2021 North American Forest Insect Work Conference

Shaping Forests: Action in a Changing World

May 26-28, 2021

2021 North American Forest Insect Work Conference

Organizers

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Sponsorship:

Kevin Chase - Bartlett Tree Experts, Charlotte, NC

Posters:

Rich Hofstetter - Northern Arizona University

Tuesday, May 25

2:00 **Forest Health Task Force**

4:00 **SFIWC Business Meeting**

Wednesday, May 26

8:00 **Welcome Remarks**

8:15 **Plenary Session 1**

A. *Shannon Lotthammer*, Assistant Forestry Commissioner, Minnesota Department of Natural Resources

B. *EAB impacts: what does the loss of ash mean for wildlife? - Alexis Grinde*, Wildlife Ecologist, Natural Resources Research Institute, University of Minnesota - Duluth

C. *Connections - Eli Sagor,* Cloquet Forest, University of Minnesota

9:45 **Break**

10:30 **Student Paper Competition - 1 - Jess Hartshorn**

A. *Following Celtis laevigata Willd. mortality and the commonly associated insects in the southeastern US - Emilee M. Poole, Michael D. Ulyshen, and Scott Horn*. *Celtis laevigata* Willd. (sugarberry) is a native tree commonly found along floodplains and rivers in the southeastern US. This species has been declining in the region since 2008, when reports were first made around Columbia, SC. Consistent symptoms are small yellow leaves, branch dieback, and premature leaf fall. A buprestid species, Agrilus macer LeConte, and a nonnative aphid, Shivaphis celti Das, are commonly associated with dying sugarberry. Efforts have been made to map the geographic range of areas with high mortality and investigate the associated insects to determine whether the species are causal agents. Although symptomatic trees are present throughout South Carolina and Georgia, our findings indicate A. macer is present in the southern United States, while most records centralize around Texas and Louisiana. This beetle is an opportunistic secondary pest on sugarberry but does not transmit harmful fungal pathogens. Future efforts to identify other contributing factors are underway as understudied, S. celti, is currently under investigation to determine its role in the mortality episode.

B. *Disease-induced changes in bark structure and pathogen interactions impact host-insect-pathogen dynamics in the beech bark disease system - Ken Windstein, Eric Morrison, Jeff Garnas.* Beech bark disease (BBD) arises from the interaction between American beech, an exotic scale insect, Cryptococcus fagisuga, and two species of Neonectria fungi. While the scale insect is a key facilitator of disease along its advancing front, the strength and nature of dynamic feedbacks between insects and fungi – particularly in the context of a variable tree response – are poorly understood in the BBD aftermath range. BBD development and severity is highly variable across time and space. We hypothesize that feedbacks between disease agents, principally indirect antagonistic effects mediated through BBD-induced changes in bark structure, are largely responsible for this variation, and so are important for understanding and managing BBD. We employed a field experiment implemented in the late summer and early fall of 2019 comprising an

artificial challenge assay experiment applying two egg densities of C. fagisuga on 80 American beech, stratified by bark response type. On half of these trees, we inoculated Neonectria faginata and N. ditissima (and their combination) in 6mm agar plugs, also across scale insect densities and bark types. The results of both field experiments were then assessed in late July 2020 to quantify scale insect establishment and fungal lesion growth. Preliminary results indicate that the area of necrosis caused by fungal inoculation growth is independent of initial scale insect density. Host bark structure, however, strongly affects fungal growth and scale insect colonization rate. Furthermore, lesion growth in the co-inoculation treatment was significantly reduced suggesting that these fungi may act as antagonists in the BBD system.

C. *Translocation and persistence of dsRNA inducing gene silencing in southern pine beetle: prospects for tree protection - Zachary A. Bragg and Lynne K. Rieske.* Exogenously applied double-stranded RNA (dsRNA) can induce potent host specific gene knockdown and mortality in insects. RNA-interference (RNAi) has proven effective in silencing genes and causing mortality in forest pests responsible for catastrophic losses, such as the southern pine beetle (Dendroctonus frontalis) and its conspecific mountain pine beetle (D. ponderosae). Yet deployment of gene silencing technologies for pest suppression in forest systems is lagging. Multiple barriers stand between laboratory screening and deployment; one such barrier is development of an efficient delivery technique. Delivery through host plants could serve as an effective mechanism for introducing pest-specific dsRNA for tree protection, but an understanding of exogenous dsRNA movement and retention through plant tissues is essential. To evaluate the persistence and movement of dsRNA within loblolly pine (Pinus taeda), seedlings were exposed to dsRNAs as a root soak and destructively sampled after exposure. Seedlings were divided into: roots, stems, needles, twigs with needles, and apical meristems, and total RNA was extracted from each tissue type, from which both semiquantitative (gel electrophoresis) and quantitative (melt curve and Sanger sequencing) analysis revealed the presence of the exogenously applied target dsRNAs. These results confirmed the presence of exogenous dsRNAs in each tissue type after 24h, 72h, 120h, and 168h of dsRNA exposure. These findings suggest that application of exogenous dsRNAs via root drench could provide single-tree protection against the southern pine beetle. Current efforts are focusing on evaluating insecticidal activity and determining the dose response.

D. *Longleaf pine savanna after wind disturbance: management practices and lower stem and root feeding beetles and their associated blue stain fungi - Crystal Bishop, Kamal J. K. Gandhi, Kier D. Klepzig, and Caterina Villari.* Hurricane Michael impacted Southwest Georgia in 2018, causing major damage to forests in its path. Following initial wind damage, trees are at an elevated risk of colonization by lower stem and root feeding beetles and their associated blue-stain fungi, which can further decrease their health as well as accrue economic depreciation. To better understand the response of these insect-fungal complexes to extreme wind events, we established a project in a 12,000 Ha longleaf pine ecosystem that had been damaged by Michael. Across this area are 15 plots with three different management treatments: wind disturbed, wind disturbed

followed by prescribed burning and salvage logging, and wind disturbed followed by prescribed burning but no salvage logging. We will use data collected from these plots to answer three research questions. First, what effects do current management treatments have on lower stem and root feeding beetle abundance? By using Lindgren funnel traps baited with attractants, we are determining beetle abundance within and among plots for a two-year collection period. Second, what fungi are commonly associated with these insects in the longleaf savanna? This question has been answered by live capturing beetles and culturing associated fungi on media selective for blue-stain fungi. Lastly, what fungi are associated with the roots of damaged pine trees within this system? To determine this, root samples from symptomatic and healthy pines were cultured to identify associated blue-stain fungi. With this project, we aim to better understand how these secondary agents affect longleaf pine forests after extreme wind damage.

E. *SPB-specific gene silencing has no effect on nontarget insects - Hannah Hollowell and Lynne K. Rieske.* The southern pine beetle (SPB) (*Dendroctonus frontalis*) has been the most destructive forest pest of the southeastern US for decades. Fortunately, RNA interference (RNAi), an emerging technology in pest suppression, shows promise for its management. RNAi is a cellular antiviral pathway triggered by exogenous double-stranded RNA (dsRNA), inhibiting the expression of targeted genes and preventing key cellular functions, thereby inducing mortality. By carefully designing dsRNAs specific to essential genes in SPB, we can trigger the RNAi pathway, silence target genes, and cause significant SPB mortality. But demonstrating the specificity of this approach is essential to its deployment. Through feeding bioassays assessing SPB-specific dsRNAs on nontarget insects, I evaluated potential lethal and sublethal effects on pine-associated insects. Nontarget insects were fed 10 ug of SPB-specific dsRNAs daily and evaluated. There was no effect on survival of the SPB-specific dsRNAs on the nontarget Ips calligraphus ($p>0.05$), and no sublethal effects on the pine defoliator, *Neodiprion lecontei*, when evaluated for larval weight gain or adult emergence ($p>0.05$). For the predatory *Coleomegilla maculata*, no effects were found on larval weight gain or fecundity ($p>0.05$). Food consumption of a detritivore, Reticulitermes flavipes, was also not affected ($p>0.05$). I plan to also conduct gene expression and bioinformatic analyses to gain a full understanding of potential nontarget effects of this innovative approach to SPB management. These findings are crucial to helping ensure the safety of deploying SPB-specific dsRNAs in forests and provide hope for the addition of gene silencing as a tool in IPM.

F. *Oystershell scale: the awakening of a sleeper species in the southwestern US - Connor D. Crouch, Amanda M. Grady, Nicholas P. Wilhelmi, Richard W. Hofstetter, Daniel E. DePinte, and Kristen M. Waring.* Oystershell scale (*Lepidosaphes ulmi*; OSS) is an emerging invasive insect that poses a serious threat to conservation of quaking aspen (*Populus tremuloides*) in the southwestern US. Aspen is considered a keystone species in the conifer-dominated West, where it provides critical habitat for a wide range of species and makes a disproportionately large contribution to biodiversity. Although

OSS's origin is uncertain, the insect is believed to have arrived in North America with European settlers and was reported as a pest of apple trees in the 1700s. OSS is now present throughout much of the US and Canada and is a common pest of many deciduous tree species, including aspen, in urban settings. Historically, OSS has not been a concern in natural forests; however, the insect has recently migrated into natural aspen forests in Arizona, where outbreaks are causing aspen dieback and mortality. We hypothesize that OSS is a sleeper species that has recently awoken and entered the spread phase of invasion. In this presentation, we discuss our concerns about OSS's hypothesized role as a sleeper species, potential interactions between OSS and climate change, and OSS's polyphagous nature, all of which contribute to its potential as a high-impact invasive insect. We also present preliminary results from our observational studies of OSS, including presence and severity of the insect, mortality rates of aspen in infested stands, and the rate of OSS intensification. We conclude by providing recommendations for future work and highlighting the OSS severity rating system that we have developed for monitoring.

G. *Impacts of a catastrophic hurricane on subcortical beetle populations in southern pine stands - Seth Spinner, Brittany F. Barnes, Elizabeth McCarty, and Kamal J.K. Gandhi.* Catastrophic wind disturbance events, such as hurricanes, tornadoes, and derechos, are major agents of ecosystem disruption in southeastern U.S. forests. On October 10th, 2018, Hurricane Michael made landfall, causing catastrophic damage to forests in Georgia and Florida. In these two states alone, this storm damaged approximately two million hectares of forests, resulting in nearly $2 billion in economic losses. Bark beetles (Coleoptera: Curculionidae: Scolytinae) frequently invade wind disturbed forests due to the influx of resources, such as weakened or recently killed trees. Similar patterns may occur after Hurricane Michael, leading to further economic damages. To date, there has been little to no research into the responses of bark beetles to catastrophic wind disturbance in southern pine forests. Our research objectives are to determine if bark beetle populations will change in number over time and if these changes will differ across various damage levels in southern pine forests. Beetle sampling was conducted during the summers of 2019 and 2020 using baited traps in fifteen loblolly pine stands that experienced 20-70% basal area loss. Preliminary results from June 2019 indicate that bark and ambrosia beetles were the most abundant in stands that experienced 20% damage and least abundant in sites that experienced >20-40 % loss. This may indicate greater diversity and availability of host resources in the least damaged pine sites. Results from this study will provide foresters with critical information regarding the timing of salvage logging in variously damaged sites to minimize economic losses from subsequent bark beetle infestations.

11:30 **Lunch**

Founders Memorial Presentation - *Appreciating our careers as brief snapshots of forests, insects, and human values, but also an opportunity to help shape their shared trajectory - Ken Raffa*

12:30 **Student Paper Competition - 2 - Deepa Pureswaran**

A. *Phytochemical response of loblolly pine (Pinus taeda) to southern pine beetle (Dendroctonus frontalis) symbiotic fungi - John de Soto, Kamal Gandhi, Kier Klepzig, and Caterina Villari.* Southern pine beetle (*Dendroctonus frontalis*) (SPB) is one of the most significant pests of pines in the southeast, capable of causing major losses. SPB is closely associated with three fungi; two mutualists, *Ceratocystiopsis ranaculosus* and *Entomocorticium* sp. A, serve as a nutritional supplement for SPB larvae, and one antagonist, Ophiostoma minus, competes for resources with SPB larvae and the mutualistic fungi. Prior research shows antagonism as a potential mechanism by which O. minus outcompetes the mutualists, but other mechanisms are possible. We hypothesize that the host defense response to O. minus, a moderately virulent plant pathogen, negatively impacts the mutualists more than O. minus due to the mutualists not being plant pathogens and therefore not having evolved abilities to withstand tree defenses. We are seeking to: (i) determine which terpenoid and phenolic defense compounds are induced in loblolly after inoculation of the three associated fungi, and (ii) test, in vitro, which individual compounds, or combination thereof, have effects on the fungi associated with SPB. We inoculated each of the three fungal species into ten mature trees within a loblolly pine stand at University of Georgia's Whitehall Forest (Athens, Georgia). We measured lesions three weeks after inoculation and collected phloem samples which we are analyzing for the presence and quantity of defense metabolites. We anticipate that these results will lead to insights into the complex tree-insect-fungus interactions within the SPB system.

B. *Identifying attractive semiochemicals for Anisandrus maiche (Stark) - Kelsey Tobin and Matthew Ginzel. Anisandrus maiche* Stark (Coleoptera: Curculionidae: Scolytinae), an exotic ambrosia beetle native to Asia, has been spreading throughout the eastern United States since 2005. In the current invaded range, its preferred host plants are not well known, however, A. maiche has been found establishing galleries in plantation grown black walnut (Juglans nigra) and nearby forested land in northwestern Indiana. It is difficult to predict the impact A. maiche could have on North American forests. In this study, we conducted field-based trapping experiments in northwestern Indiana to explore the potential of ethanol and conophthorin as semiochemical attractants for A. maiche, as well as verbenone as a repellant. A. maiche capture in ethanol baited traps was significantly higher ($p<0.001$) than any other treatment group. These findings demonstrate bottle-traps baited with ethanol are useful in monitoring for A. maiche, and aid stakeholders in establishing effective management programs. Furthermore, it appears that conophthorin repelled A. maiche in our study, suggesting that semiochemicals may hold promise for manipulating the behavior of this species using a push-pull strategy to protect high-value plantings of black walnut from attack.

C. *A novel use of protein immunomarking in studying the dispersal of woodboring beetles - Scott Gula, Vanessa M. Lopez, Ann M. Ray, Scott A. Machtley, James R. Hagler, and Matthew D. Ginzel.* Invasive woodboring beetles are among the most destructive pests of natural and managed forests worldwide. The success of eradication efforts and quarantines to limit the spread of incipient populations of these pests is dependent on

understanding their dispersal behavior. Most previous dispersal research involved capturing or rearing beetles en masse, marking them in the laboratory, releasing them in the field, and capturing them again. This process is labor intensive, time consuming, expensive, and human handling during the application of the mark can affect the behavior of the insects. There is a critical need for an affordable, efficient, and non-invasive marking technique to improve research on woodborer dispersal. We tested the efficacy of protein immunomarking for use in understanding the dispersal of woodboring beetles. Specifically, we tested the extent to which a protein mark adheres to the cuticle of emerald ash borers (*Agrilus plannipennis* Fairmaire) (Coleoptera: Buprestidae) as beetles emerge from protein-treated logs. This method has several advantages over traditional techniques including a low cost for both the protein and ELISA used to detect the protein, no need for mass rearing or capture, and the minimization of handling and disturbance to the beetles. In addition, we tested the extent to which proteins transfer from marked to unmarked beetles as well as the efficacy of various trapping methods. This novel use of protein immunomarking has potential as an effective and reliable marker for use in mark-capture and dispersal studies with buprestids, as well as other woodborers such as cerambycids and scolytids.

D. *Evaluating RNAi-mediated gene silencing for suppression of Ips calligraphus - Mary Wallace and Lynne K. Rieske.* RNA interference (RNAi), or gene silencing, is a naturally occurring cellular antiviral response. By manipulating the pathway through the introduction of carefully designed exogeneous double stranded RNA (dsRNA), we can trigger the pathway, silence essential genes, and induce mortality. Inducing mortality in a target insect with minimal off-target effects makes this technology advantageous in integrated pest management programs. Thus, RNAi is emerging as a promising pest management strategy, and is already being implemented in agriculture. Susceptibility to RNAi in other Scolytines makes it a promising management tool for Ips calligraphus, the six-spined ips. Ips calligraphus is a native North American bark beetle that, due to increasingly frequent and severe disturbance events, has become progressively more eruptive, with economic and ecological consequences in both its native and introduced ranges. To evaluate, adult beetles were fed dsRNA designed to silence specific essential genes, evaluated for mortality, and will then be evaluated for gene expression. We found evidence for activation of the RNAi pathway in the mortality assays, and are currently evaluating gene expression via qPCR. We plan to screen additional target genes for RNAi efficacy. This is the first study to investigate the feasibility of gene silencing via exogenous dsRNA in any Ips species, and is an important step toward developing this technology as an additional tool for IPM.

