70th Western Forest Insect Work Conference

Vision 2022: Lessons learned from the past for the future

Virtual - Edmonton, Alberta
April 26 - 29, 2022

DRAFT AGENDA (Times in MDT, presenters in italics)

TUESDAY, 26 APRIL

0900-0915 **VIRTUAL WELCOME TO EDMONTON/HOUSEKEEPING**
Nadir Erbilgin, Department of Renewable Resources, University of Alberta
Caroline Whitehouse, Agriculture, Forestry and Rural Economic Development, Alberta

0915-1000 **DISTINGUISHED SPEAKER**
Cree Elder Bert Auger, Whitefish Lake First Nation #459, Alberta
Introduced by: *Michael Gubbels*, Government of Alberta

1000-1045 **MEMORIAL SCHOLARSHIP (2020) PRESENTATION**
Bioclimatic drivers of synchronous western balsam bark beetle irruptions across BC
Michael Howe, University of Wisconsin-Madison

1045-1115 VIRTUAL BREAK AND SOCIAL SESSION

1115-1245 **THE IMPACTS OF DROUGHT ON FORESTS AND FOREST INSECTS**
Moderator: *Chris Fettig,* USDA Forest Service Pacific Southwest Research Station

Impacts of drought on forests and forest insects: A review
Jeff Hicke (University of Idaho), Tom Kolb, Chris Fettig, Matt Ayres, Barb Bentz, Bob Mathiasen, Jane Stewart, and Aaron Weed

Forest disturbance through multidecadal wet and dry periods of the 20th and 21st centuries in the western U.S.
Joel Egan (USDA Forest Service, Forest Health Protection), Jeffrey Kaiden, Leonid Kalchev, and Zachary Holden

Drought and The California Tree Mortality Network
Chris Fettig (USDA Forest Service), Leif Mortenson, Crystal Homicz, Jackson Audley, Beverly Bulaon, David Dralle, and Chris Looney

Warming increased bark beetle-induced tree mortality by 30% during an extreme drought in California
Zachary Robbins (Los Alamos National Laboratory, North Carolina State University), Chonggang Xu, Brian Aukema, Polly Buotte, Rutuja Chitra-Tarak, Chris Fettig, Mike Goulden, Devin Goodsman, Alexander Hall, Charles Koven, Lara Kueppers, Gavin Madakumbura, Leif Mortenson, Jim Powell, and Rob Scheller

1245-1315 VIRTUAL LUNCH

1315-1400 **FOREST ENTOMOLOGY – A HISTORICAL PERSPECTIVE**
Moderator: *Rory McIntosh*, Ministry of Environment, Saskatchewan

The changing face of forest entomology in Canada
Rory McIntosh, Ministry of Environment, Saskatchewan (special acknowledgements to Herb Cerezke, Rene Alfaro, and David Langor)

An Evolution of Approaches in Forest Entomology
Iral Ragenovich, USDA Forest Service, Forest Health Protection, Oregon

Evolution of pheromone lures, traps and tree baits: a personally biased trip down memory lane
John Borden, JHB Consulting

1400-1430 **INITIAL BUSINESS MEETING**

1515-1545 **SHERYL COSTELLO MEMORIAL FUN RUN**
Darren Blackford, USDA Forest Service, Forest Health Protection, Utah

1630-1830 **POSTER AND SOCIAL SESSION**

Influence of individual tree competition and resin duct defenses on bark beetle-caused mortality in treated and untreated ponderosa pine stands
Gia Landis (Northern Arizona University), Tristan O'Mara, José Negrón, and Kristen Waring

Return of the Beetles: an Arizona Museum Fire Story
Chrissy Mott (Northern Arizona University) and Rich Hofstetter

Cuticular hydrocarbons of *Ips pini* (Say): lessons learned to inform future chemotaxonomic studies
Lori J. Nelson (USDA Forest Service, Pacific Southwest Research Station), Steven J. Seybold, and Michael I. Haverty

WEDNESDAY, 27 APRIL

0900-0945 **DISTINGUISHED SPEAKER**

Defense strategies among long-lived pines: Does climate matter?
Barbara Bentz, USDA Forest Service, Research and Development, Utah

0945-1030 **MEMORIAL SCHOLARSHIP (2019) PRESENTATION**
Development of a semiochemical repellent for protecting walnut trees from the invasive walnut twig beetle, *Pityophthorus juglandis*
Jackson Audley, ORISE Scholar, USDA Forest Service, Pacific Southwest Research Station

1030-1100 VIRTUAL BREAK AND SOCIAL SESSION

1100-1230 **THREATS TO WESTERN FORESTS: NEW DETECTIONS OF NON-NATIVE AND POTENTIALLY INVASIVE BARK AND AMBROSIA BEETLES IN THE U.S.**
Moderator: *Robbie Flowers*, USDA Forest Service, Forest Health Protection, Central Oregon

Monitoring and mitigating the range expansion of an invasive bark beetle, *Orthotomicus erosus*, across the United States
Gabriel G. Foote (University of California-Davis), Andrew D. Graves, John P. Formby, Monica L. Gaylord, Irene D. Lona, Alyssa McAlexander, Joel D. McMillin, Lori J. Nelson, and Megan A. Siefker

The Mediterranean oak borer (MOB, *Xyleborus monographus* Coleoptera: Curculionidae: Scolytinae), an invasive ambrosia beetle infesting valley and blue oaks in Northern California
Curtis Ewing (California Department of Forestry and Fire Protection), Sheri Smith, and Michael Jones

Invasive shothole borers in urban and natural forests in Southern California
Stacy Hishinuma, USDA Forest Service, Forest Health Protection, Southern California

Results from the Columbia River corridor invasive woodborer survey in Oregon and Washington State
Wyatt Williams, Oregon Department of Forestry

1230-1300 VIRTUAL LUNCH

1300-1445 **GRADUATE STUDENT SESSION**
Moderator: *Jennifer Klutsch*, New Mexico Highlands University

Measuring changes in fuel loads with a multi-year dataset following a severe drought and bark beetle outbreaks in the Central and Southern Sierra Nevada
Crystal Homicz (University of California-Davis), Leif A. Mortenson, Beverly M. Bulaon, and Christopher J. Fettig

Long-term terpene response to mountain pine beetle attack in lodgepole and jack pines
Antonia Musso (University of Alberta), Colleen Fortier, Dezene Huber, Allan Carroll, and Maya Evenden

Production of complementary defense metabolites reflects a co-evolutionary arms race between a host plant and a mutualistic bark beetle-fungal complex
Aziz Ullah (University of Alberta), Jennifer Klutsch, and Nadir Erbilgin

Reduced relative humidity increased mountain pine beetle productivity
Rashaduz Zaman (University of Alberta), Federico Antonioli, and Nadir Erbilgin

Fatal attraction: evaluation of entomopathogenic fungus *Beauveria bassiana* for the biocontrol of the invasive mountain pine beetle, *Dendroctonus ponderosae*
Albert Remus R. Rosana (University of Alberta), Jennifer Klutsch, Stanley Pokorny, Cherry Ibarra Romero, Marco van Belkum, Nadir Erbilgin, Joerg Bohlman Allan Carroll, and John Vederas

Examining the use of biochar on spotted knapweed, *Centaurea stoebe* L., and its impact on the success of two introduced biocontrol agents, *Larinus minutus* Gyllenhal and *Cyphocleonus achates* Farhaeus (Coleoptera: Curculionidae)
Toriani Kent (University of Idaho) and Stephen Cook

1445-1515 VIRTUAL BREAK AND SOCIAL SESSION

1515-1615 **2020 FOUNDERS AWARD AND SOCIAL SESSION**
Moderator: *Joel McMillin*, Founder's Award Committee Chair, USDA Forest Service, Forest Health Protection, Arizona

Steven J. Seybold
Chemical Ecologist, Forest Entomologist, Taxonomist, and Mentor: a marriage of convenience for a remarkable career
Introduction by *Darrell Ross*, North Dakota State University
Andy Graves, USDA Forest Service, Forest Health Protection, New Mexico and *Tom Coleman*, USDA Forest Service, Forest Health Protection, North Carolina

THURSDAY, 28 APRIL

0900-0945 **DISTINGUISHED SPEAKER**

Conifer bark beetle research and management in Mexico: a summary from the last two decades.
Guillermo Sánchez-Martínez, National Research Institute on Forestry, Agriculture and Animal Husbandry, Mexico

0945-1115 **50 YEARS IN THE EVOLUTION OF BARK BEETLE SEMIOCHEMICALS.....WHAT HAVE WE LEARNED?**
Moderator: *Brian Sullivan*, USDA Forest Service Southern Research Station

Ambrosia beetle pheromone identification: then and now
John Borden, JHB Consulting

Evaluating the unparalleled success of MCH treatments for the Douglas-fir beetle
Darrell Ross, North Dakota State University

Refining MPB semiochemicals for detection in an expanded range
Jennifer Klutsch (New Mexico Highland University), Gail Classens, Caroline Whitehouse, James F. Cahill, Jr., and Nadir Erbilgin

Semiochemistry of *Dendroctonus* bark beetles: learning more and more about how little we know
Brian Sullivan (USDA Forest Service, Southern Research Station, Pineville, LA), Holly Munro, Katie O'Shields, and Kamal Gandhi

1115-1145 VIRTUAL BREAK AND SOCIAL SESSION

1145 – 1315 **OPEN SESSION - I**
Moderator: *Kathy Bleiker*, Canadian Forest Service, Pacific Forestry Centre, British Columbia

Reducing the Firewood Pathway for Forest Pests: Understanding Current Rules, Certifications, and Recommendations across North America
Leigh Greenwood (The Nature Conservancy) and Laurel Downs

The impact of flight on subsequent semiochemical-mediated communication in the mountain pine beetle, *Dendroctonus ponderosae* (Coleoptera: Curculionidae: Scolytinae)
Maya Evenden (University of Alberta), K. Jones, L. Petro, A. Musso, R. Rajabzadeh, G. Ishangulyyeva, and N. Erbilgin

