and larval parasitism by some native parasitoids of *Agrilus* spp., are important in regulating EAB densities in regenerating and surviving ash trees at these sites. To protect ash trees growing into larger size classes, *S. galinae* was released from 2015 to 2017. This species has a longer ovipositor than *T. planipennisi* and is capable of parasitizing EAB larvae through the thick bark of trees up to 58-cm DBH. Preliminary results from release sites in Connecticut, Michigan, and New York suggest *S. galinae* may successfully establish in northern climate zones.

As EAB expands to new regions of North America, additional studies are needed to 1) evaluate the establishment of EAB biocontrol agents in different climate zones; 2) determine the impacts of established biocontrol agents and other mortality factors on EAB infesting different ash species that dominate different regions of the U.S. and Canada; 3) expand foreign exploration for EAB natural enemies in different regions of Asia; 4) identify EAB-resistant ash genotypes in EAB-aftermath forests; 5) develop an area-wide integrated approach to EAB management with the use of biocontrol, cultural methods, and systemic insecticides.

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BIOLOGICAL CONTROL OF WINTER MOTH IN THE NORTHEASTERN U.S.: THE ROLE OF NATIVE NATURAL ENEMIES

Hannah J. Broadley[1], Joseph S. Elkinton[1,2], and George H. Boettner[2]

[1]Organismic and Evolutionary Biology, University of Massachusetts, 230 Stockbridge Road, Amherst, MA 01003
[2]Department of Environmental Conservation, University of Massachusetts, 160 Holdsworth Way, Amherst, MA 01003

ABSTRACT

The polyphagous caterpillar winter moth, *Operophtera brumata* L., was accidently introduced to the northeastern United States in the 1990s. Previous invasions of winter moth in Canada were successfully suppressed by the introduction of a parasitic fly *Cyzenis albicans* from winter moth's native range. Following these successes, *C. albicans* has now been established at sites across the northeastern U.S. where establishment has coincided with a dramatic decrease in winter moth density. However, this success likely depends on additional mortality from native natural enemies including predators and parasitoids. In the native range of Europe, pupal predators were found to regulate winter moth densities. Further, in the two invasive populations of winter moth in Canada, predation was found to increase following the introduction of the biocontrol agents. Our study builds on this earlier research to evaluate the role of pupal predators, parasitoids, and pathogens. Over five field seasons, we deployed winter moth sentinel pupae in the field to determine rates of predation and parasitism. We deployed pupae across 14 sites in the northeastern U.S. across a range of winter moth pupae and *C. albicans* puparia densities. We also evaluated incidences of virus and microsporidia in larvae across these years in wither moth and its native congener, Bruce spanworm.

Overall, mortality on the pupae was high across sites and years, ranging from 85 to 95% and is primary caused by a diverse community of generalist ground predators including carabid beetles, staphylinid beetles, and shrews. In years when winter moth densities were high, we did not observe density dependent mortality ($p>0.001$); however, in the most recent year as densities have decreased to a level comparable to what was found it its native range, that mortality on the pupae was density dependent ($R^2=0.39$; DF=1,34; $p<0.0001$) and has the potential to stabilize winter moth at low density. In contrast to the Canadian introductions, we found that pupal mortality has not increased with *C. albicans* establishment but has been high throughout the years of study. However, in the last three years, we have detected high parasitism rates by an Ichenumonid wasp *Pimpla* spp., which is causing additional mortality on the pupae (5 to 55% after predation). Across all the years of the study, mortality from nucleopolyhedrosis virus has been low (<5% of larvae collected) in the winter moth population is genetically distinct from the virus found in Bruce spanworm. While microsporidia are found at relative high rates in Bruce spanworm (~26%), we have not detected any in our winter moth collections. Similar to what was found in European and prior introductions in Canada, pathogens are not important in the population dynamics of winter moth.

In conclusion, our research suggests that mortality on winter moth pupae was already high in the northeast, but that the introduced biocontrol agent provides enough additional mortality to render winter

moth a non-pest.

BIOLOGICAL CONTROL OF WINTER MOTH IN THE NORTHEASTERN U.S.

Joseph S. Elkinton[1,2], George H. Boettner[1], and Hannah J. Broadley[2]

[1]Department of Environmental Conservation, [2]Graduate Program in Organismic and Evolutionary Biology, University of Massachusetts, Amherst, MA 01003

ABSTRACT

The winter moth, *Operophtera brumata* L, native to Europe, invaded the northeastern United States in the late 1990s and has become a major defoliator of forests and shade trees, as well as a serious pest of blueberries. Beginning in 2005, we collected the tachinid parasitoid *Cyzenis albicans* each year from Vancouver Island, where it had been released to control the winter moth invasion in the late 1970s. As of 2017, we have released the fly at a total 44 locations from coastal Maine to southeast Connecticut. Beginning in 2004 we established six widely-spaced sites across this region to monitor yearly changes in winter moth density and parasitism by *C. albicans*. We also measured the rate of spread of *C. albicans* along six 10 km transects in Wellesley, Massachusetts and sequenced the CO1 gene of the fly to prove that the flies we recovered match those that we had released.

As of 2017, we have established the fly at 32 of the 44 release locations. Parasitism by *C albicans* has increased to 20 - 50% at all six of our long-term study sites and winter moth densities have declined by about two orders of magnitude. The flies spread at a rate of about 4 km per year from the release point in our Wellesley's transect. Across all the release sites in the northeastern United States, the flies have now occupied nearly all of the high-density winter moth populations. In short, we believe we have converted winter moth to a non-pest status. This success mirrors earlier biological control projects in Nova Scotia and Vancouver Island. Our DNA analyses confirmed that the fly we established matches exactly the flies that were originally collected in Germany and established in Nova Scotia and Vancouver Island. It differs consistently but by only a few base pairs from a *Cyzenis* sp, presumably *Cyzenis pullula*, that we have recovered from Bruce spanworm, the native congener of winter moth in North America.

APROSTOCETUS FUKUTAI, AN ADVENTIVE BIOLOGICAL CONTROL AGENT OF CITRUS LONGHORNED BEETLE IN EUROPE

Franck Hérard[1], Matteo Maspero[2], Marie-Claude Bon[1] and Lincoln Smith[1]

[1]USDA ARS, European Biological Control Laboratory, 810 Avenue du Campus Agropolis, 34890 Montferrier-sur-Lez, France
[2]Fondazione Minoprio, Viale Raimondi, 54, 22070 Vertemate con Minoprio, Como, Italy

ABSTRACT

Citrus longhorned beetle (*Anoplophora chinensis*; CLB) has been accidentally introduced from Asia into 11 countries in Europe, where it is the target of eradication efforts. CLB has a biology similar to Asian longhorned beetle (*Anoplophora glabripennis*; ALB). It attacks many species of deciduous trees, but prefers to oviposit at the base of trees. During a survey of indigenous parasitoids in Europe, a gregarious egg parasitoid was discovered near Parabiago, Italy in 2002. It was initially described as a new species, *Aprostocetus anoplophorae* (Hymenoptera: Eulophidae), but after a multilocus genetic analysis conducted on a larger sampling across its species range, it was synonymized with *A. fukutai*, which is native to Asia. The parasitoid has been reared from CLB eggs in several locations in the Lombardy region of northern Italy. It overwinters in the larval stage, adults emerge during June to early July, and females oviposit in host eggs during the summer. A small proportion of progeny (17%) emerge in late August to early September and parasitize additional hosts, but the remaining larvae are in diapause. A survey at an undisturbed site in Lombardy indicated an average rate of parasitism of 72%, which is similar to that in an abandoned orchard of pomelos at Meizhou, Guangdong, China (80%). Surveys using cut sentinel logs exposed at CLB eradication sites in Lombardy detected parasitism at half the sites. In laboratory experiments, females parasitized 21- 69 % of exposed host eggs, producing a mean of 10 progeny per parasitized host egg and a sex ratio of 9 females: 1 male. Development time of the summer generation was 50 days at 22°C. In choice and no-choice laboratory experiments, *A. fukutai* was generally not able to parasitize ALB eggs. A method to release *A. fukutai* was developed using sentinel potted trees that were infested by CLB eggs, then by *A. fukutai* in the laboratory, then overwintered before exposing the trees at the release site for parasitoid emergence.

POSTERS

SPOTTED LANTERNFLY OUTREACH: OPENING THE FLOODGATES

Lawrence E. Barringer

Pennsylvania Department of Agriculture, Division of Entomology,
2301 N. Cameron Street, Harrisburg, PA 17110

ABSTRACT

Spotted Lanternfly (SLF) was found in Pennsylvania in 2014. At first, conventional means of outreach were utilized: pest alerts, fact sheets, activity books, and town hall meetings. In August 2017, a Facebook campaign was launched to reach new demographics using a 60 second video. Over 5.7 million postings resulted in 35,000 link clicks, 533,000 videos views, and 1.83 million interactions. Contacts reporting SLF averaged 121 emails and 57 calls per day during the 75-day campaign, roughly 10x the normal amount. This totaled 13,000 (65%) contacts out of 20,000 over the past 3 years, highlighting the role social media can play to augment traditional methods used for invasive pest outreach.