E. *Ecological role and forest regeneration impacts of the eastern spruce budworm in Minnesota and Isle Royale - Jessica M. Rootes and Brian H. Aukema.* Isle Royale National Park, located off the northeastern shore of Minnesota, consists of more than 450 islands that comprise approximately 130,000 acres of protected wilderness. This unique biosphere reserve is a haven for ungulates such as moose whose numbers have proliferated, resulting in undesirable levels of vegetation defoliation due to

overbrowsing. This defoliation is further exacerbated by the native eastern spruce budworm (Choristoneura fumiferana). Though an ongoing 50+ year study analyzes moose and wolf predator-prey relationships, more studies regarding lower trophic levels and their impacts on the island's Balsam-fir forests are needed. These studies will help to fill knowledge gaps regarding the ecological impact of efforts to relocate wolves to the island. Despite the eastern spruce budworm's potential large-scale impact and increasing populations, currently at a 20-year peak, this species has not yet been studied on Isle Royale. Outbreaks occur approximately every 35 years, last 10 years on average, and can result in 70% balsam fir and 40% white spruce mortality. My dissertation research will study the eastern spruce budworm's ecological role and effects on forest regeneration to evaluate restoration goals on Isle Royale. The project will consist of comparisons of population dynamics and related factors, such as weather conditions, parasitoids, and dispersal, between mainland Minnesota and Isle Royale.

F. *Predictors of mountain pine beetle dispersal in western Montana - August C. Kramer & Brian H. Aukema.* Mountain pine beetle is an irruptive forest insect and disturbance agent in pine forests of western North America, infesting almost all western pine species. Past outbreaks have killed tens of millions of acres of mature pines across the western United States. In spite of abundant work on the insect's ecology and tree killing capability, little is known about dispersal dynamics that are important to understand given potential threats of range expansion to pine forests of eastern North America. We exploited a recent outbreak from 2000 to 2015 in Montana that resulted in approximately six million acres of pine mortality to investigate how many fewer mountain pine beetles would be captured at distances farther away from active infestations. In the summer of 2020, we placed twenty baited Lindgren funnel traps along a 180-mile transect through western Montana from areas with established populations of mountain pine beetle to areas with no visible active infestations. Weekly collections were made from 4 August to 26 August. High numbers were captured at sites with no apparent proximate active infestations, and numbers varied weekly. While source populations cannot be confirmed, capture patterns away from pine forests can provide some insight into dispersal pressure given aerial and ground survey data.

G. *Forecasting overwintering mortality of Spathius galinae in North America - Jacob T. Wittman, Brian H. Aukema, Jian J. Duan, and Robert C. Venette.* Matching classical biological control agents to appropriate environments for introduction is necessary to optimize their release and performance. We evaluated the cold hardiness of the parasitoid Spathius galinae Belokobylskij & Strazanac, a classical biological control agent of emerald ash borer (Agrilus planipennis Fairmaire) in North America. We measured supercooling points and lower lethal (i.e., mortality) temperatures of cold acclimated, late-instar S. galinae larvae in controlled cooling assays in the laboratory. The average supercooling point of S. galinae larvae was -25°C. Most S. galinae died after reaching their supercooling point, although several larvae initiated freezing but later successfully eclosed. The presence of larvae that eclose after initiating freezing suggest that some individuals may be partially freeze tolerant. We also monitored development of mature

(cocooned) S. galinae larvae in ash segments above and beneath the snow in three locations in Minnesota in the winter of 2019 – 2020. Larvae that were exposed to -29°C exhibited nearly 100% mortality. We forecast eclosion rates of S. galinae across the range of *Fraxinus* spp. in North America based on minimum winter temperatures using models developed from these data. Our results indicate that a high proportion of S. galinae may survive in areas where minimum winter temperatures reach as low as -28°C. In areas where temperatures reach lower than -28°C, S. galinae will likely exhibit extensive mortality although a small portion of the population may survive and persist.

2:00 **Student Paper Competition - 3 - Jeff Garnas**

A. *Preference of Geosmithia morbida for low wood moisture content may explain historical outbreaks of thousand cankers disease and predict future fate of Juglans nigra within its Native Range - Geoffrey M. Williams, Matthew D. Ginzel.* Given its influence on emergent threats such as thousand cankers disease (TCD), climate change should be a key consideration in the assessment of risks to resources such as the high-value hardwood, Juglans nigra. TCD is caused by Geosmithia morbida and its vector, Pityophthorus juglandis. The success of mutualisms between fungi and bark beetles is likely to be limited by competition with other fungi that are better adapted to the physicochemical conditions of their substrate. These conditions are in turn subject to climatic variation. In particular, wood moisture content is an important factor in fungal competition, and therefore could help determine environmental suitability for thousand cankers disease. We conducted competition experiments in J. nigra wood that was naturally or artificially colonized by G. morbida and other fungi over a range of equilibrium wood moisture content expected across prevailing U.S. climatic conditions. Geosmithia morbida consistently and successfully outcompeted other fungi at very low (< 5%) equilibrium moisture content. However, Aspergillus spp., known pathogens of bark beetles, outcompeted G. morbida when colonizing low-moisture wood from Indiana. We also fit a logistic regression model to the results of the competition experiments to predict survival of G. morbida across the U.S. based on expected wood moisture content. Expected survival of G. morbida was highest in historical TCD epicenters and partly explained the low incidence and severity of TCD in the eastern U.S. Our results also predict that under future climate scenarios, the area impacted by TCD will expand into the native range of J. nigra.

B. *Evaluating the effects of regional drought and forest management on invasive Sirex noctilio congener, Sirex nigricornis - Kendra E. Wagner, Robert Jetton, Jess Hartshorn, Dimitrios Avtzis, John J. Riggins.* The European Woodwasp (Sirex noctilio Fabricius) was detected in North America in 2004. Thus far in North America, S. noctilio has not caused major tree mortality, despite its ability to cause >70% mortality in poorly managed stands throughout the Southern Hemisphere. Forest management practices (i.e. harvesting, stand density, etc.) significantly reduce *S. noctilio* related mortality, except for during significant drought years. Although not currently classified as invasive in North America, *S. noctilio* exhibits eruptive population dynamics. These populations often remain at low population levels for up to 12 years before reaching outbreak

populations, therefore it should not yet be disregarded as a significant forest pest in North America. The objectives of this study are to determine how drought conditions and basal area interact to influence native woodwasp abundance and to develop forest management recommendations to minimize outbreak potential of their conger Sirex noctilio. A cross-hatched log stack and Lindgren funnel trap was used to sample siricid populations. Treatments included thinned and unthinned pine plantations in drought and non-drought stressed areas in Mississippi, North Carolina and Ontario, Canada. We found that drought-stressed areas presented higher woodwasp capture, but that basal area had no effect. These results may advise forest management as *Sirex noctilio* increases its range to the southeastern US.

C. *Differential effects of fire regime on Ips bark beetles in longleaf pine forests - Haley M.W. Ritger, Steven T. Brantley, Joseph J. O'Brien, Kier D. Klepzig, Clinton T. Moore, Lindsay R. Boring, and Kamal J.K. Gandhi.* Investigations into *Ips* spp. interactions with prescribed fire in the Southeast have been quite limited, and no previous study included species-level analysis of all three species that co-occur in the Gulf Coastal Plain. We assessed the effects of frequent fire, fire exclusion, and fire reintroduction on Ips spp. in mature longleaf pine (*Pinus palustris* Mill.) stands across two sites with different edaphic properties (mesic and xeric) in Newton, GA. We utilized funnel and pitfall traps baited with tree volatiles and beetle pheromones to trap Ips in 2016 and 2017 and measured forest stand characteristics. We employed an information theoretic statistical approach to determine that effects of factors and their interactions on trap catches of Ips spp. varied distinctly by species. While the highest trap catches for all three Ips species were in the fire exclusion treatment at the xeric site, catches of I. grandicollis (Eichhoff) were similar at both site types for the exclusion treatment. For the fire exclusion treatment, *Ips avulsus* (Eichhoff) and *I. calligraphus* (Germar) catches were 2-10 times higher at the xeric site compared to the mesic site. We used multivariate techniques to demonstrate that fire exclusion and site type affected stand conditions. Linear regression showed that I. calligraphus trap catches were positively associated with percent basal area of understory trees and I. avulsus trap catches were negatively correlated with total basal area. Our results suggest that site soil properties and stand conditions may play an important role in how fire regime differentially affects southeastern Ips species.

D. *Community assembly of subcortical beetles and their associates on lightning-struck longleaf pine trees - Benjamin M. Gochnour, Tom Sheehan, Kier D. Klepzig, Kamal J. K. Gandhi.* Cloud-to-ground lightning strikes are a widespread and rapid disturbance that causes tree damage and mortality in southeastern forest ecosystems. Tree damage by these strikes can create hot-spots for bark and woodboring beetle (Coleoptera: Curculionidae; Buprestidae and Cerambycidae) populations, especially pest species, and may sustain them between outbreak events. The spatial and temporal structure of bark beetle populations and their associated predators and parasitoids may be sustained by lightning-struck trees, as these colonization events are discrete, periodic, ephemeral, and self-propagating. Our research objectives were to: 1) characterize the assembly of subcortical beetles and their associates arriving at lightning struck longleaf pine trees;

and 2) assess intrinsic and host variation in insect colonization dynamics. In summer 2020, detonation cord wrapped around the tree trunks of six longleaf pine (Pinus palustris) trees was used to simulate lightning strike trauma. Lindgren funnel traps, hung at several heights along the tree's trunk, were used to monitor flight and arrival activity around the tree (both before and after detonation). Three trees were cut down and logs placed in emergence chambers to examine colonization success from sections of the tree trunk associated with the funnel traps. We determined arrival order of insect species and their numbers, flight height, and colonization height. Currently, we are identifying adults to species-level, and results will be analyzed using mixed linear models. Results of this study will contribute to better understand the assembly of insect communities centered on lightning, an important and common ecological disturbance agent during storm events.

E. *Change in fuel loads following severe drought and bark beetle outbreaks in the central and southern Sierra Nevada - Crystal S. Homicz, Leif A. Mortenson, Beverly M. Bulaon, and Christopher J. Fettig.* The disturbance ecology of many conifer forests in western North America has deviated drastically from historical conditions largely as a result of fire suppression, extreme drought events, and bark beetle outbreaks. These deviations were exemplified in 2012–2015 when the worst drought in over a millennium occurred throughout parts of California. During and following the drought, a western pine beetle (Dendroctonus brevicomis) outbreak occurred in the central and southern Sierra Nevada causing severe (>90% in some areas) ponderosa pine (Pinus ponderosa) mortality. The objectives of our study are to determine changes and variations in fuel loading over time, and to determine predictive variables of fuel loading following the outbreak. A network of 180 11.3-m fixed-radius plots were installed across three elevation bands on the Eldorado, Stanislaus, Sierra and Sequoia National Forests to monitor tree mortality levels, changes in tree species composition, and changes in fuel loading. Fuels data across the plot network were measured in 2017 and 2019 using modified Brown's transects, and measurements will be repeated again in 2021 and 2023. Preliminary data show total surface fuel loading has increased from 2017 to 2019 across all national forests and elevation bands, with the largest increase on the Sierra National Forest. 1000-hour fuels increased more than any other fuels class and little change was observed in litter and duff. Better understanding of changes in fuel composition following bark beetle outbreaks in Sierra Nevada forests provides important context for land management decisions, especially as outbreaks likely increase in frequency and severity moving forward.

F. *Comparing the effects of various natural and anthropogenic disturbances on insect pollinator diversity in mid-montane forests of the Californian southern Sierra Nevada - Gabriel G. Foote.* Flower-visiting insects provide essential pollination services to herbaceous plant communities in temperate coniferous forests, thereby helping to maintain food webs and support the overall functional diversity of these systems. To guide conservation efforts for forest-associated populations in western North America, ecologists have investigated the effects of both natural (drought, insect outbreaks,

wildfire) and anthropogenic (forestry operations) disturbances on local insect pollinator abundance and diversity. However, studies comparing their community responses to the different types of forest disturbance (i.e., abiotic versus biotic or anthropogenic) that have co-occurred within an individual forest landscape are few. To address this knowledge gap, we sampled the insect pollinator community during the summer of 2020 in undisturbed forest stands, combined with neighboring stands that underwent recent (post-2015) disturbance (drought, tree harvest, wildfire) located in mid-montane forest landscapes of the Californian southern Sierra Nevada. Disturbed stands had a higher diversity of pollinators compared to neighboring, undisturbed stands. However, the magnitude of these differences varied by both disturbance type and severity. Fire-disturbed plots with intermediate (40-70%) levels of tree mortality had the greatest diversity of insect pollinators, followed by unforested plots that had experienced complete tree removal. Only drought-affected stands that experienced relatively high (> 70%) tree mortality rates had a significantly greater diversity of pollinators compared to neighboring, undisturbed stands. Across the study region, pollinator diversity was positively correlated with mean tree diameter, exposed bare ground surface area, as well as floral resource abundance, while canopy cover, shrub cover and dead wood abundance were all negatively correlated with their diversity. Combined, these results indicate that allowing for certain disturbances (e.g., moderate severity wildfires) that reduce shrub cover, expose bare ground surfaces and promote herbaceous plant growth on the forest floor may be optimal mechanisms for land managers to passively create beneficial habitat for insect pollinators in this ecoregion.

G. *Insect community responses to novel and co-evolved bark beetle pheromones: Predicting potential southern pine beetle associates in New England pine forests - Caroline Kanaskie, Matthew P. Ayres, and Jeff Garnas.* Arthropod communities associated with the southern pine beetle (SPB, *Dendroctonus frontalis* Zimmermann) are highly studied in southern U.S. forests where the beetle is among the most important pests of pine. This well-characterized community includes natural enemies, co-occurring and potentially competing Ips and other Dendroctonus bark beetles, and a suite of opportunistic species. As SPB moves north with changing climate, it will undoubtedly encounter novel communities. Community differences in the endemic and expanding range of SPB is a plausible driver of divergent behavior and population dynamics of the beetle. The SPB-associated insect community has only recently been described in detail in the expanding range as part of our research. We continue to fill this gap by comparing insect responses in New England forests to 3 different semiochemical lures: 1) SPB-focused (frontalin, alpha/beta pinene, with endo-brevicomin placed several meters away); 2) Ips-focused (ipsenol, ipsdienol, lanierone, alpha/beta pinene); 3) and a tree volatile control (alpha/beta pinene). Our study includes eight paired pitch and white pine sites (n=16) across Maine, New Hampshire, and Massachusetts. We compare traps catch across sites, latitude, and dominant pine species. These comparisons will help predict species' responses to novel SPB pheromones in the beetle's expanding range. Building on our previous study of SPB gallery communities in pitch pine in NY, this work

provides baseline knowledge of regional species pools and facilitates future study of the consequence of the arrival of a novel keystone species, including community-scale adaptation and/or shifts in composition, abundance, or behavior.

