Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Northern Research Station | General Technical Report NRS-237 | July 2025

Forest Health Publications, 2024: USDA Forest Service, Northern Research Station

Jenna Zukswert, Robert Venette, and Therese Poland, Compilers

Citation

Zukswert, Jenna; Venette, Robert; Poland, Therese, comps. 2025. **Forest health publications, 2024: USDA Forest Service, Northern Research Station.** Gen. Tech. Rep. NRS-237. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 42 p. http://doi.org/10.2737/NRS-GTR-237.

Abstract

The USDA Forest Service supports research to promote forest health and protect trees from damaging agents, such as insects and disease. The Northern Research Station of the Forest Service collaborates with many partners to conduct research at local to international scales that offers insights and solutions to challenging forest health issues and helps meet unmet forest health needs. In 2024, the Northern Research Station published 65 publications related to forest health. This document reprints the abstracts for each publication and the 2023 regional forest health goals, threats, and needs identified by the Northeast-Midwest State Foresters Alliance, a key partner of the Northern Research Station. Together, these reprints convey regional research needs and demonstrate the Northern Research Station's contributions to forest health.

Keywords: forest health, pathogen, insect, invasive, disease, plant, soil, damaging agent

Cover Photograph

Galleries under the bark of an ash tree left by emerald ash borer, central Michigan. USDA Forest Service photo by Jenna Zukswert.

Compilers

Jenna Zukswert is a science delivery specialist with the USDA Forest Service, Northern Research Station, East Lansing, MI, jenna.zukswert@usda.gov.

Robert Venette is a research biologist with the USDA Forest Service, Northern Research Station, St. Paul, MN.

Therese Poland is a research entomologist with the USDA Forest Service, Northern Research Station, East Lansing, MI.

Manuscript received for publication March 2025

Published by:
USDA Forest Service
One Gifford Pinchot Drive
Madison, WI 53726
July 2025

Visit our website at https://research.fs.usda.gov/nrs

Forest Health Publications, 2024: USDA Forest Service, Northern Research Station

Jenna Zukswert, Robert Venette, and Therese Poland, Compilers

CONTENTS

INTRODUCTION

The Forest Service, an agency of the U.S. Department of Agriculture, supports research to promote forest health and protect trees and forests from damaging agents that can kill or weaken trees, such as insects, pathogens, and non-native or invasive species. These agents may change the structure of forests and reduce the benefits forests provide, often to an unacceptable degree. Forest Service Research and Development staff work to develop tools and strategies to maintain forests that are healthy, resilient, and persistent and that have biophysical processes that lead to sustainable ecological conditions. Research is conducted to identify threats to forest health and find solutions to problems. Research findings inform and support management decisions by the National Forest System and other federal agencies, tribal governments, state agencies, municipalities, industries, and private landowners, among others, and offer insights and solutions to pressing forest health challenges from local to international scales.

Forest health research is a notable strength of the Forest Service's Northern Research Station, whose scientists work primarily within a 20-state area (bounded by Maine, Maryland, Missouri, and Minnesota) but may also conduct national and international studies. Northern Research Station scientists collaborate with a wide range of partners including researchers and practitioners at colleges and universities, other federal agencies, state government agencies, industry, tribes, and non-profit organizations to investigate a range of forest health issues.

This document pulls together forest health research published in 2024 by the Northern Research Station. Of the 65 publications, 60 were peer-reviewed journal articles and technical reports and 5 were Rooted in Research science briefs summarizing peer-reviewed publications for an audience of natural resource and land managers. Forty-seven Northern Research Station scientists and support staff personnel were involved in the research and writing of these publications. The publications are organized by topics that include bark and woodboring beetles, defoliating insects, forest diseases, invasive plants,followed by more general sections on biological invasions and forest health. These publications contribute to the body of knowledge about threats to forest health and can inform forest management that aims to protect vulnerable forest ecosystems.

For each publication in this document, we have reprinted the published abstract. We have edited abstracts lightly to better meet accessibility standards (e.g., spelling out units of measurement and some abbreviations) and made minor changes in formatting for consistency.

STATE FOREST HEALTH NEEDS: GOALS FROM THE NORTHEAST-MIDWEST STATE FORESTERS ALLIANCE

Forest Service researchers work in close partnership with a range of practitioners to conduct research that protects forest health. State forestry agencies within the Northern Research Station geographic footprint are important partners.

The Northeast-Midwest State Foresters Alliance represents these state forestry agencies, connecting them with the Forest Service and local partners to facilitate regional efforts related to forest health and other issues. As of this writing, Robert Venette and Therese Poland represent the Northern Research Station on the Northeast-Midwest State Foresters Alliance's forest health subcommittee.

Every 2 years, the Northeast-Midwest State Foresters Alliance publishes lists of forest health goals, threats, and needs for the three subregions within this group: the Northeast, the Mid-Atlantic, and the Upper Midwest. Much of the research conducted by the Northern Research Station helps fill these forest health needs. The 2023 lists are reprinted in Tables 1, 2, and 3 to increase researchers' awareness of regional forest health research needs as they plan future studies.

Table 1.—Mid-Atlantic States' List of 10 Unmet Forest Health Needs 2023

Goal	Threats	Needs
Restoration and regeneration of forest and urban forest landscapes impacted by invasive species	Emerald ash borer, beech bark disease, beech leaf disease, hemlock woolly adelgid, elongate hemlock scale	Increased support and funding for tree pest and disease resistance breeding programs (such as an Eastern U.S. Coalition for Forest Tree Breeding)
Address climate change impacts through adaptive management to maintain forest health	Direct damage from severe weather patterns and indirect impacts of a changing climate on seed masting and viability and shifting phenology and distribution of pests and pathogens	Better understanding of climate change impacts to urban and rural forests and development and implementation of adaptation strategies to improve or maintain healthy and sustainable forest landscapes
Maintain healthy oak species in forest and urban forest landscapes	Spongy moth	Funding for the eradication, slow the spread, and suppression programs
	Oak wilt and bacterial leaf scorch	Support for research and implementation of management strategies
	Oak decline, including rapid white oak mortality	Research on the causes of decline and mortality coordinated across states and regions and development of management options
Maintain healthy eastern hemlock in forest and urban forest landscapes	Hemlock woolly adelgid and elongate hemlock scale	Continued support for the National Hemlock Woolly Adelgid Initiative which supports outreach, survey, suppression, technology transfer, and restoration
Early detection of new and emerging forest health threats to allow for rapid response	Emerging and unknown pests and diseases	Support and build infrastructure for states to access and utilize the latest technology for pest and disease detection (e.g., environmental DNA, remote sensing tools)
Reduced prevalence of non-native invasive plants in forest and urban forest ecosystems	Non-native invasive plants	Support for PRISMs (or similar cooperative efforts) across the sub-region, mapping and inventory, integrated pest management, and education and outreach for invasive plants
Maintain healthy pine species in forest and urban forest landscapes	Southern pine beetle	Development of guidelines for prevention and suppression strategies
	White pine decline and associated insect and disease pests and root disease	Collaboration with silviculturists to coordinate silviculture and pest management options for various pine habitats

Source: Northeast-Midwest State Foresters Alliance, Forest Health Committee. 2023. Forest health needs lists. 3 p. Unpublished document. On file with: 444 Capitol Street NW, Suite 387, Washington, DC 20001.

Table 2.—Northeastern States' List of 10 Unmet Forest Health Needs 2023

Goal	Threats	Needs
Improve ability to respond to forest health threats	Fragmentation of funding into multiple grant opportunities with separate RFP and grant administration load and no continuity of funding level. Long timelines on grant processes and delayed awarding of funds. Simultaneously core costs of response have increased due both to new threats and increased cost of doing business. Lack of flexibility delays responses to novel pests.	USDA Forest Service share funding to the states primarily through the Core Grants, rather than multiple small grants, so states can be more flexible and efficient with resources to respond to forest pest issues and use fewer valuable resources in administration of those funds. Funds for emerging pests must be flexible, activities locally driven, and nimble in application.
Identify and respond quickly to emerging threats and developing incidents (such as defoliation events) to increase likelihood of success	Emerging and unknown pests get established under the radar	Support modern early detection projects (e.g., environmental DNA, high throughput metabarcoding DNA). Build national and regional infrastructure to carry out work. Continue existing efforts (early detection and rapid response) and other lower-tech sampling methods. Support public outreach and engagement. Develop modern reporting tools.
	State capacity to employ remote sensing, machine learning and change detection technologies is limited	States need improved technology access and transfer. Encourage development of affordable, improved and new remote sensing tools.
Maintain healthy and diverse hardwood forests	Threats from invasive pathogens (oak wilt, beech leaf disease) to hardwood species	Survey and control funding to find oak wilt when outbreaks are small. Add to current hemlock woolly adelgid funding resources for detection of oak wilt and beech leaf disease (enhanced survey funds).
	Resurgence of naturalized invasive insects (*Lymantria dispar dispar* and browntail moth)	Research into the current browntail moth and *Lymantria dispar dispar* outbreak especially in regards to Entomophaga effectiveness and limitations of other natural control processes
Maintain healthy and productive forests by improving understanding and addressing impacts on forest health due to climate change	Climate change contributes to underlying stress on trees and direct damage from severe and variable weather. It also favors some pests and diseases leading to levels of injury and mortality not observed in the past.	Monitor changes in forest health related to changing climate, identify mitigation strategies, and implement them
Maintain hemlock forests	Exotic insects (hemlock woolly adelgid and elongate hemlock scale and novel disease (hemlock tip blight) suppress health	Continue support for hemlock survey, hemlock woolly adelgid biocontrol and hemlock health research. Increase support for research and demonstration of practical restoration to productive forests. Increase research into effectiveness of elongate hemlock scale treatment and control options.
Maintain ash in the ecosystem	Emerald ash borer-induced ash mortality	Increase support for projects that keep ash on the landscape and mitigate damage from emerald ash borer
		Increase core funding to help offset loss of monitoring funds from USDA Animal and Plant Health Inspection Service so ash resource monitoring can continue
Successful eradication of Asian longhorned beetle	Delay in detection allows Asian longhorned beetle to spread	Good lure/trap combo and survey funds to find Asian longhorned beetle infestations when they are small. Increase opportunities for staff to observe active outbreaks and share knowledge with Asian longhorned beetle eradication program staff for improved diagnostics.