Are the spruce budworm and two-year-cycle budworm moth temporally isolated?
Felix Sperling (University of Albert), Tyler Nelson, and Zachary MacDonald

Mountain pine beetles and the once and future whitebark forests of the greater Yellowstone ecosystem
Erin Shanahan (US National Park Service) and Jesse Logan

Detection of Bark Beetle Attack Using Remote Sensing and Machine Learning: Expectations vs. Reality
Seyed Mojtaba Marvasti-Zadeh (University of Alberta), Rudraksh Kapil, Guillermo Castilla, Devin Goodsman, Nilanjan Ray, and Nadir Erbilgin

1315-1345 VIRTUAL LUNCH

1345-1500 **HIGH ELEVATION FORESTS – RESILIENCE OR DECLINE?**
Moderator: *Lorraine Maclauchlan*, Ministry of Forests, Lands, Natural Resource Operations & Rural Development, British Columbia

Subalpine fir decline in the US Rocky Mountains: multi-scale factors associated with mortality and forest response
Brian J. Harvey (University of Washington) and Mike Battaglia

Bioclimatic drivers of synchronous western balsam bark beetle irruptions across British Columbia
Michael Howe (University of Wisconsin-Madison), Lucas Peng, and Allan Carroll

***Abies lasiocarpa* Consortium**
Celia Boone, Ministry of Forests, Lands, Natural Resource Operations & Rural Development, British Columbia

Rnai for use in lethal trap trees
Jeanne Robert, Ministry of Forests, Lands, Natural Resource Operations & Rural Development, British Columbia

FRIDAY, 29 APRIL

0900-0945 **DISTINGUISHED SPEAKER**

Lessons learned, lost, and levered: some thoughts on the conference theme
John Acorn, University of Alberta

0945-1115 **CURRENT ISSUES IN MEXICO**

Moderator: *Guillermo Sánchez-Martínez*, National Research Institute on Forestry, Agriculture and Animal Husbandry, Mexico

The growing importance of conifer sawflies in the sierras of Mexico
Ernesto González-Gaona, National Research Institute on Forestry, Agriculture and Animal Husbandry, Mexico

The importance of ambrosia beetles in Mexico
Armando Equihua-Martinez (Instituto de Fitosanidad, Colegio de Postgraduados, Mexico) and Edith G. Estrada-Venegas

Integrated forest pest management under the Mexican context
David Cibrián-Tovar, Universidad Autónoma Chapingo, Texcoco, Mexico

The Siricidae of Mexico
Guillermo Sánchez-Martínez (National Research Institute on Forestry, Agriculture and Animal Husbandry, Mexico) and David R. Smith

1115-1145 VIRTUAL BREAK AND SOCIAL SESSION

1145-1315 **OPEN SESSION - II**

Moderator: *Devin Goodsman*, Canadian Forest Service, Northern Forestry Centre, Alberta

MCH-based semiochemical protection of spruce trees from the spruce beetle, *Dendroctonus rufipennis*, in the Intermountain West and Alaska
Jackson P. Audley (USDA Forest Service, Pacific Southwest Research Station), Christopher J. Fettig, A. Steve Munson, Elizabeth E. Graham, Darren C. Blackford, Leif M. Mortenson, Jason E. Moan, Jessie Moan, and Agenor Mafra-Neto

Drought and defense: The effects of short- and long-term drought on tree resource safety margins and impacts for bark beetle attack
Amy Trowbridge, University of Wisconsin-Madison

Efficacy of trunk injection and spray treatments for management of goldspotted oak borer on coastal live oak in Southern California
Don Grosman (Arborjet, Inc.) And Kelly Parkins

Using fungal volatiles to enhance monitoring and management of bark and ambrosia beetle pests
Matthew Ethington (USDA FS Rocky Mountain Research Station) and Matthew Ginzel

Oribatid mites as bioindicators in Alberta's forests
Lisa Lumley (Alberta Biodiversity Monitoring Institute), Ermias Azeria, Victoria Giacobbo, and Tyler Cobb

1315-1345 VIRTUAL LUNCH

1345-1415 FINAL BUSINESS MEETING

1415-14:30 **RAFFLE FOR MEMORIAL SCHOLARSHIP**
Monica Gaylord, USDA Forest Service, Forest Health Protection, Arizona

14:30-15:15 **GROUP DISCUSSION AND CLOSING REMARKS**
Caroline Whitehouse, Agriculture, Forestry and Rural Economic Development, Alberta
Nadir Erbilgin, Department of Renewable Resources, University of Alberta
Elder Bert Auger, Whitefish Lake First Nation #459, Alberta

Meeting arrangements: Caroline Whitehouse (caroline.whitehouse@gov.ab.ca)
Scientific program: Nadir Erbilgin (erbilgin@ualberta.ca), Caroline Whitehouse, Kathy Bleiker, Darren Blackford, Dezene Huber, Monica Gaylord, Devin Goodsman, Andy Graves, Jennifer Klutsch, Lorraine Maclauchlan, Rory McIntosh

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Lessons learned, lost, and levered: some thoughts on the conference theme

John Acorn
Department of Renewable Resources, University of Alberta, Edmonton, AB

How does one "learn a lesson" in entomology? It would seem that on the one hand, a lesson is simply the acquisition of new knowledge; on the other, a lesson involves something moral. Morally, "learning a lesson" is a triumph, while not learning a lesson constitutes a failure. Having worked extensively in television and book publishing, and as the instructor for a senior undergraduate course on the subject of science communication, I have wrestled extensively with the question of how we learn and communicate not just lessons, but anything at all. It now seems obvious, to a majority of people involved in the study of communication, that communication is: 1) difficult but not impossible, despite appearances to the contrary on both counts, and 2) mediated by various cognitive tendencies, most of which are not under rational or voluntary control. Here, I will present a few anecdotes from my own work with entomological research, to illustrate some of the difficulties that we predictably encounter. Most researchers are aware of such errors as confirmation bias, and rationalization in the face of cognitive dissonance, but in order to more consistently "learn our lessons," we need to broaden our understanding of the communication process to include not just logical fallacies, but also conceptual metaphor, ontology and the philosophy of mind, modes of cognition, and the tendency of ecology to create and then reify its abstractions. Understanding these subjects and phenomena will not necessarily ensure success, but it should reduce the rate at which lessons are either forgotten, or levered through a process of rationalization.

Development of a semiochemical repellent for protecting walnut trees from the invasive walnut twig beetle, *Pityophthorus juglandis*

Jackson P. Audley
USDA Forest Service, Pacific Southwest Research Station, Davis, CA

Walnut twig beetle (WTB), *Pityophthorus juglandis* Blackman, and the associated fungal pathogen, *Geosmithia morbida*, comprise the thousand cankers disease (TCD) complex impacting walnut, *Juglans* spp., and wingnut, *Pterocarya* spp. Both organisms are invasive across much of the Western US, including California, and in several Eastern US states. Adult WTB introduce spores of *G. morbida* to the host's phloem upon entering the bark to feed and reproduce. Following repeated WTB attacks, beetle feeding and localized cankers caused by *G. morbida* coalesce to girdle branches, causing a progressive, top-down dieback in walnut trees. Management options for WTB and TCD remain limited. WTB's host specificity makes this system a good candidate for a semiochemical repellent management strategy. Here I present results of experiments investigating WTB chemical ecology. First, we confirmed WTB's ability to discriminate among host and several nonhost trees in a riparian forest setting. Next, we conducted a series of trapping assays screening six possible repellent semiochemicals at variable release rates. Compounds included: *R*-(+)-limonene; *S*-(-)-limonene; *R*-(+)-verbenone; *S*-(-)-verbenone; racemic chalcogran; and racemic *trans*-conophthorin. Then, we tested for additive or synergistic effects of combinations in subtractive-combination assays. Finally, we tested the best performing combinations on individually treated walnut trees in tree-protection assays. The highest release rates of both enantiomers of limonene, *R*-(+)-verbenone, chalcogran, and *trans*-conophthorin reduced trap catches by ≥ 90%. Subtractive-combination assays revealed similar efficacy among combinations, therefore, we proceeded with *R*-(+)-limonene, *trans*-conophthorin, and *R*-(+)-verbenone. Results from three tree protection assays indicated our repellents were effective in preventing WTB landings within 200 cm of the semiochemicals. We were unable to determine the repellent effect between 200 and 500 cm due to localized WTB landing response to the pheromone lure. This work identified several promising compounds for protecting trees from WTB/TCD, however, more work is needed to determine an effective strategy for preventing WTB colonization of walnut trees.

MCH-based semiochemical protection of spruce trees from the spruce beetle, *Dendroctonus rufipennis*, in the Intermountain West and Alaska

Jackson Audley [1], Christopher Fettig[1], Steve Munson[2], Elizabeth Graham[3], Darren Blackford[2], Leif Mortenson[4], Jason Moan[5], Jessie Moan[6], and Agenor Mafra-Neto[7]
[1]Pacific Southwest Research Station, USDA Forest Service, Davis, California
[2]Forest Health Protection, USDA Forest Service, Ogden, Utah
[3]Forest Health Protection, USDA Forest Service, Juneau, Alaska
[4]Pacific Southwest Research Station, USDA Forest Service, Placerville, California
[5]Alaska Division of Forestry, Anchorage, Alaska
[6]Forest Health Protection, USDA Forest Service, Anchorage, Alaska
[7]ISCA Technologies Inc. Riverside, California

Spruce beetle, *Dendroctonus rufipennis* Kirby, is the most significant pest of mature spruce trees and populations have reached outbreak levels in recent years across several states in the Intermountain west, British Colombia, and Alaska. A novel formulation of the antiaggregation pheromone 3-methyl-2-cyclohexen-1-one (MCH) in the proprietary, biodegradable release technology SPLAT (ISCA Technologies Inc., Riverside, CA) was recently made and tested for protecting Douglas-fir trees against the Douglas-fir beetle, *D. pseudotsugae* and spruce trees from *D. rufipennis*. Here, we report the results from tree protection studies in Wyoming and Utah and from trapping assays (following failure of a tree protection experiment) in Alaska. We tested two doses of MCH (3.5 and 7 g A.I.) plus additional compounds including those in the *Acer* kairomone blend (AKB) and acetophenone and green leaf volatiles. Both doses of SPLAT MCH with acetophenone and green leaf volatiles and the high dose of SPLAT MCH and AKB effectively protected the treated trees and neighboring spruce trees within 11.3 m around the treated trees. We deployed similar treatments using the high dose of SPLAT MCH on spruce in Utah in 2021. Initial assessment of trees indicated similar levels of colonization prevention. We plan to reassess the trees in 2022 and to re-treat (but not re-bait) these trees to evaluate efficacy through an on-going outbreak. Complete failure of the same treatments in Alaska in 2019 led us to test additional semiochemicals, including octenol, in two trapping assays in 2021. All repellent treatments reduced trap catches equally in both assays. We plan to treat trees at two locations in Alaska in May of 2022.