PRESENCE OF A BIOLOGICAL CONTROL STRAIN OF PARASITIC NEMATODE HAS UNEXPECTED EFFECTS ON EGG STERILIZATION OF *SIREX NOCTILIO*

Tonya D. Bittner[1], Nathan P. Havill[2], Isis A. L. Caetano[1], Ann E. Hajek[1]

[1]Cornell University, Department of Entomology, Ithaca, NY 14853
[2] USDA Forest Service, Northern Research Station, 51 Mill Pond Rd., Hamden, CT 06514

ABSTRACT

Sirex noctilio Fabricius is an invasive woodwasp in North America and elsewhere that attacks pine trees (*Pinus* spp.). The biological control agent, *Deladenus siricidicola* Bedding (Kamona strain), is successfully being used to control *S. noctilio* in Oceania and South America. Nematodes in the genus *Deladenus* can be mycophagous and free-living, or parasitic in siricids. Certain strains (including Kamona) can sterilize some or all of the eggs of *S. noctilio* when juvenile nematodes enter the eggs. We tested the biological control agent *D. siricidicola* Kamona against *S. noctilio* in North America. However, in North America, an existing strain of *D. siricidicola* that does not sterilize (non-sterilizing or NS) is already present, presumably introduced along with this invasive woodwasp. The possible interactions between the sterilizing strain and the established non-sterilizing strain could include competitive exclusion, coinfection within wasps, or hybridization. In 2013 and 2014, we inoculated logs already infested with *S. noctilio* larvae with Kamona and determined infection and sterilization rates of emerged adult wasps. To identify nematodes to strain, we sequenced a mitochondrial gene, and this suggested 2% of infections were Kamona (n=94 wasps). This method could not distinguish hybrids, so we isolated 16-42 individual nematodes from within a subsample of 14 wasps and from within 8 sterilized eggs from 4 of these wasps; a total of 418 nematodes were analyzed. These nematodes, in addition to representative NS (n=153) and Kamona (n=44) nematodes, were genotyped with 8 microsatellite loci and analyzed with the program NewHybrids for their probability of membership in a parental strain or hybrid class. Kamona did hybridize with NS at a low rate (9 hybrids out of 418 nematodes, 2%). Fifteen percent of the 418 nematodes were pure Kamona. Inside of eggs, we found varying mixtures of Kamona, F2, and NS nematodes; NS has never been reported inside of eggs previously. Within three female *Sirex*, the genetic composition of nematodes inside eggs was similar to that of nematodes in the hemocoel. In the eight female wasps sampled, we expected wasp sterilization to be directly related to infection by Kamona, however, the percentage of eggs sterilized did not increase with increasing percentage of Kamona and hybrids. Hybridization between these two strains of *D. siricidicola* could change the essential character of the commonly occurring non-sterilizing strain, but with unpredictable effects on control of introduced *Sirex*.

NORTHEAST REGIONAL INVASIVE SPECIES & CLIMATE CHANGE MANAGEMENT NETWORK

HOW CAN WE MANAGE FOR UPCOMING BIOLOGICAL INVASIONS IN LIGHT OF CLIMATE CHANGE?

Carrie Brown-Lima[1], Bethany Bradley[2], Toni Lyn Morelli[3], Valerie Pasquerella[2], and Audrey Bowe[1]

[1]New York Invasive Species Research Institute, Cornell University,
[2]Department of Environmental Conservation, University of Massachusetts Amherst,
[3]Northeast Climate Science Center

ABSTRACT

Invasive species managers and policy makers have requested more and better information on how to manage natural areas and invasive species in light of climate change. Additionally, the amendment to the executive order on invasive species issued on December 5, 2016 ordered that agencies should "consider the impacts of climate change when working on issues relevant to the prevention, eradication, and control of invasive species, including in research and monitoring efforts…" however how to do this isn't clear to most managers and policy makers.

Unable to identify synthesized research that addressed this specific challenge presented by a changing climate, NYISRI reached out to scientists from the Northeast Climate Science Center and the University of Massachusetts Amherst to begin to tackle these questions. Encouraged by widespread interest from the scientific and management communities, these initial talks formed the basis of what became the Northeast Regional Invasive Species and Climate Change (NE RISCC) Management Network.

Since its inception, the RISCC Network has organized workshops and other events to further its purpose, in addition to the 2017 RISCC Management Symposium. On July 21st 2016, RISCC held the Northeast Invasive Species and Climate Change Workshop which resulted in a report detailing research and information needs, management considerations, and laying out long-term and short-term goals for the Network. RISCC will also be hosting webinars featuring research that marries invasive species and climate change issues.

The RISCC webpage contains links to pertinent research papers, recordings, and online resources, as well as summaries of past meetings. Since 2016, the group's membership has grown to include over 150 managers and researchers representing organizations across the Northeast and Midwest. Our list-serve provides a venue for circulating recent research papers on topics of invasive species and climate change, and sharing information on related upcoming events and conferences.

To learn more about the RISCC Network and to join the RISCC listserve, visit the RISCC Webpage (http://people.umass.edu/riscc/index.html) or contact NYISRI Director Carrie Brown-Lima (cjb37@cornell.edu).

ASIAN LONGHORNED BEETLE (ALB), *ANOPLOPHORA GLABRIPENNIS*, ERADICATION PROGRAM

Paul Chaloux[1] and Josie Ryan[2]

[1]USDA Animal and Plant Health, Inspection Service, Riverdale, MD 20737
[2]USDA Animal and Plant Health , Inspection Service, Amityville, NY 11701

ABSTRACT

Asian longhorned beetle (ALB), *Anoplophora glabripennis*, initial detections in the United States include Brooklyn, NY (August 1996), Chicago, IL (July 1998), Jersey City, NJ (October 2002), Worcester, MA (August 2008), and Bethel, OH, (June 2011). ALB has the potential to be one of the most destructive and costly invasive species to enter the United States. Some of the industries at risk include timber export, saw logs, fuel wood, nursery stock, lumber, maple syrup, and fall foliage tourism. ALB also has the potential to cause significant ecological and environmental impacts. The goal of the eradication program is to eliminate the beetle in the United States to protect forest products industries, hardwood forests and park lands, and the quality of the urban environment. To achieve this goal, the ALB program uses area-wide, science-based eradication protocols. The strategy is based on a combination of tactics which include exclusion through solid wood packing material regulations, establishing quarantines around known infestations, conducting visual survey of host trees, tree removal, chemical treatment, tree replanting, and outreach efforts. Recent achievements include removing the 26 square mile quarantine in eastern Queens, New York, using a new risk modeling system in Massachusetts to help plan survey progression, and removing 5 square mile quarantine in Stonelick/Batavia townships in Ohio. Eradications have been declared in Illinois (2008), Islip, New York (2011), New Jersey (2013), Manhattan and Staten Island, New York (2013) and Boston, Massachusetts (2014). The program continues efforts to eradicate ALB in New York, Massachusetts and Ohio.

APPLICATION OF CHEMICAL FINGERPRINTING AS A TOOL TO SCREEN TREES FOR RESISTANCE AGAINST INVASIVE AND NON-NATIVE PATHOGENS

Anna O. Conrad[1], Richard Sniezko[2], Luis Rodrigez-Saona[3], and Pierluigi Bonello[4]

[1]Department of Plant Pathology, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210 [2]USDA Forest Service, Dorena Genetic Resource Center, 34963 Shoreview Drive, Cottage Grove, OR 97424
[3]Department of Food Science and Technology, The Ohio State University, 2015 Fyffe Road, Columbus, OH 43210

ABSTRACT

The introduction of non-native and invasive plant pathogens presents unique challenges for maintaining healthy forests. In many instances, strategies for managing diseases caused by these organisms are limited. Identifying and breeding trees for resistance is one viable strategy, but it can be hindered by a lack of available rapid and reliable phenotyping methods. Fourier-transform infrared (FT-IR) and Raman spectroscopy are two approaches that may be useful for phenotyping trees for disease resistance more rapidly. Using these approaches, a chemical "fingerprint" is produced. Chemometrics is then used to identify spectral regions associated with traits of interest, such as disease resistance, and statistical models are developed to predict resistance based on those spectral regions. The objective of our research is to develop, optimize, and validate protocols for analyzing tree extracts and tissues using FT-IR and Raman spectroscopy, with the aim of simplifying and speeding up the identification of resistant trees. We previously found that FT-IR spectroscopy combined with chemometrics could be used to distinguish between coast live oak (*Quercus agrifolia*) that were resistant and susceptible to *Phytophthora ramorum*. Currently, we are testing the approach on additional forest pathosystems including, Port-Orford-cedar (*Chamaecyparis lawsoniana*) and *Phytophthora lateralis*, and whitebark pine (*Pinus albicaulis*) and *Cronartium ribicola*, and are focusing on the application of Raman spectroscopy. Ultimately, our goal is to have a field-ready protocol for tree disease phenotyping based on FT-IR and/or Raman spectroscopy to rapidly identify resistant trees for use in breeding and disease management programs.

ACULOPS MOSONIENS (ACARI: ERIOPHYOIDEA) A POTENTIAL BIOCONTROL AGENT OF *AILANTHUS ALTISSIMA*

Massimo Cristofaro[1], Francesca Marini[1], Radmila Petanovic[2], Domenico Valenzano[3], Matthew Augé[1], Biljana Vidovic[2] and Enrico de Lillo[3]

[1]BBCA onlus, Via Angelo Signorelli 105 00123 Rome, Italy
[2] Univeristy of Belgrade Nemanjina 6, 11080 Belgrade - Zemun, Serbia
[3]University of Bari Aldo Moro via Amendola 165/A, 1-70126 Barti, Italy

ABSTRACT

Ailanthus altissima, commonly called tree of heaven, is a fast-growing deciduous tree, native to China. It is a serious invasive species worldwide (Europe, Asia, South Africa, South Eastern Australia, North America) of disturbed urban sites, competing with autochthonous flora and causing structural damage to railways, roads and buildings. In addition, in rural areas it invades cropland, fencerows, forest edges and rocky areas. The total eradication of this alien species is problematic, and efforts have to be addressed for the ecological preservation of the ecosystems by the use biological and integrated control approaches. Among the potential candidate agents associated with the target weed, eriophyid mites can play a relevant role, because they are obligate plant feeders with high host specificity and a significant impact on their hosts. Few eriophyoid species were found to be associated with *A. altissima* in its native range, but recently a new eriophyid species has been described in Hungary, and it appears to offer a concrete chance to have a potential biocontrol agent which does not need to be imported. *Aculops mosoniensis* (Ripka & Érsek) forms dense populations on the undersurface of the leaflets, which are responsible of making the lamina narrow, deformed, twisted, with edges folded or rolled downward toward the main vein of the leaflets. Drying and necrosis of the apical parts of the stems have been observed on heavily infested plants, and dense infestations on young plants are associated with the premature loss of leaves. First surveys showed that *A. mosoniensis* occurs in several European countries (i.e. Austria, Croatia, Greece, Hungary, Italy, FYROM, Serbia, Slovakia and Slovenia) and few states of US (i.e. Pennsylvania and West Virginia). Based on the induced damages on the host plant, *A. mosoniensis* seems to be a promising candidate agent for biological control of tree of heaven; for this reason field observations and laboratory bioassays on the biology, host specificity and impact of this eriophyid mite on the target plant species are currently under evaluation in Italy.