Source: Northeast-Midwest State Foresters Alliance, Forest Health Committee. 2023. Forest health needs lists. 3 p. Unpublished document. On file with: 444 Capitol Street NW, Suite 387, Washington, DC 20001.

Table 3.—Upper Midwestern States' List of 10 Unmet Forest Health Needs 2023

Goal	Threats	Needs
Recover diversity and full function of lowland and riparian forests impacted by invasive species and native species undergoing changes in population dynamics	Emerald ash borer removes all ash species in as canopy dominant species of lowland and riparian forests and in urban forests	Critical need for development and distribution of emerald ash borer -resistant and genetically diverse ash planting stock for recovery of forests where green, black, and white ash have been eliminated by emerald ash borer. Work has begun but needs to be continued.
		Support for development of practical methods of diversifying northern swamps and financial support for public and private landowners to implement diversification of this low monetary but high ecological value forest type
	Hemlock woolly adelgid removes eastern hemlock from riparian forests	Critical need for development and distribution of hemlock woolly adelgid-resistant hemlock. This breeding program must start with eastern genotypes but as potentially resistant hemlock from the Lakes States become apparent, these could be entered into the breeding program. Work has begun but needs to be continued.
Minimize impacts of invasive plants on forests	Many invasive plants are successful because of inadequate natural enemies in North America. This competitive advantage helps them displace native trees.	Support an increase in biological control options for the managing invasive plants species through prospecting and testing candidate biological control species, encouraging timely approval of vetted species, and cooperative production and release of approved species
Maintain oak as a dominant forest component	Causal factors are unknown for oak decline, preventing effective management	Support research examining the causes and possible management options for oak declines
Reduce and minimize injury to trees and forests from legal use of agricultural herbicides dicamba and 2,4-D	Long-term impacts are unknown regarding off-target herbicide injury to trees and forests related to changes in use patterns of dicamba and 2,4-D in field crop systems	Support research examining the impacts of dicamba and 2,4-D injury on the physiology, growth, and longevity of mature trees
Maintain pine-dominant and codominant forests	Heterobasidion root disease impacts pine and spruce growth for an unknown period once established in a stand	Silvicultural research on early intervention, recovery, tree spacing, and species diversity to recover heterobasidion root disease stands
Restoration of eastern forests from loss of tree species due to invasive pests and diseases	Invasive pests and diseases are removing trees species and genera from eastern forests. For long-term recovery of these forests, managers need genetically diverse, resistant or tolerant seed and planting stock of these species. In recent decades, tree breeding has been neglected. Tree-breeding programs that exist are not coordinated and supported for optimal rate of progress in resistance development and transfer to propagation and planting out.	Critical need for the Forest Service and states to increase coordination and support for eastern tree breeding programs and moving improved stock into out plantings. Work has started on these issues and needs to be continued.
Maintain healthy and productive forests by addressing impacts on forest health due to climate change through adaptive management	Climate change contributes to underlying stress on trees and direct damage from severe and variable weather. It also favors some pests and diseases leading to levels of injury and mortality not observed in the past.	Monitor changes in forest health related to changing climate, identify mitigation strategies, and implement them
Make use of satellite imagery to monitor changes in forest health	Technological help is needed for states to make greater use of satellite imagery in monitoring forest health	States need Forest Service help in accessing and using high resolution satellite imagery. Delays in getting data is a significant problem. Comparison of satellite data with that from visual aerial survey is needed to allow use of data collected with different technology.

Source: Northeast-Midwest State Foresters Alliance, Forest Health Committee. 2023. Forest health needs lists. 3 p. Unpublished document. On file with: 444 Capitol Street NW, Suite 387, Washington, DC 20001.

INSECT PESTS

Bark Beetles and Wood Borers

Asian Longhorned Beetle (*Anoplophora glabripennis*)

Cui, Mingming; Roe, Amanda D.; Boyle, Brian; Keena, Melody; Wu, Yunke; Braswell, W. Evan; Smith, Michael T.; Gasman, Ben; Shi, Juan; Javal, Marion; Roux, Geraldine; Turgeon, Jean J.; Hamelin, Richard; Porth, Ilga. 2024. **Tracking the North American Asian longhorned beetle invasion with genomics.** Evolutionary Applications. 17: e70036. https://doi.org/10.1111/eva.70036.

Biological invasions pose significant threats to ecological and economic stability, with invasive pests like the Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky) causing substantial damage to forest ecosystems. Effective pest management relies on comprehensive knowledge of the insect's biology and invasion history. This study uses genomics to address these knowledge gaps and inform existing biosurveillance frameworks. We used 2,768 genome-wide single nucleotide polymorphisms to compare invasive *A. glabripennis* populations in North America, using genomic variation to trace their sources of invasion and spread patterns, thereby refining our understanding of this species' invasion history. We found that most North American *A. glabripennis* infestations were distinct, resulting from multiple independent introductions from the native range. Following their introduction, all invasive populations experienced a genetic bottleneck which was followed by a population expansion, with a few also showing secondary spread to satellite infestations. Our study provides a foundation for a genome-based biosurveillance tool that can be used to clarify the origin of intercepted individuals, allowing regulatory agencies to strengthen biosecurity measures against this invasive beetle.

Qin, Haiwen; Xu, Huachao; Capron, Arnaud; Porth, Ilga; Cui, Mingming; Keena, Melody A.; Deng, Xiaofang; Shi, Juan; Hamelin, Richard C. 2023. **Is there hybridization between 2 species of the same genus in sympatry?—the genetic relationships between *Anoplophora glabripennis, Anoplophora chinensis,* and putative hybrids.** Insect Science. 31: 633–645. https://doi.org/10.1111/1744-7917.13256.

Anoplophora glabripennis (Asian longhorned beetle) and *Anoplophora chinensis* (citrus longhorned beetle) are native forest pests in China; they have become important international quarantine pests. They are found using the same *Salix aureopendula* host tree of Cixi, Zhejiang province, China. On this host tree, we collected additional beetles that appeared to be morphologically intermediate between Asian longhorned beetle and citrus longhorned beetle. By using a stereoscope, we observed that there were several bumps on the base of the elytra, which was inconsistent with Asian longhorned beetle, which typically has a smooth elytral base, but was more like citrus longhorned beetle, which has numerous short tubercles on the elytral base. Given their sympatry and intermediate morphology, we hypothesized that these may represent Asian longhorned beetle × citrus longhorned beetle hybrids. We studied the genomic profiles for 46 samples (Asian longhorned beetle, citrus longhorned

beetle, and putative hybrids) using genotyping-by-sequencing, providing a reduced representation of the entire genome. Employing principal component analyses on the 163 genotyping-by-sequencing-derived single nucleotide polymorphism data, we found putative hybrids tightly clustered with Asian longhorned beetle, but genetically distinct from the citrus longhorned beetle individuals. Therefore, our initial hybrid hypothesis was not supported by genomic data. Further, while mating experiments between adult Asian longhorned beetle and citrus longhorned beetle were successful in 4 separate years (2017, 2018, 2020, and 2021), and oviposition behavior was observed, no progeny was produced. Having employed population genomic analysis and biological hybridization experiments, we conclude that the putative hybrids represent newly discovered morphological variants within Asian longhorned beetle. Our approach further confirmed the advantage of genome-wide information for *Anoplophora* species assignment in certain ambiguous classification cases.