Defense strategies among long-lived pines: Does climate matter?

Barbara J. Bentz
USDA Forest Service, Logan, UT

Several high-elevation five-needle pines that grow in the western United States (US) are among the longest-lived conifers worldwide. Three species, *Pinus longaeva*, *P. balfouriana*, and *P. aristata*, are close relatives in the Balfourianae or bristlecone subsection. Each species has a relatively disjunct distribution that does not overlap with the other Balfourianae species. *Pinus flexilis*, however, commonly occurs in the same stands with each of these Balfourianae species, but it also has a much larger distribution that extends across the western US and Canada. The four species have varying susceptibility to a key herbivore, the mountain pine beetle (*Dendroctonus ponderosae*). *Pinus longaeva* and *P. balfouriana* are attacked less frequently than the other two species, and in a laboratory study very few mountain pine beetle adults (54) emerged from *P. longaeva* compared to *P. flexilis* (4389). We investigated constitutive and induced defenses in these species and analyzed potential tradeoffs in defense strategies. The influence of climate on defense strategies among sites sampled within each species was also investigated. Finally, factors contributing to recent and unexpected mortality in *P. longaeva* will be discussed.

A. lasiocarpa Consortium

Celia Boone
Ministry of Forests, Lands, Natural Resource Operations and Rural Development, British Columbia

Subalpine fir, *Abies lasiocarpa* (Hook.) Nutt., is an economically and ecologically important conifer in British Columbia. Provincially, it only contributes 14% to provincial timber supply, however, this proportion has been increasing steadily in the north. Subalpine fir also has a significant role in habitat and ecological maintenance, particularly considering hydrology and endangered or threatened species. Climate change models predict increasing stress on forest ecosystems due to overall warming trends and shifting moisture regimes. Research into subalpine fir decline using long-term data sets indicate that subalpine fir is disproportionately affected by insects and pathogens when the climate is warmer and drier. The B.C. Regional Forest Entomologists have established an *A. lasiocarpa* Consortium that will collaborate with federal and academic researchers to investigate threats to the subalpine fir ecosystems throughout the province in four proposed research studies.

AMBROSIA BEETLE PHEROMONE IDENTIFICATION: THEN AND NOW

John H. Borden
JHB Consulting

This presentation focuses on the historic eight-year journey travelled in the last century to identify, synthesize and evaluate the aggregation pheromone of the striped ambrosia beetle, *Trypodendron lineatum* (Coleoptera: Curculionidae: Scolytinae). It then contrasts the historic path with the much shorter and easier journey taken in the current century to identify the aggregation pheromone of the birch-infesting congeneric beetle, *T. betulae*, taking advantage of more modern technology. Historically, studies on the *T. lineatum* pheromone were justified by the facts that in the 1970s it and two *Gnathotrichus* spp. caused $95-189 million in annual damage to the British Columbia timber industry, and that spraying log booms on fresh and salt water with lindane to prevent ambrosia beetle attack was no longer permitted. Overwintering *T. lineatum* were collected in litter and duff and pieces of old-growth stumps, and allowed to emerge in a used construction trailer, yielding 50,000 beetles, half of which were females. These were allowed to attack ethanol-treated bolts of Douglas-fir, yielding 450 g of frass as starting material, which was sent to the laboratory of pioneering pheromone chemist Milt Silverstein at the SUNY College of Environmental Science and Forestry at Syracuse, NY. The pheromone isolation, identification and synthesis process involved six complex chemical procedures at Syracuse and corresponding bioassay at Simon Fraser University, Burnaby, BC, of 71 extracts and fractions against 440 groups of eight male beetles each. Field verification of the pheromone identity was done by experimental testing of microgram quantities of the new pheromone lineatin. In contrast, Identification of 3*S*,6*R*- and 3*R*,6*R*-linalool oxide pyranoid as the aggregation pheromone of *T. betulae* required only two years, using 148 female beetles excised from two newly attacked paper birch logs, precise identification by GC-EAD and GC-MS, and validation in field experiments employing multiple-funnel (Lindgren) traps that replaced the sticky traps used in earlier days. Finally, use of pheromone-based mass trapping in two of the eight procedures employed in IPM of ambrosia beetles in BC is reviewed. Begun in 1982 and run every year since, this is now the world's longest continuously running pheromone based IPM program.

EVOLUTION OF SCOLYTID PHEROMONE TRAPS, LURES AND TREE BAITS

John H. Borden
JHB Consulting

This presentation explains that the principles on which traps and lures for bark and timber beetles have remained the same from the outset, but that technological sophistication had enabled considerable improvement over the years. Examples are based largely on my personal experience. Trap design is based on three principles: 1) some sort of barrier to flying beetles that may or may not present and attractive visual image, 2) an adaptation that accommodates placement of an attractive volatile lure, and 3) a means for arresting and capturing incoming beetles. Evolution of trapping systems is traced from pioneering glass barrier traps over a greenhouse cage developed by John Chapman and Bill Nijholt to sticky vanes and cylinders engineered by Lloyd Browne, and paper wrap-around traps devised by Gerry Lanier. Sticky traps proved to be highly effective in trapping western pine beetles, elm bark beetles and ambrosia beetles, among other targets. However, they were universally unpopular because they were costly, cumbersome, disaster-prone, time-consuming, sticky (yes sticky), messy and generally infuriating. The led to the invention of non-sticky alternatives that included bucket traps devised by Lloyd Browne and John Moser, Alf Bakke's Norwegian drainpipe traps, Niemeyer's Schlitzfalle trap, and ultimately to Staffan Lindgren's widely used multiple-funnel traps. Traps for scolytid beetles also led to spinoffs that included Synergy Semiochemicals' multiple-funnel or panel traps with a wide "Allison collar" that replaced the lowest funnel and Alpha Scents' black panel trap, both of which were directed at large woodboring beetles, and purple triangle traps for emerald ash borers. Turning to lures, they are based on two options: 1) a reservoir surrounded by a semi-permeable rate-limiting barrier, and 2) a solid or semi-solid substance in which a semiochemical is embedded. The former trends toward a zero-order release rate with constant release of a volatile until the reservoir is empty, and the latter trends toward first-order release wherein initial high release declines rapidly to plateau at a very low level. Tree baits are essentially the same as trap lures, but with unnecessary host stimuli omitted. Simple early lures like an upside-down saltshaker have evolved into more sophisticated lures such as plastic sleeves for high release of host volatiles, and bubblecaps and flexlures for slow release of pheromones. Holders for tree baits have evolved from chunks of 2x4 lumber with holes drilled in them to plastic sachets that can be stapled to a tree and waxy (SPLAT) dollops applied to the bark with a pressurized dispenser. In all cases, determination of release rate is critical and should be demanded by users.

Forest disturbance through multidecadal wet and dry periods of the 20th and 21st centuries in the western U.S.

Joel M Egan, Jeffrey Kaiden, Leonid Kalchev, and Zachary Holden
USDA Forest Service, Northern Region, Forest Health Protection, Missoula Field Office

Widespread, synchronized forest disturbances throughout the western United States have occurred within the 20th and 21st centuries in conjunction with dry multidecadal time periods. During dry cycles, the frequency of wildfire and bark beetle outbreaks increase while forest vulnerability and the potential for compounding disturbance is elevated. Conversely, during multidecadal wet cycles, spatially expansive disturbance is muted while ample moisture supports recruitment success, biomass growth and density increases, and shade tolerant/drought intolerant species proliferation. This talk will review the recent history of dry and wet multidecadal climate cycles and their associated wildfire and bark beetle disturbances, from early 1900s to present, from a broad-level temporal perspective that spans the western U.S. Information that will be covered includes: 1) moisture cycle dynamics associated with widespread synchronized disturbances; 2) the last dry cycle analogous to our current 2000-2021 dry period; 3) impacts of long-term wet cycle in the 20th century on forest succession and disturbance; 4) temperature forcing of moisture reductions and disturbance implications; and 5) development of western forest vulnerability layer based on chronic exposure to dry conditions.

The importance of ambrosia beetles in Mexico

Armando Equihua-Martinez and *Edith G. Estrada-Venegas*
Instituto de Fitosanidad, Colegio de Postgraduados, Mexico.

The ambrosia beetles are an important component in Wood decomposition processes. Most species establish on dying or dead plants. During the last decades, many species have moved through commercial trade to news areas around the world. In Mexico, there is a special interest in species that have been associated with pathogenic fungi, particularly those that represent a risk for the avocado industry. In Mexico, a National Monitoring System has been established for early detection by two government institutions; Direccion General de Sanidad Vegetal and CONAFOR. Native species of ambrosia beetles in Florida, USA have been associated with the lateral transfer of pathogenic fungi carry out by introduced species of insects of the genera *Xyleborus* and *Euwallacea.* With the purpose to study the native ambrosia beetle in México, various studies have developed in the States of Michoacán, Nayarit, Mexico, Veracruz, Chiapas, Nuevo Leon, and Puebla. Considering the potential transmission of pathogenic fungi by native species of ambrosia beetles, we focused our research on diversity and behavior, primarily on avocado-producing areas in México as well as other areas in the country.