LYCORMA DELICATULA ELECTROPHYSIOLOGY – IN PURSUIT OF HOST-PLANT KAIROMONES

Nathan T. Derstine[1,2], Isaiah Canlas[1,2], Daniel Carrillo[2], and Miriam Cooperband[1]

[1]USDA-APHIS-PPQ-S&T, Otis Laboratory, 1398 West Truck Rd., Buzzards Bay, MA 02542

[2]University of Florida, Tropical Research and Education Center, 18905 SW 280 Street, Homestead, FL 33031

ABSTRACT

The spotted lanternfly, *Lycorma delicatula* (White), is an invasive generalist phloem feeder from China. Its primary host is tree-of-heaven (*Ailanthus altissima)*, an invasive species from China now ubiquitous in the United States. Notably, *L. delicatula* feeds on and causes damage to agricultural crops such as grapes and apples, in addition to walnut, oak, maple, willow, and many others. Current eradication efforts are hampered by the lack of a highly attractive lure and effective trap. With the aim of enhancing our previously developed methyl salicylate lures, we collected volatiles from six different plant hosts and developed GC-EAD techniques to screen volatiles for electrophysiological activity. Briefly, the head was removed, and from one of the antennae the entire apical arista and basal bulb of the flagellum were removed with fine forceps. A glass-saline recording electrode was brought into contact with the resulting cavity on the pedicel, the segment containing the majority of the antennal sensilla. The ground electrode was placed into the base of the head. Recordings of antennal responses to different host plant volatile profiles revealed 39 unique antennally active host-plant volatiles, 19 of which have been chemically identified so far.

Dual choice behavioral bioassays were used to evaluate compounds for attraction. We compared antennally active compounds singly and in blends in y-tube bioassays against either a blank control or the current best attractant, methyl salicylate. The best blend contained 7 synthetic compounds including 0.5 mg of methyl salicylate, which was preferred over 2 mg of methyl salicylate. Further blend and lure development is ongoing. The development of GC-EAD capabilities for *L. delicatula* greatly catalyzes the process of lure development for survey and trapping programs while offering insights into the basic biology of *L. delicatula*.

WHAT IS CAUSING THE EMERGING BEECH LEAF DISEASE?

Carrie Ewing[1] and Pierluigi (Enrico) Bonello[1]

[1]The Ohio State University, 2021 Coffey Rd., Columbus, OH 43210

ABSTRACT

First discovered in 2012 in northeast Ohio, an emerging epidemic called beech leaf disease (BLD) is spreading rapidly among American beech trees *(Fagus grandifolia)*. In only five years, the disease has affected forests in over eleven counties in northeast Ohio and northwest Pennsylvania and has been reported in New York state and Ontario, Canada during the summer of 2017. In 2016, the disease had affected approximately 2,525 ha of forest in Ohio alone. In addition, symptoms of the disease have also been recorded on European beech *(F. sylvatica)* and possibly Oriental beech *(F. orientalis)* in several nurseries in northeast Ohio in 2017. The symptoms of BLD are characterized by a dark banding pattern occurring on the leaf in the initial stages of infection, followed by the thickening, crinkling, and darkening of the entire leaf in the next growing season. Eventually no new leaves are produced and the buds desiccate on the infected branches, leading to tree mortality. The objective of this project is to discover, and possibly isolate, the causal agent of BLD. Since the symptoms are noticeable in the leaves, foliage samples from American beech trees were collected at two time points during the growing season (mid-June and late-August) in 2017 from eight different permanent plots established in Ohio and Pennsylvania, in collaboration with the Cleveland Metroparks and the Pennsylvania Bureau of Forestry. The sites were divided into four symptomatic sites, three asymptomatic sites, and one control site in Columbus, Ohio where the disease has not yet been reported. The foliage from the trees at the symptomatic sites was further divided by specimens with early symptoms and late symptoms. Overall, 101 trees were sampled and 217 foliage samples were collected. We will use next generation sequencing (NGS) approaches to simultaneously screen for the four main plant pathogen groups, including viruses, bacteria, fungi, and phytoplasmas. We hope that a comparison of the microbial communities in the leaves of the different symptom classes will allow us to identify a candidate causal agent. The ultimate goal of this project is to isolate the causal agent of BLD in order to determine proper management approaches to reduce the spread of the disease to additional beech forests in North America and elsewhere around theworld.

SIREX NIGRICORNIS F. (HYMENOPTERA: SIRICIDAE): DESCRIBING A NOVEL SYSTEM FOR LIVE-TRAPPING WOOD BORERS, AND RELATING OVIPOSITION AND DEVELOPMENT TO BOLT AGE

Jessica A. Hartshorn[1,2], Larry D. Galligan[1], Ace J.W. Lynn-Miller[1], and Fred M. Stephen[1]

University of Arkansas[1], Minnesota Department of Natural Resources[2]

ABSTRACT

Sirex nigricornis F. (Hymenoptera: Siricidae) is a pine-inhabiting woodwasp native to eastern North America. A non-native congener, *S. noctilio* F., was discovered along the southeastern shore of Lake Ontario in New York in 2004 and its current distribution now includes seven northeastern states, Ontario, and Quebec.

Research on these two species, and their associates, requires efficient methods for collection of, and oviposition by, live females in artificial conditions. A description of a novel live-trapping method for collection of adult females *S. nigricornis* is provided. Live traps successfully captured adult female *S. nigricornis* as well as a variety of other wood boring insects (e.g. Coleoptera: Cerambycidae, Hymenoptera: Ibaliidae).

Moisture content has been implicated as a key factor in determining host suitability for their oviposition and development and may be an important factor in creation of a laboratory colony. We measured changes in moisture content along the length of shortleaf pine bolts over time and exposed *S. nigricornis* mating pairs to ten replicates of three treatments (0, 15, 30 days field-seasoned) of shortleaf pine bolts. Laboratory emergence was monitored and oviposition preference was quantified among bolt ages and associated moisture contents. Moisture content decreased over time, with the majority of moisture loss occurring at the ends of bolts. Females significantly preferred drilling in freshly cut bolts, however, successful development and emergence occurred only in 15-day-old bolts. Both sexes emerged from bolts indicating successful mating. Future studies incorporating laboratory rearing should keep bolts protected from wood-borers either outdoors, or in a humidity and temperature controlled room to mimic environmental conditions, for approximately 15 days prior to exposure to siricid mating pairs.

AGRILUS SMARAGDIFRONS, AN EAST ASIAN METALLIC WOOD-BORING BEETLE (COLEOPTERA: BUPRESTIDAE), NEW IN NORTH AMERICA: FRIEND OR FOE?

E. Richard Hoebeke[1], Eduard Jendek[2], James E. Zablotny[3], Ryan Rieder[4], Rosa Yoo[5], Vasily V. Grebennikov[6], And Lily Ren[7]

[1]Georgia Museum of Natural History and Department of Entomology, University of Georgia, Athens, GA 30602

[2]Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences, Department of Forest Protection and Entomology, CZ-165 21 Praha 6-Suchdol, Czech Republic

[3]USDA Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Romulus, MI 48174

[4]New Jersey Department of Agriculture, Division of Plant Industry, Trenton, NJ 08625
[5]New Jersey Department of Environmental Protection, Forest Service, Trenton, NJ 08625

[6]Canadian Food Inspection Agency, K.W. Neatby Building, Ottawa, Ontario, K1A 0Y9

[7]Beijing Key Laboratory for Forest Pest Control, Beijing Forestry University, Beijing, Haidian District, Post Code: 100083, China

ABSTRACT

The jewel beetle genus *Agrilus* Curtis is recognized as a hyper-diverse genus with over 3,000 valid nominal species. Because of the detection of Emerald ash borer (*A. planipennis*) in Michigan in 2002, the North American *Agrilus* fauna has been under close scrutiny for the presence of other adventive species. As the result of ongoing surveys for EAB in North America, we report an eleventh non-native *Agrilus* in North America, the East Asian *A. smaragdifrons* Ganglbauer, developing on tree of heaven, *Ailanthus altissima* (Mill.) Swingle (Simaroubaceae).

The New Jersey Department of Agriculture, Division of Plant Industry, Bureau of Plant Pest and Disease Control began an official survey for emerald ash borer (*A. planipennis*) in 2011 following the first detections of this invasive wood-boring beetle in the neighboring states of Maryland (2003, 2006), Pennsylvania (2007), and New York (2009). Once a trap catch was determined to be negative for EAB, it was then screened for all Buprestidae. The by-catch was placed in plastic vials with 70% ethyl alcohol and was set aside for further identification.