3:30 Concurrent Session 1

A. *Using big data to answer big questions in forest entomology - Angela Mech, Ashley Schulz, Ruth Hufbauer.* Availability and accumulation of data over the last few decades has allowed us to reexamine many unanswered questions, with large datasets being at the core of many multifaceted projects that have furthered the field of forest entomology. Our symposium will highlight some of the diverse uses of large data that have helped answer questions about predicting, monitoring, understanding, and controlling forest pests, and how these answers can be used to promote action that will keep our forests healthy.

   i. Towards machine-assisted classification of bulk invertebrate specimens - Jarrett Blair
   ii. Genetic and environmental factors influencing pine host quality in the mountain pine beetle outbreak - Janice Cooke
   iii. Forest integrated pest management programs in the U.S. with focus on the National Gypsy Moth Slow the Spread Program - Tom Coleman
   iv. Macroscale pest invasion dynamics and impacts in forest ecosystems across the U.S. - Songlin Fei
   v. Synthesis and utilization of big data for forecasting the impacts of non-native forest insects in North America - Ashley Schulz
   vi. Species-area relationships and other factors explaining numbers of native and non-native insect species utilizing North American and European host tree species - Sandy Liebhold

B. Invasive ambrosia beetles in North America - Bob Rabaglia, Sheri Smith. Invasive ambrosia beetles have had an impact on the health of North America's urban and rural forests. In the past 30 years there has been an increasing number of these non-native beetles and impacts. This session will discuss the species present in North America, highlight a few species having significant impacts, research to understand and manage them, and potential invaders in Asia.

   i. *Intro and overview of invasive ambrosia beetles in North America - Bob Rabaglia.* There are nearly 70 species of non-native bark and ambrosia beetles established in North America. Several species of ambrosia beetles in the tribe xyleborini are impacting urban and rural forests in the southeastern US and California. Surveys by the USDA Forest Service and APHIS target new introductions of these species at ports and high-risk locations across the US. As introductions and establishments of new non-natives continue it is important to understand pathways, target early detections and assess impacts of current and potential invaders across North America.
   ii. *Update on invasive ambrosia beetles in California - Sheri Smith and Stacy Hishinuma.* The Mediterranean oak borer (MOB), Xyleborus monographus, is an

invasive ambrosia beetle native to the Mediterranean region, including Europe, the Middle East, and North Africa, where it primarily attacks oak species. The first North American infestations of MOB were confirmed in valley oaks in Napa County, California in late 2019, followed by Lake and Sonoma Counties in early 2020, and Sacramento County in September 2020. MOB attacks at least 12 species of oaks in its native range. In California, it has been found infesting two species of white oak: most commonly valley oak and, to a lesser extent, blue oak. Several species of fungi have been found associated with MOB in Napa County, and research is underway to determine if these fungi cause tree diseases. For more information and a MOB pest alert can be found here: https://www.ucanr.edu/sites/mobpc/ In southern California, two species within the Euwallacea fornicatus species complex, Euwallacea fornicatus (polyphagous shot hole borer) and E. kuroshio (Kuroshio shot hole borer), have caused extensive tree mortality in urban areas. These beetles are now established in Santa Barbara, Ventura, Los Angeles, Orange, Riverside, San Bernardino, San Diego, and San Luis Obispo Counties with overlapping ranges in some counties. A statewide strategic initiative is underway to control these beetles through: 1) research and technology development; 2) survey, detection, and rapid response; 3) examining greenwaste and firewood as pathways for movement; 4) outreach and education. For more information please visit: https://ucanr.edu/sites/pshb/

iii. *Update on red bay ambrosia beetle and laurel wilt in the southeast - Bud Mayfield.* The redbay ambrosia beetle (RAB), Xyleborus glabratus, was first detected in North America in 2002 near Savannah, GA and has since spread throughout the southeastern United States. One of its symbiont fungi, Raffaelea lauricola, causes a vascular disease known as laurel wilt that has killed hundreds of millions of trees in the family Lauraceae. This presentation will examine the known distribution, hosts, impacts, and management challenges associated with this insect-pathogen complex and its status as a potential threat to lauraceous plants in other regions of the world.

iv. *Xyleborine ambrosia beetles in southeast Asia and potential new invaders - Sarah Smith and Anthony Cognato.* The greatest source of introduced xyleborine ambrosia beetles is Southeast Asia. Yet prior to 2019, a review of the fauna and comprehensive identification keys were non-existent. Recently 315 xyleborines mostly occurring mainland southeast Asia were reviewed in an illustrated monograph. Sixty-three new species were described, and other taxonomic changes were made. Dichotomous keys and web-based multi-entry keys were included. In addition, the foundation for a two gene DNA identification scheme was developed for the fauna. We discuss the limits of morphological and DNA diagnostic characters, potential new invaders, and future taxonomic research.

C. *Impacts of listing the monarch butterfly under the endangered species act: ecology, policy, and conservation - Rich Hofstetter.* Recent studies found that if current trends

continue, both the western and eastern monarch populations face migratory collapse within the next 20 years. In the 1990s the eastern population numbered nearly 1 billion butterflies, and the western population numbered more than 1.2 million. Last year's winter counts recorded fewer than 30,000 western monarchs and around 225 million eastern monarchs. Forest habitat restoration and conservation efforts may benefit or be hampered by listing the monarch under the Endangered Species Act. In this session, we discuss the politics, ecology, citizen science, and conservation of the monarch butterfly as well as its use of forest habitats and interactions with forest ecosystems.

i. *Warranted, but precluded: what that means for monarchs and the people who care about them' - Karen Oberhauser.*
ii. *Partnering to bring all hands on deck for monarch conservation - Wendy Caldwell*
iii. *Adult monarch abundance is higher in burned sites than in grazed sites - Julia Leone*
iv. *Historical monarch overwintering colonies in central Mexico, 1976–1991 - Wayne Thogmartin*
v. *Southwest milkweeds and their use by Monarchs - Rich Hofstetter*
vi. *The critical roles of the Texas corridor for eastern Monarch migration - Bob Coulson*

D. *Open Session 1 - Nathan Havill*

i. *Healthy Trees, Healthy Cities - Chuck Bargeron, Michelle Johnson, Rich Hallett, Rachel Holmes.* New tree-killing insects and diseases are often spotted first in cities, making tree health monitoring a priority not only for these trees themselves, but for the health of the entire North American forest ecosystem. Seven years ago, The Nature Conservancy, USDA Forest Service, and University of Georgia partnered on the development of a scientifically rigorous, non-stressor specific tree health monitoring protocol called Healthy Trees, Healthy Cities. The protocol is non-stressor specific making it a critical tool for the early detection of new, unknown insects or diseases. Furthermore, the protocol and an associated smart phone application (app) and web-based "dashboard" leverage the expertise of civic scientists and professionals alike, increasing public awareness of tree health issues. Learn about the methodology, new tools and updated training resources, as well as examples of where these tools have been used to improve tree health efforts in cities.
ii. *Balsam woolly adelgid mortality patterns in Idaho: from invasion to long-term establishment - Gina Davis, Laura Lowrey, Tom Eckberg, Jeffrey A. Hicke.* More than 110 years after first reported in Brunswick, Maine the nonnative balsam woolly adelgid, BWA (Adelges piceae), continues to be a significant pest of true fir (Abies) species in eastern and western North America. Over the decades, reports of BWA-caused damage demonstrated that the intensity and extent of tree mortality varied temporally, spatially, and among host species. Further investigation into stand-level mortality patterns occurred during two separate

monitoring efforts in Idaho where BWA-caused mortality rates were estimated following the discovery of BWA in the state (1986-2004) and after it was well established in most of the state (2008-2018). Observations from these two monitoring efforts are synthesized and address two key question; should forest managers expect similar stand-level mortality of true fir forests from BWA into the future; and if so, how much time do they have for mitigating losses once BWA infestations are evident?

iii. *Stand structure and climate influences on balsam woolly adelgid damage in Idaho: A statistical analysis of field measurements - Jeffrey A. Hicke, Gina Davis, Ekaterina Smirnova, Leonid Kalachev, Laura Lowrey, Tom Eckberg.* Balsam woolly adelgid (BWA) is an invasive insect in the western United States, attacking subalpine firs (Abies lasiocarpa) and grand firs (Abies grandis). Little is known about the stand structure and climate conditions favorable for BWA in these forests. In 2018, tree and insect characteristics at 28 sites in Idaho were measured for the third time; previous measurements occurred 5 and 10 years before. Here our objective was to identify stand and climate variables leading to BWA damage and tree mortality. We used generalized additive modeling, which allows nonlinear relationships between the response and explanatory variables. We modeled the proportion of host trees associated with BWA infestation. We considered multiple explanatory variables grouped by process (insect pressure, stand structure, host species and size preferences, temperature, and precipitation) to avoid multicollinearity issues. We used a modified forward selection process and considered AIC and cross-validation. The top model included insect pressure (proportion of live host species basal area with BWA present five years ago) as the most important variable. Basal area (BA) of host species 10 years ago, growing season precipitation, and water-year mean temperature were also included. The BWA response variable linearly increased with increasing insect pressure, increased roughly linearly with increasing host BA, decreased with increasing temperature, and had a humped-shaped relationship with precipitation in which the highest BWA damage occurred at intermediate values. Our results inform forest managers about the stand and climate conditions that make subalpine and grant fir stands susceptible to balsam woolly adelgid.

iv. *Insects respond to different systemic insecticides in different ways -Rhoda deJonge, Breanne Aflague, Jeff Garnas.* Here we explain the unique mode-of-action of azadirachtin-based insecticides, and review recent studies that use this active ingredient to control the invasive emerald ash borer (EAB). Azadirachtin is a plant-based active ingredient used in number of organic insecticides on the market. It controls insect pests by working within the insect-specific hormonal pathways, preventing molting, as well as limiting feeding and fecundity. We will share preliminary findings from a recent study conducted by Lallemand Plant Care (LPC) and the University of Toronto that reviews survivorship of

azadirachtin-treated ash trees after ~10 years of EAB presence. As well, we will share results of a recent field trial conducted by the University of New Hampshire to determine the efficacy of azadirachtin-based insecticides in a New England woodlot during peak EAB invasion. This brief talk will inform urban forestry professionals on actions they can take to maintain the health and survivorship of ash trees in their urban forests in order to preserve a diversity of age-classes and urban canopy cover, even during the peak of an EAB invasion.

v. *Asian Giant Hornet Program Update - Karen Ripley.* Asian giant hornet (Vespa manadarinia) was first detected in WA in 2019. Information about the pest including biology, range, and potential impacts are discussed. An overview of the response from WSDA is given including accomplishments from 2020. Program status in 2021 is provided and research projects being conducted are outlined.

vi. *What is an adelgid, anyway? Species delimitation and invasion history in Adelgidae - Nathan Havill.* Several adelgid species are high-impact invasive pests in forests and tree plantations in North America and Europe. Adelgid taxonomy is notoriously unstable due, in part, to their complex polymorphic life cycles that complicate morphological species delimitation. Genetic studies to inform adelgid systematics and population genetics can help us better understand their biology and inform pest management. I will discuss recent progress towards understanding the biogeographic history of adelgids using genetic data, focusing on hemlock woolly adelgid, balsam woolly adelgid, and pine adelgids (Pineus spp.). It is common for adelgid species complexes to be in the midst of transition between a holocyclic life cycle (with host alternation and a sexual generation) and an anholocyclic life cycle (with no host alternation and only asexual generations). This pattern has implications for their taxonomy, pest impact, and invasion history

5:00 **Poster Session and Student Poster Competition** - Rich Hofstetter

A. *Assessing the cold tolerance of elongate hemlock scale and its ability to establish in Minnesota - Marie Hallinen, Brian Aukema, Angie Ambourn, and Robert Venette.* The elongate hemlock scale (EHS), *Fiorinia externa* Ferris (Hemiptera: Diaspididae) is an insect from eastern Asia introduced to New York in the early 20th century. While it was historically found relatively close to its introduction point, it has greatly expanded its range since the 1970s and is now found in several New England and mid-Atlantic states and as far west as Michigan. In 2018, 2019, and 2020 EHS was found infesting wreaths, trees, and other greenery shipped into Minnesota to supplement Minnesota-grown Christmas trees. This armored scale has a wide host range and may feed and reproduce on many native local hosts, including firs and spruces, threatening forest health in addition to the Christmas tree industry in Minnesota. To assess the ability of EHS to survive winter temperatures in Minnesota we plan to measure the supercooling point, lower-lethal temperature, and lower lethal time of its overwintering stage. We will use

these experiments to evaluate EHS's ability to potentially expand westward and overwinter in Minnesota.

B. *Forest thinning improves native bee foraging habitat and is associated with increased bee abundances - Cora Davies and Thomas Seth Davis.* In North American conifer forests, thinning operations are broadly implemented as a means of fire hazard mitigation, ecological restoration, and timber harvest. Effects of thinning on forest bee communities are poorly understood but could be important for conservation of biodiversity and ecosystem services. Here, we test the hypothesis that thinned forest stands have greater diversity of native bee species than non-treated forests. To address this, native bee assemblages were collected across the growing season and compared between ponderosa pine stands treated by mechanical thinning and non-treated stands. Associations between native bee communities and forest conditions were analyzed. Forest structure, floral resources, nesting habitat, and bee assemblages differed between treated and non-treated stands. Forest basal area at non-treated sites was on average 3.5 times greater than treated sites, and canopy openness was greater at treated sites. Fuel loads were similar between treated and non-treated sites. Floral resources were >2.5 times more abundant at treated sites; floral abundance was highest in June and decreased throughout the summer. Native bees were two times more abundant in treated stands. Our results suggest that (1) forest thinning has significant impacts on both floral resources and bee nesting habitats within 2-8 years post-treatment; (2) bee assemblages likely respond to this variation, and this difference is especially apparent later in the growing season. We conclude that forest thinning for ecological restoration in ponderosa pine habitats is likely to improve resources utilized by native bees and are associated with increased bee abundances in the wildland-urban interface.

C. *Fear no weevil: understanding factors affecting hazelnut weevil infestation to safeguard a novel agroforestry crop - Pheylan A Anderson, Hailey N Shanovich and Brian H Aukema*. Hybrid hazelnut crosses between the European hazelnut (*Corylus avellana*) and the American hazelnut (*Corylus americana*) are an emerging agroforestry crop in the Midwestern United States. European hazelnuts typically produce high yields, while American hazelnuts exhibit greater cold-hardiness and disease resistance. Hybrid hazelnuts are envisioned as a foundational species for making agroecosystems more sustainable: the perennial shrubs hold soil tightly, cycle nutrients, and do not require annual tillage inputs. However, little is known about how local insect communities will affect this novel crop. The hazelnut weevil, *Curculio obtusus*, is native to the US and typically infests native hazels in forests throughout the eastern United States. Curculio obtusus has been found to infest these new hybrid hazelnut cultivars across the Midwest, but little is known about what factors influence the severity or distribution of field infestations. We studied within-field distribution of *C. obtusus* by collecting a subsample of ten nuts from each of the 184 nut-bearing plants in an experimental hybrid hazelnut field in Rosemount, MN, and checked each for larvae or exit holes. Approximately 25% of the nuts were infested with hazelnut weevil larvae, highlighting

the need for understanding factors influencing the insect's infestation patterns. We analyzed spatial trends and whether factors such as plant genotype, historical rates of nitrogen application, plant height, and yield could predict weevil infestation using generalized linear mixed effect models.

D. *Future directions of eastern larch beetle research in Minnesota - Emily R. Althoff and Brian H. Aukema.* Eastern larch or tamarack, *Larix larcina* (Du roi) K. Koch, ranges from Maine to Minnesota and Alaska in the United States, spanning almost 40,000 ha. of northern Minnesota. Within this range, tamaracks contribute to habitats for several birds and mammals and provide water filtration in northern wetlands, playing an essential role in these ecosystems. However, in the last 19 years, 40% of the state's 1.26 million acres of tamarack stands have been killed by eastern larch beetle, Dendroctonus simplex LeConte. Historically, ELB has only attacked tamarack stressed by windfall, fire, mechanical injury, defoliation, drought, or flooding. This trend has changed in recent years as an outbreak of ELB has been ongoing in Minnesota since 2000. Previous studies have shown that warmer summer and/or extended growing seasons are facilitating bivoltine life cycles in a proportion of the population, demonstrating that some insects can reproduce without an obligate overwintering period. Information on the management of ELB is currently sparse as it has not been a widespread problem historically. In our future work, we plan to investigate stage-specific development and temperature triggers of a potential diapause in ELB, investigate potential semiochemical attractant or repellent lures for monitoring or management, and further advance understanding of associated natural enemies and competitors. Ultimately, we hope to assist in improving management practices and expand knowledge on how climate change influences insect development.

E. *The efficacy of systemically injected Azadirachtin products at different doses and injection frequencies to control for the emerald ash borer (Agrilus planipennis Fairmaire, EAB) - Breanne Aflague, Rhoda deJonge, Jeff Garnas.* Injection of systemic insecticides is currently the most effective way to protect trees from the emerald ash borer, Agrilus planipennis Fairmaire (EAB). While previous academic studies have shown emamectin benzoate to be a highly effective active ingredient of these systemics, research on the use of azadirachtin-based insecticides in the control of EAB are limited. Azadirachtin is a botanically-derived active ingredient that is used when an effective low-toxic option for insect control is desired. Azadirachtin persists in trees for up to two years but can fluctuate seasonally; therefore, injection frequencies and doses are important factors to consider. We tested the efficacy of two azadirachtin-based systemics, Lalguard Aza (6% a.i. at both 4 ml and 6.5 ml/inch DBH dose rates) and TreeAzin (5% a.i. at a 12.5 ml/inch DBH dose) injected either annually or biennially, and compared them to untreated ash trees in a New Hampshire woodlot. Live larval densities where highly variable and differed moderately across treatments (including controls). Late instar larvae, however, were significantly reduced by the annual application of the Lalguard's low dose and at both injection frequencies by TreeAzin and Lalguard's high dose (Likelihood ratio chi-squared = 130.2; df = 6; $P < 0.001$). We also found an important effect of tree

microenvironment (i.e., soil saturation) and old gallery density on larval densities and growth. These results suggest that both doses and injection frequencies of the Lalguard AZA and TreeAzin products are equivalently effective against EAB, though uptake can be inhibited in water-saturated microsites.