Using fungal volatiles to enhance monitoring and management of bark and ambrosia beetle pests

Matthew Ethington [1,2] and Matthew Ginzel[2,3]
[1]USDA FS Rocky Mountain Research Station
[2]Department of Entomology, Purdue University
[3]Department of Forestry and Natural Resources, Purdue University

Native and invasive bark and ambrosia beetles threaten the health and productivity of natural and planted forests worldwide. Management of these pests often relies on semiochemical-based tactics, but these can be ineffective at monitoring low-level populations or in decreasing population densities. We tested the hypothesis that fungal and non-host volatiles play a role in host colonization and modify attraction of these beetles to monitoring lures. Over three years (2017-2020) a suite of fungal and non-host volatiles were tested in trapping experiments conducted in Washington and Indiana, with the walnut twig beetle (*Pityophthorus juglandis* Blackman) and exotic ambrosia beetles [*Xylosandrus crassiusculus* (Motchulsky), *Xylosandrus germanus* (Blandford), and *Xyleborinus saxesenii* (Ratzeburg)] as the focal species at each location, respectively. Two fungal alcohols, both emitted by a symbiotic fungus, enhanced attraction of walnut twig beetles to their pheromone lure. Conversely, one fungal and two non-host volatiles reduced attraction to the same pheromone lure. The response of ambrosia beetles differed by species, but all behaviorally active compounds reduced attraction to their current monitoring lure (ethanol). Attraction of *X. crassiusculus* to ethanol was reduced by four fungal alcohols, while attraction of the congeneric *X. germanus* was reduced by three fungal alcohols and one non-host volatile. The attraction of *X. saxesenii* to ethanol was also reduced by two fungal alcohols, although this response was not consistent through all experiments. These findings demonstrate that fungal and non-host volatiles may play a role in increasing the efficacy of semiochemical-based monitoring and management tactics for bark and ambrosia beetle pests.

The impact of flight on subsequent semiochemical-mediated communication in the mountain pine beetle, Dendroctonus ponderosae (Coleoptera: Curculionidae: Scolytinae)

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Flight polyphenisms occur as discrete or continuous traits in insects. The mountain pine beetle (*Dendroctonus ponderosae*) exhibits polyphenic variation in flight distance but the consequences of this flight variation on subsequent semiochemical-mediated host colonization is unknown. This study assessed the effect of flight on two particular aspects of beetle biology: (1) the relationship between flight distance and pheromone production in male and female beetles; and (2) the relationship between flight and orientation response to host volatiles. A 23-h flight treatment was applied to beetles using computer-linked flight mills. In experiment 1, both flown and unflown (control) beetles entered lodgepole pine bolts, which were aerated to collect pheromone. In experiment 2, flown and unflown beetles were assayed in a 4-way olfactometer to measure their response to volatiles emitted from lodgepole pine phloem. Production of the aggregation pheromone trans-verbenol by female beetles was influenced by both percent weight lost during flight and flight distance. Male production of *exo*-brevicomin was affected by beetle condition following flight but not by the energy used during flight. Flight treatment did not directly affect orientation to host volatiles, but the energy use during flight and the body condition of beetles after flight did. Beetles with higher lipid content that were in better condition following flight treatment spent less time near the phloem sources than beetles with low lipid content in poor condition. These novel results give new insight into the effect of energy use through flight on semiochemical-mediated behaviours and the polyphenic flight of mountain pine beetles.

The Mediterranean Oak Borer (MOB, *Xyleborus monographus* Coleoptera: Curculionidae: Scolytinae) an invasive ambrosia beetle infesting valley and blue oak in Northern California.

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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 October 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. All ambrosia beetles (like MOB) grow fungi inside their galleries and use it as food for larvae and adults. Oak trees infested with MOB are most easily identified by damage caused by the beetle's tunneling activity (galleries) in the xylem. MOB galleries are often trellis-like, very crowded and intersecting, fan out in a single plane and 1.2-1.5 mm in diameter. Cooperative work is ongoing to 1) provide information regarding the origin, distribution, and age of the infestations, 2) determine estimated rate of spread, 3) identify the locations of un-infested susceptible oaks to develop a broader tree inventory in order to estimate potential economic losses as this invasive insect continues to spread, 4) evaluate the flight periodicity, flight height, lure efficacy and mode of attack, 5) evaluate the efficacy of deterrent chemicals and, 6) determine best practices for the disposal of infested wood. For more information and a MOB pest alert can be found here: https://www.ucanr.edu/sites/mobpc/

Drought and The California Tree Mortality Network

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Much of California experienced a severe drought in 2012–2015 inciting a large tree mortality event in the central and southern Sierra Nevada. We discuss the California Tree Mortality Network (CTMN) established to determine causal agents and rates of tree mortality, and effects on forest structure and composition. CTMN consists of 180 11.3-m fixed-radius plots installed in three elevation bands on the Eldorado, Stanislaus, Sierra and Sequoia National Forests where tree mortality was most severe. About 49% of trees died between 2014 and 2017. Tree mortality ranged from 46% on the Eldorado National Forest to 59% on the Sierra National Forest. Significantly higher levels of tree mortality occurred at the lowest elevations (60%) compared to the highest elevations (46%). Significant reductions in tree size and density were observed. Ponderosa pine, *Pinus ponderosa*, exhibited the highest levels of tree mortality (90%), with 39% of plots losing all ponderosa pine. Mortality of ponderosa pine was highest at the lowest elevations, concentrated in larger-diameter trees, and attributed primarily to western pine beetle, *Dendroctonus brevicomis*. Sugar pine, *P. lambertiana*, exhibited the second highest levels of tree mortality (48%), with mortality concentrated in the mid-diameter classes and attributed primarily to mountain pine beetle, *D. ponderosae*. White fir, *Abies concolor*, and incense cedar, *Calocedrus decurrens,* exhibited 26% and 23% mortality, respectively. Tree mortality (numbers of trees killed) was positively correlated with initial live tree density and slope. The implications of these and other results to management of drought-impacted forests are discussed in addition to an expansion of research foci within the CTMN.

Monitoring and mitigating the range expansion of an invasive bark beetle, *Orthotomicus erosus,* across the United States

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Mediterranean pine engraver, *Orthotomicus erosus*, is an exotic pest of Mediterranean pines in urban forests of the southwestern United States. Originally detected in Fresno Co., California in 2004, *O. erosus* has since been collected by survey traps deployed throughout metropolitan areas of Nevada (Clark Co.), Utah (Washington Co.) and Arizona (Maricopa, Mohave, and Pima Co.). At these locations, high mortality rates of Mediterranean pines, primarily *Pinus halepensis* and *Pinus eldarica*, have been attributed to *O. erosus* herbivory in recent years. This eastward range expansion of *O. erosus* is likely attributed to human transport of infested plants and wood materials. Laboratory studies indicate that *O. erosus* can reproduce in all pines and several other related conifers in the USA. As such, the growing populations of this beetle in the Southwest raise the issue of its further spread eastward to the southeastern states, representing a potential link to valuable timber and pulp resources. Here, we discuss current monitoring efforts for tracking the beetle's potential movement across Arizona and into New Mexico and western Texas, as well as into native pine landscapes surrounding metropolitan areas in AZ. A semiochemical-based strategy for protecting susceptible host trees from *O. erosus* herbivory in urban areas is also discussed. Overall, this project highlights the need for collaborative efforts among land managers to track the movement of this exotic species and prevent its continued range expansion through targeted management of infested wood.

The growing importance of conifer sawflies in the sierras of Mexico

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The sawflies of the Diprionidae family cause defoliation in conifers including *Pinus*, *Juniperus*, *Abies* and *Pseudotusga*, they are generally found at the endemic level, although they can cause epidemic outbreaks in hundreds or thousands of hectares; in the last 20 years, outbreaks have occurred in Durango (150 ha), Jalisco (5,000 ha), Chihuahua (3,000 ha), San Luis Potosí (800 ha), Guanajuato (150 ha), Guerrero (2,500 ha), and Oaxaca (4,500 ha) among others. The genera involved are: *Zadiprion*, *Neodiprion* and *Monoctenus*. The National Forestry Commission, in charge of combating these outbreaks, financed a research project (CONACYT-2017-CO2: 291304) to determine the current status of taxonomy, phenology, distribution and management of sawflies in Mexico. In the Monocteninae subfamily, three species *Monoctenus sanchezi* present in San Luis Potosí and Guanajuato (epidemic), *M. cuauhtemoci* n. sp (epidemic) in Guerrero and *M. sadadus* in Veracruz and Durango (historical records) were determined. From the subfamily Diprioninae in the genus *Neodiprion*, *N. abietis* was detected in Chihuahua (endemic), *N. autmnalis* in Chihuahua (epidemic), *N. omosus* at the endemic level in Aguascalientes, Durango, Hidalgo, Michoacán and Veracruz and *N. bicolor* in Oaxaca (epidemic). The *Zadiprion* genus is the most widely distributed and diverse, registering damage by *Z. falsus* in Chihuahua, Durango, Jalisco, Michoacán and Sonora (epidemic level), *Z. ojedae* in Chihuahua, *Z. townsendi* in Chihuahua, *Z. jeffreyi* in Baja California and *Z. rohweri* in Coahuila (the last four at the endemic level), *Z. howdeni* in Oaxaca (epidemic), *Z. roteus* in Coahuila, State of Mexico and Querétaro (endemic), *Z. borjai* n. sp (in registration process, epidemic) in Tamaulipas. Maps of the current and potential distribution of the three genera were made and the phenology of the main species was followed. The main parasitoids within the families Ichneumonidae (*Olesicampe* and *Exenterus*), Tachinidae (*Winthemia* and *Chetogena*, Bombyllidae (*Hemipenthes*) and Mantispidae (*Plega spinosa*) were identified. Six strains of Nuclear Polyhedrosis Virus isolated from *Zadiprion* and *Monoctenus* were obtained from the which the most aggressive was the Ixtapa Zihuatanejo strain in Guerrero and a methodology for its in vivo increase was established.