In 2015, two trap samples were found to contain a distinct but unrecognized species of *Agrilus* from two separate EAB trapping locations; the identification of these beetles, however, remained inconclusive. One male was collected in a green Lindgren funnel trap near Washington Rock, New Jersey in June 2015. An additional three females and one male from Washington Rock and two additional localities in New Jersey (Taylor Wildlife Preserve and South Bound Brook) were collected in May and June 2015 and 2016. These specimens were positively identified as *A. smaragdifrons* by the senior author and confirmed by E. Jendek.

Interestingly, an ongoing EAB biosurveillance program in New England utilizing the native ground-nesting wasp *Cerceris fumipennis* Say also detected the presence of *A. smaragdifrons* in at least one location in central Connecticut in 2015. It also came to our attention later in 2016 that *A. smaragdifrons* was collected as by-catch in other state trapping surveys (Pennsylvania, New York). The earliest known record of *A. smaragdifrons* in the U.S. is based on an image found on BugGuide and labeled "unknown buprestid – *Agrilus*." The specimen that was photographed was observed at "Liberty State Park, Hudson Co., New Jersey, June 2011."

Identification of *A. smaragdifrons* among native North American *Agrilus* is simple and unmistakable. There is no other Nearctic *Agrilus* that possesses such an obviously flattened frons, long and bisinuate prehumerus (prehumeral carina), and the aedeagus with distinctly expanded parameres.

The current global distribution of this species includes East Asia (native): China: Beijing, Gansu, Shaanxi, Sichuan, Tianjin, and North America (adventive): United States: Connecticut, New Jersey, New York, Pennsylvania.

Based on field observations in China and the U.S., the adult and larval host plant of *A. smaragdifrons* has been revealed to be tree of heaven, *Ailanthus altissima*. At least 32 species of arthropods have been recorded in association with the genus *Ailanthus* in China (Zheng et al. 2004). However, no species of Buprestidae have been previously documented from this tree host.

The first-time discovery of *A. smaragdifrons* in New Jersey was facilitated by the timely examination of specimens trapped as by-catch in EAB monitoring traps. We strongly recommend that further attention be given to non-target insects that are captured during future trapping surveys.

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DISPERSAL OF THE PARASITOIDS INTRODUCED FOR THE BIOLOIGCAL CONTROL OF EMERALD ASH BORER (COLEOPTERA: BUPRESTIDAE) ALONG AN ASH CORRIDOR IN WESTERN NEW YORK

Michael I. Jones[1], Juli R. Gould[2], Melissa L. Warden[2] and Melissa K. Fierke[1]

[1]SUNY, College of Environmental Science and Forestry, Syracuse, New York 13210

[2]USDA APHIS PPQ S&T, 1398 West Truck Road Buzzards Bay, MA 02542

ABSTRACT

We established a field study to assess dispersal capabilities of the parasitoids introduced to North America for the biological control of emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae). In 2013 and 2014, we released *Spathius agrili* Yang (Hymenoptera: Braconidae), *Tetrastichus planipennisi* Yang (Hymenoptera: Eulophidae), and *Oobius agrili* Zhang and Huang (Hymenoptera: Encyrtidae) at 5 km intervals along 15 km of an ash (*Fraxinus* spp.) corridor along which EAB was still dispersing. From 2013 to 2017, we deployed yellow pan traps every 250 m in the study area to detect dispersal along the corridor. In 2014, 2015, and 2016, ash health data were collected at each trap location. In 2016, additional traps were established parallel to the study area to detect dispersal away from the corridor.

Emerald ash borer was recovered in traps each year of the study and severity of ash decline aligned with EAB trap detections to indicate progression of the infestation. *Tetrastichus planipennisi* was first recovered in 2014 and trap catches increased each subsequent year of the study. The other parasitoid species were not recovered. In 2016, *T. planipennisi* was detected ~ 10 km from release points, had caught up to EAB populations at the leading edge of the infestation, and were detected in traps ~ 3.9 km away from the corridor. By 2017, *T. planipennisi* was well established across the entire study area. This study highlights the successful establishment and dispersal of *T. planipennisi* and suggests it will be an important biological control agent of EAB in North America.

INTER- AND INTRA-SEXUAL SELECTION IN *ANOPLOPHORA GLABRIPENNIS* (COLEOPTERA: CERAMBYCIDAE) AND THE IMPACT OF DIFFERENT PERCEIVED SEX RATIOS

Melody A. Keena, Vicente Sánchez

USDA Forest Service, Northern Research Station, 51 Mill Pond Rd., Hamden, CT

ABSTRACT

The behaviors of *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae) after inter- and intra-sexual interactions between both solitary and paired individuals at different sex ratios were observed on an *Acer platanoides* L. (Sapindales: Sapindaceae) branch in the laboratory. Intra-sexual contact was generally ignored by females but between males resulted in battles with one male ultimately retreating from the other. When the male size differed larger males won battles, while equally sized males split the wins and battled longer. When males initiated inter-sexual contact they quickly found and mounted the female. The female determined if and how long the male could copulate with her by controlling access to her genital opening and males would eventually dismount if the female remained unreceptive. After successfully copulating, males ignored female intruders and fought off male challengers, generally without dismounting. Some males would not accept the female and dismounted without attempting to copulate. Individual age and size were not predictive of either female or male choice in a mate. Mating duration was affected by both female receptivity and perceived sex ratios. Male interruptions of the pair shortened time in copula. Male skewed sex ratios (1F:2M) significantly shortened the time a male would stay with an unreceptive female while female skewed sex ratios (2F:1M) did not impact mating duration. Probability of dispersal both from and within the branch, was greater for smaller individuals of both sexes and for males in male skewed sex ratios.

These results have some management implications for the eradication programs. First, when all the factors that influence the propensity to disperse are taken together adult *A. glabripennis* are most likely to disperse either when population densities are very low or very high (less at intermediate densities). At lower population densities the need to disperse to find a mate is high. At very high population densities host quality declines, size variation tends to increase, and there will be more intra-sexual encounters resulting in aggression. Low density dispersal may make finding the last infested trees more difficult, but could increase female trap catch and the number of beetles that never find mates, both of which help reduce overall population density. Secondly, there is no indication that female fertility will be affected by population density or sex ratio as long as she finds a mate(s). At low population densities single pairs will stay together long enough for the female to remain fertile for life. At higher population densities one minute of copulation is sufficient to transfer sperm and the likelihood that a female will have multiple mates, again ensures she is fertile for life.

LOCATING PERSISTING EASTERN HEMLOCKS FOR HEMLOCK WOOLLY ADELGID SURVIVAL SCREENING: A NATURAL AND NECESSARY APPROACH TO HEMLOCK RESTORATION

Ian G. Kinahan, Chad M. Rigsby, Richard A. Casagrande and Evan L. Preisser

Department of Biological Sciences, The University of Rhode Island, Kingston, RI, 9 E. Alumni Ave., Kingston, RI 02881

ABSTRACT

Despite half a century of widespread, inexorable defoliation by Hemlock Woolly Adelgid (*Adelges tsugae*), individual Eastern Hemlocks (*Tsuga canadensis*) persist in adelgid-infested forests throughout the Northeast. However, healthy trees and trees declining significantly more slowly exist, interspersed among long-standing snags. Specifically, we have documented healthy hemlocks surviving among stands that have experienced substantial mortality in Pennsylvania's Northeast and Southwest counties. Additionally, although fewer sites were visited in New Jersey, we have detected a significant number of persisting trees within certain areas of the Delaware Water Gap National Recreation Area (Western NJ). These remaining hemlock trees display traits that suggest a naturally elevated level of resistance, characterized by considerable temporal and proximal exposure to the adelgid. Field observations confirmed these trees to be healthy, and often adelgid-free, or very low-level infestations. With permission, cuttings from individuals of these populations will be collected for controlled propagation and adelgid resistance assays. Resistant genotypes will be provided to the Pennsylvania Department of Conservation and Natural Resources for a reforestation program, as well as for use in the establishment of a Northern – region hemlock resistance breeding program in partnership with the U.S. Forest Service and the Holden Arboretum (Kirtland, OH).

DISTRIBUTION AND PHENOLOGY OF THE BROWN MARMORATED STINK BUG IN LIGHT OF CLIMATE CHANGE

Erica Jean Kistner

USDA Agricultural Research Service, Midwest Climate Hub, National Laboratory for Agriculture and the Environment, 1015 N. University Boulevard, Ames, IA 50011

ABSTRACT

The invasive brown marmorated stink bug, *Halyomorpha halys* (Stål; Hemiptera: Pentatomidae), has recently emerged as a harmful agricultural pest in North America and Europe. This highly polyphagous insect has over 300 reported host plants, including important horticultural crops. Originally from East Asia, *H. halys* is spreading rapidly worldwide. As with many invasive insects, climate is likely the dominant force determining *H. halys* distribution and densities in its invaded range given the lack of natural enemies and an abundance of suitable host plants. Climate change will add further complications to managing this species in terms of both geographic distribution and population growth. This study used CLIMEX, to compare potential *H. halys* distribution under recent and future climate models using one emission scenario (A2) with two different global circulation models, CSIRO Mk3.0 and MIROC-H. Simulated changes in seasonal phenology and voltinism were examined.

On a global scale, potential *H. halys* range expanded polewards and contracted from its southern temperature range limits under future climate scenarios. Climate change enabled *H. halys* to expand its range northward to higher latitudes in Europe and North America while suitable *H. halys* range in southeastern United States contracted. All future climate scenarios explored here suggest that the invasion threat posed to Europe and Canada will greatly intensify. Prolonged periods of warm temperatures resulted in longer growing seasons. However, future climate scenarios also indicated that rising summer temperatures decrease *H. halys* growth potential compared to recent climatic conditions, which in turn, may reduce mid-summer crop damage. Climate change may increase the number of *H. halys* generations produced annually, thereby enabling the invasive insect to become multivoltine in the northern latitudes of North America and Europe where it is currently reported to be univoltine. Model projections suggest that prime horticultural production areas in Europe, northeastern United States, and southeastern Canada are at greatest risk from *H. halys* under both recent and possible future climates. The results of this study can inform biosecurity planning and pest management by identifying regions of increasing as well as decreasing risk from *H. halys* in light of climate change.