F. *Elucidating stand-level characteristics critical for maintaining insect pollinators in working forests - Christine Favorito, James A. Martin, Angela Larsen-Gray, Daniel Greene, Christine Cairns Fortuin, Brittany F. Barnes, Elizabeth McCarty, and Kamal J.K. Gandhi.* Insect pollinators provide critical services to both people and forest ecosystems through crop and native plant pollination. Of the many insect pollinators present in forests, two of the most important indicators of ecosystem function and health are Hymenoptera (bees) and Diptera (flies). Unfortunately, bees are globally declining due to many factors including habitat loss and climate change, while the trend for many fly species is unknown. It is important to recognize the various and common aspects of forest structure and composition that best support these pollinators. Few studies have focused on pollinators in forests, and even less have focused on private, working forests, which make up 86% of forests in the southeastern U.S. We aim to compare populations and communities of wild bee and fly pollinators in various age classes of working forests, and to test the effects of stand-level structure and composition on bee and fly populations and communities. We are sampling bee and fly pollinators in 32 loblolly pine (*Pinus taeda*) stands with four age-classes in the Upper Coastal Plain region of Georgia using pan and blue vane traps in a randomized block design. We are measuring aspects of forest structure and composition (e.g., understory plants and coarse-woody debris) critical for these pollinators. We are currently identifying collected specimens to species. Results from this study will inform land managers of beneficial forest management practices for these pollinators that provide billions of dollars in pollination services annually.

G. *Ecological role and forest regeneration impacts of the eastern spruce budworm in Minnesota and Isle Royale - Jessica M. Rootes and Brian H. Aukema.* Isle Royale National Park, located off the northeastern shore of Minnesota, consists of more than 450 islands that comprise approximately 130,000 acres of protected wilderness. This unique biosphere reserve is a haven for ungulates such as moose whose numbers have proliferated, resulting in undesirable levels of vegetation defoliation due to overbrowsing. This defoliation is further exacerbated by the native eastern spruce budworm (Choristoneura fumiferana). Though an ongoing 50+ year study analyzes moose and wolf predator-prey relationships, more studies regarding lower trophic levels and their impacts on the island's Balsam-fir forests are needed. These studies will help to fill knowledge gaps regarding the ecological impact of efforts to relocate wolves to the island. Despite the eastern spruce budworm's potential large-scale impact and increasing populations, currently at a 20-year peak, this species has not yet been studied on Isle Royale. Outbreaks occur approximately every 35 years, last 10 years on average, and can result in 70% balsam fir and 40% white spruce mortality. My dissertation research will study the eastern spruce budworm's ecological role and effects on forest

regeneration to evaluate restoration goals on Isle Royale. The project will consist of comparisons of population dynamics and related factors, such as weather conditions, parasitoids, and dispersal, between mainland Minnesota and Isle Royale.

H. *Effect of a pine host volatile, 4-allylanisole, on southern pine beetle behavior - Sara K. O'Shields, Kamal J.K. Gandhi, Brian T. Sullivan, and Holly L. Munro.* Southern pine beetle, *Dendroctonus frontalis* Zimmerman (SPB) is a forest pest that has destroyed millions of acres of pines (*Pinus* spp.) in the eastern United States. SPB utilizes semiochemicals to initiate mass attacks and overcome host defenses. Likely because of SPB's close evolutionary history with host pines, specific host volatiles can enhance or inhibit SPB's response to its aggregation pheromone. One host volatile, 4-allylanisole (4 AA), was demonstrated in the 1990s to be an inhibitor of SPB aggregation, however, in recent field tests 4AA strongly enhanced SPB attraction when paired with commercial lures. It is not yet understood why the results of the earlier and recent studies were different, and thus the biological significance of the contrasting studies is unknown. The goal of our current research is to explore this relationship and determine what factors influence SPB response to 4 AA. We will investigate how proximity of infested trees, trap-type, and presence of other semiochemicals (such as isomers of the SPB pheromone brevicomin and specific host odors) may affect SPB's responses to 4 AA.

I. *Determining the impact of two biological control agents, Laricobius nigrinus and Leucopis spp. on Adelges tsugae populations and hemlock tree health in the eastern United States - Carrie E Preston, Scott Salom, Albert Mayfield, Mark Whitmore, Jerome Grant, Tim Tomon, Biff Thompson, John Seiler, and Tim Kring. Laricobius nigrinus*, a biological control agent of *Adelges tsugae*, the hemlock woolly adelgid (HWA), has been able to establish populations at a high percentage of release sites throughout the eastern United States. While this specialist predator of HWA sistens nymphs and progrediens eggs impacts the sistens generation, progrediens populations appear to be able to rebound, likely due to the lack of specialist predators for this generation. Recently, Leucopis argenticollis and Leucopis piniperda, predators that are host specific to HWA in the Pacific Northwest, have been proposed as additional biological control agents that could aid in controlling HWA populations in the eastern US. *Leucopis* spp. have been observed feeding on both generations of HWA, therefore if *Leucopis* spp. were able to establish in areas where *L. nigrinus* is present, there could be constant predation pressure on HWA, potentially preventing HWA populations from rebounding. In 2019, four sites with established *L. nigrinus* populations and high HWA populations were selected for a study to determine the impact of *L. nigrinus* and *Leucopis* spp. on HWA populations and to see if their predation would also have an effect on hemlock tree health. Mesh cages were applied on treatment branches with high HWA densities and to control branches, with low HWA densities, to compare the effect of both predators together and separately on the HWA population, to determine mesh cage effects, and to compare hemlock tree health measurements.

J. *Efficacy of different packaging types and storage conditions for preventing active ingredient loss and cross-contamination of forest insect lures - William P. Shepherd and*

Brian T. Sullivan. Commercial devices for releasing forest insect attractants and repellants (used for monitoring pest populations and protecting trees) are commonly stored in a variety of packaging and conditions for extended periods. The packaging is permeable to varying degrees depending on its composition, thickness, closure type, storage temperature, and the chemical properties of the lure components. The packaging typically used by manufacturers, as well as practitioners who re-package the lures, consists of various plastics sometimes combined with other materials. Excessive permeability of the packaging may result in significant cross-contamination among different lures stored in proximity, which can alter the activity of the devices when deployed. Additionally, escape of chemicals from insufficient packaging may affect lure shelf-life and increase personnel exposure. We sent a survey to U.S. Forest Service, Forest Health Protection entomologists who regularly use semiochemical lures, asking them to describe semiochemicals used, target insects, release device construction, storage and transport practices, and general observations and concerns. Responses were used to help select relevant variables that we could test in experiments aimed at formulating recommendations regarding packaging of release devices. We measured rate of weight loss from lures and packaging both at room temperature and in consumer-grade freezers for (1) single vs. multiple layers of polyethylene bags and (2) various brands and thicknesses of Mylar bags, closed with zip lock-type seals or heat-sealed. The polyethylene bags were unable to prevent loss of volatiles at room temperature from any of the lures tested, although additional layers of bags delayed or slowed these losses.

K. *Janet's looper northern jump: status of the range and host expansion of a native invasive defoliator in northern New Mexico - Jennifer Klutsch, Andy Graves, John Formby, Anna Schoettle, and Dan Ryerson.* Janet's looper (Nepytia janetae) recently jumped 200 miles north in NM defoliating 12,000 acres and expanding into Rocky Mountain bristlecone (Pinus aristata) and limber pine (P. flexilis). The addition of another invasive threat on top of white pine blister rust to high-elevation ecosystems can have major consequences for the maintenance of particularly Rocky Mountain bristlecone. While Janet's looper can cause significant mortality in its native range, factors driving outbreaks are generally not known. Tree chemical defenses are associated with host suitability in other tree-defoliator systems and may be factors determining host suitability in the expanded host range of Janet's looper. We describe this recent expansion and propose a project to investigate site conditions and tree defenses in the expanded range of Janet's looper in the Sangre de Cristo Mountains, NM. Stands of Douglas-fir (*Pseudotsuga menziesii*), one of the historical hosts of Janet's looper along with 5-needle pines that have been defoliated and not defoliate will be sampled for needle defenses to identify factors associated with potential host suitability. Identifying the defenses that protect these high-elevation trees against this climate change-facilitated native invasive and site conditions are crucial to monitor the forest health in ecosystems already threatened by the invasive white pine blister.

L. *Spatial and temporal heterogeneity after Hurricane Michael affects woodboring beetle populations and communities in southern U.S. pines - Chelsea N. Miller, Brittany F. Barnes, Sarah Kinz, J. T. Vogt, and Kamal J. K. Gandhi*. Catastrophic wind disturbances including hurricanes, tornados, and derechos are a major cause of tree mortality in the southeastern U.S. Hurricane Michael, a Category 5 hurricane with wind speeds of 259 kph, made landfall in Florida on 10 October 2018, damaging ~1.13 million hectares of forest and over $1 billion in timber damage. Trees were uprooted, crowns, stems, and boles were snapped; stands were further subjected to prolonged flooding. Additional losses may occur from bark (Curculionidae) and woodboring (Buprestidae, Cerambycidae) beetles that infest wind-disturbed forests. Epidemic outbreaks following catastrophic disturbances can result in the spread of beetles from damaged to healthy trees, further exacerbating losses. Here, we characterize the responses of woodboring beetles to Hurricane Michael in Florida pine-dominated stands. We hypothesize that: 1) beetle populations will increase over the sampling period, and 2) that changes in populations will vary across stands with different levels of damage. To test these hypotheses, we sampled woodboring beetles using baited traps in 2019 and 2020 from 15 stands with low (<25% loss), moderate (25-75%), and high (>75%) damage (5 plots/category). Species thus far include at least 19 species such as *Monochamus* spp., *Acanthocinus* spp., *Curius dentatus*, *Xylotrechus sagittatus*, and *Buprestis lineata*. Preliminary results from 2019 indicate support for intermediate disturbance hypothesis, where highest numbers of woodboring beetles were trapped in moderately disturbed forests, particularly in September. Hence, moderately disturbed forests may need to be managed first to minimize future economic losses from beetle outbreaks following this and future wind disturbance events.

6:30 **Adjourn**

Thursday, May 27

8:30 **Plenary Session 2**

A. *The macroecology of historical insect invasions - Sandy Liebhold*, USDA Forest Service

B. *Beyond Buzz - How to Harness the New Media Environment to Conserve the Actual Environment - Andrew Revkin*, Columbia University

9:30 **Break**

10:00 **Concurrent Session 2**

A. *Managing bark beetles during a period of rapid environmental and socioeconomic change - Chris Asaro, John Nowak, Chris Fettig.* The rapid pace of environmental and socioeconomic change poses considerable challenges to forest managers throughout North America. The goal of this 2-hr workshop is to explore relevant issues to the management of bark beetles within the broader social, political and biophysical environment. Changes in the frequency and severity of other disturbance regimes and stressors, forest ownership and land use patterns, and market forces will be discussed for each of five regions. Speakers will address how these factors influence management

considerations today, and more importantly how anticipated changes will likely influence management considerations and bark beetle impacts in the future.

i. *Managing bark beetles during a period of rapid environmental and socioeconomic change: A brief introduction - Chris Asaro, John Nowak, and Chris Fettig.*
ii. *Northeastern U.S. - Matt Ayers*
iii. *Southeastern U.S. - Kamal Gandhi*
iv. *Bark beetles are eating the West: Changing environmental and socioeconomic influences - Chris Fettig*
v. *Western Canada - Kathy Bleiker*
vi. *Alaska - Jason Moan*

B. *Domestic invasive species: curtailing the threats in our own backyard - Rob Venette, Andrew Graves.* The concomitant movement of wood and insects within (and across) national borders creates opportunities for the introduction of invasive pests. A common misperception is that invasive pests must come from overseas. This session begins with select cases that illustrate the severe impacts that can occur when forest pests are moved to naïve ecosystems that are still within national borders. We apply a simple framework to assess how risks associated with these species might differ within a country. Lastly, we discuss potential management options that would not necessarily require federal regulatory but could mitigate these risks.

i. *Welcome - Andrew Graves and Rob Venette*
ii. *Heading west: Ips grandicolis is on the move - Brian Aukema*
iii. *Goldspotted oak borer and walnut twig beetle, domestic invasive species from the western U.S. - Andrea Hefty*
iv. *Forest insects from Mexico and Central America: Cause for concern? - Jorge Macias Samano*
v. *Simplified risk assessments for domestic invasive species - Rob Venette*
vi. *Management options for domestic invasive species - Andrew Graves*

C. Range expansion and climate change - Mike Howe

i. *Outbreaks and range dynamics of baldcypress leafroller in the southeastern U.S. - Samuel F. Ward and Kristy M. McAndrew.* Several recent outbreaks of native forest insects have been unprecedented in their extent and/or severity. The first recorded outbreak of baldcypress leafroller (*Archips goyerana* Kruse; Lepidoptera: Tortricidae), a native defoliator of baldcypress, began in Louisiana in 1983. For years following the onset of the outbreak the causal agent was believed to be a congener, fruittree leafroller (*A. argyrospila* Walker), as baldcypress leafroller was not formally described until 2000. The outbreak is still ongoing, surpassing 100,000 hectares of defoliation in 2017 alone, but has remained confined to southern Louisiana. However, baldcypress leafroller has been reported from Mississippi and the range of baldcypress extends across the southeastern US and reaches southern portions of the midwestern and northeastern US. The range limits of endemic populations of baldcypress

leafroller and factors inhibiting such populations from reaching epidemic levels remain unknown. A quantitative analysis of the initiation, persistence, and spread of defoliation in Louisiana will be presented along with a summary of (i) previously reported evidence for drivers of the outbreak and (ii) ongoing efforts to quantify the range dynamics of epidemic and endemic populations.

ii. *It's a dry heat: How trees reprioritize carbon in a hotter, drier world and the potential impacts for bark beetle ecology - Amy Trowbridge.* Heat and drought affect plant chemical defenses and thereby plant susceptibility to pests and pathogens. Yet, our understanding of the impacts of heat and drought on defense is primarily based on data from potted seedlings, making it unclear how older age classes respond to stress. Furthermore, the carbon pools that support secondary metabolism under predicted drought stress are largely assumed. We measured needle and woody tissue secondary metabolites and primary physiology from mature Pinus edulis during a unique temperature and drought manipulation field experiment. While heat had no effect on total monoterpene concentrations, trees under combined heat and drought exhibited ~85% and 35% increases in needle and woody tissue, respectively, over multiple years. Physiological variables explained less than 10% of the variation in total monoterpenes for both tissue types while starch and glucose + fructose measured one-month prior explained ~25% of woody tissue total monoterpene concentrations. Notably, some key monoterpene compounds with known roles in bark beetle ecology decreased. These shifts may make trees more favorable for bark beetle attack rather than well-defended, which one might conclude if only considering total monoterpene concentrations. Our results point to cumulative effects of heat and drought that reprioritize specific carbon pools toward defense.

iii. *The importance of energy-water limitation threshold in drought impact studies - Joan Dudney.* Forest diebacks have increased in magnitude in many regions in response to greater water limitation. "Hotter droughts" are predicted to increase under climate change and result in significant restructuring of forest composition and ecosystems services. Many drought-related studies, however, focus on water limited systems, where water—not energy—poses the greatest constraint on photosynthesis. Contrary to expectation, hotter, drier conditions in energy limited systems may cause greater growth, as the growing season is extended. Thus, identifying the location of the energy-water limitation threshold is critical to predict forest mortality under climate change. Here we assess the impacts of the recent extreme drought in California (~2012-2015) on whitebark pine across the central and southern Sierra Nevada. We use a combination of over 700 tree-rings and over 1,000 stable isotope samples to test whether extreme drought led to greater growth or greater physiological stress. We show that during extreme drought, the energy-water limitation threshold shifted upslope into higher elevation forests. Trees growing near this

threshold experienced some physiological stress, but trees far from this threshold experienced positive growth. These results suggest that extreme drought has a more nuanced effect on average productivity for forests that occur across strong climatic gradients.

iv. *Suitability of current and future climates in Canada and the United States for the potential establishment of the European spruce bark beetle, Ips typographus - Kishan Sambaraju and Chantal Côté.* Non-native pest introductions pose a serious threat to forest health worldwide. In North America, exotic bark beetles are commonly intercepted at the ports of entry, and among the species reportedly encountered, the European spruce bark beetle (*Ips typographus* L.) is one of the most frequent. Native to Eurasia, this species causes serious damage to Norway spruce (*Picea abies* (L.) H. Karst.) in its indigenous range; however, I. typographus also has the capacity to survive and reproduce on important North American spruce species. Climate plays a critical role in regulating multiple aspects of I. typographus life history such as voltinism, flight behavior, and population density. We used species distribution models (SDMs) to assess whether climates in Canada and the United States are suitable for the potential establishment of I. typographus. We also wanted to assess future geographic shifts in climatic suitability in this region under climate change. Species distribution models are modeling algorithms that associate species occurrences with predictors such as climate variables and can be used to characterize habitat suitability for a target species as well as to quantify spatio-temporal shifts as environment changes. These modeling approaches are flexible (e.g., can use presence-only data) and are applicable at different spatial scales with readily-available climatic datasets. Using SDMs, we linked the distribution of I. typographus in Eurasia with biologically-relevant climatic variables that likely play important roles in limiting the distribution of this insect. We then projected the potential distributions of I. typographus in North America. Our results suggest that climatic suitability will improve in the future for *I. typographus* compared with the current conditions and that northward shifts in suitable climates will occur under climate change.

v. *Emigration or Establishment? Exploring mountain pine beetle range expansion into whitebark pine in British Columbia - Michael Howe, Allan Carroll, Claudio Gratton, and Kenneth F Raffa.* Warming temperatures are allowing native insect herbivores to expand into regions that previously exceeded their thermal tolerance. Latitudinal and elevational range expansions are yielding new insect-plant interactions that can fundamentally alter ecosystem processes. Bark beetles cause the most widespread morality to conifers globally but are limited in their range by host availability and minimum temperatures. Recently, several beetle species have expanded their geographic ranges to cause significant mortality to naïve and semi-naïve host tree species. However, it is unknown whether these expansions are caused by emigration from the historical host, or

establishment within the newly accessed range. We tested these two non-mutually exclusive hypotheses by compiling publicly available data which had spatially-explicit information on mountain pine beetle (Dendroctonus ponderosae Hopkins, MPB) infestations in British Columbia on its primary historical host, lodgepole pine (Pinus contorta), and the beetle's expansion into high-elevation areas with endangered whitebark pine (Pinus albicaulis) communities. Data were compiled over a 20-year period, from 2000-2019. We constructed random-forest models predicting mountain pine beetle infestation severity as a function of geographic location, stand characteristics, regional bioclimatic data, cold suitability metrics, and estimates of beetle propagule pressure.