Reducing the Firewood Pathway for Forest Pests: Understanding Current Rules, Certifications, and Recommendations across North America

Leigh Greenwood and Laurel Downs
The Nature Conservancy

Forest pests, both native and non-native, can be transported long distances in or on infested or contaminated firewood. In the USA, both state and federal regulations have changed rapidly in the last few years, due to a variety of programmatic and scientific transitions. This webinar will highlight the release of a new report written by staff of The Nature Conservancy's Don't Move Firewood campaign, covering what regulations and recommendations are in place or proposed at this time. We will describe how the current regulatory and outreach environments applying to the inter- and intra-state movement of firewood vary greatly in type and prevalence across the United States, as well as discuss similarities and differences to the systems held by Canadian provinces.

EFFICACY OF TRUNK INJECTION AND SPRAY TREATMENTS FOR MANAGEMENT OF GOLDSPOTTED OAK BORER IN SOUTHERN CALIFORNIA

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The invasive goldspotted oak borer (GSOB), *Agrilus auroguttatus*, is threatening the health and survival of oak trees in several southern California counties. Direct control option for GSOB were limited to frequent bark sprays. From the Lost Valley site in the core area (San Diego Co.) of the infestation, we report an on-going investigation of the impact of *A. auroguttatus* on coast live oak, *Quercus agrifolia*, before and after treatment with a systemic insecticide, emamectin benzoate or contact insecticide, bifenthrin. Trunk injection treatments containing emamectin benzoate have been found to be as effective as bifenthrin bark sprays in reducing the number of new adult emergence, level of bleeding on bark surface, and tree mortality compared to untreated checks. After 2 years post treatment, it appears that we have achieved a level of "herd immunity", reduced untreated check tree mortality, in the study area.

Subalpine fir decline in the US Rocky Mountains: multi-scale factors associated with mortality and forest response

Brian J. Harvey, Mike Battaglia
University of Washington)

Understanding how drivers of ecological disturbance operate across scales is important in an era of increasing disturbance activity. Severe and extensive Dendroctonus bark beetle outbreaks across western North America have left in their wake dominance by shade-tolerant and commonly late-seral trees such as subalpine fir (Abies lasiocarpa), which can foster resilience of forest cover. However, subalpine fir decline (SFD) is a poorly understood phenomenon that has killed trees across millions of hectares in western North America with unknown consequences for future forest resilience. How different factors (e.g., climate, topography, host-tree characteristics and abundance) govern SFD presence and severity across spatial scales from individual trees to a subcontinental scale has not been explored in a single framework. Here, we combine broad-scale geospatial data on SFD occurrence, stand-scale field data on SFD severity, and fine-scale individual tree data on mortality to test the relative importance of factors related to SFD across spatial scales spanning >10 orders of magnitude (<1M to >10M hectares). At the broadest scale (subcontinental, ~25 M ha), annual areal extent of SFD over time increased sharply with antecedent drought. At regional- (~6 M ha) and stand- (0.1 – 0.25 ha) scales, the occurrence and severity of SFD was spatially associated with more mesic topographic positions and greater host-tree abundance. Finally, at the individual tree- and tree-neighborhood- (<1 m) scale, the probability of mortality increased for larger trees and trees closer to dead conspecific neighbors. The positive temporal association of SFD with drought at broad scales versus the positive spatial association of SFD with mesic sites at fine scales suggests strong importance of local biotic processes in mediating drought-driven forest decline, and highlights the need for understanding multi-scale drivers of ecological disturbance.

Impacts of drought on forest insects and diseases in the United States

J. A Hicke, T. E. Kolb, C. J. Fettig, M. P. Ayres, B. J. Bentz, R. Mathiasen, J. E. Stewart, and A. S. Weed

Severe droughts have occurred recently in the United States, and given future climate change, the extend, frequency, and severity of future droughts are expected to increase associated with warming and changes in precipitation. Widespread tree mortality from insects and pathogens has occurred in the United States during the last few decades, suggesting a role associated with climate change. Here we review and synthesize the scientific literature on the role of drought in influencing outbreaks of insects and pathogens. For many forest insects, especially bark beetles, moderate drought results in reduced beetle performance, whereas severe drought results in increased susceptibility of host trees to attack. Sapfeeders appear to have the greatest effects during moderate drought. For some pathogens (primary pathogens and those whose lifecycle depends on moisture), drought reduces performance. For other insects and pathogens, drought either has little effect or can reduce outbreak probability. Additional research needed to increase understanding of the role of droughts is summarized.

Invasive shothole borers (ISHB) in urban and natural forests in Southern California

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The polyphagous and Kuroshio shothole borers (Euwallacea fornicatus and E. kuroshio, respectively), collectively referred to as the invasive shot hole borers (ISHB), are invasive ambrosia beetles that have caused widespread mortality of urban hardwood trees in Southern California. These beetles have overlapping and expanding ranges spanning Los Angeles, Orange, Riverside, San Bernardino, San Diego, Santa Barbara and Ventura Counties. With state and federal funding, the Statewide Strategic Initiative to Control Fusarium Dieback-Invasive Shot Hole Borers in California has expanded monitoring efforts over the past three years. A statewide trapping and survey coordinator organized county-lead trapping programs in each infested county and the counties on the leading edge of the infestation. In addition, a participatory science (citizen science) program called Bad Beetle Blitz was organized by the University of California Agricultural Natural Resources, Resource Conservation District of the Santa Monica Mountains, and the Los Angeles County Agricultural Commissioner/Weights and Measures. The program was used to delimit the extent of ISHB infestation in high-risk areas of Los Angeles County. Participants attended a six-hour training which included an online course, two workshops, and after-training office hours. In 2020, trainings were held fully online. In 2021, trainings included an in-person field day. More than 120 reports of suspected ISHB infestations were collected and checked by experts. Preliminary data suggest that accuracy of reported infestations was affected by the delivery of training (in-person vs. online). This program will be expanded in the future to include volunteers throughout the state for early detection and rapid response efforts.

Measuring changes in fuel loads with a multi-year dataset following a severe drought and bark beetle outbreak in the Central and Southern Sierra Nevada

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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 loads over time, and to determine predictive variables of fuel loads 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 forest structure, and changes in fuel loads. Fuels data across the plot network were measured in 2017, 2019 and 2021 using modified Brown's transects, and measurements will be repeated in 2023. Preliminary data show total surface fuel loads have increased from 2017 to 2021 across all national forests and elevation bands. The greatest change was observed on the Sierra National Forest where mean surface fuel load more than doubled. Better understanding of changes in fuel composition following bark beetle outbreaks in Sierra Nevada forests provides important context for land management decisions, especially as severe drought and bark beetle outbreaks likely increase in severity moving forward.

Bioclimatic drivers of synchronous western balsam bark beetle irruptions across BC

Michael Howe, Lucas Peng, Allan Carroll.

Synchronous outbreaks of western balsam bark beetle have impacted a large proportion of subalpine fir forests across British Columbia. We compiled aerial overview survey data at a 1 km^2 resolution from 1998-2019 across the province to explore the spatiotemporal dynamics, drivers of outbreaks, and evidence for increasing landscape susceptibility to this understudied insect. In total, we found that outbreaks of western balsam bark beetle are largely synchronous at large spatiotemporal scales, outbreaks are driven by shifting bioclimatic conditions, and the ramifications of these altered climatic regime may already be apparent.

Examining the use of biochar on spotted knapweed, *Centaurea stoebe* L., and its impact on the success of two introduced biocontrol agents, *Larinus minutus* and *Cyphocleonus achates*

Toriani Kent

Spotted knapweed (*Centaurea stoebe* L.) is one of the most important invasive weeds in the western United States, causing a reduction in productivity, less foraging habitat for wildlife and increased erosion and stream sedimentation in areas where it invades. Two of the most widely used biological control agents against spotted knapweed are *Larinus minutus* Gyllenhal (seed-head weevil) and *Cyphocleonus achates* Farhaeus (Knapweed root weevil) (Coleoptera: Curculionidae). However, their impact alone has not been enough to meet management needs. Biochar has been investigated as a potential management tool against invasive plants and as an alternative to removal or biological controls alone that have not met management needs. This work examined the effects of biochar as a soil amendment on the susceptibility of spotted knapweed to *L. minutus* and *C. achates*, two biological control agents feeding on different parts of the plant. The nursery experiments showed an increase in attack and presence of offspring in plants attacked by *C. achates* in the presence of biochar. The attack by *L. minutus* was not as straightforward, and the addition of biochar appeared to make seed heads less acceptable, as well as decreasing the total number of seed heads per plant. The results suggest that using biochar as a soil amendment in areas with spotted knapweed present would be most effective in conjunction with *C. achates* as the biological control agent, and the lower concentration tested in is this study (10% by volume) provided better results compared to the higher concentration tested (25%).

Refining MPB semiochemicals for detection in an expanded range

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Mountain pine beetle (MPB, *Dendroctonus ponderosae*) has expanded its host range into naïve lodgepole pine forests in Alberta, Canada and killed a large number of pine trees. We investigated whether semichemical tools developed in the beetle's historical range were suitable for monitoring MPB in this new environment and at the low population levels found in the leading-edge of expansion. A field trial suggested that a combination of MPB pheromones and two host volatiles together (terpinolene and myrcene) caught the most beetles compared to lures with single host volatiles or other combinations. Also, we varied the release rates of female MPB aggregation pheromone *trans*-verbenol and tree volatiles to identify density dependence in catches of beetles in traps. We found that very low local densities of MPB were more attracted to higher release rates of pheromone compared to areas with relatively greater MPB densities in the leading-edge zone. These studies identify that by refining tools used in MPB's historical range we may be able to detect and monitor MPB at low densities in Alberta more efficiently.