TRICHOFERUS CAMPESTRIS (CERAMBYCIDAE): PORT INTERCEPTIONS IN WOOD PACKAGING, INLAND DETECTIONS, AND RISK OF ESTABLISHMENT IN THE UNITED STATES

Sindhu Krishnankutty[1], Ann Ray[1], Hannah Nadel[2], Scott Myers[2], John Molongoski[2], Steven Lingafelter[3] and Yunke Wu[4]

[1]Department of Biology, Xavier University, 3800 Victory Pkwy., Cincinnati, OH 45207

[2]USDA-APHIS-PPQ-CPHST Otis Laboratory, 1398 W. Truck Rd., Buzzards Bay, MA 02542

[3]USDA-APHIS-PPQ, Pan American Ave and 1st Street, Douglas, AZ 85607

[4]Department of Ecology and Evolutionary Biology, Cornell University, Corson Hall, Ithaca, NY 14853

ABSTRACT

Trichoferus campestris, a cerambycid native to Asia, is a pest of quarantine concern in the US, Canada, and Europe, as it attacks dead and live wood over a very broad host range. In the US, it was detected in several states and is established in Utah and Illinois, and possibly elsewhere. The establishment risk of this beetle in other parts of the US is high because of its frequent introduction through multiple pathways into urban areas and into commodity distribution centers linked to US ports, and its potential to inhabit natural and urban forests as well as agricultural lands. In this study, we compiled interception and detection data useful to map the risk of this species in the US. As of June 2016, the PestID database in the Agricultural Quarantine Activity System (AQAS) recorded 45 separate interceptions at 13 US ports through multiple pathways, namely wood packing material (WPM), wood products, and passenger baggage. Records exist of domestic detections of adult *T. campestris* in 14 states in both residential and commercial properties. We tested if the intended-destination of cargo intercepted with *T. campestris*-infested WPM can be used as a predictor of inland introductions, assuming established trade routes exist between export-import partners. We found that of 24 intended-destination counties (IDCs) for WPM infested with *T. campestris*, 13 were in or adjacent to detection areas; we therefore concluded that IDCs can play some role in prediction of inland introductions. We are currently collaborating with analysts in the Pest Epidemiology and Risk Analysis Laboratory to develop a pest risk map for *T. campestris* that integrates risks associated with several invasion correlates including trade, the WPM pathway, and climate suitability. The map will enable informed prioritization of resources in detection surveys and will serve as a model for other wood borers identified in the WPM pathway.

EFFICACY OF BARK SPRAYS AND TREE INJECTION IN CONTROLLING THE SPOTTED LANTERNFLY, *LYCORMA DELICATULA*

Phil Lewis

USDA APHIS PPQ; Otis Methods Laboratory 1398 W. Truck Rd., Buzzards Bay, MA 02542

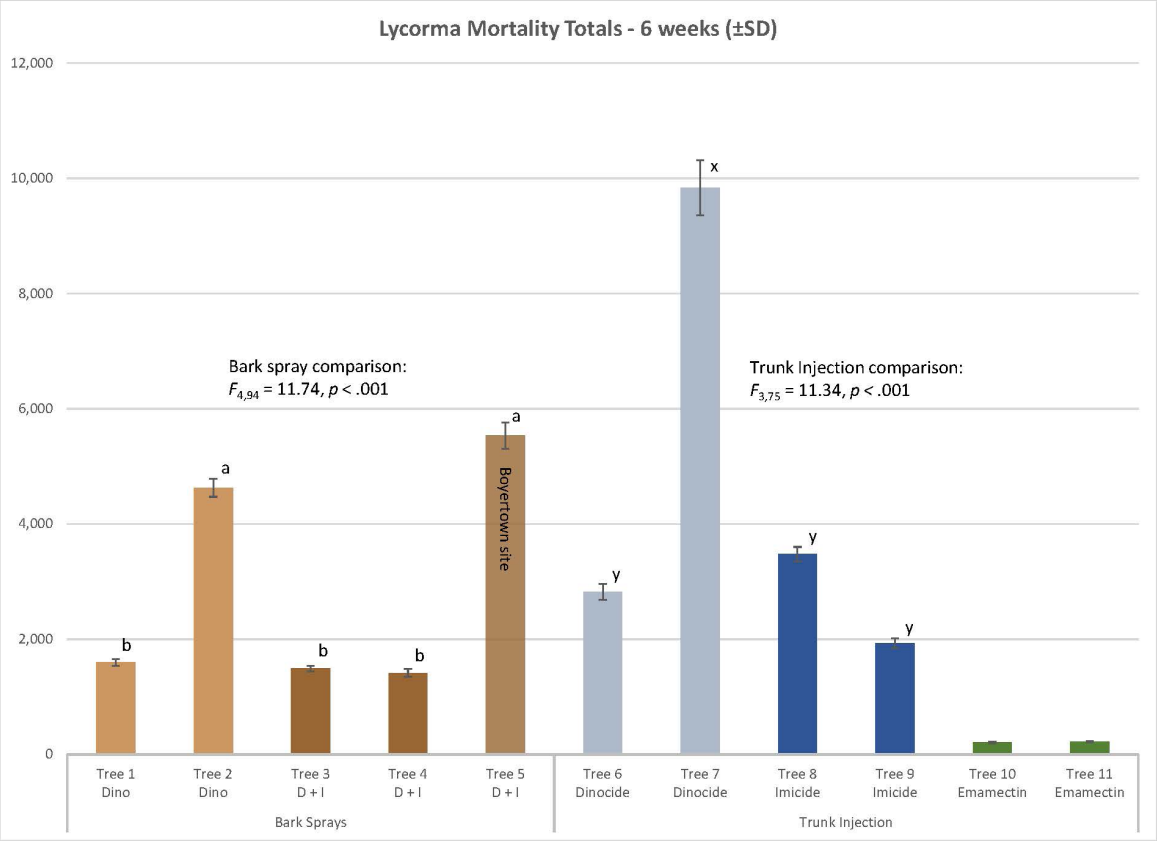
ABSTRACT

Spotted lanternfly (*Lycorma delicatula*), a sap feeding insect native to Taiwan and China, was first detected in the United States in 2014. Commodities that are at risk and could be impacted in Pennsylvania include the state's grape, apple and stone fruit industries ($180 million annually) and pine and hardwood lumber sales ($12 billion). Field populations are currently known to be present in 13 counties in southeastern Pennsylvania, with 7 counties added in November, 2017. Ongoing eradication efforts include outreach and education activities, host tree removal and using the preferred host, Tree of Heaven (*Ailanthus*), as a trap tree via the application of a systemic insecticide to the lower portion of the tree trunk.

Safari 20SG (dinotefuran) was applied alone and in combination with Merit 2F (imidacloprid) with a bark spray method, using a one-gallon sprayer at the maximum labeled rate(s) for this application type. Trunk injectable formulations of dinotefuran, imidacloprid (Dinocide Hp and Imicide Hp, Mauget Co.) and emamectin benzoate (Tree-age, Arborjet, Inc.) were applied to trees by basal tree injection using 2mL of product per diameter inch of tree via a QUIK-jet AIR device and tapered stainless steel injection tips inserted into 7/32" drill holes. Treatments were applied in late August to landscape *Ailanthus* trees that were located at a single property in Douglassville, PA that had many *Ailanthus* trees and a heavy lanternfly infestation. Each treatment was comprised of two trees between 5" and 8" diameter (6.4" average, 1.0" = SD), as well as a control group. Tarps were placed under the treated trees and dead lanternfly were counted regularly for 6 weeks.

Over 34,000 dead spotted lanternfly (SLF) adults were counted over the 6 week period of this study, with one tree accounting for about 30% of the total (Figure 1). In contrast, 102 adults were collected from tarps under the two control trees. The following statements summarize the results:

1. Adult SLF are susceptible to dinotefuran and imidacloprid applied by either method.
2. A bark spray using both insecticides did not increase mortality ($F_{1,94} = 0.22$, ns).
3. Emamectin benzoate was not effective against spotted lanternfly.
4. More SLF adults were killed by trunk injection treatments as compared to mortality from trees with bark spray treatments ($F_{1,170} = 5.29$, $p = .022$).
5. Individual trees are highly variable in attractiveness to SLF (Figure 1).**Figure 1.** SLF adult mortality totals over a 6 week period by insecticide and treatment method.


Lycorma Mortality Totals - 6 weeks (±SD)
12,000
10,000
8,000
6,000
4,000
2,000
0
Bark spray comparison:
$F_{4,94} = 11.74, p < .001$
Trunk Injection comparison:
$F_{3,75} = 11.34, p < .001$
Boyertown site
a
a
b
b
b
y
x
y
y
Tree 1 Dino
Tree 2 Dino
Tree 3 D + I
Tree 4 D + I
Tree 5 D + I
Tree 6 Dinocide
Tree 7 Dinocide
Tree 8 Imicide
Tree 9 Imicide
Tree 10 Emamectin
Tree 11 Emamectin
Bark Sprays
Trunk Injection

PEST-INDUCED CHANGES IN FOREST CARBON AND NITROGEN CYCLING CAN BE LARGE AND MAY LAST FOR CENTURIES

Gary M. Lovett and Katherine F. Crowley

Cary Institute of Ecosystem Studies, Box AB, 2801 Sharon Turnpike, Millbrook, NY 12545 USA

ABSTRACT

As tree species composition changes in the Northeastern U.S. due to invasive forest pests or other stressors, the extent to which forests will sequester nitrogen (N) and carbon (C) remains uncertain. We used a species-specific, dynamic forest ecosystem model (Spe-CN) to investigate how C and N cycling varies among stands dominated by different species, receiving varied atmospheric N inputs, or undergoing species change due to invasive forest pests. In model simulations, nitrate leaching varied widely among stands dominated by 12 tree species abundant in Northeastern U.S. forests, and was generally greater for deciduous (except red oak) than for coniferous species. Simulation of pest invasion impacts showed that if emerald ash borer kills the ash trees in a stand dominated by white ash, and if the ash is replaced by sugar maple, N leaching will increase for decades afterward. However, if the white ash is replaced by red oak, leaching is predicted to decline. If beech bark disease causes a conversion of beech-dominant stand to sugar maple, predicted N leaching increases and ecosystem C pools increase over the long term (~100 y). If hemlock woolly adelgid causes the replacement of hemlock by yellow birch, N leaching is predicted to decline initially, and ecosystem C pools are predicted to increase over the long term. The results indicate that pest-induced effects on forest C and N cycling can be large and variable, and depend on the identity of the declining and replacing tree species. However these effects are predictable based on knowledge of the attributes of the trees, and they should be incorporated into models that predict future ecosystem functioning in the Northeastern U.S.