D. Open Session 2 - Ashley Schulz

i. *Functional traits drive bee community responses to habitat variability in managed southeastern forests - Christine Cairns Fortuin and Kamal JK Gandhi.* Human management of forest systems generates multiple variables which can influence wild bee communities including the creation of gaps and edges, variations in canopy openness, removal or accumulation of dead wood, and variations in depth of soil organic layer. The ways in which wild bees respond to this variability may be mitigated by functional traits such as nesting preferences, diet, seasonality, size, or degree of sociality of wild bee species. To understand how bee communities respond to edges and habitat variability generated by forest management practices, we sampled bees in four replicates of three site-types across a gradient from the edge of a forest road: mature hardwood stands, managed pine stands, and regenerating clearcuts in the Georgia Piedmont. Each site was surveyed for nesting habitat indicators including depth of duff layer, volume of downed wood, decay class of downed wood, and number of standing snags. Regenerating clearcuts had higher alpha diversity of wild bees but displayed higher functional overlap in the bee community that favored soil nesting groups. Hardwood forests provided more nesting niche opportunities leading to higher functional diversity and beta diversity, and instead supported more cavity nesting, softwood nesting, solitary, and early season bees. In contrast, pine forest road edges support a diversity of large-bodied, litter-nesting and specialist bees. Nesting habitat indicators explained 53% of the variation in functional nest guild composition. Overall, results indicate that nesting traits are significant drivers of wild bee community responses to human management in forest systems, and merits consideration in restoration and conservation efforts.

ii. *Emerging molecular technologies for bark beetle management - Bethany R Kyre and Lynne K. Rieske.* Bark beetles of the genus Dendroctonus pose a significant threat to coniferous forests worldwide. With 19 species occurring globally, the 5 species found in the United States alone were responsible for over 200 million hectares of damage in 2017 – 2018. Increasingly erratic weather patterns and a

history of hands-off silviculture practices have allowed for devastating and persistent outbreaks within the native ranges of Dendroctonus species, as well the invasion into naïve forests outside of their endemic ranges. Emerging molecular approaches involving gene silencing via RNA interference (RNAi) to manage invading populations have proven efficient with both southern pine beetle, *Dendroctonus frontalis* (SPB), and mountain pine beetle, *D. ponderosae*, wherein the ingestion of exogenous dsRNAs resulted in near one hundred percent mortality for both species; with additional work focusing on dsRNA efficacy in Ips and wood boring beetles. In addition to the successful activation of the RNAi pathway, assessment of nontarget effects and translocation of exogenous dsRNAs throughout host tissues after root absorption has also been demonstrated, making way for the potential success of tree level protection. However, forest level protection faces additional hurdles. Current efforts are focusing on the role of genetic variation in primer design, and potential methods for landscape level deployment strategies. Although additional work is needed, gene silencing using RNAi provides hope for managing these persistent and recalcitrant forest insects

iii. *Temperature effects on Spotted Lanternfly Phenology - Melody A. Keena, Devin Kreitman, Anne Nielsen, and George Hamilton. Lycorma delicatula* (White), an invasive planthopper from Asia, is an emerging pest in North America. It is important to understand its phenology in order to determine its potential range in the United States. The lower threshold for egg development was estimated as 7.39°C. Eggs held at constant 10, 15, and 20°C were estimated to require 635, 715, and 849 DD7.39, respectively, to develop. Egg hatch rates were highest when held at a constant 15°C, though high rates were also obtained when eggs were held for 84 days at 10°C, then moved to 25°C. Almost all eggs enter diapause since very few eggs were able hatch when moved to 25°C after 7 days of chill at either 5 or 10°C. Nymphal developmental rate increased with temperature from 15°C to 30°C for all instars, then declined again at higher temperatures. Nymphal survival was lower at 35°C than between 15-30°C for all instars, and first instars placed at 5, 10, and 40°C all died without molting. The lower developmental threshold was found to be 13.00±0.42°C for first instars, 12.43±2.09°C for second instars, 8.48 ± 2.99°C for third instars, and 6.29 ± 2.12°C for fourth instars. The degree-day (DD) requirement for nymphs in the previous instar to complete development to reach the second instar, third instar, fourth instar, and adult was 166.61, 208.75, 410.49, and 620.07 DD (base varied), respectively. These results provide key data to support the development of phenology models and help identify the potential range of *L. delicatula* in North America.

iv. *Impact of biological control agents on Canadian emerald ash borer parasitoids - C. J. K. MacQuarrie, M Gray, G Jones, T Ladd.* Three biological control agents have been released in Canada for the control of emerald ash borer. These

species were released as part of the US-lead effort to reduce the impact of the pest on ash trees in North America. The first releases of Tetrastichus planipennisi were made in 2013 with Oobius agrili and Spathius galinae following in 2015 and 2017. Beginning in 2018 we initiated experiments to examine the impact and dispersal of these parasitoids in the Canadian ash ecosystem. These experiments were intended to determine if the parasitoids were contributing to population regulation, and to determine if and how far the insect has spread. To examine the impact of the parasitoids on population dynamics we used a series of sequential caging studies to partition the attack of parasitoids on resident emerald as borer in some of the oldest release sites. In our dispersal experiment we used pan traps established at 2-30 Km from the oldest release sites to examine dispersal in southwestern Ontario, Canada. The results of these experiments will be used to estimate the contribution of these biological control agents to regulation of emerald ash borer in Canada.

v. *The Effect of Host Plant on the Nymphal Development of Spotted Lanternfly - Devin Kreitman, Melody A. Keena, Anne Nielsen, and George Hamilton.* *Lycorma delicatula* (White), an invasive planthopper from Asia, is an emerging pest in North America that was first introduced in 2014. Even though it has a broad host range, it is heavily associated with Ailanthus altissima (Miller). Due to its polyphagous nature, it is important to understand how host plants affects its phenology. Nymphs were reared on the following host plants at a constant 25°C: *Acer rubrum* (L.), *A. altissima*, Celastrus orbiculata (Thunberg), *Ocimum basilicum* (L.), *Rosa multiflora* (Thunberg), *Salix babylonica* (L.), and *Vitis labrusca* (L.). The development rate and weight were compared for nymphs reared on each host. First and second instar nymphs developed at similar rates on all hosts that were tested. It was found that third instar *L. delicatula* nymphs took longer to develop on S. babylonica than on *A. altissima* or *V. labrusca*. Females weighed more and took longer to develop than males in the third and fourth instars. Survival was variable and the number of hosts that it could utilize to complete an instar decreased as instar increased. Implications for phenology modeling was discussed

vi. *Subterranean survivorship, timing of emergence, and potential supplementary diet of Laricobius spp. (Coleoptera: Derodontidae), biological control agents for the hemlock woolly adelgid - Jeremiah R. Foley, Albert Mayfield, and Scott M. Salom.* *Laricobius* spp. share the Derodontidae clade with three other family members (*Derondontus*, *Nothoderodontus*, and *Peltastica*) and together, are collectively known as the “tooth-necked” fungus beetles. From the literature, all genera except Laricobius consumes fungi. Laricobius spp. are specialist predators of Adelgidae and presumably no longer feed on fungi. Additionally, Laricobius nigrinus and L. osakensis have been used as biological control agents for the hemlock woolly adelgid (HWA), *Adelges tsugae*, for the past 16 and 10 years, respectively. *Laricobius* spp. spends half of their univoltine life cycle

within the arboreal habitat of hemlocks and the other half beneath hemlocks, in a subterranean habitat. Most of the literature on *Laricobius* spp. has focused on their arboreal habitat and few studies have documented their subterranean biology. Historically, lab-rearing these beetles has been limited by significant mortality (~40%) during the subterranean portion of this insects' life cycle. Herein, we describe the subterranean biology of *L. nigrinus* and *L. osakensis* in terms of their supplementary diet and field survivorship.

vii. *Great Lakes Basin Forest Health Collaborative: What it's all about - Rachel Kappler, Courtney Blashka, David Burke, Eboni Hall, Carolyn Pike, and Jennifer Koch.* Eastern forests including those in the Great Lakes basin, have been severely impacted by invasive insects and diseases culminating in decreased biodiversity, altered forest ecology, and reduced ecosystem services. Five native ash species (*Fraxinus* spp.) are threatened with extinction as a result of the emerald ash borer (*Agrilus planipennis*) including green ash (*F. pennsylvanica*), an important riparian species and black ash (*F. nigra*), the loss of which has the potential to convert northern wetland forests to open marsh. Common northeastern forest types containing beech (*Fagus grandifolia*) and eastern hemlock (*Tsuga canadensis*) are under siege from beech bark disease, beech leaf disease, hemlock woolly adelgid (HWA), and elongate hemlock scale. The newly formed Great Lakes Basin Forest Health Collaborative (GLB FHC), a partnership with Holden Forests & Gardens, American Forests and the USDA Forest Service, was formed to help advance resistance breeding for these important tree species. The primary mission is to use a participatory approach by establishing a network of partners and provide training and technology transfer. In turn, partners provide volunteers and other resources to work together with the FHC on activities including the identification of survivor trees with potential resistance, clone bank and/or seed orchard establishment, and seed collections, with the long term goal of producing improved seed sources to restore impacted forests. We are currently developing a partner network within the GLB for initial projects that include the identification and propagation of lingering ash trees that have survived long term EAB infestation and seed collections for conservation of eastern hemlock. We anticipate expanding to projects in the future that involve breeding for HWA resistance and identifying beech trees that remain healthy in areas heavily impacted by beech leaf disease. Once networks are established, the FHC can quickly mobilize to address new damaging pests as they arise

12:00 Lunch (on own)

1:30 Concurrent Session 3

A. When do old plays work & when do we need to rewrite them? - part 1 - Chris MacQuarrie, Sandy Smith. This symposium presents – When do Old Plays Work & When Do We Need to Rewrite Them? Managing insect populations can be thought of developing a playbook of tactics and strategies that seek to exploit weaknesses in the

pest's defenses. When we encounter new pests or new outbreaks of old pests we often draw on the successful plays from the past. However, under climate change, range expansions and invasions of new pests sometimes those old plays may not always work. Using examples from previous successful management of native and invasive pests we will examine how these successful plays have influenced the management of more recent pest problems, and where the old playbook has needed to be re-written.

i. *Introduction - Chris MacQuarrie.*
ii. *You shall not pass! Using knowledge on population dynamics to manage spruce budworm - Jacques Régnière.* Over the last several decades, much has been learned on the ecology, population dynamics, and management of the spruce budworm in eastern Canadian boreal forests. Evidence increasingly supports the idea that this insect is indeed regulated by a multiple-equilibrium system, where populations are kept in check by natural enemies until they escape and rise to outbreak level where negative feedbacks limit their further growth and eventually cause their decline. All of this occurring in a context of high mobility, connecting regional meta-populations through moth migration. We will discuss the evidence for these statements, the ongoing research and modeling, and their implications for pest management.
iii. *The role of native natural enemies in the successful biological control of winter moth in the northeastern United States - Hannah J. Broadley, Joseph S. Elkinton, and George H. Boettner.* Winter moth, *Operophtera brumata*, a polyphagous caterpillar was accidentally introduced to the northeastern United States in the 1990s. Previous invasions of winter moth in Canada were successfully suppressed following the introduction of two biological control agents winter moth's native range - *Cyzenis albicans* and *Agrypon flaveolatum*. In our work, we did not use *A. flaveolatum* due to concerns about its host specificity. We established *C. albicans* at sites across the northeastern U.S. and establishment has coincided with a dramatic decrease in winter moth density. However, this success 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. We built on this earlier research and, over five field seasons, deployed winter moth sentinel pupae in the field to determine rates of predation and parasitism across a range of winter moth pupae and *C. albicans* puparia densities. Prior to the establishment of *C. albicans* in years when winter moth densities were high, we did not observe density dependent mortality. Since 2016 however, *C. albicans* has become widely established and winter moth densities have decreased to a level comparable to what was found it its native range. We have found that mortality on the pupae was density dependent and thus may stabilize winter moth at low density. Overall, our research shows 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.

iv. *A new strategy for an old pest: the early intervention strategy against the spruce budworm - Véronique Martel and Rob Johns.* The spruce budworm (SBW), *Choristoneura fumiferana* (Lepidoptera: Tortricidae), is an old pest, but with cyclic outbreaks occurring every 30-40 years. Each outbreak is slightly different, depending on the forest composition, the climate or our use of the forest. Although SBW management has started as early as in the 1950s, the strategies used have changed radically through time: from broad-spectrum insecticides like DDT to more specific biopesticides like Btk, our environmental concerns have transformed pest management. In addition to the change in insecticides used, we also have a better understanding of the population dynamics of this pest, helping us elaborate new strategies. The Early Intervention Strategy has been tested since 2014 in New Brunswick as a way to affect SBW populations, preventing them from rising, instead of limit the impact of high density populations on the forests. The history of SBW management, our understanding of population dynamics and the success of the Early Intervention Strategy against the SBW will be presented.

v. *Lucas Roscoe.*

vi. *(Wood) boring phenology for the interest of emerald ash borer invasion management - Ken Dearborn.* The invasive emerald ash borer has forever altered the eastern forests of North America. Phloem-feeding larvae have strangled ash, Fraxinus, in 35 US states and five Canadian provinces. Tracking life-stage specific development in growth chambers across biologically-relevant temperatures will increase the accuracy of phenology-based predictions. These growth rates will inform models to mitigate range expansion and predict long-term impacts. For eggs and larvae, 7 and 10 °C appear to be below developmental thresholds with zero eggs hatching and no larvae progressing to second instars. Egg development duration was shorter as temperatures increased from 15 to 35 °C (62 versus 8 days). Larval development within F. pennsylvanica was faster at 30 °C than at 25 °C with more than 50% of larvae completing development from eclosion to prepupae at 30 °C in 45 days. At 30 °C, larvae took residence in mini-bolts at a higher rate in F. pennsylvanica (3.31 ± 0.19 larvae/mini-bolt) compared to F. excelsior (1.13 ± 0.13). Larval development to the first prepupa took 50% longer in F. excelsior than F. pennsylvanica. Future work will include more temperatures for both ash species and compare host differences on growth rates. These growth rates will be used to determine where a life cycle can completed and to enhance biological control release timing.