Influence of individual tree competition and induced defenses on bark beetle mortality in treated and untreated ponderosa pine stands

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Resilience and resistance are important factors to consider when managing forest stands, especially with climate change in mind. In the US Southwest, management objectives often aim to create complex spatial patterns leading to variable tree densities which can affect tree resilience and resistance to bark beetles. With climate change, bark beetle outbreaks have become more frequent and cover larger spatial scales. Typically, silvicultural treatments are implemented to reduce competition and increase tree growth and vigor. The effect of treatments and variable spatial patterns on bark beetle-caused mortality and resistance to bark beetle attacks has not been well-studied. Our project aims to examine a variety of silvicultural strategies and their effect on resiliency and resistance to bark beetles by using paired individual tree and stand-scale data. Our objectives are to quantify relationships between stand attributes and bark beetle-caused mortality, compare mortality and stand attributes in treated and untreated stands, and assess the impact of treatments on resin duct defenses, as an indicator of resistance to bark beetles, on national forest and tribal lands. In this poster presentation, we will present an overview of the project, our methods, and expected outcomes. This research will increase our knowledge of how management actions influence bark beetle-caused tree mortality under endemic bark beetle populations and how to best enhance stand resilience and resistance under changing conditions.

Oribatid mites as bioindicators in Alberta's forests

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Oribatid mites are among the most abundant and diverse soil mesofauna, and are used as bioindicators to monitor changes in soil. The Alberta Biodiversity Monitoring Institute (ABMI) has monitored oribatid mites across Alberta for more than a decade, along with other flora and fauna. The ABMI uses specific protocols to collect organic soil, from which oribatid mites are extracted and identified to species. The ABMI has used this species-level data to produce province-wide models of taxon intactness, richness, uniqueness, relative abundance in reference and current conditions, and species' responses to habitat and human disturbance types. We are also analyzing oribatid mite community composition in response to habitat, human disturbance and spatial-climatic factors, including in response to forestry in the oil sands region. In parallel, the mites are curated and available for future examination, and taxonomic resources have been developed to aid identification and to maintain records of oribatid species documented in Alberta. Overall, ABMI's inclusion of oribatid mites provides a bioindicator specific to monitoring soil, helps us to document their diversity, ecology, and trend in response to environmental change, and increases their functionality as indicators in other monitoring and research efforts.

Detection of Bark Beetle Attack Using Remote Sensing and Machine Learning: Expectations vs. Reality

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Bark beetle outbreaks are some of the most damaging disturbances to forest ecosystems, with long-lasting economic and ecological impacts. In an outbreak, tree-killing bark beetles attack healthy trees by entering the bark, breeding, and laying eggs under the bark that the process eventually results in the death of the trees in the year of the attack. It is accordingly necessary to use proactive management strategies and sanitation felling while providing detailed information regarding the location of infested trees as well as the stages of attacks. However, field surveys are labor-intensive, irregular, time-consuming, challenging for broad areas, and expensive with subjective conclusions. A promising alternative is remote sensing of bark beetle attacks, providing efficient and user-friendly data acquisition tools through various platforms and imaging systems. The most challenging objective of using remote sensing technology is detecting the early stages of bark beetle attacks. In recent years, machine learning has been incorporated with remote sensing technology to analyze captured data, design learning strategies, and build accurate computational models for automatic interpretation systems. However, various characteristics related to bark beetles, host tree species, imagery systems, and analyzing methods affect the effectiveness of attack detection systems. This talk will focus on the possibilities and challenges of using remote sensing and machine learning methods to detect the early stages of bark beetle attacks (i.e., green attacks).

The changing face of forest entomology in Canada.

Rory McIntosh
Saskatchewan Ministry of Environment

Since the early 20th Century, forest entomologists have evolved though several phases to keep pace with changing philosophies and demands on the forest. Forest entomology has transitioned from the early days of surveillance, bionomics, identification and discovery, through a period of developing detection, management, and control systems designed to mitigate pest outbreaks to an integrated holistic ecosystem approach to forest disturbance. A broad review of landmark events that have shaped the direction, practice, and science of forest entomology to address forest insect disturbances in Canada, is presented.

Return of the Beetles: An Arizona Museum Fire Story

Chrissy Mott, Rich Hofstetter
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Large scale post-fire restoration practices focus on prevention of further degradation of forest and cultural resources, but we know very little about the impacts of these management efforts on the insect community and their potential effects on vegetation recovery. We studied post-fire habitats for beneficial insects within the context of existing BAER treatments, to determine if the increased complexity of insect communities has a long-term effect on reestablishing vegetation. Through our earlier and ongoing efforts monitoring fire scars from slash pile burns, we have determined that several critical nutrient-cycling insect taxa are diminished in fire-disturbed areas. We hypothesize that altering habitat complexity will draw in diverse arthropods that are critical to soil nutrient cycling and stabilization and accelerate native plant recovery. We installed pitfall traps near established BAER transects to monitor pre-and post-monsoon ground-dwelling arthropods and recovering vegetation after mulch treatments across the area. We found multiple taxa within the mulch treatments that are not present in our other study sites across northern Arizona, indicating some potential for additional habitat in post-fire mulch-treated areas. This study will aid in evaluating the long-term ecological effects of immediate post-fire erosion control treatments, answering fundamental questions about post-fire insect recolonization and habitat requirements, and their effects on nutrient cycling and vegetation success. This may allow BAER treatments to provide sustainable and long-term soil stability and vegetation recovery, further protecting life, infrastructure, and natural and cultural resources in the aftermath of catastrophic fire.

Long-term terpene response to mountain pine beetle attack in lodgepole and jack pines

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Insect herbivores must contend with constitutive and induced plant defences. The mountain pine beetle (*Dendroctonus ponderosae* Hopkins; MPB) has expanded its range east of the Rocky Mountains into the boreal forest in Alberta and is encountering evolutionarily naïve lodgepole and jack pines. Previous studies have examined terpene profiles prior to (constitutive) and just after (induced) mass attack but the terpene profile of trees post-overwintering is unknown. We manipulated mass attack densities in lodgepole and jack pines in the field and measured individual and total terpene amounts and diversity in phloem pre-attack, post-attack, and post-overwintering. Total terpenes as well as many individual terpenes increased at the post-attack stage but were only significantly higher post-overwintering in both lodgepole and jack pines. Chemical diversity was not different at the different stages of the attack, but individual trees had distinct chemical communities. Lodgepole pines had greater amounts of total constitutive terpenes compared to jack pine, but jack pine had higher induced terpenes compared to lodgepole pine. Since phloem terpene content is increased post-overwintering, trees that survive minor attacks or are "strip attacked" could be more toxic to MPB that try to colonize in the subsequent year.

Cuticular hydrocarbons of *Ips pini* (Say): lessons learned to inform future chemotaxonomic studies

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Chemical characters of insects, such as cuticular hydrocarbons (CHCs), can be useful taxonomic tools. CHCs play important roles in waterproofing and chemical communication and are generally species specific. Differences in CHC profiles have been used to delineate species in many insects, including bark beetles and other forest insects. The potential utility of using CHCs to recognize cryptic species or elucidate species complexes has been demonstrated in the genus *Ips* DeGeer for species in the *grandicollis* subgeneric group, and in other Scolytine beetle genera such as *Conophthorus*, *Dendroctonus*, and *Euwallacea*. CHC profiles were characterized by gas chromatography-mass spectrometry for samples of pine engraver, *I. pini* (Say), collected from geographic locations in North America. Qualitative differences were found in cuticular hydrocarbon profiles between California and New York populations of *I. pini* which correspond to known pheromone races for this species. In preliminary investigations we discovered unexpected variability in CHC profiles taken from curated *Ips* beetles, which led to testing the effects of common methods used for collecting and preserving insect specimens on the CHC profile of adult *I. pini*. Specifically, we evaluated: (1) the effect of sample size; (2) the effect of solvents (ethanol versus hexane); (3) the number and duration of solvent extractions; (4) the effect of exposure to ethyl acetate in a killing jar before extraction; and (5) presence or absence of phoretic mites. Standard collection, storage, and extraction methodology for optimal characterization of CHCs of bark and ambrosia beetles is proposed, allowing comparison of analyses performed by different researchers. Examination of these chemical characters could add to the understanding of species complexes of forest insects in the western U.S.

An Evolution of Approaches to Forest Entomology

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Over the span of a career there have been many changes in forest entomology. The presentation provides a "fly-by" of some of the societal, political, and technological changes in the field. Beginning with the "uniqueness" of being one of the very few women in the field, and highlighting some of the significant changes in pesticide use, forest management, and aerial survey.

Warming increased bark beetle-induced tree mortality by 30% during an extreme drought in California

Zachary Robbins, Chonggang Xu, Brian Aukema, Polly Buotte, Rutuja Chitra-Tarak, Chris Fettig, Mike Goulden, Devin Goodsman, Alexander Hall, Charles Koven, Lara Kueppers, Gavin Madakumbura, Leif Mortenson, Jim Powell, and Rob Scheller
Presenter: Los Alamos National Laboratory, North Carolina State University

Quantifying the responses of forest disturbances to climate warming is critical to our understanding of carbon cycles and energy balances of the Earth system. The effect of future warming and drought on bark beetle outbreaks is complex as multiple drivers of these events may respond both independently and interdependently. Using a novel model of bark beetle biology and host tree interactions, we assessed how contemporary warming affected western pine beetle (*Dendroctonus brevicomis*) populations and the mortality of its host, ponderosa pine (*Pinus ponderosa*), during an extreme drought in the Sierra Nevada, California. Further, to forecast the likelihood of future western pine beetle attacks, we simulated WPB outbreaks under future climate and forest growth. When compared with field data, our model captured the western pine beetle flight timing and rates of ponderosa pine mortality observed during the drought (2012-2015). We attribute a ~30% increase in ponderosa pine mortality during drought directly to increases in western pine beetle voltinism. The modeled likelihood of future outbreak frequency appeared most connected to drought frequency, while outbreak severity (based on tree mortality) appeared most connected to stand basal area. We found that ponderosa pine basal area frequently failed to recover to pre-2012 levels, and in climate scenarios with more frequent future drought, it appears a lower basal area equilibrium was reached. While ponderosa pine density may decline under increased future droughts and warming, we find that limiting densification may reduce severe outbreaks, such as those seen in the 2012-2015 drought.