PESTLENS: AN EARLY-WARNING SYSTEM SUPPORTING U.S. SAFEGUARDING AGAINST EXOTIC PLANT PESTS

Douglas McPhie[1], Roslyn Noar[1], Sherrie Emerine[1], and Stephanie Carmack[1]

[1]North Carolina State University, Center for Integrated Pest Management,
1730 Varsity Drive, Raleigh, NC 27606, USA

ABSTRACT

Safeguarding actions aimed at preventing the introduction and minimizing the impact of exotic plant pests rely on current information about those pests. PestLens, a cooperative effort of the United States Department of Agriculture's Plant Protection and Quarantine (PPQ) and the Center for Integrated Pest Management at North Carolina State University, is PPQ's phytosanitary early-warning system that helps PPQ to stay current on exotic plant pest information. PestLens gathers information from a wide range of sources, including several hundred scientific journals, web sites, e-mail groups, newsletters, and automated internet search queries; summarizes this information and provides relevant background knowledge; and reports the information in a weekly e-mail notification that is available to the broader scientific community. In addition, PestLens provides a secure web-based platform for existing groups within PPQ that are responsible for specific safeguarding functions to make, coordinate, and document safeguarding decisions and actions in response to the information reported in each PestLens article. They then record their decisions and actions in the PestLens web system, ensuring a timely response to new pest information.

DETERMINING THE PHENOLOGY OF SILVER FLY (*LEUCOPIS* SPP.) ON HEMLOCK WOOLLY ADELGID (*ADELGES TSUGAE*) IN THE EASTERN US

Alexandra Neidermeier[1], Kyle Motley[1], Nathan Havill[2], Darrell Ross[3], Albert Mayfield[4], Mark Whitmore[5], Kimberly Wallin[1,6]

[1]University of Vermont, Rubenstein School of Environment and Natural Resources, Burlington, VT
[2]USDA Forest Service, Northern Research Station, Hamden, CT
[3]Oregon State University, Department of Forest Ecosystems and Society, Corvallis, OR
[4]USDA Forest Service, Southern Research Station, Asheville, NC;
[5]Cornell University, Ithaca, NY
[6]USDA Forest Service, Northern Research Station, Burlington, VT

ABSTRACT

Hemlock woolly adelgid, *Adelges tsugae* Annand, has been a harbinger for the disappearance of eastern and Carolina hemlock trees (*Tsuga canadensis* and *T. caroliniana*) from landscapes in eastern North America. Several insect predators show promise for biological control across *A. tsugae*'s native range. These include *Laricobius nigrinus* and two species of silver flies, *Leucopis piniperda* and *Leucopis argenticollis,* from the Pacific Northwest. We are researching *Leucopis* spp. due to their synchronous life cycle with *A. tsugae*, ability to reduce *A. tsugae* population numbers in experimental trials, and success of the genera in other regions of the world for controlling adelgids. This study will focus on the effects of temperature, geography, interactions with *L. nigrinus*, and full tree enclosures on *Leucopis* spp.'s success to reduce *A. tsugae* in eastern US. Initial results indicate altered voltinism between *Leucopis* spp. in the eastern United States versus the Pacific Northwest.

EMERALD ASH BORER (EAB) *AGRILUS PLANIPENNIS* INTEGRATED PEST MANAGEMENT PROGRAM

Robyn Rose,[1] Gregory Aydelotte,[2] and Scott Pfister[3]

[1]USDA Animal and Plant Health, Inspection Service, Riverdale, MD 20737
[2]USDA Animal and Plant Health, Inspection Service, Murfreesboro, TN 37130
[3]USDA Animal and Plant Health, Inspection Service, Buzzards Bay, MA 02532

ABSTRACT

The goal of the APHIS emerald ash borer (EAB), *Agrilus planipennis*, program is to maintain ash as a viable component of the North American landscape. EABis a non-native pest that attach all 16 native ash trees in the United States. It was first found in 2002 in southeastern Michigan and adjacent areas in Windsor, Ontario, Canada. Infestations exist in Washington D.C. and in 32 states. While eradication technologies are not currently available, APHIS continues to work with state and federal partners to identify tools to manage EAB populations including biological control. As the insect continues to be found beyond the quarantine boundaries, and with program appropriations declining, APHIS intends to publish a proposed rule for public comment which would eliminate the domestic regulatory component of the program and redirect available resources toward biological control. APHIS and the Forest Service have found three potential biological control agents from China, all parasitic stingless wasps—*Spathius agrili*, *Tetrastichus planipennisi*, and *Oobius agrili*—that were first released in the US in 2007. A fourth wasp, *Spathius galinae*, was released in 2015. *S. agrili*, *T. planipennisi*, and *S. galinae* parasitize EAB larvae, and *O. agrili* parasitizes EAB eggs. *T. planipennisi* ovipositors can reach EAB larvae in smaller diameter treeswhich should promote regrowth of small ash trees. In 2017 at least one out of the four different parasitoids were released in 26 states and offsprings were successfully recovered in 14 states, which means populations are reproducing and continuing to attack and kill EAB. APHIS wants to eventually release parasitoids in all infested counties. The development and release of biological control agents for EAB provides a way to mitigate and control infestations by focusing directly on the pest and its ability to spread.

THE ROLE OF PHYLOGENETIC DIVERSITY IN FACILITATING PLANT INVASIONS

R. Kirsten Tyler and Kimberly F. Wallin

Rubenstein School of Environment and Natural Resources,
University of Vermont, 81 Carrigan Drive, Burlington, VT

ABSTRACT

The mechanisms that facilitate plant invasions remain unclear at this point. Development of effective preventative policy relies heavily on increased understanding of the factors relating to successful establishment and spread of introduced species. Scientists have proposed many hypotheses to explain invasion success but fundamental questions remain unresolved, such as which species invade and which ecosystems are most susceptible to plant invasion.

Charles Darwin observed that species living in stable, consistent conditions with intense competition for long periods of time would be better suited to new habitats. These observations have been associated with the evolutionary history of a region which can be estimated using the proxy of phylogenetic diversity (PD).

There is some evidence that plants native to regions with diverse evolutionary histories are more likely to become invasive, however previous works were limited to a specific part of the globe. Thus, we still lack global patterns of species invasions that are necessary to understand the factors related to invasion success and potentially prevent future invasions.

The purpose of this study is to expand upon Darwin's observations and explore the role of PD on the probability of introduced species becoming invasive in an introduced region. We will focus on a set of invasive species to evaluate their global invasion success and explain it using the differences in PD between native regions and introduced regions. We expect to see that species with origin regions of greater phylogenetic diversity will be more likely to invade regions of lower phylogenetic diversity.

A global approach to invasion science is powerful in building a general understanding of the factors that influence species invasions. The outcomes of this study have numerous implications for understanding the global dynamics of how and why species invade at multiple scales.

ACOUSTIC SIGNALS OF WOOD-BORING LARVAE AND WAY TO AUTOMATED DETECTION

Alexander Yakubovskiy[1], Hannah Nadel[2], Sindhu Krishnankutty[3], Alexander Sutin[1], Hady Salloum[1], Nikolay Sedunov[1], Timothy Flynn[1]

[1]Stevens Institute of Technology, 1 Castle Point on Hudson, Hoboken, NJ 07030, USA
[2]USDA-APHIS Otis Laboratory, 1398 West Truck Road, Buzzards Bay, MA 02542, USA
[3]Xavier University, 3800 Victory Pkwy., Cincinnati, OH 45207

ABSTRACT

Wood boring larvae produce sound pulses during feeding that can be used for larval detection. A major problem of automated detection of wood-boring larvae is detecting insect-induced sound pulses with noise in the background. To develop an acoustic signature detection algorithm, numerous acoustic signals made by the larvae of *Anoplophora glabripennis* (Asian Longhorned Beetle) and *Agrilus planipennis* (Emerald Ash Borer) were collected in a quarantine facility at the USDA-APHIS PPQ Otis laboratory. We also recorded and analyzed typical background noise pulses, namely, speech, knocking and tapping made by humans, and sounds of electronic equipment. In the conducted analyses, we considered features of both sound pulses of larvae and typical noise pulses. The extracted and evaluated features of those sound pulses were based on estimation of the duration, spectrum and spectrogram of the signal, and spectrum and spectrogram of the signal envelope (estimated via Hilbert transform). Some noise pulses (knocking and tapping) are longer than the larval bite sounds, while some (electronic beeps) are similar in duration. Speech includes fragments (vowels) which are much longer than larval bite sounds, but also very short fragments inside the vowels (high-pitched harmonics). Spectral content of some non-insect sounds differs from the larval feeding sounds. The envelope spectra appeared to be an informative feature. These features were integrated into an automatic infestation-detection algorithm based on the multi-feature classification. The current version of an automatic detector demonstrated a 0.9 probability of correct detection, with low false alarms in difficult scenarios with the number of non-insect sounds similar to the number of insect sounds. This work has been funded by the Department of Homeland Security Science and Technology Directorate.