B. *Insect photography training - part 1 - Holly Munro.* This workshop will help attendees develop photography skills that are useful for publications, extension/outreach work, and recreational fun. The goals are to learn specifics on, 1) composition, such as depth

of field, lines, contrast, viewpoint, depth, negative and filled space, and lighting, 2) become familiar with photography equipment and settings both on cell phones and cameras, and 3) get hands on training and feedback.

   i. *General photography*
   ii. *Macrophotography and equipment*

C. *In search of fresh, tractable solutions to the wicked problem of destructive, non-native forest pests - part 1 - Enrico Bonello.* Wicked problems are those that lack a singular solution and change in response to attempts to solve them. Invasions of forest environments by insect pests and pathogens are definitely a wicked problem. The organizational infrastructure for combatting such invasions is decentralized, with responsibilities spread across multiple public and private entities, and as a result, incapable of protecting forest resources. Recent advances, e.g. in host resistance breeding, show promise as tools to rapidly and effectively deal with invasive forest pathogens, but as seen with infectious diseases such as the current COVID-19 pandemic, even the most promising solutions face serious implementation challenges. The COVID-19 pandemic highlights the perils of lack of national and global coordination in combating sinister, destructive pests, and may add needed perspective to the discussion of international approaches to combat invasive forest pests. This symposium will be a forum to discuss fresh solutions to this pernicious issue.

   i. *What is wickedness and how does it apply to the forest health crisis? - Geoff Williams.*
   ii. *Damian Adams*
   iii. *Assessing and managing invasive species: The need for a global framework - Matt Ginzel.*
   iv. *Engaging stakeholders in advocating promising strategies to curb destructive non-native pests - Faith Campbell*
   v. *Reducing the importation of forest pests and pathogens through Tree-Smart Trade - Gary Lovett*
   vi. *Using collective actions to address a social dilemma: Insights from invasive plant management by private forest landowners - Zhao Ma*

D. *Open Session 3 - Bill Riel*

   i. *Impacts of mountain pine beetle outbreaks on the structure and composition of and snag longevity in lodgepole pine forests - Jackson P. Audley, Christopher J. Fettig, A. Steven Munson, Justin B. Runyon, Leif A. Mortenson, Brytten E. Steed, Kenneth E. Gibson, Carl L. Jørgensen, Stephen R. McKelvey, Joel D. McMillin, and Jose F. Negrón.* Following historic mountain pine beetle, Dendroctonus ponderosae Hopkins (Coleoptera: Curculionidae), outbreaks in the Intermountain West, U.S. from 2004-2012, we investigated resulting tree mortality and the effects on forest structure and composition. A network of 125, 0.081-ha circular plots was established in lodgepole pine, Pinus contorta, forests in Colorado, Idaho, Montana, Utah, and Wyoming. Plots were installed in 2010 and sampled annually through 2019. 5107 trees died across the network, 98.6% of which were lodgepole pine. Most of the observed tree mortality (68.8%) was

attributed to D. ponderosae. The resulting mortality significantly reduced mean diameters at breast height (dbh; by 5.3%), quadratic mean diameter (by 8.6%), tree height (by 15.9%), numbers of trees (by 40.8%), basal area (by 52.9%), and stand density index (by 51.8%). Tree density significantly declined for all diameter classes (5-cm classes) except for the smallest (7.5-12.5 cm). Subalpine fir, Abies lasiocarpa, was well represented in the understory regeneration. We observed more A. lasiocarpa than P. contorta seedlings (≤0.3 m tall) in all states except Montana. An increased number of A. lasiocarpa saplings (>0.3 m tall and <7.6 cm dbh) contributed to the increase in the number of saplings observed across all states from 2010 to 2018. The number of snags (standing dead trees) increased substantially (by 1324.7%). Interestingly, 75.3% snags remained standing in 2019, prompting an interest in understanding snag longevity. We modeled snag fall rates using a Cox's proportional hazard model to estimate retention time and identify factors contributing to snag fall. Our model predicted a half-life of 16 years for lodgepole pines killed by D. ponderosae. Northern facing aspect was the most significant factor in prolonging snag retention. Snag height was also positively correlated with longer retention times except when a snag had a greater height to diameter ratios (i.e., tall with small dbh).

ii. *Elongate hemlock scale in Michigan: distribution, impacts, and natural enemies - Toby R. Petrice, Therese M. Poland, and F. William Ravlin*. Elongate hemlock scale, *Fiorinia externa* Ferris (Hemiptera: Diaspididae), is an invasive pest of eastern hemlock trees. This insect has been established in the Northeastern U.S. since the early 1900s but has just recently been discovered in Michigan. Managers are concerned about the impacts this pest may have on eastern hemlock and other host species in the Great Lakes region. In 2020, we initiated studies in Michigan to determine 1) the distribution and impacts of elongate hemlock scale on eastern hemlock and other host species (*Picea* spp., and *Abies*); and 2) the presence and impacts of natural enemies on elongate hemlock scale. At two locations where elongate hemlock scale is established in Michigan, we recorded elongate hemlock scale density, lifestages present, parasitism, predators, and hemlock shoot growth. We found that elongate hemlock scale was present on almost all trees at each site and scale infestations on individual trees ranged from very high (182 scales/100 needles) to low (2 scales/100 needles). Most live elongate hemlock scales overwintered as adult females with or without eggs; however, all life stages could be found at any given time during the season. To date, elongate hemlock scale has not been recovered from non-hemlock hosts (*Picea* spp. or *Abies* spp.) at survey sites. The scale parasitoid, *Encarsia citrina* Craw (Hymenoptera: Aphelinidae), was recovered from both sites with overall parasitism of female elongate hemlock scale averaging 44 %. We also recovered the predatory scale picnic beetle,

Cybocephalus nipponicus (Endrödy-Younga) (Coleoptera: Cybocephalidae) from both sites.

iii. *Why isn't hemlock woolly adelgid killing trees in its native range? The role of insect predators in managing hemlock woolly adelgid - Ryan S. Crandall, Joseph S. Elkinton, Jeffrey A. Lombardo.* For decades, hemlock woolly adelgid (HWA), *Adelges tsugae*, has devastated hemlocks (*Tsuga* spp.) in the eastern United States. Fortunately, the HWA biological control program has successfully established predatory beetle Laricobius nigrinus at many sites in the eastern U.S. However, recent studies have shown that although *L. nigrinus* exerts significant predation rates on the HWA spring generation, overall densities of HWA were not reduced. To better understand host tree and natural enemy influences on HWA populations in its native range, we conducted a predator exclusion study at the Washington Park Arboretum in Seattle, Washington. Using native western hemlock (*Tsuga heterophylla*), as well as plantings of mature eastern hemlock (*Tsuga canadensis*), we tested the effects of predation, as well as tree species, on the survival of HWA cohorts experimentally inoculated on pairs of branches. Predators were excluded on one branch of each pair with mesh bags. In both rounds of experiment, after successful inoculation of equivalent densities of HWA spring generation on both pairs of branches, we found that western HWA settled preferentially on western hemlock and that insect predators were responsible for significantly reducing and maintaining low densities of HWA on branches without bags. Round two results suggest that summer-active predators were responsible for significant reduction of the HWA spring generation. Our results demonstrate the importance of summer-active predator acting on the spring generation in reducing HWA densities. We also found that tree resistance did not play a significant role suppressing HWA densities as shown by HWA readily colonizing western hemlock.

iv. *Formation of stable hybrid zone between the invasive winter moth and the native Bruce spanworm in eastern North America - Jeremy C. Andersen, Nathan P. Havill, Joseph S. Elkinton.* Winter moth (*Operophtera brumata*) is a non-native invasive species that causes widespread defoliation to a number of forest, ornamental, and orchard tree and shrub species. Beginning in 2007 we established a transect along Route 2 in Massachusetts and in 2016 we established a transect along Route 1 in Connecticut in an effort to 1) document the westward spread of winter moth into the interior portions of New England, 2) to examine the presence of a hybrid zone, and 3) to identify abiotic factors associated with the spread of winter moth. Along our Route 2 transect, the leading edge of the winter moth invasion (i.e., where 10% of individuals were estimated to be winter moth) expanded at a rate of 5.48 ± 3.75 km/year while the core population (i.e., where 90% of individuals were estimated to be winter moth) moved 1.40 ± 3.48 km/year during that same period. In contrast along Route 1 in Connecticut the leading edge retreated 14.7 km while the core

population expanded 18 km in the three years of study. Along both transects we documented extremely high levels of hybridization with an average observed hybridization rate of 5.9 ± 0.7% across Route 2 and 4.9 ± 1.9% across Route 1. Our results indicate that while dynamic in nature, winter moth continues to spread westward into the interior portions of New England and that it has the potential become an important defoliator across much of the northeastern United States. Our documentation of a stable hybrid zone with high levels of genomic interchange between winter moth and Bruce spanworm suggests that the introgression of adaptive alleles is occurring, though what effect this has on the pest status of each species remains to be seen

v. *Abnormally high rainfall may cause regional hemlock woolly adelgid decline in the northeastern U.S. - Jennifer L. Chandler, Joseph S. Elkinton, David A. Orwig.* The exotic invasive forest pest, hemlock woolly adelgid (HWA; *Adelges tsugae*) is the cause of widespread hemlock (*Tsuga* spp.) mortality throughout the eastern United States. Since its arrival in the northeastern U.S. in the 1980's, HWA has steadily spread throughout eastern hemlock (*T. canadensis*) stands. However, in 2018, anecdotal evidence suggested a sharp, widespread HWA decline in the northeastern U.S following a summer of heavy rainfall. To quantify this decline in HWA density and investigate its cause, we re-surveyed HWA in hemlock stands along a long-term HWA-monitoring transect from northern Massachusetts to southern Connecticut. As previous research documented presence of native fungal entomopathogens on HWA in New England and rainfall is known to facilitate the propagation and spread of fungus, we hypothesized that heavy rainfall may facilitate fungal infection of estivating nymphs of the sistens generation leading to a decline in HWA density. We tested this hypothesis by applying a rain-simulation treatment to hemlock branches with existing HWA infestations in western MA. Our results indicate a regional-scale decline and subsequent rebound in HWA density that correlates with rainfall at each site. Experimental rain treatments led to higher proportions of diseased and dead estivating nymphs compared to controls. This observational and experimental evidence of a rainfall-mediated HWA decline, in conjunction with no evidence for increased winter mortality, implicate heavy rainfall as the cause of the regional-scale drop in HWA density. Isolation of the fungal pathogen(s) responsible for this HWA mortality is underway and may lead to identification of novel biocontrol agents

vi. *Emerald ash borer adult feeding preferences and larval performance on susceptible and "lingering" ash tree selections - Therese M. Poland, Jennifer L. Koch, Kathleen Knight, David Carey, Mary E. Mason, Toby R. Petrice.* The emerald ash borer (EAB), *Agrilus planipennis*, is the most destructive invasive forest insect pest ever to have invaded North America. It was first detected in 2002 near Detroit Michigan and has since spread to 38 states and 5 Canadian provinces where it has killed hundreds of millions of ash trees in urban and

natural forests and threatens the entire ash resource. In its native range in far eastern Russia, northern China, Japan, and Korea, it is generally only a pest of non-native ash or indigenous ash species that are stressed by other factors. Long term monitoring plots established in forested areas throughout Ohio and southeast Michigan, helped to identify surviving ash that may have reduced susceptibility or increased resistance to EAB. Individual "lingering" ash trees were selected for propagation and further experimentation that were 10 cm DBH or greater, had healthy canopies, and had survived for at least two years after stand mortality due to EAB exceeded 95%. Subsets of these select surviving trees were used in bioassays to determine EAB adult host choice and feeding preferences and larval development and survival. We compared the number of adults present on leaves of different lingering ash genotypes and susceptible controls as well as the area of foliage consumed in multiple choice experiments using cut leaves in screen cages or sleeve cages on pairs of live potted trees in a greenhouse. We also compared larval weight, developmental stage, and the number of larvae killed by host tree defenses by affixing eggs onto grafted ramets of lingering ash selections and susceptible controls. Our results demonstrate that some selections were significantly less preferred for feeding by EAB adults. Similarly, several lingering ash selections also displayed resistance to EAB through reduced larval weight, delayed larval development, and/or larger numbers of larvae killed by host tree defenses. These measurable phenotypes likely explain why some ash genotypes have survived EAB attack longer than the majority of their counterparts, and indicate that more than one mechanism may be responsible. Clone tests of lingering ash genotypes have been planted to assess field performance relative to the bioassay results. Genetic studies are underway to develop a breeding program to generate seed improved for EAB resistance, appropriate for ash restoration plantings.

vii. N.F. Quinn, J.S. Gould, C.E. Rutledge, J.S. Elkinton, and J.J. Duan. *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), or emerald ash borer is an invasive wood-boring pest of ash trees (*Fraxinus* spp.) in the US. It is responsible for catastrophic decline of ash in urban and forested ecosystems, resulting in millions of dollars in injury and losses. Biological control is thought to be one of the most promising management options available to reduce A. planipennis spread and impact. To this end, from 2015 to 2017 two larval parasitoids of A. planipennis from its native range, *Spathius galinae* Belokobylskij & Strazenac (Hymenoptera: Braconidae) and *Tetrastichus planipennisi* Yang (Hymenoptera: Eulophidae), were released in wooded areas in New York and Connecticut. The purpose of this study was to measure the long-term spread and phenology of the released parasitoids. From May to September 2020, sentinel ash logs containing EAB larvae were deployed in naturally occurring A. planipennis - infested trees at each release site. Additional logs were deployed in 2 km intervals up to 14 km away from the release site. Logs were replaced every two

weeks and the parasitization rate was recorded. Each month, three trees from each release area were cut and debarked to record A. planipennis infestation levels, natural parasitization rates, and *A. planipennis* and parasitoid phenology. We observed that both S. galinae and *T. planipennisi* emerged from the first replicate of logs deployed from the end of May to early June as far as 12 km away from the release site. Parasitization peaked in July and August, with sentinel logs deployed at each distance producing both species throughout the summer until mid-September. Both S. galinae and T. planipennisi were collected 14 km away from the release sites, the greatest distance away from the release sites sampled. Debarked trees produced similar findings, with relatively more immature specimens of both parasitoids collected in May and June, while adults and cocoons were relatively more frequently observed in samples collected from July and August. Our results indicate that the classical biological control program initiated several years ago has successfully produced a self-sustaining population of both *S. galinae* and *T. planipennisi*. Additionally, our results suggest that these parasitoids are capable of spreading relatively quickly. This can be used to inform future release efforts, allowing for strategic spacing of release points across geographic regions. Overall, our study suggests that both *S. galinae* and *T. planipennisi* may continue to spread, increasing the biological control of *A. planipennis* over time across spatial scales.

viii. *The role of native natural enemies in the successful biological control of winter moth in the northeastern United States - Hannah J. Broadley, Joseph S. Elkinton, George H. Boettner.* Winter moth, *Operophtera brumata*, a polyphagous caterpillar was accidentally 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. We established C. albicans at sites across the northeastern U.S. and 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. We built on this earlier research and, over five field seasons, deployed winter moth sentinel pupae in the field to determine rates of predation and parasitism, m across a range of winter moth pupae and C. albicans puparia densities. Mortality on the pupae was high across sites and years (85 to 95%) and is primary caused by a diverse community of generalist ground predators. In years when winter moth densities were high prior to the establishment of *C. albicans* we did not observe density dependent mortality. Since 2016 however, *C. albicans* has become widely established and winter moth densities have decreased to a level comparable to what was found it its native range. And we have found that

mortality on the pupae was density dependent and thus may stabilize winter moth at low density. Overall, our research shows 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.

3:00 – 3:30 Break

3:30 - 5:30 Concurrent Session 4

A. *When do old plays work & when do we need to rewrite them? - part 2 - Chris MacQuarrie, Sandy Smith.*

i. *The legacy of managing mountain pine beetle in British Columbia: the science and the policy - Lorraine Maclaughlan.* The pine forests of British Columbia have experienced many large-scale mountain pine beetle (MPB) outbreaks that have resulted in mortality of hundreds of millions of trees over expansive areas of forest. In response to these landscape-level events, foresters and scientists have developed a suite of management strategies and tactics to mitigate the impacts of MPB. When major infestations of both spruce beetle and MPB erupted in central B.C. in the 1970s and 1980s this prompted the B.C. government to develop a coordinated response, resulting in the creation of the Pest Management Program (now Forest Health); and, so began the battle of the beetles in B.C. When the last, and largest, MPB outbreak on record began to develop in north central British Columbia during the 1990s, federal and provincial governments once again looked to their top scientists for guidance to take on this monumental challenge. In this presentation I will describe intervention techniques used to control MPB, and B.C.'s current strategies that incorporate new technology, modelling, harvesting and scientific insight. I will also highlight the never-ending challenges faced by forest mangers such as sheer physical scale, climate change and the biological, social and political intricacies. But the most pressing questions may be what have we learned and how will our future management of MPB differ?

ii. *How have phytosanitary approaches to address forest-product pest management changed? - Meghan Noseworthy.* In the past, pest mitigation of forest products has relied mainly on fumigation and heat treatments to reduce the associated pest risk. Today a wider variety of options are available, including systems approaches, new methods for applying heat treatment and lower dosages of both fumigants and heat. International and regional standards for phytosanitary measures provide guidelines for adoption of new treatments, and options available for appropriate pest-risk reduction measures, with the ultimate goal of reducing the movement of plant pests and protection of forests.

iii. *Entomology notes from a small island: impact & management of invasive forest pests in Britain - Daegan Inward.* The spread of invasive species by international trade is a global concern, and Great Britain's long trading history has provided a wealth of opportunity for the accidental (and deliberate) introduction of non-

native organisms to its shores. Yet compared with continental Europe and North America, the impact of invasive forest insects in Britain has been relatively limited to date. This talk will explore key introductions and pest threats from recent years, what factors might be limiting more widespread damage, and whether this can help to direct horizon scanning and surveillance activities in an uncertain future.