RNAi for use in lethal trap trees

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The spruce beetle, like the mountain pine beetle, is a natural, eruptive forest pest that has historically had economically devastating outbreaks in British Columbia. Currently, a recommended population reduction method for spruce beetle is conventional trap trees. Spruce beetle prefers windthrown trees, and so conventional trap trees functionally "mop up" excess flying beetles in order to prevent mass attack on standing healthy trees. This project is focused on developing RNA interference (RNAi) technology that can be used to kill bark beetles in a conventional trap tree system. The goal is to eliminate the expense and logistical constraints for removing and destroying live beetle trap trees. RNAi technology exploits a natural pathway in an insect's cell and can be tailored to target individual species, unlike chemical pesticides such as the discontinued monosodium methanearsenate (MSMA). Combining RNAi technology with established conventional trap tree protocols will potentially create a lethal trap system that is cost effective, non-toxic and targeted.

Fatal attraction: evaluation of entomopathogenic fungus *Beauveria bassiana* for the biocontrol of the invasive mountain pine beetle, *Dendroctonus ponderosae*

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Mountain pine beetle (MPB), *Dendroctonus ponderosae*, has infested ~16Mha of British Columbia killing >50% lodgepole pine, *Pinus contorta*. At present, it is functionally an invasive species in Alberta, killing and reproducing in evolutionarily naïve populations of lodgepole pine, jack pine (*P. banksiana*), and their hybrids. We undertook investigations to study whether an entomopathogenic fungal pathogen, *Beauveria b*assiana can be utilized against MPB as a biological control agent and reduce the potential of range expansion into the Canadian Boreal Forest. *B. bassiana* is an entomopathogenic fungus utilized as a bio-control agent in agricultural settings to kill arthropod pests. We have screened ~150 strains of *B. bassiana* representing Canada- and world-wide collections for virulence factors against MPB. The fungal strains were also screened for UV-light resistance and desiccation tolerance to account for the major abiotic factors that could potentially limit the survival of the fungal species in nature. The strains were categorized based on pigment production, conidial density, myceliation rate and antifungal susceptibility. The results of our infection models on both MPBs and honeybees showed differential results. Although the fungus can colonize other insects, in-vivo honeybee infection model revealed ~5% mortality, representing the natural death rate of the hive population. Conversely, laboratory results indicated 100% killing effect and mycosis against laboratory-reared and field-collected MPBs. The LT50 (lethal time 50) ranges from 2-5 d + 0.33 d and LT100 ranges from 4-6 + 0.5 d. This is the first account utilizing *B. bassiana* as a biological control agent of MPB in Western Canada.

Evaluating the Unparalleled Success of MCH Treatments for the Douglas-fir Beetle

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Application of the antiaggregation pheromone 3-methylcyclohex-2-en-1-one (MCH) to protect high-value, high-risk Douglas-fir trees during outbreaks has been used operationally in the US for 22 years. At least three companies have registered formulations of MCH and sales continue to rise each year. The treatment is highly effective at preventing the infestation of live trees during any stage of outbreaks and at any population density of the Douglas-fir beetle. Despite over 30 years of research to develop similar treatments for the mountain pine beetle and spruce beetle, those efforts have essentially been unsuccessful. The history of efforts to develop anti-aggregation treatments for those species illustrate a pattern of trying to engineer a technological answer to why the treatments are not effective rather than an objective assessment of the biological feasibility of such treatments. It is well known in other systems that pheromone-based treatments which are effective for one species may not be effective for closely related species due to differences in biology, ecology, and population dynamics of those species. For example, mating disruption is highly effective for the western pine shoot borer which reaches maximum densities of several hundred individuals per acre, but, is not at all effective for the Nantucket pine tip moth which can reach densities of thousands per acre. The reason that application of MCH targeting the Douglas-fir beetle is so effective compared to similar treatments for the mountain pine beetle and spruce beetle is likely due to the much lower population densities of Douglas-fir beetle during outbreaks. Continuing efforts to develop antiaggregation treatments for the mountain pine beetle and spruce beetle are unlikely to ever be successful in developing an operational management treatment, waste limited resources for forest entomology research, and create a generally negative attitude toward pheromone-based treatments for bark beetles among resource managers whose first experience is using antiaggregation pheromones for one of those species.

Conifer bark beetle research and management in Mexico: a summary from the last two decades

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There are 13 *Dendroctonus* species native to Mexico, six of them are classified as aggressive and seven as non-aggressive. Furthermore, 12 *Ips* species are known to occur in the forest of this country, most of them acting as secondary insects, although in some cases they have caused considerable tree mortality during drought periods. From 2000 to 2010, three major bark beetle outbreaks occurred in northern Mexico; the first one was caused by the Roundheaded Pine Beetle (*Dendroctonus adjunctus*) on *Pinus arizonica*, in Chihuahua, the second by the Douglas-fir beetle (*Dendroctonus pseudotsugae* barragani) on Douglas-fir (*Pseudotsuga menziesii*) in Coahuila, Durango and Chihuahua, and the third by the Smaller Mexican Pine Beetle (*Dendroctonus mexicanus*) on *Pinus leiophylla* and *Pinus teocote* in Aguascalientes. During 2011-2021, outbreaks that required considerable attention were caused by *Dendroctonus mexicanus* in Aguascalientes, *D. mexicanus* and *Ips lecontei* in Durango and Chihuahua, *Dendroctonus frontalis* and *D. mexicanus* in Querétaro, Michoacán and Oaxaca, and *D. adjunctus* in Oaxaca. Most bark beetle infestations had occurred in forests receiving no silvicultural management and after long drought periods. Four lines of research have received the most attention: 1) basic research on bark beetle chemical ecology 2) field research on the use of semiochemicals for bark beetle monitoring and control, 3) modeling of bark beetle behavior under climate change scenarios, and 4) the impact of semiochemicals and pyrethroid insecticides on target and nontarget organisms, soil, and water. Field studies on the use of semiochemicals have served to determine the flight seasonal pattern for *D. adjuntus*, *D. pseudotsugae barragani*, *D. mexicanus,* and *Dendroctonus brevicomis*, and to corroborate the coexistence of *D. mexicanus* and *D. frontalis* in most sierras of Mexico. Furthermore, the effectiveness of the 3-Methylcyclohex-2-en-1-one (MCH) in reducing aggregation of *D. pseudotsugae barragani* and Douglas-fir mortality has been demonstrated. The antiaggregative effect of Verbenone has been tested against *D. mexicanus* and *D. frontalis* with equivocal results. Field studies have demonstrated that *D. frontalis* and *D. mexicanus* respond differently to commercially available lures and we can select a product in accordance with the geographic region and the objective of use (i.e. monitoring or mass trapping). Recent studies have proven that MCH and Verbenone are safe for non-target freshwater invertebrates. On the other hand, among three pyrethroids used for bark beetle control in some countries (bifenthrin, cypermethrin, and deltamethrin) cypermethrin is the most effective and the least toxic for freshwater invertebrates. Bark beetle control in Mexico is an activity regulated by the Secretariat of Environment and Natural Resources (SEMARNAT). Allowed control practices are indicated at the Mexican Official Standard NOM-019-SEMARNAT which is updated every 7 to 10 years. The current version has incorporated the use of semiochemicals for bark beetle monitoring and control and, at the same time, maintains other mechanical and chemical control practices.

The Siricidae of Mexico

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Siricid woodwasps (Hymenoptera: Siricidae) are important wood-boring insects in natural forests and tree plantations. In 2004, *Sirex noctilio* Fabricius, a Euro Asiatic species, was discovered in New York (USA) and Eastern Canada, after being found in other countries beyond its native range. That finding encouraged the monitoring of *S. noctilio* in Eastern North America and the revision of the Siricidae of the Western Hemisphere (Schiff et al. 2012). However, knowledge of Siricidae of the sierras of Mexico is lacking. The scarce records in formal insect collections are mainly from specimens intercepted (from timber) at checkpoints on the US-Mexican border. As part of several conifer bark beetle trapping studies, conducted in the sierras of Mexico, we captured siricid woodwasps specimens that were attracted to semiochemical-based bark beetle lures installed on funnel traps. Other specimens were collected directly from their host when ovipositing in currently bark beetle-infested trees or while emerging from tree logs. Given the importance of this insect group, we stated as objective to determine the species of Siricidae found in the sierras of Mexico, with specific data about their location and environment. The species determination was made through the observation of the external morphology based on Schiff et al. (2012). The following species were identified: *Sirex obesus* Bradley, *Sirex areolatus* Cresson, *Xeris morrisoni* Cresson, *Urocerus californicus* (Ashmead), and *Sirex* sp. circa *nitidus*. Other species reported in the literature for Mexico are *Sirex mexicanus* Smith and *Sirex xerophilus* Schiff. We believe that all these species are found within their native range in Mexico.

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Mountain Pine Beetles and the Once and Future Whitebark Forests of the Greater Yellowstone Ecosystem

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Modeling research predicted that the environment for mountain pine beetles in whitebark stands would vastly improve with a warming climate. By the early 2000's, these projected conditions were realized as witnessed by the mortality of an estimated 75 – 80% of cone-bearing, whitebark pine trees in the GYE in less than a decade. It is likely that this unprecedented outbreak would have continued in the absence of a 2009, mid-October cold snap anomaly across the entire GYE that effectively shut down the epidemic. However, after 10 years of flourishing in whitebark pine forests, endemic beetle populations had become well established in these high elevation ecosystems. And as favorable conditions return, these endemic populations are poised for explosive population growth. The drivers of whitebark pine decline are numerous and the increasing magnitude of these threats tests our ability to effectively steward whitebark pine in the present while considering future ecological change. Understandably, managing for the persistence of whitebark pine under rapid climate change is a challenging mission. So how can we move forward in a concerted effort knowing that the return to historical conditions in high-elevation ecosystems is unlikely? The answer to this depends on the identified ecological values or services that we are working to maintain to the best of our collective abilities. Based on the emerging science on whitebark pine heath and our collective personal observations over the past 20 years, we use the Climate Smart Conservation and Resist-Accept-Direct frameworks as guides for innovation, flexibility, and enabling rapid management responses and actions to help preserve whitebark pine health and the high-elevation resources we value.