Trotter, R. Talbot, III; Warden, Melissa L.; Vazquez, Ryan J.; Ryan, Josie K.; Pfister, Scott. 2024. **ALB Hazard Management and Monitoring Version 1.0: an assessment and tracking tool for Asian longhorned beetle eradications in the United States.** Gen. Tech. Rep. NRS-222. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 24 p. https://doi.org/10.2737/NRS-GTR-222.

The Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky) poses a significant ecological and economic threat to forested landscapes. Based on the potential cost of uncontrolled infestations, countries in North America and Europe have adopted policies of eradication when breeding populations are found. In the absence of effective traps and remote sensing tools, eradication programs depend on the use of effort intensive visual surveys to identify and remove individual infested host trees. The risk of infestation on the landscape changes as surveys are conducted (reducing risk) and new infested trees are detected (increasing risk), with the method and timing of survey playing roles in risk mitigation. ALB Hazard Management and Monitoring 1.0 is a set of analysis and ArcGIS tools designed to allow managers to track changes in risk as eradication programs work to push beetle populations towards extinction, and to facilitate the analyses of planned survey programs to identify survey strategies that optimize their reduction of risk at a landscape scale.

Emerald Ash Borer (*Agrilus planipennis*)

Gould, Juli S.; Booth, Theresa; Sawallich, Nicole; Petrice, Toby. 2024. **Emerald ash borer biological control release and recovery guidelines.** Riverdale, Maryland: U.S. Department of Agriculture, Animal Plant Health Inspection Service, Agricultural Research Service, Forest Service. 75 p.

Emerald ash borer, a beetle from Asia that feeds on ash trees, was discovered as the cause of extensive ash mortality in southeast Michigan and adjacent areas of Canada in 2002. It is thought that this destructive pest was introduced in the early 1990s in infested solid wood packaging material originating in Asia. Emerald ash borer feeds on ash species in the genus *Fraxinus* causing widespread ash mortality and significant economic, environmental, and social impacts. As of March 2024, emerald ash borer infestations in the United States were known in Alabama, Arkansas,

Colorado, Connecticut, Delaware, District of Columbia, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Nebraska, New Hampshire, New Jersey, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, Rhode Island, South Carolina, South Dakota, Tennessee, Texas, Vermont, Virginia, West Virginia, and Wisconsin and the Canadian provinces of Manitoba, New Brunswick, Nova Scotia, Ontario, and Québec. The continued spread of emerald ash borer threatens our ash resources and will permanently alter forest ecosystems in North America. Ash wood is used for a variety of applications including tool handles, baseball bats, furniture, cabinetry, solid wood packing materials, pulp, and paper. Native Americans utilize black ash for basketry, which is both economically and culturally important. In addition to its value to the timber industry and the forest ecosystem, ash was a popular landscape tree and the spread of emerald ash borer has urban, suburban, and nursey industry impacts as well. The program aims to maintain ash as a viable part of the American landscape by managing known infestations with a robust biological control program, while also incorporating other integrated pest management methods and outreach to minimize emerald ash borer's impacts.

Wilson, Caleb J.; Petrice, Toby R.; Poland, Therese M.; McCullough, Deborah G. 2024. **Tree species richness and ash density have variable effects on emerald ash borer biological control by woodpeckers and parasitoid wasps in post-invasion white ash stands.** Environmental Entomology. 53(4): 544–560. https://doi.org/10.1093/ee/nvae060.

Emerald ash borer (*Agrilus planipennis* Fairmaire) (Coleoptera: Buprestidae) is the most destructive insect to invade North American forests. Identifying habitat features that support emerald ash borer's natural enemies is necessary to enhance biological control. In many forest ecosystems, tree species diversity has been linked with reduced pest abundance and increases in natural enemy abundance. We assessed the influence of tree species richness, ash density, and proportion of total ash basal area on ash canopy condition, emerald ash borer larval densities, and biocontrol by woodpeckers and parasitoids in pairs of healthy and declining overstory (diameter at breast height greater than 10 centimeters) and recruit-sized ash (diameter at breast height between 2 and 10 centimeters) in four post-invasion forests in Michigan, USA. Tree species richness and ash density were not significantly associated with emerald ash borer larval densities, ash canopy dieback and transparency, and woodpecker predation of emerald ash borer larvae. In declining and healthy overstory ash, woodpeckers killed 38.5 ± 3.9 percent and 13.2 ± 3.7 percent of larvae, respectively, while the native parasitoid *Phasgonophora sulcata* Westwood killed 15.8 ± 3.8 percent and 8.3 ± 3.0 percent and the introduced parasitoid *Spathius galinae* Belokobylskij & Strazanac killed 10.8 ± 2.5 percent and 5.0 ± 2.6 percent of emerald ash borer larvae. Parasitism by *P. sulcata* was inversely related to ash density while parasitism by *S. galinae* was positively associated with ash density. Ash density, but not tree diversity, appears to differentially influence biological control of emerald ash borer by parasitoids, but this effect is not associated with reduced emerald ash borer densities or improved canopy condition.

Other Bark Beetles and Wood Borers

Cao, Liang-Ming; Xie, Ji-Yu; Wang, Xin-Geng; Wang, Xiao-Yi; Poland, Therese M.; Petrice, Toby R.; Yang, Zhong-Qi. 2024. **Description of a new species of the genus *Atanycolus* Foerster (Hymenoptera: Braconidae) parasitizing *Lamprodila nobilissima bellula* (Lewis) (Coleoptera: Buprestidae) in China.** Zootaxa. 5448(2): 248–260. https://doi.org/10.11646/zootaxa.5448.2.5.

Atanycolus yangi sp. nov. (Hymenoptera, Braconidae), a new species parasitizing the flatheaded wood borer, *Lamprodila nobilissima bellula* (Lewis) (Coleoptera: Buprestidae), is described. *Lamprodila nobilissima bellula* is a serious wood boring pest of Rosacea trees in North China. We collected adult specimens of *A. yangi* sp. nov. searching for hosts on infested tree trunks and confirmed the host-parasitoid association by dissecting parasitized hosts from infested trees in the field and rearing the parasitoid from *L. nobilissima bellula*-infested host tree logs in the laboratory. Adult images for both sexes of the new parasitoid species are provided. A morphological identification key to Oriental and Palaearctic species similar to *A. yangi* sp. nov. is also presented.

Duan, Jian J.; Johnson, Todd D.; O'Dea, Justin K.; Petrice, Toby R.; Haack, Robert A. 2024. **The ecology, economics, and management of *Agrilus* beetles.** Current Forestry Reports. 10: 487–509. https://doi.org/10.1007/s40725-024-00230-8.

The genus *Agrilus* has over 3,341 described species, making it the largest genus in the Animal kingdom. Most *Agrilus* are univoltine and have a narrow host range. Chemical, tactile, and visual cues of host plants are used by adult *Agrilus* to select suitable hosts for consumption by adults and larvae. Most *Agrilus* larvae develop within the cambial region, constructing galleries that effectively girdle the host plant. Mechanisms of host plant resistance are being explored. Diverse groups of natural enemies attack all life stages of *Agrilus* species, with some coevolved specialist parasitoids being introduced successfully to suppress *A. planipennis* in North America. Climate change, leading to warmer and drier conditions, will influence the distribution and population dynamics of many *Agrilus* species. Many research gaps still exist in the areas of biocontrol, host plant resistance, and sustainable management strategies for this important group of plant pests.

Haack, Robert A. 2024. **Observations on the oak twig pruner, *Anelaphus villosus* (Coleoptera: Cerambycidae), in Michigan: size of twigs pruned, insect survival, and seasonality of twig drop.** The Great Lakes Entomologist. 56: 166–174. https://doi.org/10.22543/0090-0222.2464.

The oak twig pruner [*Anelaphus villosus* (Fabricius)] is likely a species complex, with *A. parallelus* (Newman) recently recognized as a synonym. The *parallelus* form of *A. villosus* is considered the subject of this paper. In Michigan, oak twig pruner has a 2-year life cycle, with twigs pruned primarily in even-numbered years and adults emerging from the fallen twigs in odd-numbered years. During 1990 to 2011, I studied various aspects of oak twig pruner life history in southern Michigan (Ingham County). Based on measurements from over 300 infested oak twigs, they averaged

43.1 centimeters long, 9.4 millimeters in diameter at the pruned end, weighed 22.9 grams (dry weight of woody material), and had 57 leaves. Oak twig pruner adults emerged in 1991 from 15.9 percent of 290 pruned twigs that had fallen in 1990 and were left on the forest floor until December 1990 when placed in individual sleeve cages and later reared indoors in early 1991. Likely parasitoids of oak twig pruner emerged from 15.5 percent of these same 290 twigs. No linear relationship was found between the dry weight of oak twig pruner adults and the size or weight of the twigs in which they developed. During inspections along the same 1-kilometer-long forest path from 1994 to 2011, recently fallen pruned twigs were only found in even-numbered years, usually starting in late May to early June, peaking between late June to mid-July, and ending between August to December. The annual number of pruned twigs found along this same 1-kilometer section of trail varied from a low of 24 twigs in 2004 to a high of 168 in 2006. For all years combined, 89 percent of the recently fallen infested twigs collected on the ground in June had green foliage, compared with 52 percent of the twigs collected in July, 7.3 percent in August, and 2.6 percent in September.