B. *Insect photography training - part 2 - Holly Munro.*
    i. *How to take photographs with a cell phone, helpful tips, and useful equipment/settings*
    ii. *How to take photographs with a camera, helpful tips, and useful equipment/settings*
    iii. *Post conference feedback on images via e-mail*
C. *In search of fresh, tractable solutions to the wicked problem of destructive, non-native forest pests - part 2 - Enrico Bonello.*
    i. *Genetic Resistance in forest trees: Time to move it to the forefront - Richard Sniezko*
    ii. *Centers for forest pest control and prevention: Our call to action? - Enrico Bonello*
D. *Highlighting early career professionals in forest health - Jess Hartshorn, Molly Darr.* The symposium will have broad interest in that the proposed speakers' areas of interest span climate change impacts on tree defenses to insects and pathogens, population genetics of pests in forests, social impacts of forest management, and impacts of invasive species
    i. *Impacts of tree ontogeny and biotic stressors on the composition of secondary metabolites within the phloem tissue of two species of ash (Oleaceae: Fraxinus) in New Hampshire - Todd Johnson.* Since its accidental introduction into North America three decades ago, the invasive emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) has spread rapidly throughout the United States and killed millions of ash trees (Oleaceae: *Fraxinus*). This has resulted in severe ecological damage to natural and managed forests and economic losses exceeding billions of dollars. While most North American ash that are attacked by *A. planipennis* die, there is increasing evidence that some trees have the capacity to resist the beetle for longer periods of time, or to avoid attack altogether. This pattern is exemplified in smaller diameter ash trees where *A. planipennis* experience reduced levels of larval survival relative to larger trees of the same species. Here we report on our ongoing study to understand how ontogeny influences the composition of constitutive secondary metabolites, and how artificial infestation by *A. planipennis* and application of the plant hormone methyl jasmonate may interact with ontogeny to alter these chemical profiles within the phloem of green (*Fraxinus pennsylvanica*) and white (*Fraxinus americana*) ash across four diameter classes. Preliminary analysis indicates that prior to induction, the composition of secondary metabolites is similar

regardless of size class. After induction, there is a large divergence in the composition of secondary metabolites according to size class, which may reflect that defensive strategies of ash are age-dependent. This research will increase our understanding of defensive strategies of *Fraxinus*, informing horticultural or silvicultural strategies to maintain healthy ash in light of the current invasion by *A. planipennis*.

ii. *The value of hybrid and nonnative ash for the conservation of ash specialists in regions invaded by emerald ash borer - Kayla Perry*

iii. *Browntail moth: of all the labs in all the towns, you had to fly into mine - Angela Mech.*

iv. *What bugs trees: an interdisciplinary approach to evaluating insect disturbances in western North America. - Jodi Axelson.* In western North America, disturbances impact thousands to millions of hectares of forests annually, and in many regions, insects are the leading cause. Forest insects can be characterized by their guilds, each leaving their own signature on tree growth, mortality, and ecological patterns and processes. Two insect guilds – bark beetles in the genus Dendroctonus and defoliators in the genus Choristoneura have extensive ranges throughout North America and in many systems result in significant damage. Bark beetles are tree killers and outbreaks result in large pulses of mortality of their hosts. Thus, outbreaks are a stand releasing disturbance at small spatial scales, and at large spatial scales can reorient successional trajectories across the landscape. Defoliators, on-the-other hand, rarely result in the death of their host, and instead outbreaks result in stand-to-landscape scale suppression signals in the tree-ring record. Here, I evaluate the compositional and structural changes that resulted from extensive bark beetle outbreaks in mixed conifer forests of the Sierra Nevada in California during and after the 2012-16 drought. At the stand scale I will explore how wood anatomical characteristics are modified by a chronic western spruce budworm outbreak in xeric Douglas-fir forests of southern British Columbia.

5:00 **Break**

5:30 **Banquet –** *Not Boring: How digging deep and branching out will shape the future of forest entomology - Kristie Riddick, Bug Chicks*

Student Awards

Friday, May 28

8:30 **Business meeting and awards**

9:00 **Concurrent Session 5**

A. *Macroscale drivers of forest insect dynamics: distributions, abundances, and impacts - organizers - Sam Ward.* This session will cover several different mechanisms by which native and non-native forest insects undergo large scale shifts in their distributions and/or abundances. Presentations will focus on the drivers of invasions (arrival,

establishment, and spread), range shifts, and outbreaks. Speakers will highlight the many contributions macroscale ecology (a growing subdiscipline in ecology) has already made to forest entomology, and identify areas in which the diversity of technologies used in macroscale investigations (e.g., remotely sensed and other forms of big data) can be further leveraged and integrated to understand the dynamics of insect populations.

i. *Exploiting species-habitat networks to improve wood-boring beetle surveillance in areas surrounding entry-points - Davide Rassati, Manuela Branco, Claudine Courtin, Massimo Faccoli, Nina Feddern, Emily Franzen, André Garcia, Martin Gossner, Mats Jonsell, Matteo Marchioro, Petr Martinek, Alain Roques, Jon Sweeney, Lorenzo Marini.* Ever-increasing international trade along with ongoing changes in trade networks is causing an impressive number of forest insect introductions. This trend is particularly evident for wood-boring Coleoptera, especially bark and ambrosia beetles, longhorn beetles, and jewel beetles. Traps baited with attractive lures placed around entry points are commonly used to complement visual inspections and improve chances of intercepting incoming species soon after their arrival. Nonetheless, it is still unclear which are the optimal sites where to set up these traps and how landscape composition can affect the chances of intercepting incoming species. In order to investigate these patterns, we used multi-funnel traps baited with a multi-lure blend in areas surrounding 13 entry-points, which were spread in a number of countries (France, Portugal, Italy, Sweden, Italy, USA, Canada, Switzerland and Czech Republic). Sixteen traps were deployed at each selected site based on a grid of 2 x 2 km defined a priori, with one trap per each cell of the grid. Selected sites covered a gradient of forest cover (from urban-dominated areas to forest-dominated areas). Traps were left in the field for 5 months and all trapped beetles were identified to species. Linking the structure of native and exotic wood-boring beetle communities to landscape composition at different spatial scales (i.e., within-site and among-sites) it will be possible to understand where exotic species are more prone to establish after their arrival in a new environment, and thus which are the optimal sites where to set up baited traps

ii. *Alien forest pest explorer: an online portal for exploring ranges of non-indigenous forest pests and the status of their host tree species - Randall S. Morin, Songlin Fei, Andrew M. Liebhold, and Susan J. Crocker.* Invasions of damaging non-native forest pests are known to affect growth and mortality of host trees. National forest inventory data collected by the US Forest Service's Forest Inventory and Analysis (FIA) program can be used to quantify the impact of these pest species on host tree abundance as well as host growth and mortality rates. The Alien Forest Pest Explorer (AFPE) has been revamped as a portal for the exploration of spatial data describing the ranges of known damaging non-indigenous forest pests established in the United States and the status and trends in their host tree species. The online, interactive tool includes dozens of forest insects and about 15 species of forest pathogens. This site can be used to view and download maps and pest alerts for each of the forest pests

as well as statistics about their host tree species from regional FIA data. The AFPE was designed as a data resource for forest health specialists, foresters, and the public. The home page includes a data dashboard that allows for national/regional examination of the number of pest invaders and host tree densities that are at risks. Additionally, individual data dashboards for the most widely distributed and damaging pests provide for investigation of pest range spread, host tree abundance trends, and host tree growth and mortality statistics. Such results demonstrate how forest pest invasions can profoundly modify forest dynamic processes, resulting in long-term changes in forest ecosystems.

iii. *Assessing drivers of local range expansion across the invasive range of a high-profile insect pest - Gabriela C. Nunez-Mir, Jonathan A. Walter, Kristine L. Grayson, and Derek M. Johnson.* Macroscale studies are able to produce useful insights for invasion management, particularly when localized information about the dynamics of specific invasive species is unavailable. Here, we present a macroscale study of the roles of invasion drivers on the local dynamics of a high-profile pest, *Lymantria dispar*. Specifically, we assessed the relative effects of various anthropogenic and environmental variables on local diffusive spread rates of this high-profile pest across its invasive range in the United States. We applied a Bayesian probabilistic framework to annual gypsy moth trap catch data from 1985 to 2015 in order to determine the probability of gypsy moth establishment in 5 by 5 km quadrats. We then calculated the establishment rate of 8,010 quadrats by measuring the number of years from first detection of L. dispar to the year when probability of establishment was 99% or more in these quadrats. To assess the effects of environmental and anthropogenic variables on each quadrat's establishment rate, we performed linear mixed-effects regression models for three different sub-regions within the invasive range, plus a range-wide model. Seasonal temperatures were found to be the primary drivers of local establishment rates across. Furthermore, the effects of some factors waiting times to establishment varied across sub-regions. Our findings describe a hierarchy of factors that influence local range dynamics of a high-profile pest, and describe how these interactions change across the U.S. invasive range, highlighting the utility of macroscale studies.

iv. *A review of forest disturbance attribution using remote sensing - Arjan J.H. Meddens, Amanda Stahl, and Robbie Andrus.* Ecological disturbances are an integral component of forest ecosystem dynamics. Remotely sensed data offer a spatially extensive and temporally consistent record over the past several decades (e.g., Landsat 1984 to present) for monitoring disturbances in forest ecosystems. Researchers have developed methods to successfully detect many types of abiotic and biotic disturbances that operate across a range of spatial and temporal scales during the last two decades. Many studies have highlighted that disturbances can be detected with relatively high levels of accuracy (~90%). Far fewer studies have demonstrated methods to accurately attribute detected disturbances to a specific disturbance type, and land managers need to know

disturbance type to inform effects on forest dynamics. Our objective was to synthesize studies that report on (semi-) automated forest disturbance attribution using remotely sensed data and/or geospatial analysis. We report on the current state of algorithm development (i.e., methods), evaluation methods, and the accuracy of attribution by disturbance type. Finally, we make recommendations for future directions that will improve automated disturbance attribution.

v. *Tree diversity and bark beetle outbreaks in subalpine forests of the Rocky Mountains - Sarah J. Hart.* Coincident with recent warm and dry conditions, native bark beetles have killed conifer trees across 22.5 M hectares of forest in the western United States. In the Interior West, much of the tree mortality has been concentrated in subalpine forests, where the mountain pine beetle (MPB; *Dendroctonus ponderosae*), spruce beetle (SB; *D. rufipennis*), and western balsam bark beetle (WBBB; *Dryocoetes confusus*), have caused extensive mortality lodgepole pine (*Pinus contorta*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*), respectively. Given these bark beetle species affect only one or several tree species, a common management goal to mitigate the effects is to promote species diversity. Yet, many stands are composed of a mix of pine, spruce, and fir and it remains poorly understood how tree species diversity affects tree survival in the face of multiple bark beetle outbreaks. Here, I use USFS Forest Inventory and Analysis (FIA) data to examine the effects of diversity on patterns of tree mortality due to MPB, SB, or WBBB activity across subalpine forests. I found the probability of either MPB, SB or WBBB occurring within a stand was greatest when all three hosts were present, but the severity of cumulative bark beetle activity was greatest when only one host was present. In stands with multiple hosts, the co-occurrence of multiple bark beetle species occurred infrequently (ca. 5% of plots), but generally resulted in higher severity infestation. These results highlight the importance of managing forests in the context of multiple bark beetle species.

vi. *A method for detecting fundamental changes in population dynamics across landscapes and over time - Devin W. Goodsman.* I will introduce an approach that enables researchers to confirm that a fundamental change in population dynamics has occurred. This approach will enable researchers to delineate regions in which population dynamics have changed. I will then demonstrate the approach using several historical data-sets of insect abundance collected by the Canadian Forest Service.

B. *Caught in the middle: forest insect and disease challenges in Minnesota - Brian Aukema.* This session highlights forest insect and disease challenges of relevance to Minnesota, the state that was expected to be the host before the meeting went virtual. This session showcases how state, federal, and university partnerships engage to prioritize and confront forest health challenges whose impact reaches beyond the state's borders. This session will highlight basic, applied, and regulatory issues across several forest types in the Great Lakes region.

i. The Minnesota Invasive Terrestrial Plant and Pest Center model - Rob Venette.

ii. *The search for associational protection in urban forests treating for emerald ash borer - Dora Mwangola.*
iii. *Image analysis homes in on oak wilt pockets in Minnesota - Rachael Dube.*
iv. *Resurgence of larch casebearer - Samuel Ward.*
v. *Trichoferis campestris, a new exotic woodborer now found in Minnesota - Grace Haynes*
vi. *A new pest of concern in the state with regulatory implications: elongate hemlock scale - Angie Ambourn.*

C. *When 'native' species have an 'exotic' response - Tara Bal.* Challenges with new associations between organisms continue to emerge due to multiple factors. Significant 'exotic' damaging agents may no longer be coming from a different continent, but with climate change and anthropogenic change, novel encounters will occur, as endemic species respond via range expansion, population dynamics, trophic interaction shifts, or in other ways. Forest pest management has been increasingly balancing efforts between 'exotic' and 'native' pests, which poses additional challenges for the larger social and political landscape as we develop a better understanding of how species will respond, leading to decisions about how species interactions are mitigated
    i. *Eastern larch beetle: celebrating twenty years of outbreak (and counting) - Brian Aukema.* The eastern larch beetle, Dendroctonus simplex, is found throughout the range of eastern larch or tamarack, Larix laricina. Native to North America, the insect typically colonizes weakened or downed tamarack but may kill live trees when populations build. Tree-killing outbreaks have historically not lasted more than two to five years. In the Great Lakes region, however, eastern larch beetle has been killing mature tamarack since 2001. In Minnesota, a 20-year outbreak now covers more than 500,000 acres of mature tamarack covertype in the northern part of the state. In this presentation, I summarize past research on correlates of the outbreak related to changing climatic conditions and preview the next steps we'll be undertaking to understand the behavior of this system.
    ii. *Phenological synchrony between eastern spruce budworm and its host trees increases with warmer temperatures in the boreal forest - Deepa Pureswaran.* Phenological synchrony between herbivorous insects and their host trees is critical to insect performance in temperate climates with short growing seasons. Climate change is predicted to alter relationships between trophic levels by changing the phenology of interacting species. We tested whether synchrony between two critical phenological events, budburst of host species and larval emergence from diapause of eastern spruce budworm, increased at warmer temperatures in the boreal forest in north-eastern Canada. Budburst was up to 4.6±0.7 days earlier in balsam fir and up to 2.8±0.8 days earlier in black spruce per degree increase in temperature, in naturally occurring microclimates. Larval emergence from diapause did not exhibit a similar response to increased microclimate temperature. Instead, larvae emerged once average ambient temperatures reached 10°C, regardless of differences in microclimate. Phenological synchrony (lag between onset of budburst and peak larval

emergence) increased with warmer microclimates, tightening the relationship between spruce budworm and its host species. Synchrony increased by up to 4.5±0.7 days for balsam fir and up to 2.8±0.8 days for black spruce per degree increase in temperature. Our results suggest that under a warmer climate, defoliation would begin earlier in the season, potentially increasing damage on the primary host, balsam fir. Black spruce, a secondary host which escapes severe herbivory because of a two-week delay in budburst, would become more suitable as a resource to the spruce budworm. The northern boreal forest where black spruce dominates but balsam fir is a significant component could become more vulnerable to outbreaks in the future.

iii. *Drivers increasing ticks and tick-borne diseases in North America - Maria Diuk-Wasser.* Tick-borne diseases continue to emerge and geographically expand in North America and worldwide. Factors driving the spread of Ixodes spp., the vectors of Lyme disease and other 6 human pathogens in the US, include climate and land use changes, tick vector and host population growth, as well as changes in people's behaviors affecting exposure. Other expanding endemic tick vectors include the lone star tick, Amblyomma americanum, and the dog tick, Dermacentor variabilis. The longhorned tick, Haemaphysalis longicornis, has recently invaded North America and is a potential vector. of human and livestock pathogens. I will describe the patterns and drivers of emergence of these endemic and invasive ticks, and discuss approaches to control or mitigate human health risks.

iv. *Southern pine beetle behavioral shifts through space and time - Steve Clarke.* As an eruptive bark beetle, the southern pine beetle (SPB), Dendroctonus frontalis Zimmermann, can exhibit invasive behavior during periodic outbreaks. Behaviors also can vary by season, location, and forest composition. The potential causes and consequences of behavioral shifts will be discussed.

v. *Shifting mountain Pine Beetle range and implications of host expansion in naïve forests - Allan Carroll.*

10:30 Break

11:00 Concurrent Session 6

A. *Status and management of world changing invasive forest pests - Scott Salom.* Part of our changing world in forestry has been the devastation caused by non-native insects and plant pathogens. While there are literally hundreds of species that could be covered, five species, four of which have a long history of impacting our forest ecosystems and one more recent, are presented here in the context of: 1. Current spread, damage, and impacts; 2. Integrated efforts towards management; and 3. Predicting the aftermath of invasion and success in management. Each pest has had major investment in study, and as a result, demonstrate the challenges that are faced when non-natives flourish in North America attacking trees and other plants with little or no resistance to them. It is suggested that investment into the study and management of forest pests, whether native or non-native, requires urgency as we struggle to maintain healthy native forest ecosystems.