Are the spruce budworm and two-year-cycle budworm moth temporally isolated?

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Two major forest defoliator species of the spruce budworm complex (*Choristoneura fumiferana* and C. occidentalis) interbreed freely in laboratory settings, but natural hybridization rates have not been reliably quantified due to their indistinguishable morphology. We collected adult individuals across their expected zone of sympatry in west-central Alberta at 10-day intervals over two successive years, assigning taxonomic identities using numerous DNA markers. We found unexpectedly broad sympatry between *C. fumiferana* and *C. occidentalis biennis*, with substantial overlap of regional flight periods. However, flight period divergence was much more apparent on a location-by-location basis, highlighting the importance of considering spatial scale in these analyses. Phenological comparisons were further complicated by the biennial life cycle of C. o. biennis, the main subspecies of *C. occidentalis* in the region, and the occasional occurrence of the annually breeding subspecies *C. o. occidentalis*. Nonetheless, we demonstrate that biennialism is not a likely contributor to reproductive isolation within the species complex. Overall, interspecific F1 hybrids comprised 2.9% of sequenced individuals, confirming the genomic distinctiveness of *C. fumiferana* and *C. occidentalis*, while also showing incomplete reproductive isolation of lineages. Finally, we used FST-based outlier and genotype–environment association analyses to identify several genomic regions under putative divergent selection. These regions were disproportionately located on the Z linkage region of *C. fumiferana*, and contained genes, particularly antifreeze proteins, that are likely associated with overwintering success and diapause. In addition to temporal isolation, we conclude that other mechanisms, including ecologically mediated selection, are contributing to evolutionary divergence within the spruce budworm species complex.

Semiochemistry of *Dendroctonus* Bark Beetles: Learning More and More About How Little We Know

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Dendroctonus bark beetles are among the most significant mortality agents of conifers in North and Central America, and semiochemicals are essential to their capacity to kill trees. Understandably, semiochemistry of this genus has received extensive investigation, since disruption of chemical communication holds the promise of environmentally friendly, narrowly targeted pest management tools. However, to date there has been only limited success in development of semiochemical-based management for *Dendroctonus* pests. All aggressive species of bark beetles appear to face essentially the same challenge: attacking hosts in sufficient numbers to overwhelm constitutive resin defenses while avoiding harmful levels of competition. The uniformity of this goal implies that semiochemical systems of different, aggressive species should be likewise uniform, with the same types of behaviors being elicited and identical functional roles being fulfilled. However, with our growing appreciation for the complexity with which semiochemicals can influence the behavior of aggressive bark beetle species, it is clear that there is no single template for their chemical ecology, and discoveries in one bark beetle system cannot be expected to advance understanding in others. Furthermore, recent research has underscored how behavioral responses to a particular semiochemical are often governed by unknown or poorly understood variables of the environment or the insect populations. Such interactions could make efficacy of semiochemical applications highly unpredictable. In this presentation, we use examples from species of *Dendroctonus* to highlight these and other issues which may create major barriers to the development of semiochemical-based technology for management of destructive bark beetles.

Integrated Forest Pest Management under the Mexican Context

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Forest resources in México are vast and diverse. Management sceneries include natural, planted and urban forests. The natural forest covers 34 million of ha temperate vegetation, mainly conifers, and mixed broadleaf trees, (12.9 are under federal protection, almost 7.5 with forest management plans for timber production, and 13.6 without forest management plans). The planted forest has two components, the fast-growing commercial plantations with 350,000 ha, and plantations with restoration and social scope, highlighting the new official program (Sembrando Vida), which is planting wood and fruit trees in one million ha. The urban forest is huge with 40 cities with more than 400,000 inhabitants, trees are part of their landscape and people are given much importance to green spaces. Several insects are major pests in these sceneries. For the most important pests an Integrated Forest Pest Management (MIPF) approach is the best strategy to attend to infestations. The concepts of MIPF and Forest Health now are better accepted by society, but high-quality information is needed to accomplish specific MIPFs, and this is only true for a few pests, like pine bark beetles, pine sawflies, mahogany shoot borer, and leaf cutter ants. Mexican society is now more critical to accept the chemical method to control pests, the biological and cultural methods are gaining acceptance. Spatial and remote sensing technology is growing in several sceneries like protected areas and rapid growth tropical plantations. The new book “Fundamentos de Manejo Integrado de Plagas Forestales en México” offers basic information on the subject.

Drought and defense: The effects of short- and long-term drought on tree resource safety margins and impacts for bark beetle attack

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Drought affects plant chemical defenses and thereby plant susceptibility to pests and pathogens. Monoterpenes are of particular importance for conifers as they play critical roles in defense against bark beetles. To date, most work seeking to understand the impacts of drought on monoterpene production in conifers has primarily focused on young potted seedlings, leaving it unclear how older age classes that are realistically vulnerable to bark beetles might respond to stress. At the molecular level we have yet to determine what specific carbohydrate resources are used to support monoterpene synthesis under drought stress and bark beetle attack, and furthermore, whether this level of knowledge can help us predict dynamics that emerge at the landscape level. To gain a more robust understanding of drought-induced outbreak events in semi-arid ecosystems, our lab relies on long-term simulated drought manipulation field experiments and employs a combination of metabolomics, chemical ecology and plant ecophysiology techniques. In this talk, I will discuss salient results from two separate field experiments focused on the chemically-mediated interactions between pinon pine (*Pinus edulis*) and the pinon engraver beetle (*Ips confusus*). The cumulative and synergistic effects of heat and drought on carbohydrate prioritization towards chemical defenses will be presented as well as the subsequent impacts on the beetle and its fungal symbionts.

Production of complementary defense metabolites reflects a co-evolutionary arms race between a host plant and a mutualistic bark beetle-fungal complex

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Intra-specific variation in conifers has been extensively studied with respect to defense against herbivores and pathogens. While studies have shown the ability of individual or specific mixtures of compounds to influence insects and microbes, research testing biologically relevant mixtures of defense compounds reflecting intra-specific variation amongst tree populations to enemy complexes is needed. We characterized the variations in lodgepole pine monoterpenes from a progeny trial in western Canada and grouped trees in four clusters using their monoterpene profiles. We then selected 11 representative families across four clusters and amended their entire monoterpene profiles (with the exception of β-phellandrene) in media to determine how representative families affect the performance of the mountain pine beetle or its fungal symbiont. We placed adult beetles or inoculated fungus on the amended media and measured beetle performance and fungal growth as a proxy to host suitability. We found that different clusters or families differentially influenced beetle or fungal responses. However, monoterpene profiles of trees suitable to the beetle or the fungus were dissimilar. These outcomes reflect a co-evolutionary arms-race between the host and the bark beetle-fungus complex, which has resulted in the production of complementary defense metabolites among different pine populations to enhance tree survival.

Results from the Columbia River corridor invasive woodborer survey in Oregon and Washington

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Despite safeguarding measures, new exotic forest insects are escaping detection and becoming established in the U.S. at the rate of 2.5 species per year. Technology that enables land managers and scientists to detect early the exotic invasive wood-boring insect species in the taxa Buprestidae, Cerambycidae, Scolytinae and Hymenoptera (i.e. "wood-boring insects") is critical in providing the successful rapid response and eradication. Oregon and Washington are under increasing threat from these types of exotic species arriving through global trade and international ports on the Columbia River. For three years (2016-2018) we conducted a survey at 16 sites along approximately 150 km of the Columbia River Corridor, representing a variety of forest types from state-managed hemlock/Douglas-fir; urban forests of the Portland metro area; and to arid pine/Douglas-fir forests at the eastern survey extent. At each site, eight Lindgren funnel traps with unique baits and lures, some of which were new to the market, were established April thru September. In 2018, we also placed funnel traps in tree canopies vs ground-based traps alone. Across all years and all traps, we collected a total of 2,225 samples, over 400,000 individual specimens and over 200 species of native and exotic wood-boring insects. We detected four new first detections in Oregon, one of which was a new record for North America, the Mediterranean oak borer, *Xyleborus monographus* (Fabr.). Over 90% of the total trap catch abundance was a single exotic species, *Xyleborinus saxesenii* (Ratzburg). The four traps placed in the tree canopies in 2018 caught over two times the species richness and total abundance per trap that their counterparts on the ground captured. This pattern was particularly apparent for Scolytinae captured in a-pinene/EtOH traps and Cerambycidae captured in monochamol traps. Exceptions to this pattern included *Phaenops drummondi*, *Scolytus* sp. and *Monochamus* sp, both of which were captured in higher numbers in the ground-based traps. We observed temporal and spatial patterns in trap captures as well. For instance, *Monochamus* sp peaked in the late summer in the eastern portion of the sample area. Early detection is essential to stopping an invasion before it becomes established and too widespread to eradicate. Our project intends to help protect Pacific Northwest forests from exotic invasive wood-boring insect species by informing managers when and how to run surveillance for broad taxonomic diversity of exotic invasive wood-boring insect species.

Reduced relative humidity increased mountain pine beetle productivity

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The global climate is changing gradually and Canada's forests are expected to be affected in complex ways ranging from tree growth and mortality rates to pest disturbances. The parts of western Canada are expected to be warmer and drier with lower summer precipitation which can increase the risk of wildland fire occurrence and frequent drought. Mountain pine beetles (MPB), one of the most destructive forest insect pests in the Prairies and British Columbia, are expected to expand their range under future prospective climate changes. In the current study, we have tested the reproduction success and biology of mountain pine beetles under moderate and low relative humidity (RH) levels. Overall, lower RH treatment (33% of RH) exerted higher reproductive success with higher oviposition gallery initiation (86.37%), egg production, larval emergence, and higher adult beetle emergence than moderate RH treatment (65% RH; current average relative humidity trend in western Canada) (68.57%,t=2.596, df=18). The number of abandoned parental galleries is higher in moderate RH treatment. We conclude that female beetles may have a particular hygro preference in oviposition as total egg production increases with decreasing relative humidity. Humidity treatment can play a key role in the management of this pest complex.