Haack, Robert A.; Blank, Richard W. 2024. **Observations on a *Dendroctonus simplex* (Coleoptera: Curculionidae: Scolytinae) outbreak in a rangewide tamarack (*larix laricina*) provenance plantation in Michigan.** The Great Lakes Entomologist. 56: 175–185. https://doi.org/10.22543/0090-0222.2467.

A tamarack [*Larix laricina* (Du Roi) K. Koch] provenance plantation, consisting of 33 seed sources from the United States and Canada, was established in 1969 in southern Michigan (Kalamazoo County). About half of the trees were removed in fall 1984 when the stand was thinned, with the cut trees piled on the edge of the stand. The stand then experienced a severe ice storm in January 1985. The eastern larch beetle, *Dendroctonus simplex* LeConte, colonized the cut logs in 1985 and also infested many of the standing trees. By the end of 1986, over half the remaining trees had been killed by *D. simplex*, with 6 seed sources suffering no beetle-related tree mortality, 20 having 20 to 61 percent tree mortality, and 7 having 67 to 100 percent mortality. Mean tree height and diameter at breast height were negatively related to the latitude of the seed source origin. However, no significant linear relationships were found between percent tree mortality in 1986 with either mean tree diameter at breast height or latitude of the seed-source origin, but there was a significant negative relationship with increasing ice-storm damage.

Haack, Robert A.; Petrice, Toby R.; Foltz, John L.; Ye, Hui. 2024. **Impact of debarking and bark grinding on survival of *Ips calligraphus* (Coleoptera: Curculionidae: Scolytinae).** The Great Lakes Entomologist. 57(1–2): 32–41. https://doi.org/10.22543/0090-0222.2476.

Chipping and debarking of infested woody material such as branches and logs are common sanitation methods used to kill bark- and wood-infesting insects. The sixspined ips, *Ips calligraphus* (Germar), is a native North American bark beetle (Coleoptera: Curculionidae: Scolytinae) that infests several pine (*Pinus*) species. We evaluated *I. calligraphus* mortality after debarking and grinding, using 12 recently cut longleaf pine (*Pinus palustris* Mill.) logs that had undergone natural colonization for three weeks in Florida. Initial bark beetle densities were estimated from samples collected the day before debarking. Similar amounts of bark were collected at three steps in the debarking

and grinding processes: first immediately after debarking, and then after grinding and screening as either "fines" that fell through the screen, or as larger bark nuggets and flakes that stayed on top of the screen. Half the bark was inspected by hand on the day of debarking while the other half was placed in rearing cans and monitored for live beetles for the next 10 weeks. Percent mortality was estimated by comparing the number of emerged beetles collected from the rearing cans to the estimated initial adult beetle populations just prior to debarking. Overall, mortality was estimated at 99.4 percent after debarking and 100 percent after grinding for *I. calligraphus*, and 98.9 percent after debarking and 99.8 percent after grinding for the two smaller Ips species combined: *Ips avulsus* (Eichhoff) and *Ips grandicollis* (Eichoff). These findings are discussed in relation to the Eurasian scolytine *Tomicus piniperda* (L.), a bark beetle similar in size to *I. calligraphus*, which was established throughout the Great Lakes region at the time of this study.

Miller, Daniel R.; Mayfield, Albert E.; Poland, Therese M. 2024. **Enantiomeric composition of *α*-pinene affects catches of bark and wood boring beetles, and associated species, in ethanol-baited multiple-funnel traps.** Journal of Economic Entomology. 117(4): 1526–1536. https://doi.org/10.1093/jee/toae100.

In 2009, we determined the effects of the enantiomeric composition of the kairomone, α-pinene, on trap catches of arboreal beetles (Coleoptera) in stands of eastern pine trees with resin dominated by (+)-*α*-pinene. We hypothesized that the responses of beetles would correlate with the predominant enantiomer of *α*-pinene found in host pines. Lures of (+)-, racemic (±), and (−)-*α*-pinene were added separately to ethanol-baited multiple-funnel traps. Species such as *Monarthrum mali* (Fitch), *Dendroctonus terebrans* (Olivier), *Ips grandicollis* (Eichhoff), and *Pachylobius picivorus* (Germar) (Coleoptera: Curculionidae) showed a preference for traps co-baited with (–)-*α*-pinene. *α*-Pinene enhanced attraction of *Hylastes salebrosus* Eichhoff, *Hylastes porculus* Erickson, and *Hylastes tenuis* Eichhoff (Coleoptera: Curculionidae) to ethanol-baited traps with no effects from enantiomeric composition of *α*-pinene. The attraction of the ambrosia beetles, *Xyleborinus saxesenii* (Ratzeburg) and *Dryoxylon onoharaense* (Murayama) (Coleoptera: Curculionidae) to ethanol-baited traps was interrupted by the addition of *α*-pinene, regardless of enantiomeric composition. Species such as *Xylosandrus germanus* (Blandford), *Cnestus mutilatus* (Blandford) and *Stenoscelis brevis* (Boheman) (Coleoptera: Curculionidae) were unaffected by the presence of *α*-pinene. Trap catches of some species of longhorned beetles and bark beetle predators (Coleoptera: Cerambycidae, Cleridae, Elateridae, Histeridae, and Trogossitidae) were increased by the addition of α-pinene, although results varied by location. *Platysoma* spp. (Coleoptera: Histeridae) showed a marked preference for traps co-baited with (+)-*α*-pinene in Florida and Georgia. In summary, we found that the enantiomeric composition of *α*-pinene in hosts was not a good predictor of enantiomeric preferences by beetles.

Roy, Kylle; Mikros, Dan; Cha, Dong H.; Dunkle, Ellen J.; Juzwik, Jennifer; Ginzel, Matthew. 2024. **The efficacy of the semiochemical repellent verbenone to reduce ambrosia beetle attack on healthy and *Ceratocystis*-infested 'ōhi'a trees.** Trees, Forests and People. 18: 100735. https://doi.org/10.1016/j.tfp.2024.100735.

The *Ceratocystis* fungal disease complex, rapid 'ōhi'a death, has killed over one million 'ōhi'a (*Metrosideros polymorpha*), the keystone tree species of Hawai'i. The causal fungi can be spread by invasive ambrosia beetles (Coleoptera: Curculionidae) through fungal inoculum found on their bodies and in the frass they produce. Thus, there is a critical need to manage beetle attack on 'ōhi'a trees to curtail subsequent pathogen spread and disease development. In this experiment at Waiākea Forest Reserve, we tested the potential of the semiochemical repellent, verbenone, in a commercial formulation, to protect healthy and rapid 'ōhi'a death-affected 'ōhi'a from ambrosia beetle attack in each of the 2022 and 2023 field seasons. Landing rates of ambrosia beetles on healthy and diseased trees were quantified over 16 weeks each year, using sticky traps on ethanol-baited trees that also received either a low (72 grams) or high (108 grams) dose of verbenone or untreated controls. In addition, we used gas-chromatography mass-spectrometry to measure verbenone emission over 16 weeks in 2022. We found that the low dose of verbenone is the most effective and economical application to reduce beetle landing on healthy 'ōhi'a trees and the high dose may be needed to reduce attraction to diseased 'ōhi'a. Despite a large decrease in verbenone emission levels by week 8, the low dose effectively reduced beetle captures on healthy trees for 14 weeks and the high dose reduced landing rates on diseased trees for 10 to 14 weeks. Our results indicate verbenone may significantly lower ambrosia beetle attack on 'ōhi'a, and thus, lead to reduction in the spread of rapid 'ōhi'a death.

Šenfeldová, Soňa; Atkinson, Thomas H.; Knížek, Miloš; Rabaglia, Robert J.; Havill, Nathan P.; Ward, Samuel F.; Turčáni, Marek; Liebhold, Andrew M. 2024. **Determinants of host breadth in non-native bark and ambrosia beetles.** Forest Ecology and Management. 562: 121908. https://doi.org/10.1016/j.foreco.2024.121908.

Most phytophagous insects are specialists, so availability of suitable host plants often may be a critical factor limiting establishment of non-native insect species. Here we investigate the extent to which established non-native tree-feeding insects utilize hosts that are native to the invaded range as well as hosts that are themselves non-native. We accomplish this by comparing host use among all native and non-native bark beetles and pinhole borers (Scolytinae and Platypodinae) established in Europe and North America reported in the literature. These groups of insects are well-known for the disparity among species in specialized behavior and development tied to host physiology. We find considerable variation in host breadth, as measured by species-level and genus-level host richness and phylogenetic diversity of hosts, among different feeding guilds (ambrosia beetles, true bark beetles, twig beetles, and others). In each region, ambrosia and twig beetles exhibit the greatest diversity of hosts. Host breadth on native plants was generally greater for native beetle species than for non-native beetle species. In contrast, host breadth of non-native beetles is generally greater on non-native plants than on plants native to the focal region. These results indicate that successful invasion of these insect herbivores is dependent on the prior introduction of their non-native host plants, or the availability of native hosts that are closely related to their ancestral host plants.