i. *European gypsy moth - Tom Coleman.* After more than 150 years gypsy moth still dominates forest pest management in the USA. Since the late 1860's, European gypsy moth continues to be a prominent threat to oak-dominated forests in the USA. Cyclical outbreaks continue to impact the eastern part of the country with recent outbreaks occurring in Connecticut, Massachusetts, and Rhode Island (2015 to 2018) and western Virginia (2016 to 2018). In recent years, populations have increased in Michigan and Pennsylvania, necessitating suppression treatments in 2021. Gypsy moth spread from quarantined areas has been limited by an aggressive management program. The USDA National Gypsy Moth Management Program guides gypsy moth management with four strategies: 1) Suppression, 2) Slow-the-Spread, 3) Eradication, and 4) Regulatory activities. Recent eradication treatments have successfully eliminated outlying populations in several eastern, central, and western states. For 20 years, the National Gypsy Moth Slow the Spread Program, comprised of multiple state and federal agencies and a non-profit foundation, has been the focus of gypsy moth management. Slow the Spread annually monitors tens of thousands of traps and treats hundreds of thousands of acres with mating disruption and biological control strategies, which target newly established populations. The program has successfully slowed the rate of spread of gypsy moth with a comprehensive integrated pest management program. Eradication treatments and an international monitoring program have successfully prevented the establishment of Asian gypsy moth in the USA.

ii. *Spread, impact and management of hemlock woolly adelgid in eastern North America - Albert Mayfield, Scott Salom, Robert Jetton, Nathan Havill, Rusty Rhea.* Seven decades after its initial introduction, the hemlock woolly adelgid (HWA) continues to gain new ground in its persistent invasion of hemlock forests in eastern North America. Although eastern hemlock is not a prized commercial timber species, substantial ecological and aesthetic impacts from HWA are compounded by economic costs associated with property value losses, management efforts, and research. Applications of existing tools and new developments in the areas of biological control, chemical control, silviculture, gene conservation, and host resistance are important near- and long-term components of an integrated management approach to this persistent invasive pest.

iii. *Protection of ash stands against emerald ash norer with biological control: Recent progress and potential for success - Jian J Duan, Therese Poland, Leah S. Bauer, Roy Van Driesche, and Joe Elkinton.* Ash trees (*Fraxinus* spp.) are an important component of both natural forests and urban plantings in the United States and Canada. However, the unexpected arrival of emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire) from Asia during the 1990s threatens the persistence of North American ash in mixed hardwood stands. Despite early efforts by U.S. and Canadian regulatory agencies to eradicate and contain EAB after its discovery in southeast Michigan in 2002, this invasive beetle has spread to 38 U.S. states and five Canadian provinces and has killed hundreds of millions

of ash trees in both urban and natural forests. Although systemic insecticides are now available to control EAB in ash trees, injections are used mainly to protect high-value landscape trees in urban areas. Introduction and establishment of natural enemies from the pest's native range (northeast Asia) for biological control provides a viable option for long-term and sustained suppression of EAB in natural forests. Implementation of biological control for EAB began in 2007 in southern Michigan after APHIS issued permits allowing environmental release of three EAB parasitoid species from China. These biocontrol agents included two larval parasitoids, *Tetrastichus planipennisi* (Eulophidae) and *Spathius agrili* (Braconidae), and an egg parasitoid, *Oobius agrili* (Encyrtidae). In 2015, a fourth EAB larval parasitoid, *Spathius galinae* (Braconidae) from the Russian Far East, was approved for release. With the help of researchers, land managers, and landowners, EAB parasitoids have been released over 25 EAB-infested states and two Canadian provinces since 2007. In this presentation, we first briefly review the current EAB biocontrol program that involves introduction and establishment of hymenopteran parasitoids from northeast Asia and then present our most recent findings on the impact of these introduced natural enemies on EAB population growth and ash stand recovery in the aftermath of the initial EAB outbreak. In particular, we will discuss whether natural enemies (parasitoids) can hold EAB populations to a low enough density to allow ash to regenerate and recover.

iv. *Status and impacts of laurel wilt disease in North America - John J. Riggins, John P. Formby, Frank H. Koch, Jason A. Smith, Marc Hughes, Adam Chupp, Natalie Dearing, Hannah Bares, Natraj Krishnan, Richard Brown, Kelly Oten, Don Duerr.* Laurel wilt is a non-native tree disease that continues to impact naïve plants of the family Lauraceae in the United States. This disease is caused by an introduced vector (*Xyleborus glabratus*) and a pathogenic fungal symbiont (*Raffaelea lauricola*). All North American shrub and tree species in the plant family Lauraceae that have been tested thus far are susceptible. We estimated that over 300 million individual redbay trees (*Persea borbonia*), or >1/3 of the pre-invasion population, succumbed to the disease within the first 15 years of the invasion. Genetic markers indicated that the vector and pathogen entered North America as a single introduction. We studied the cold temperature ecophysiology of X. glabratus and concluded that less than 1% of sassafras trees in North America occur in a climate cold enough to limit the beetles' eventual range. With apparent minor limitations on the spread of LWD, trophic cascades in the wake of this devastating invasion are possible. To document the radiating impacts of this disease on invertebrates that rely on hosts within the Lauraceae, we compiled a database of all known invertebrate interactions with North American Lauraceae, which yielded a list of 178 associated invertebrate species, at least 24 of which may suffer substantial declines alongside their lauraceous hosts. Overall, the lack of effective control options and a vector system well-suited to invading new territory in North America have enabled LWD to become one of the most destructive tree diseases on record.

v. *Successful biological control of winter moth, Operophtera brumata, in the northeastern United States - Joseph S. Elkinton, George H. Boettner, Hannah J. Broadley, Richard Reardon, Ronald Weeks.* Winter moth, *Operophtera brumata* L., native to Europe, invaded the northeastern United States in the late 1990s, where it caused widespread defoliation of forests and shade trees ranging from 2,270 to 36,360 ha per year between 2003 and 2015 in Massachusetts. In 2005, we initiated a biological control effort based on the specialist tachinid parasitoid *Cyzenis albicans*, which had successfully controlled winter moth in Nova Scotia in the 1950s and British Columbia in the 1970s. Each year for 14 years, we collected several thousand individuals of *C. albicans* from British Columbia and released them across widely spaced sites in the northeastern United States. As of 2020 we had established *C. albicans* at 41 of 44 sites from coastal Maine to southeastern Connecticut. By 2016 winter moth densities (pupae/m2) had declined at least 10-fold at six widely spaced release sites and the decline was coincident with the onset of 10-40% parasitism. At one site where this decline occurred in 2012, winter moth densities have remained low for eight subsequent years. Since 2016, defoliation by winter moth in Massachusetts has been reduced to undetectable levels by aerial survey. DNA sequencing of the CO1 barcoding region of the mitochondrial gene confirmed that all *C. albicans* reared from winter moth were distinct from flies reared from Bruce spanworm, *Operophtera bruceata*, the native congener of winter moth. Parasitism was thus the result of the introduced flies from Vancouver Island and not from native flies. As far as we know, winter moth represents the only example of biological control that has succeeded in reducing a major forest defoliator, attacking many tree species, to non-pest status anywhere in the world.

vi. *Impacts of spotted lanternfly on hardwood trees - Kelli Hoover, Osaiyekemwen Uyi, Emily Lavely, and David Eissenstat.* Spotted lanternfly (SLF) is a voracious, phloem-feeding planthopper first discovered in N. America in one county in Southeastern Pennsylvania about 6 years ago. There are now 32 PA counties in quarantine and breeding SLF populations in 8 other states, most with state-mandated quarantine zones. SLF adults use transportation corridors as a pathway for long distance spread; they hitchhike on railroad cars, trucks, and in cargo holds of airplanes. SLF is polyphagous in both its native and introduced ranges but has a strong preference for the invasive plant *Ailanthus altissima* (tree of heaven). In a study using 4 established hardwood tree species in large enclosures, half that contained Ailanthus and half that did not, SLF developed from egg to adult and produced viable eggs. However, it took adults two weeks longer to begin oviposition in the absence of Ailanthus. This study also allowed us to document host preference by life stage over the course of the season and there was a negative relationship between diameter growth and host preference. In studies using a common garden, red maple, silver maple, and Ailanthus had reduced photosynthesis, stomatal conductance, transpiration and carbohydrate content following moderate or high SLF feeding pressure. Documenting impacts on tree health (growth) in forest ecosystems is a difficult

undertaking, in large part because of the unpredictable nature of this pest. SLF nymphs and adults can move long distances during a season that lasts from May through early November. Slowing the spread of SLF is proving to be a major challenge for pest managers.

B. *Balsam woolly adelgid: range expansion, climate change, and the effects and impacts on ecosystems and management - Lia Spiegel, Iral Ragenovich.* In the late 1950's and early 60's Balsam woolly adelgid caused significant mortality in both the eastern and Pacific northwestern true fir communities. Almost 50-70 years later it has begun significant range expansion into the interior west, affecting new ecosystems. Changes in length of season and warming temperatures may be influencing populations. In areas where it has been long established, residual host may be growing into a new susceptible stage. There will be no formal presentations in this workshop, rather it will be a conversation about the most current knowledge and research, as well as making recommendations, and identifying research needs.
    i. *What do we know about BWA phenology and what is still missing?*
    ii. *What do we know about environmental effects on BWA; and BWA range expansion and ecological effects of BWA on resources?*
    iii. *What do we know about BWA impacts on trees, species susceptibility, and location?*
    iv. *What management options (i.e. suppression, genetic resistance, or silviculture, etc) are currently available or needed?*

C. *Biochar as a soil amendment treatment for restoring forest stands - Steve Cook.* As a soil amendment, biochar is useful for sequestering carbon, with other benefits related to its physical structure that increases the retention of H2O and nutrients while reducing soil acidity and nutrient leaching. Biochar treatments can directly impact plant health and improve habitat for beneficial microorganism but can also cause shifts in soil microbial communities. Additionally, some insects show delayed development, decreased fecundity, lowered egg hatch and increased mortality under various application conditions. Such indirect affects need further examination. The session will address direct and indirect effects of biochar on soil properties and biotic communities.
    i. *Changes in insect communities following biochar applications in restoration projects - Steve Cook.*
    ii. *Biochar influence on termite populations and communities - Brad Kard.*
    iii. *Fungal community composition following treatment with soil amendments - Daniel Lindner.*
    iv. *Impact of biochar on physical and chemical properties of soil - Deborah Page-Dumroese.*

D. *Open Session 4 - Jeff Garnas*
    i. *What's the buzz? Bees, biological control, and Chinese tallow tree (Triadica sebifera) - James Vogt, Rabiu Olatinwo, Michael Ulyshen, Rima Lucardi and Jessica McKenney.*
    ii. *Comparing the role of propagule pressure in the colonization success of Hylurgus ligniperda and Ips pini - Kevin Chase, D Kelly, AM Liebhold, and EG Brockerhoff.* A crucial factor affecting the colonization process of invading species is

propagule pressure, the size and frequency of arriving populations. A key determinant contributing to propagule pressure effects on invasion success is the 'Allee effect', which is defined as increasing population growth with increasing abundance. We conducted parallel experimental releases using two species of bark beetles, *Hylurgus ligniperda* in New Zealand and *Ips pini* in North America, to (i) quantify colonization thresholds, (ii) empirically test for Allee effects, and (iii) assess the role propagule pressure in invasion success. Establishment success was positively associated with release density (i.e., propagule pressure) for both species but colonization success generally occurred at lower densities for *H. ligniperda* than for *I. pini*. We discuss the biological characteristics determining colonization success. Our results linking invasion failure to small founding population sizes generally support the theoretical literature on the role of propagule pressure and Allee effects in biological invasions.

iii. *Amitinol: A possible pheromone component for I. calligraphus that is generated post-release - Brian T. Sullivan and William P. Shepherd.* The pine-killing bark beetle *Ips calligraphus* has been shown to release a two-component aggregation pheromone consisting of the monoterpenes ipsdienol and cis-verbenol; these are produced by attack-initiating males shortly after entering the phloem. To identify attack-mediating semiochemicals for this species that may have been overlooked in previous research, we investigated beetle olfactory sensitivities using gas chromatography-electroantennographic detection (GC-EAD). As expected, ipsdienol and cis-verbenol present in volatiles collections of male-initiated gallery entrances produced strong antennal responses; however, a third compound not previously reported in association with I. calligraphus, amitinol, also produced strong responses from antenna of both sexes. Hindgut extracts of male beetles contained ipsdienol and cis-verbenol but no more than trace amitinol, whereas frass extruded from galleries contained all three compounds. A similar finding was reported for ipsdienol-producing species of *Ips* in Europe, and these researchers showed that amitinol could arise from rearrangement of ipsdienol under conditions of low pH. Trapping experiments failed to find behavioral activity for amitinol with *I. calligraphus* when the compound was presented either with or without the known components of the aggregation pheromone. The origins of amitinol and its possible role in the chemical ecology of Ips calligraphus and other species of Ips will be discussed.

iv. *Gene silencing as a novel tool for emerald ash borer management - Flavia Pampolini and Lynne K. Rieske.* RNA interference (RNAi) is a naturally occurring cellular immune response triggered by exogenous double-stranded RNA (dsRNA) that induces the RNAi pathway, leading to silencing of genes and disruption of protein function. The sequence complementarity of the RNAi pathway allows for targeted suppression of genes essential for insect survival, which enables development of pest management strategies specific to a given pest species. Manipulating the RNAi pathway can cause mortality in the highly

invasive emerald ash borer (EAB), *Agrilus planipennis*. We found no nontarget effects of dsRNAs targeting the EAB genes hsp, shi and sn-rnp in model insects representing five functional guilds, confirming a high degree of specificity to the target insect. Additionally, we found no effects of the EAB-specific ds RNAs on the classical biological control agents. Effective delivery of the dsRNA is challenging, particularly in systems with long-lived, endophagous insects such as the EAB. Using confocal microscopy we demonstrate uptake, movement, and insecticidal activity of labeled dsRNA in green, F. pennsylvanica, and tropical ash, F. uhdei, through root and/or petiole absorption. Although our findings provide a proof of concept that delivery of dsRNAs through topical or systemic application is feasible, in order to move this technology to the deployment stage practical delivery methods must be fully evaluated. Current efforts are focused on gaining a greater understanding of the spatial and temporal distribution of EAB-specific dsRNAs in ash seedlings.

v. *Effects of prescribed fire and forest age on pollinator diversity in the longleaf pine ecosystem - Michael D. Ulyshen, J. Kevin Hiers, Scott M. Pokswinksi, Audrey C. Wilson, Gunnar C. Ohlson, and Conor Fair.* There is much interest in preserving and restoring the remaining fragments of longleaf pine forest on the southeastern U.S. coastal plain. This endangered ecosystem is famous for its high diversity of fire-adapted plants and other organisms, but few efforts have been made to describe the associated bee community or to develop management recommendations for conserving this fauna. Results from three studies aimed at addressing these questions will be discussed. The first study found a positive relationship between pyrodiversity (i.e., heterogeneity of burn history on the landscape) and the diversity of both bees and butterflies. It also suggests that high burn frequency over large areas may have a negative effect on these insects. The second study found a higher concentration of ground-nesting bee nests in regularly-burned forests than in forests burned less frequently. The third study found few differences in bee diversity between old-growth and mature secondary longleaf pine forests, suggesting that recovering forests can still support a high diversity of pollinators. In addition to establishing baseline knowledge about the bees of the longleaf pine ecosystem, this work will provide land managers with important information for protecting pollinators throughout much of the southeast.

vi. *Landscape and local factors driving species richness of longhorned beetles and bees in a fragmented landscape - Traylor, C.R., M.D. Ulyshen, J.V. McHugh.* Insect communities respond to a variety of factors, ranging from local habitat conditions to processes operating at a landscape scale. Specific influences may vary between taxa that have different life histories or dissimilar resource requirements. Within forests, the diversity of saproxylic insects is often used as an indicator of overall forest health, and these species facilitate the decomposition of woody debris. In recent years, increased attention has also been given to pollinators in forests. Pollinators can obtain a variety of resources from forests, and they move between forests and other land uses. Yet, how

these two groups respond to landscape factors in forests is relatively understudied. Here, we investigate how native longhorned beetle and bee diversity are affected by local forest conditions and landscape context. Longhorned beetles (Coleoptera: Cerambycidae) comprise a diverse family that mostly tracks fresh deadwood resources. Bees (Hymenoptera: Apoidea: Anthophila) are significant pollinators of native trees and forbs. We sampled these insects from forests in Athens, GA, along gradients of both forest age and landscape forest amount. Other local and landscape factors were also measured and included in the analysis. These relationships with species richness will be discussed along with implications for conservation.

12:30 **Adjourn**