THE HIDDEN INSECT FAUNA OF STREET TREES IN WASHINGTON, DC

Kasey M. Yturralde[1], Richard M. Turcotte[2], Marc DiGirolomo[3], and Earl Eutlser[1]

[1]Urban Forestry Division, District Department of Transportation, 55 M Street, SE, Washington, DC 20003
[2]USDA Forest Service, Northeastern Area, Forest Health Protection, 180 Canfield St., Morgantown, WV 26505
[3]USDA Forest Service, Northeastern Area, Forest Health Protection,271 Mast Road Durham, NH 03824

ABSTRACT

Urban forests are particularly vulnerable to introductions of exotic insect pests due to high levels of commerce and human movement in and out of cities. Early detection of exotic wood-boring insects is challenging due to their cryptic lifestyles where the majority of their life cycle occurs within hosts. Having programs in place in urban forest ecosystems that enable early detection of exotic insect pests is critical to preventing their establishment, spread, and subsequent damage to urban forest resources. To that end, Urban Forestry Division (UFD) of the District of Columbia, Earth Conservation Corps (ECC), and US Forest Service Northeastern Area collaborated on a cryptic wood-borer detection program designed to take advantage of the plentiful wood samples from urban forest management for use in the detection of exotic insect pests.

Urban Forestry Division maintains the health of District street trees, which includes tree removal and regular pruning of dead wood. Wood samples were collected from declining street trees throughout the District and species were chosen according to their representation in the street tree population. Wood samples were collected from an individual tree for each rearing tube and stored at room temperature with exposure to sunlight at ECC's Matthew Henson Earth Conservation Center between 2014 and 2016. Rearing tubes were checked weekly with assistance from ECC Leaders.

Thirty-six species of wood-boring beetles were identified from samples that included *Acer rubrum*, *Ulmus americana*, *Prunus* spp., *Quercus* spp., and *Fraxinus* spp. Eight species of bark and ambrosia beetles (Scolytinae), seven species of Cerambycid beetles, and one Buprestid species were identified. This sampling method revealed the presence of three Scolytinae species not previously detected by the USFS Early Detection Rapid Response Program conducted in 2016. Two such species, *Pseudopityophthorus pruinosus* (Eichoff) and *P. pubescens* (Blackman) were collected from *Q. palustris* and *Q. rubra*, respectively, while *Hylesinus californicus* (Swaine) was collected from the *Fraxinus* sample. Collections from *Q. palustris* also revealed the presence of a Staphylinid beetle, *Eudectus crassicornis* (LeConte), which previously had only been reported in LA, GA, and FL. This detection method may prove useful in other urban areas as it is relatively inexpensive, can easily be integrated into urban forest management, and complements traditional semiochemical-based trapping methods.

ATTENDEES

Name	Affiliation	Email address
Kate Aitkenead	USDA APHIS PPQ	kate.r.aitkenhead@usda.gov
Jeremy Allison	Great Lakes Forestry Center	jeremy.allison@canada.ca
Jeremy Anderson	University of CA Berkeley	
Ellen Aparicio	USDA ARS	Ellen.Aparicio@ARS.USDA.gov
Tom Baker	Penn State University	tcb10@psu.edu
Phillip Baldauf	USDA APHIS PPQ ALB	phillip.m.baldauf@aphis.usda.gov
Yuri Baranchikov	Sukachev Institute of Forest SB RAS	baranchikov yuri@yahoo.com
Lawrence Barringer	PA Dept. of Agriculture	lbarringer@pa.gov
Charles Bartlett	Univeristy of Delaware	bartlett@udel.edu
Timothy Barwise	Massachusetts Dept. of Conservation & Recreation	Timothy.Barwise@MassMail.MA.US
Tonya Bittner	Cornell University	tdb68@cornell.edu
Gwylim Blackburn	Canadian Forest Service	gwylimseatonblackburn@canada.ca
Joyce Bolton	USDA ARS	joyce.bolton@ars.usda.gov
Pierluigi Bonello	Ohio State University	bonello.2@osu.edu
Hannah Broadley	University of MA Amherst	hbroadley@cns.umass.edu
Carrie Brown-Lima	NY Invasive Species Research Institute, Cornell University	cjb37@cornell.edu
Russ Bulluck	USDA APHIS	russ.bulluck@aphis.usda.gov
John Burch	USDA APHIS PPQ	John.M.Burch@aphis.usda.gov
Faith Campbell	Center for Invasive Species Prevention	phytodoer@aol.com
Christa Carignan	University of MD Extension/ Home & Garden Information Ctr	christa@umd.edu
Kristen Carrington	WV Dept. of Agriculture	kcarrington@wvda.us
Paul Castrovillo		
Paul Chaloux	USDA APHIS	paul.chaloux@aphis.usda.gov
Edward Chen	University of FL	
Ruixi Chen	SUNY	crx0609@sina.com
David Clement	University of MD Extension/ Home & Garden Information Ctr	clement@umd.edu
Anna Conrad	OH State University	conrad.245@osu.edu

Name	Affiliation	Email address
Robert Cooke		
Rick Cooksey	USDA Forest Service	rcooksey@fs.fed.us
Sharon Coons	PA Bureau of Forestry	scoons@pa.gov
Miriam Cooperband	USDA APHIS	mirian.f.cooperband@aphis.usda.gov
Allard Cosse	USDA APHIS	allard.cosse@aphis.usda.gov
Stephen Covell	USDA Forest Service	scovell@fs.fed.us
Ryan Crandall	University of MA	rscrandall91@gmail.com
Jill Dalton	Canadian Food Inspection Agency	jill.dalton@inspection.gc.ca
Ka Daradom		
Eric Day	VA tech	ericday@vt.edu
Kimberly Dean	USDA APHIS PPQ	Kimberly.Dean@aphis.usda.gov
Nathan Derstine	USDA APHIS	nathan.derstine@aphis.usda.gov
Heather Disque	MDA, Forest Pest Management	heather.disque@maryland.gov
Andrea Diss-Torrance	WI DNR	andrea.disstorrance@wisconsin.gov
Denise Dodd	VA Tech Entomology	drdodd@vt.edu
Kellie Dodds	Mauget	kdodds@jjmauget.com
Tyler Draeden		
Jian Duan	USDA APHIS BIIRU	jonathan.schmude@ars.usda.gov
Tom Eager	USDA Forest Service	teager@fs.fed.us
Donald Eggen	PA DCNR Bureau of Forestry	deggen@pa.gov
Avraham Eitam	USDA APHIS PPQ	avraham.eitam@aphis.usda.gov
Carrie Ewing	Ohio State University	ewing.244@buckeyemail.osu.edu
Hajar Faal	SUNY	jhajar.faail@gmail.com
Mark Faulkenberry	PA Bureau of Forestry	
Melissa Fierke	SUNY	mkfierke@esf.edu
Kelby Fite	Bartlett Tree Research	kfite@bartlett.com
Robbie Flowers	USDA Forest Service FHP	robbieflowers@fs.fed.us
Matthew Ginzel	Purdue University	mginzel@purdue.edu
Marina Golivets	University of Vermont	mgolivet@uvm.edu

Name	Affiliation	Email address
Demian Gomez	University of Florida	demiangomez@ufl.edu
Ken Gooch	Massachusetts Dept. of Conservation & Recreation	ken.gooch@state.ma.us
Julie Gould	USDA APHIS	juli.r.gould@aphis.usda.gov
Jerome Grant	University of Tennessee	jgrant@utk.edu
Rachel Griesmer-Zakhar	Farifax Co. Forest Pest Mgt.	rachel.griesmer-zakhar@fairfax-county.gov
Donald Grosman	Arborjet, Inc.	dgrosman@arborjet.com
Dawn Gundersen-Rindal	USDA, ARS	Dawn.Gundersen-Rindal@ARS.USDA.GOV
Laurel Haavki	USDA Forest Service	jhaavik@fs.fed.us
Anne Hairston-Strang	MD DNR Forest Service	anne.hairston-strang@maryland.gov
Larry Hanks	University of Illinois	hanks@life.illinois.edu
Jessica Hartshorn	Minnesota DNR	jessica.hatshorn@state.mn.us
Nathan Havill	USDA Forest Service, NRS	nphavill@fs.fed.us
Deborah Hayes	MD Dept. of Agriculture	deborah.hayes@maryland.gov
Javier Herida	Synergy Semiochemicals Corp.	synergy@semiochemical.com
Daniel Herms	Davey Tree Expert Co.	dan.herms@gmail.com
Richard Hoebeke	University of Georgia	rhoebeke@uga.edu
Kim Hoelmer	USDA ARS	ki.hoelmer@ars.usda.gov
Jingsheng Hu	USDA ARS	jing.hu@ars.usda.gove
Kamela Jayanthi	Penn State University	jaiinsect@gmail.com
Robert Jetton	Camcore, NC State University	rmjetton@ncsu.edu
Lea Johnson	University of Maryland	leaj@umd.edu
Sarah Johnson	PA Bureau of Forestry	sarajohnso@pa.gov
Michael Jones	SUNY ESF	mijone01@syr.edu
Sharon Jones	USDA ARS	sharon.jones@as.usda.gov
Amanda Kaye	USDA APHIS PPQ	Amanda.C.Kaye@aphis.usda.gov
Jonathan Kays	University of Maryland Extension	jkays@umd.edu
Melody Keena	USDA Forest Service-NRS	mkeena@fs.fed.us
Nicole Keleher	Massachusetts Forest Health	nicole.keleher@state.ma.us