Defoliating Insects

Spongy Moth (*Lymantria dispar*)

Blackburn, Gwylim S.; Keeling, Christopher I.; Prunier, Julien; Keena, Melody A.; Béliveau, Catherine; Hamelin, Richard; Havill, Nathan P.; Hebert, Francois Olivier; Levesque, Roger C.; Cusson, Michel; Porth, Ilga. 2024. **Genetics of flight in spongy moths (*Lymantria dispar* ssp.): functionally integrated profiling of a complex invasive trait.** BMC Genomics. 25(1): 541. https://doi.org/10.1186/s12864-023-09936-8.

Flight can drastically enhance dispersal capacity and is a key trait defining the potential of exotic insect species to spread and invade new habitats. The phytophagous European spongy moths (*Lymantria dispar dispar*) and Asian spongy moths (a multispecies group represented here by *L. d. asiatica and L. d. japonica*), are globally invasive species that vary in adult female flight capability—female Asian spongy moths are typically flight capable, whereas female European spongy moths are typically flightless. Genetic markers of flight capability would supply a powerful tool for flight profiling of these species at any intercepted life stage. To assess the functional complexity of spongy moth flight and to identify potential markers of flight capability, we used multiple genetic approaches aimed at capturing complementary signals of putative flight-relevant genetic divergence between European and Asian spongy moths: reduced representation genome-wide association studies, whole genome sequence comparisons, and developmental transcriptomics. We then judged the candidacy of flight-associated genes through functional analyses aimed at addressing the proximate demands of flight and salient features of the ecological context of spongy moth flight evolution. Candidate gene sets were typically nonoverlapping across different genetic approaches, with only nine gene annotations shared between any pair of approaches. We detected an array of flight-relevant functional themes across gene sets that collectively suggest divergence in flight capability between European and Asian spongy moth lineages has coincided with evolutionary differentiation in multiple aspects of flight development, execution, and surrounding life history. Overall, our results indicate that spongy moth flight evolution has shaped or been influenced by a large and functionally broad network of traits. Our study identified a suite of flight-associated genes in spongy moths suited to exploration of the genetic architecture and evolution of flight, or validation for flight profiling purposes. This work illustrates how complementary genetic approaches combined with phenotypically targeted functional analyses can help to characterize genetically complex traits.

Wolz, Marina; Höcherl, Amelie; Hübner, Jeremy; Tschorsnig, Hans-Peter; Whitmore, Daniel; Leroy, Benjamin M. L.; Weisser, Wolfgang W.; Mitesser, Oliver; Zakharov, Evgeny V.; Hebert, Paul D.N.; Liebhold, Andrew M.; Müller, Jörg. 2024. **Response of parasitoid communities to insecticide application during a Lymantria dispar outbreak in mixed oak forests.** Journal of Applied Ecology. 61(11): 2774–2785. https://doi.org/10.1111/1365-2664.14791.

In the temperate mixed oak forests of Central Europe, outbreaks of insects such as the spongy moth, *Lymantria dispar*, can cause severe defoliation and insecticide is sometimes applied for their control. Parasitoids, mainly Hymenoptera and Diptera, are

among the most diverse and important natural enemies of caterpillars in these forests. However, due to their cryptic lifestyle and taxonomic difficulties, we lack knowledge on the impact of insecticide applications on complex host-parasitoid networks. In a large-scale field experiment, we tested the effect of spraying the lepidopteran-specific insecticide Mimic (tebufenozide) on the abundance and community composition of both adult and larval parasitoids. We combined morphological identification, DNA barcoding and metabarcoding to identify parasitoid adults or inside caterpillars, both sampled by canopy fogging during an outbreak and 2 subsequent years. We analyzed the abundance of parasitoids, community composition and network specialization using statistical methods that account for sample incompleteness in host-parasitoid data. For adult parasitoid assemblages, we found strong annual effects on abundance, with highest numbers of adult parasitoids occurring in the outbreak year, as well as on annual changes in community composition, but no effect linked to insecticide application. However, the abundance and species number of immature parasitoids revealed negative effects of insecticide application, while community composition was only affected by annual variation. Coverage-based network analyses showed a reduction of taxonomic network diversity and network specialization associated with insecticide application in the first 2 years. This real-world experiment shows that parasitoid populations respond immediately to large-scale outbreaks but only limited to local disturbances. Results indicate that this group of natural enemies exhibits high mobility, enabling them to track host populations across large spatial scales. However, our observation of reduced network specialization after insecticide application is a warning signal that ecosystem function, and consequently natural pest control services, may be impaired by human interference at the local stand scale.

Other Defoliating Insects

Cao, Liang Ming; Wang, Xiao Yi; Petrice, Toby R.; Poland, Therese M. 2024. **A checklist of the predators and parasitoids of the fall webworm *Hyphantria cunea* (Drury) (Lepidoptera, Erebidae) from around the world.** ZooKeys. 1211: 251–348. https://doi.org/10.3897/zookeys.1211.123574.

A checklist of 488 fall webworm *Hyphantria cunea* (Drury) natural enemies was compiled based on documentation in previous research across its world distribution, including 289 predators and 199 parasitoids. Predators in the checklist include 67 species from 17 families of Insecta, 1 species of Chilopoda, 183 species from 22 families of Arachnida, 1 species of Reptilia, 4 species from 2 families of Amphibia, 33 species from 18 families of Aves. In addition, the checklist includes fall webworm parasitoids from 18 families of Insecta. Among continents, 128 predators and 76 parasitoids were distributed in North America, 78 predators and 62 parasitoids in Asia, and 88 predators and 68 parasitoids in Europe.

Cooke, Barry J.; Robert, Louis-Etienne; Sturtevant, Brian R.; Kneeshaw, Dan; Thapa, Bina. 2024. **Confronting the cycle synchronisation paradigm of defoliator outbreaks in space and time—evidence from two systems in a mixed-species forest landscape.** Journal of Ecology. 112(1): 152–173. https://doi.org/10.1111/1365-2745.14226.

Defoliators cause extensive damage in boreal and temperate forests of the world. Considerable effort has been invested to understand their individual population dynamics, and despite ample theorizing, there is little empirical evidence on factors causing spatial synchrony of pest eruptions at landscape scales. We report on the landscape-level effect of forest configuration and composition on the intensity of outbreaks of spruce budworm and forest tent caterpillar in a mixedwood boreal forest in northern Minnesota (USA) and adjacent Ontario (Canada), and how this is related to the degree of spatial synchrony in each species' outbreak cycling. Using a large spatiotemporal tree-ring reconstruction of outbreak impacts across these two systems, we evaluate two contrasting theories governing defoliator outbreaks: harmonic oscillation (a.k.a. "clockwork") and relaxation oscillation (a.k.a. "catastrophe"), each with consequences linked to top-down versus bottom-up influences on outbreak behavior in time and space. We find synchrony varies temporally, among outbreak cycles and in direct proportion to cycle peak intensity; however, cycle peak intensities are distributed bimodally in time, and so, therefore, are synchrony coefficients. Spatially, the area where each pest species currently cycles with the greatest peak intensity and synchrony is where their preferred host trees are currently found in greatest proportion. Despite overall synchrony in cycling, we found, in both systems, a persistent negative spatial correlation among successive eruptive pulses of defoliation. Many of these eruptions failed to spread spatially and to coalesce with other spot eruptions to form extensive area-wide outbreaks. Eruptions often fail to spread at the hardwood-conifer interface, resulting in outbreak pulses that systematically bounce back and forth between landscape types, particularly when systems were cycling at low amplitude. These over-dispersed spatial patterns of pulse impact are consistent with a contagious theory of eruption and outbreak spread. They could be considered consistent with harmonic oscillation theory only for populations cycling at different frequencies, with cycling frequency determined by host forest landscape structure. We find that defoliator outbreak dynamics across systems include spatiotemporal signatures of each theoretical paradigm—suggesting a hybrid approach will better characterize outbreak behavior. Host concentration influences which paradigm dominates the spatial dynamics in any given forest landscape context. Because of the synchronizing effect of host concentration on forest insect spatial dynamics, mixedwoods appear to be less prone to intense, synchronized defoliator attack than forests of pure hardwood or pure conifer.

Li, Yong-Ping; Zhou, Hai-Yan; Yang, Yang; Ye, Hui; Haack, Robert A.; Cao, Jun. 2024. **Morphological characterization and distribution of antennal sensilla of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) using scanning electron microscopy.** Microscopy Research and Technique. 1–14. https://doi.org/10.1002/jemt.24644.

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is a globally significant agricultural pest, causing severe damage to corn production in China. Chemical odor-based trapping is a major approach for fall armyworm control, making it essential to understand the fall armyworm antennal sensillum types to enhance development of effective chemical odor attractants. In this study, we comprehensively examined the antennal sensilla types of fall armyworm,

identifying eight types and two subtypes, including Böhm's bristles, sensilla trichoidea, sensilla chaetica (I and II), sensilla coeloconica, sensilla styloconica, sensilla squamiformia (I and II), sensilla auricillica, and sensilla basiconica. Sensilla chaetica II, and sensilla squamiformia II are reported for the first time for fall armyworm in this study. Detailed low-voltage field emission scanning electron microscope images and descriptions are provided for each sensillum type. This study provides the morphological information to aid in conducting antennal sensillum neurophysiological tests on fall armyworm.

Medzihorský, Vladimír; Mally, Richard; Trombik, Jiří; Turčáni, Marek; Medzihorská, Michaela; Shoda-Kagaya, Etsuko; Martin, Grant D.; Sopow, Stephanie; Kochi, Kaori; Liebhold, Andrew M. 2024. **The demise of enemy release associated with the invasion of specialist folivores on an invasive tree.** Ecography. e07082. https://doi.org/10.1111/ecog.07082.

There is a long history of humans either intentionally or accidentally moving plant species to areas outside of their native ranges. In novel environments, populations of many of these plant species exhibit explosive population growth and spread, in part due to the absence of coevolved enemies such as herbivorous insects. However, over time such enemies can "catch up" with their host and re-establish host–herbivore relationships. Though this phenomenon has been documented in several systems, little evidence exists on how this reassembly of enemies results in increased levels of herbivory. In this study, we focus on the case of black locust *Robinia pseudoacacia*, a sparsely populated tree species when growing on undisturbed sites in its limited native range in the eastern USA but a highly invasive species, especially in disturbed environments, in most temperate world regions. We recorded folivore damage on invasive populations in five continents, including both native and invaded portions of North America. Here, we investigated (1) how total foliage damage and damage caused by different groups of folivores differs among regions; (2) how seasonal development of folivore damage differs among regions; (3) how folivory varies with distance from the native range within North America; and (4) how the number of recorded specialist folivores correlates with the amount of folivory. We observed strong differences among regions in the amount and type of folivore damage, with the native range experiencing the highest damage, especially that caused by the native chrysomelid beetle *Odontota dorsalis*, which is limited to the native and invaded North American range of *R. pseudoacacia*. Among world regions, total folivory is negatively associated with the distance from the native range and positively associated with the number of established *R. pseudoacacia* specialist folivore species, supporting the hypothesis that global patterns of herbivore invasions are associated with diminished enemy release.

Scale Insects

Crouch, Connor D.; Grady, Amanda M.; Wilhelmi, Nicholas P.; Hofstetter, Richard W.; Moore, Margaret M.; Waring, Kristen M. 2024. **Extent, impacts, and drivers of oystershell scale invasions in aspen ecosystems.** NeoBiota. 95: 1–33. https://doi.org/10.3897/neobiota.95.121748.

Invasive herbivores that kill foundation tree species pose a major threat to forest ecosystem sustainability. One important foundation tree species in the interior western United States is quaking aspen (*Populus tremuloides* Michx.), which is threatened by recent outbreaks of an invasive insect, oystershell scale (*Lepidosaphes ulmi* Linn.). Oystershell scale outbreaks were first reported in 2016, when oystershell scale began causing dieback and mortality of aspen in wildland forest settings in northern Arizona. Since then, oystershell scale has been observed in other locations across Arizona and in other western states, and recent studies in Arizona have highlighted the threat that oystershell scale poses to aspen sustainability, warranting a comprehensive survey of oystershell scale invasions and their impacts on aspen ecosystems. We sampled aspen populations across Arizona and addressed three questions: (1) What is the geographic extent of oystershell scale in Arizona? (2) What impacts does oystershell scale have on aspen? (3) Which biotic and abiotic factors influence the proportion of aspen stems infested by oystershell scale? Oystershell scale was present in 29 percent of our 220 study plots and had a negative impact on aspen forest health. Oystershell scale was associated with crown damage and tree mortality, especially of intermediate-sized, recruiting stems. Climate was the most important driver of oystershell scale infestation, with warmer, drier conditions resulting in significantly more oystershell scale. Oystershell scale was also associated with less recent fire, presence of ungulate management strategies (e.g. fenced exclosures) and stands with a greater density of aspen saplings. We conclude by providing oystershell scale monitoring and management recommendations, based on our findings, and emphasize that active management—such as prescribed fire, reduced reliance on ungulate exclosures or thinning—is required to suppress oystershell scale populations and mitigate damage to aspen ecosystems.

Crouch, Connor D.; Hofstetter, Richard W.; Grady, Amanda M.; Edwards, Nylah N.S.; Waring, Kristen M. 2024. **Oystershell scale (Hemiptera: Diaspididae) population growth, spread, and phenology on aspen in Arizona, USA.** Environmental Entomology. 53(2): 293–304. https://doi.org/10.1093/ee/nvae006.

Oystershell scale (*Lepidosaphes ulmi* L.) is an invasive insect that threatens sustainability of aspen (*Populus tremuloides* Michx.) in the southwestern United States. Oystershell scale invasions have created challenges for land managers tasked with maintaining healthy aspen ecosystems for the ecological, economic, and aesthetic benefits they provide. Active management is required to suppress oystershell scale populations and mitigate damage to aspen ecosystems, but before management strategies can be implemented, critical knowledge gaps about oystershell scale biology and ecology must be filled. This study sought to fill these gaps by addressing three questions: (1) What is the short-term rate of aspen mortality in oystershell scale-infested stands in northern Arizona, USA? (2) What are the short-term rates of oystershell scale population growth on trees and oystershell scale spread among trees in aspen stands? (3) What is the phenology of oystershell scale on aspen and does climate influence phenology? We observed high levels of aspen mortality (annual mortality rate equals 10.4 percent) and found that oystershell scale spread rapidly within stands (annual spread rate equals 10 to 12.3 percent). We found first, second, and young third instars throughout the year and observed two waves of first instars (i.e., crawlers),

one throughout the summer and a second in mid-winter. The first wave appeared to be driven by warming seasonal temperatures, but the cause of the second wave is unknown and might represent a second generation. We provide recommendations for future oystershell scale research, including suggestions for more precise quantification of oystershell scale phenology, and discuss how our results can inform management of oystershell scale and invaded aspen ecosystems.

Venette, Robert C.; Ambourn, Angie; Aukema, Brian H.; Jetton, Robert M.; Petrice, Toby R. 2024. **Hosts and impacts of elongate hemlock scale (Hemiptera: Diaspididae): a critical review.** Frontiers in Insect Science. 4: 1356036. https://doi.org/10.3389/finsc.2024.1356036.

Fiorinia externa Ferris, elongate hemlock scale, was inadvertently introduced to North America from Japan. This insect is particularly problematic on hemlock, *Tsuga* spp., though it has been reported in association with several other conifers. The evidence that other conifers might be hosts, capable of supporting growing populations of the insect, has not been previously reviewed. Our review confirms that *F. externa* is an oligophagous pest of members of Pinaceae. Although species of Cupressaceae and Taxaceae have been reported as hosts of *F. externa*, they seem unable to support population growth of this pest. Evidence of the tree-killing potential of the insect, even on suitable hosts, is remarkably scant. The degree of pest risk posed by *F. externa* with respect to tree mortality in areas beyond the geographic range of hemlock seems modest, but uncertain.

Other Insect Pests

Dial, Dustin T.; Weglarz, Kathryn M.; Brunet, Bryan M.T.; Havill, Nathan P.; von Dohlen, Carol D.; Burke, Gaelen R. 2024. **Whole-genome sequence of the Cooley spruce gall adelgid, *Adelges cooleyi* (Hemiptera: Sternorrhyncha: Adelgidae).** G3: Genes, Genomes, Genetics. 14(1): jkad224. https://doi.org/10.1093/g3journal/jkad224.

The adelgids (Adelgidae) are a small family of sap-feeding insects, which, together with true aphids (Aphididae) and phylloxerans (Phylloxeridae), make up the infraorder Aphidomorpha. Some adelgid species are highly destructive to forest ecosystems such as *Adelges tsugae*, *Adelges piceae*, *Adelges laricis*, *Pineus pini*, and *Pineus boerneri*. Despite this, there are no high-quality genomic resources for adelgids, hindering advanced genomic analyses within Adelgidae and among Aphidomorpha. Here, we used PacBio continuous long-read and Illumina RNA-sequencing to construct a high-quality draft genome assembly for the Cooley spruce gall adelgid, *Adelges cooleyi* (Gillette), a gall-forming species endemic to North America. The assembled genome is 270.2 megabases in total size and has scaffold and contig N50 statistics of 14.87 and 7.18 megabases, respectively. There are 24,967 predicted coding sequences, and the assembly completeness is estimated at 98.1 and 99.6 percent with core BUSCO gene sets of Arthropoda and Hemiptera, respectively. Phylogenomic analysis using the *A. cooleyi* genome, three publicly available adelgid transcriptomes, four phylloxera transcriptomes, the *Daktulosphaira vitifoliae* (grape phylloxera) genome, four aphid genomes, and two outgroup coccoid genomes fully resolves adelgids and phylloxerans

as sister taxa. The mitochondrial genome is 24 kilobases, among the largest in insects sampled to date, with 39.4 percent composed of noncoding regions. This genome assembly is currently the only genome-scale, annotated assembly for adelgids and will be a valuable resource for understanding the ecology and evolution of Aphidomorpha.