Name	Affiliation	Email address
Ashley Kennedy	University of Delaware	kennedyA@udel.edu
Colleen Kenny	Maryland DNR Forest Service	colleen.kenny@maryland.gov
Ian Kinahan	University of Rhode Island	ikinahan@uri.edu
Erica Kistner	USDA-ARS	erica.kistner@ars.usda.gov
Colleen Kitzmiller	USDA - APHIS	colleen,Kitzmiller@aphis.usda.gov
Kier Klepzing	Joseph W. Jones Ecological Research Center	kier.klepzig@jonesctr.org
Kathleen Knight	USDA Forest Service	ksknight@fs.fed.us
Frank Koch	USDA Forest Service	fhkoch@fs.fed.us
Jennifer Koch	USDA Forest Service	jkoch@fs.fed.us
Amy Korman	Penn State Extension	amk6396@psu.edu
Carol Kreger	USDA APHIS	ckherbalist@yahoo.com
Sindhu Krishnankutty	Xavier University/APHIS PPQ S&T	sindhu.Krishnankutty1@gmail.com
Flora Krivak-Tetley	Dartmouth College	fkt.gr@darmouth.edu
Walter Kuentzel	University of Vermont	walter.kuentzel@uvm.edu
Craig Kuhn	Maryland Dept. of Agriculture, Forest Pest Management	craig.kuhn@maryland.gov
Paul Kurtz	NJ Dept. of Agriculture	paul.kurtz@ag.nj.gov
Zachary Ladin	University of Delaware	zach@udel.edu
Judy Laplante	Canadian Food Inspection Agency	julie.laplante@inspection.gc.ca
Kristi Larson	University of MA - Amherst	jonathan.schmude@ars.usda.gov
Stephen Lavallee	USDA APHIS PPQ	stephen.g.lavallee@aphis.usda.gov
Elizabeth Lebow	US Forest Service	etlebow@fs.fed.us
Phil Lewis	USDA APHIS	phillip.a.lewis@aphis.usda.gov
Houping Liu	PA Bureau of Forestry	hliu@pa.gov
Chis Looney	WA state Dept. of Agriculture	clooney@agr.wa.gov
Vanessa Lopez	USDA Forest Service - FHP	vanessalopez@fs.fed.us
Gary Lovett	Cary Institute of Ecosystem Studies	lovettg@caryinstitute.org
Douglas Luster	USDA ARS	doug.luster@ars.usda.gov
Tom Macy	Ohio Dept. Natural Resources	thomas.macy@dnr.state.oh.us

Name	Affiliation	Email address
Mary Kay Malinoski	University of MD Extension	mkmal@umd.edu
Tim Marasco	PA Bureau of Forestry	
James Marra	WA State Dept. of Agriculture	jmarra@agr.wa.gov
Anne Marsh	USDA Forest Service	annemarsh@fs.fed.us
Phil Marshall	Indiana Dept. Natural Resources	pmarshall@dnr.in.gov
Kirk Martin	USDA APHIS	kirk.w.martin@aphis.usda.gov
Charles Mason	Penn State University	cjm360@psu.edu
Tiffany Mauro	USDA APHIS PPQ	Tiffany.R.Mauro@aphis.usda.gov
Mark Mayer	NJ Dept. of Agriculture	mark.mayer@ag.nj.gov
Tom McAvoy	VA Tech Dept. of Entomology	tmcavoy@vt.edu
Rachel McCarthy	Cornell University	rachel.mccarthy@cornell.edu
Beth McClelland	VA Dept. of Agriculture	beth.mcclelland@vdacs.virginia.gov
Tina McIntyre	VA Dept. of Agriculture	tina.mcintyre@vdacs.virginia.gov
Michael McManus	USDA Forest Service	mlmcmanus@fs.fed.us
Zhaojun Meng		meng217721@gmail.com
Jocely Millar	University of CA	jocelyn.millar@ucr.edu
Bruce Moltzan	USDA Forest Service	bmoltzan@fs.fed.us
Karl Morris	SMB Live Science	karl.morris@sbm-company.com
Heather Moylett	USDA APHIS	heather.moylett@aphis.usda.gov
Hannah Nadel	USDA APHIS PPQ	hannah.nadel@aphis.usda.gov
Alexandra Neidermeier	University of VT	aneiderm@uvm.edu
George Nelson	USDA APHIS PPQ	George.J.Nelson@aphis.usda.gov
Rachel Nyce	USDA APHIS PPQ	Rachel.s.nyce@aphis.usda.gov
William Oldland	USDA Forest Service	woldland@fs.fed.us
Andrei Orlinski	EPPO	orlinski@eppo.int
Subba REddy Palli	University of KY	jonathan.schmude@ars.usda.gov
Micahel Parisio	MN Dept of Natural Resources	michael.parisio@state.mn.us
Pat Parkman	Univeristy of Tennessee	jparkman@utk.edu
Gregory Parra	USDA APHIS	greg.parra@aphis.usda.gov

Name	Affiliation	Email address
Gina Peters	PA Dept. Conservation & Natural Resources	gipeters@pa.gov
Robert Pfannenstiel	USDA APHIS PPQ	bob.pfannenstiel@aphis.usda.gov
Therese Poland	USDA Forest Service	tpoland@fs.fed.us
Tim Price	PA Bureau of Forestry	tprice@pa.gov
Bob Rabaglia	USDA Forest Service	brabaglia@fs.fed.us
Kenneth Raffa	University of Wisconsin	kraffa@wisc.edu
Ann Ray	Xavier University	annie.m.ray@gmail.com
Lynne Rieske-Kinney	University of Kentucky	Lrieske@uky.edu
John Riggins	Mississippi State University	silvacare.llc@gmail.com
Chad Rigsby	University of Rhode Island	rigsby@uri.edu
Jim Rollins	Mauget	jrollins@jjmauget.com
Alain Roques	INRA	
Jill Rose	WV Dept. of Agriculture	jrose@wvda.us
Krista Ryall	Natural Resources Canada	
Gerardo Sanchez	Ministry of Agriculture Spain	gsanchez@mapama.es
Frank Sapio	USDA Forest Service FHAAST	fsapio@fs.fed.us
Linda Saunders	USDA ARS BIIRU	Linda.Saunders@ARS.USDA.GOV
Andrea Savage	USDA APHIS PPQ	andrea.b.savage@aphis.usda.gov
Jonathan Schmude	USDA-ARS-BIIRU	jonathan.schmude@ars.usda.gov
Diana Sherman	USDA-ARS-FDWSRU	diana.sherman@ars.usda.gov
Nina Shishkoff	FDWSRU ARS USDA	nina.shishkoff@ars.usda.gov
Greg Shriver	University of Delaware	
Aaron Shurtleff	MD Dept. of Agriculture	aaron.shurtleff@maryland.gov
Lincoln Smith	USDA ARS EBCL	link.smith@ars.usda.gov
Erica Smyers	Penn State University	ecs5026@psu.edu
Michael Sparks	USDA ARS	Michael.Sparks@ars.usda.gov
Sven-Erik Spichiger	PA Dept. of Agriculture	ssiichiger@pa.gov
Robin Spitko	Mauget	rspitko@jjmauget.com
Owen Stelzig	University of Maryland	

Name	Affiliation	Email address
Chris Stelzig	Entomological Society of America	cstelzig@entsoc.org
Fred Stephen	University of Arkansas	
Catherine Stragar	Maryland Dept. of Agriculture	stragarc@gmail.com
Jill Swearingen		jilswearingen@gmail.com
Jon Sweeney	Canadian Forest Service, Natural Resources Canada	jon.sweeney@canada.ca
Levente Szocs	NARIC FRI	szocs!@erti.hu
Daria Tatman	USDA ARS BIIRU	Daria.Tatman@ARS>USDA.GOV
Colleen Teerling	Maine Forest Service	colleen.teerling@maine.gov
Elizabeth Tweksbury	University of Rhode Island	lisat@uri.edu
Biff Thompson	Maryland Dept. of Agriculture	Biff.Thompson@maryland.gov
Ashley Toland		
Timothy Tomon	PA Bureau of Forestry	ttomon@pa.gov
Sarah Travalio	NY State Office of Parks & Recreation & Historic Preservation	sarah.travalio@parks.ny.gov
Matthew Travis	USDA APHIS PPQ	matthew.a.travis@aphis.usda.gov
Robert Trumbule	Maryland Dept. of Agriculture	robert.trumbule@maryland.gov
R. Kirsten Tyler	University of Vermont	rkirsten.tyler@uvm.edu
Ryan Vazquez	APHIS PPQ	ryan.vazquez@aphis.usda.gov
Kimberly Wallin	University of Vermont	kimberly.wallin@uvm.edu
Kristopher Watson	UT Dept. of Agriculture & Food	pnelson@utah.gov
Craig Webb	USDA APHIS PPQ	craig.a.webb@aphis.usda.gov
Ronald Weeks	USDA APHIS	ronald.d.weeks@aphis.usda.gov
Mafalda Weldon	USDA APHIS	mafalda.weldon@aphis.usda.gov
Mark Whitmore	Cornell University	mark.whitmore@cornell.edu
Timothy Widmer	USDA ARS FDWSRU	tim.widmer@ars.usda.gov
Richard Wilson	Ontario Ministry of Natural Resources and Forestry	richard.wilson@ontario.ca
Jacob Wittman	University of Minnesota	wittm094@umn.edu
ian Xu	SUNY	txu01@syr.edu

Name	Affiliation	Email address
Rosa Yoo	New Jersey State Forestry	Rosa.Yoo@dep.nj.gov
Kasey Yturralde	DDOT	kasey.yturralde@dc.gov
Lewis Ziska	USDA ARS	lziska@ars.usda.gov