Fraver, Shawn; Bosely-Smith, Colby; Seirup, Camilla; Guiterman, Christopher H.; Schmeelk, Thomas; Teets, Aaron; Van Kampen, Ruth; Kenefic, Laura S. 2024. **Dendrochronological reconstruction of arborvitae leafminer (*Argyresthia* spp.) outbreaks on northern white-cedar (*Thuja occidentalis*) in Maine, USA.** Canadian Journal of Forest Research. 54(4): 479–485. https://doi.org/10.1139/cjfr-2023-0193.

Although northern white-cedar (*Thuja occidentalis*; henceforth cedar) is thought to have few insect pests, arborvitae leafminers (primarily *Argyresthia thuiella*) have been known to cause leaf necrosis. Yet, historical evidence for leafminer outbreaks is limited. We combined leafminer larval surveys conducted between 1950 and 1992 with tree-ring analyses from eight cedar stands to reconstruct a history of leafminer outbreaks in Maine, USA. Our tree-ring data show distinctive two- to three-year growth reductions that we attribute to leafminers. Several such growth reductions correspond to peak leafminer larval abundances, providing evidence that the reductions are reliable indicators of leafminer activity. Outbreak severity within a site was unrelated to cedar abundance. Outbreak periods thus identified (beginning ca. 1919, 1937, 1950, 1962, mid-1970s, but not at all sites) suggest that leafminer damage may have been more prevalent (albeit patchy) than previously thought. This historical information is relevant given current outbreaks in Maine and elsewhere.

Keena, Melody A. 2024. **Effects of temperature on the survival of spotted lanternfly active life stages when held without food.** Agricultural and Forest Entomology. 26(3): 366–372. https://doi.org/10.1111/afe.12619.

Spotted lanternfly, *Lycorma delicatula* White (Hemiptera: Fulgoridae), is an invasive southeast Asian planthopper that was recently introduced into the eastern United States and spreads along human transportation corridors by "hitch-hiking" on vehicles and cargo. To better understand the risk of establishment when mobile life stages are moved, it is critical to know how long spotted lanternfly mobile life stages will survive without food and water under different temperatures. This work reports on spotted lanternfly first, second, and third instar nymphal and adult survival without food over the 10 to 30 degrees Celsius temperature range. Survival time without food declined exponentially as temperature increased for all life stages of spotted lanternfly that were evaluated. At temperatures less than 30 degrees Celsius, first instar nymphs survived longer than second or third instar individuals. Female adults survived about 1 day longer than male adults at all but 10 and 25 degrees Celsius. Without food, 99 percent of all adults of both sexes are predicted to be dead in less than a week over the temperature range evaluated. First instars, which were the smallest, survived the longest and their survival exponentially decreased as temperature increased. This suggests that more attention to first instar movement may be warranted. The data presented here will provide a basis for assessing the risk of survival of transported spotted lanternfly active life stages along various pathways.

FOREST DISEASES

Oak Wilt (*Ceratocystis fagacearum*)

Novi, Vinni Thekkudan; Aboubakr, Hamada A.; Moore, Melanie J.; Zarouri, Akli; Juzwik, Jennifer; Abbas, Abdennour. 2024. **A rapid LAMP assay for the diagnosis of oak wilt with the naked eye.** Plant Methods. 20: 119. https://doi.org/10.1186/s13007-024-01254-8.

Oak wilt disease, caused by *Bretziella fagacearum,* is a significant threat to oak (*Quercus* spp.) tree health in the United States and Eastern Canada. The disease may cause dramatic damage to natural and urban ecosystems without management. Early and accurate diagnosis followed by timely treatment increases the level of disease control success. A rapid assay based on loop mediated isothermal amplification was first developed with fluorescence detection of *B. fagacearum* after 30-minute reaction time. Six different primers were designed to specifically bind and amplify the pathogen's DNA. To simplify the use of this assay in the field, gold nanoparticles were designed to bind to the DNA amplicon obtained from the loop mediated isothermal amplification reaction. Upon inducing precipitation, the gold nanoparticle-amplicons settle as a red pellet visible to the naked eye, indicative of pathogen presence. Both infected and healthy red oak samples were tested using this visualization method. The assay was found to have high diagnostic sensitivity and specificity for the *B. fagacearum* isolate studied. Moreover, the developed assay was able to detect the pathogen in crude DNA extracts of diseased oak wood samples, which further reduced the time required to process samples. In summary, the loop mediated isothermal amplification assay coupled with oligonucleotide-conjugated gold nanoparticle visualization is a promising method for accurate and rapid molecular-based diagnosis of *B. fagacearum* in field settings. The new method can be adapted to other forest and plant diseases by simply designing new primers.

Sapes, Gerard; Schroeder, Lucy; Scott, Allison; Clark, Isaiah; Juzwik, Jennifer; Montgomery, Rebecca A.; Guzmán, J. Antonio; Cavender-Bares, Jeannine. 2024. **Mechanistic links between physiology and spectral reflectance enable previsual detection of oak wilt and drought stress.** Proceedings of the National Academy of Sciences. 121(7): e2316164121. https://doi.org/10.1073/pnas.2316164121.

Tree mortality due to global change—including range expansion of invasive pests and pathogens—is a paramount threat to forest ecosystems. Oak forests are among the most prevalent and valuable ecosystems both ecologically and economically in the United States. There is increasing interest in monitoring oak decline and death due to both drought and the oak wilt pathogen (*Bretziella fagacearum*). We combined anatomical and ecophysiological measurements with spectroscopy at leaf, canopy, and airborne levels to enable differentiation of oak wilt and drought, and detection prior to visible symptom appearance. We performed an outdoor potted experiment with *Quercus rubra* saplings subjected to drought stress and/or artificially inoculated with the pathogen. Models developed from spectral reflectance accurately predicted ecophysiological indicators of oak wilt and drought decline in both potted and field experiments with naturally grown saplings. Both oak wilt and

drought resulted in blocked water transport through xylem conduits. However, oak wilt impaired conduits in localized regions of the xylem due to formation of tyloses instead of emboli. The localized tylose formation resulted in more variable canopy photosynthesis and water content in diseased trees than drought-stressed ones. Reflectance signatures of plant photosynthesis, water content, and cellular damage detected oak wilt and drought 12 days before visual symptoms appeared. Our results show that leaf spectral reflectance models predict ecophysiological processes relevant to detection and differentiation of disease and drought. Coupling spectral models that detect physiological change with spatial information enhances capacity to differentiate plant stress types such as oak wilt and drought.

Other Forest Diseases

Butnor, John R.; Wilson, Cornelia Pinchot; Bakır, Melike; D'Amato, Anthony W.; Flower, Charles E.; Hansen, Christopher F.; Keller, Stephen R.; Knight, Kathleen S.; Murakami, Paula F. 2024. **Cold tolerance assay reveals evidence of climate adaptation among American elm (*Ulmus americana* L.) genotypes.** Forests. 15: 1843. https://doi.org/10.3390/f15111843.

The American elm (*Ulmus americana* L.), once a dominant species in North American floodplain forests, has suffered significant population declines due to Dutch elm disease. Despite this, some elms persist, potentially exhibiting disease resistance and climate-adaptive traits that could facilitate restoration. Understanding these traits is crucial for selecting genotypes suited to current and future climatic conditions, particularly in colder regions. This study evaluated the mid-winter cold tolerance of American elm genotypes across a climatic gradient to ascertain evidence of local climate adaptation. We used relative electrolyte leakage to assess mid-winter cold tolerance of current-year shoots on eleven survivor genotypes from New England and one susceptible, control genotype from Ohio. The lethal temperature, at which 50 percent of cellular leakage occurs, was determined and compared with 30-year climate data to identify potential climate adaptation. Genotypes from colder regions exhibited greater cold hardiness, indicating local adaptation to climate. Observed mid-winter lethal temperature values (−42.8 to −37.7 degrees Celsius) were in excess of the 30-year minimum air temperature, even at the coldest source location. This calls into question whether mid-winter cold tolerance is the critical period for injury to American elm and more attention should be given to environmental conditions that cause deacclimation to cold. By understanding the adaptive capacity of American elm, managers can better select mother trees for regional seed orchards, ensuring the long-term success of restoration initiatives.

Juzwik, Jennifer; Hughes, Marc A.; Keith, Lisa M. 2024. **Pathogenicity and colonization of *Metrosideros polymorpha* by *Ceratocystis huliohia*.** Forest Pathology. 54: e12865. https://doi.org/10.1111/efp.12865.

Both *Ceratocystis lukuohia* and *C. huliohia* have been associated with rapid 'ōhi'a death, an emerging threat to 'ōhi'a (*Metrosideros polymorpha*), a keystone forest tree species. The vascular wilt disease caused by *C. lukuohia* has been recently described

and is responsible for the widespread rapid 'ōhi'a death epidemic on Hawai'i Island. However, the role of *C. huliohia* in rapid 'ōhi'a death development and tree death is not clear. Artificial inoculation of field-grown 'ōhi'a with *C. huliohia* and dissections of naturally infected, early symptomatic forest trees were conducted to confirm pathogenicity on field grown trees and the pattern of internal colonization. In two trials, crowns of trees with main stems inoculated with *C. huliohia* were visually healthy at the time of tree harvest after 43 to 55 days in the first trial and after 91 days in the second trial. However, elliptical inner bark cankers underlain by reddish-brown xylem were associated with the inoculation points. Similar canker and stain symptoms were found on stems and branches of 'ōhi'a (24 to 26 centimeter trunk diameter) naturally infected by *C. huliohia*. This xylem stain manifested as multiple distinct elliptical cankers or the coalescing of multiple cankers. The pathogen was commonly isolated from the perimeter of the stained outer sapwood and to a depth of 4 centimeters. The coalescence of multiple cankers was associated with the crown symptoms observed on the naturally infected forest trees that were dissected. Multiple *C. huliohia* infections that lead to coalescing cankers which subsequently girdle stems likely occurs over 1 or more years compared to the shorter time (e.g., months) required for *C. lukuohia*-caused death to occur.

INVASIVE PLANTS

Bataineh, Mohammad M.; Fraser, Jacob S.; Pile Knapp, Lauren S. 2024. **Characterization of Chinese tallow invasion in the southern United States.** Forests. 15(1): 202. https://doi.org/10.3390/f15010202.

Chinese tallow is a non-native invasive tree expanding in range and abundance throughout the southern United States. Several biogeographical studies mapping tallow distribution and examining key underlying environmental factors relied on the USDA Forest Service, Forest Inventory and Analysis (FIA) data, representing forest lands at scales of approximately 2,400 hectares. However, given that most invasive trees, like tallow, are cosmopolitan and dynamic in nature, FIA data fail to capture the extent and severity of the invasion especially outside areas classified as forest lands. To develop tallow maps that more adequately depict its distribution at finer spatial scales and to capture observations in nonforest lands, we combined verified citizen science observations with FIA data. Further, we described spatiotemporal patterns and compared citizen science to FIA and other previously published distribution maps. From our work, although tallow is prevalent in the South, Louisiana, Texas, and Mississippi were the most invaded states. Tallow was associated with flatwoods and prairie grasslands of the Gulf Coast. Annual extreme minimum temperatures of less than −12.2 degrees Celsius (10 degrees Fahrenheit) represented the northern limit of naturalized tallow populations. Tallow's northward and inland expansion was captured in citizen science and FIA data, indicating a tallow spread rate ranging from 5 to 20 kilometers annually over the last decade. Systematic sampling, such as FIA, and citizen science data both have their own unique pitfalls. However, the use of citizen science data can complement invasive plant distribution mapping, especially when combined with data from established systematic monitoring networks. This approach provides for a more complete understanding of invasive tree extent and spatiotemporal dynamics across large landscapes.

D'Antonio, Carla M.; Rehm, Evan; Elgersma, Cheryl; Yelenik, Stephanie G. 2024. **Influence of native woody understory on invasive grasses and soil nitrogen dynamics under plantation and remnant montane tropical trees.** Ecosystems. https://doi.org/10.1007/s10021-024-00922-z.

While the influence of canopy trees on soils in natural and restored forest environments is well studied, the influence of understory species is not. Here, we evaluate the effects of outplanted native woody understory on invasive grass biomass and soil nutrient properties in heavily grass-invaded 30+-year-old plantations of a native nitrogen-fixing tree *Acacia koa* in Hawai'i. We analyze soils from under *A. koa* trees with versus without planted woody understory and compare these to soils from under remnant pasture trees of the pre-deforestation dominant, *Metrosideros polymorpha* where passive recruitment of native woody understory has occurred since the cessation of grazing. Simultaneously, we experimentally planted understory species at three times the density used by managers to see if this could quickly decrease grass biomass and change soil nutrient dynamics. We found that invasive grass biomass declined with understory planting in surveyed and experimental sites. Yet, woody understory abundance had no effect on nitrogen cycling. Short-term nitrogen availability and nitrification potential were higher under *A. koa* than *M. polymorpha* trees regardless of understory. Net nitrogen mineralization either did not differ (approximately 1 month) between canopy species or was higher (171-day incubations) under remnant *M. polymorpha* where organic matter was also higher. The only influence of understory on soil was a positive correlation with loss-on-ignition (organic matter) under *M. polymorpha*. We also demonstrate differential controls over nitrogen cycling under the two canopy tree species. Overall, understory restoration has not changed soil characteristics even as invasive grass biomass declines.

Markus, Trisha M.; Pile Knapp, Lauren S.; Coyle, David R.; Wang, G. Geoff. 2024. **Seasonal light response curves of *Ligustrum sinense*: a test of extended leaf phenology.** In: Bragg, D.C.; Oswald, B.P.; Koerth, N.E., eds. Proceedings of the 22nd biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-274. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 210–218. https://doi.org/10.2737/SRS-GTR-274-Pap34.

Chinese privet (*Ligustrum sinense*, hereafter: privet) is an invasive shrub common throughout the eastern and southeastern United States. The foremost concern of privet is its highly competitive nature; it displaces native plants, their associated pollinators, and wildlife communities. Extended leaf phenology is an adaptation which allows understory plants in deciduous forests to take advantage of higher sunlight levels during the dormant season when canopy foliage is absent and has been associated with many invasive plant species. To measure the extended leaf phenology potential of privet, we created light response curves for privet along two habitat types (forest edge and forest interior) using a gas exchange analyzer. Privet actively photosynthesized after native canopy leaf-off, and carbon assimilation rates did not differ between habitats. We observed habitat and seasonal variability in privet leaf shedding and leaf replacement, with privet retaining leaves in both

habitats throughout October 2019 to February 2020. Individuals along the forest edge shed leaves in November 2020, and privet in the interior habitat did not shed leaves until February 2021. Our results provide evidence of the competitive extended leaf phenology potential of privet and suggest potential issues for planning winter foliar herbicide applications based on current management recommendations.

Robinov, Larissa; Kurtz, Cassandra M. 2024. **An assessment of invasive plant species in New Hampshire forests.** Res. Note NRS-313. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 p. https://doi.org/10.2737/NRS-RN-313.

Invasive plant species threaten ecological integrity with their aggressive growth habits and ability to outcompete native vegetation. Invasive plant species typically have competitive advantage over native species due to traits such as earlier leaf out, prolific reproductive capability, and fewer natural predators. Thus, invasive plant species can dominate a site and decrease the presence of native species, which affects biodiversity in the area.

Vaughn, Karen; Pile Knapp, Lauren S.; Wang, G. Geoff. 2024. **Evaluating dormant-season herbicide applications for the control of Chinese privet (*Ligustrum sinense*).** In: Bragg, D.C.; Oswald, B.P.; Koerth, N.E., eds. Proceedings of the 22nd biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-274. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 221–230. https://doi.org/10.2737/SRS-GTR-274-Pap36.

Chinese privet (*Ligustrum sinense*) is an aggressive, nonnative shrub of the southeastern United States. Its evergreen leaves allow for herbicide treatment in the dormant season when the impact to native species can be minimized. The purpose of this study was to determine which combination of chemical herbicide (glyphosate, metsulfuron, or a mixture of both) and application method (backpack sprayer or mistblower) applied during the dormant season would result in the greatest control of Chinese privet with minimal nontarget impacts. Study results suggest that herbicide, regardless of the chemical formulation, will kill more than 50 percent of the basal area of Chinese privet. However, glyphosate did impact native species that remained green and resulted in an increase in Japanese stiltgrass (*Microstegium vimineum*). Mistblowers were more effective at controlling Chinese privet than backpack sprayers regardless of herbicide. Although no differences in native species richness were found between the method of application, mistblowers also had fewer impacts on native flora, including tree and shrub reproduction, than backpack sprayers. Mistblowers are not commonly used for controlling invasive shrubs; however, their utility for controlling large and tall shrub infestations should be considered.

GENERAL BIOLOGICAL INVASIONS

Bertelsmeier, Cleo; Bonnamour, Aymeric; Brockerhoff, Eckehard G.; Pyšek, Petr; Skuhrovec, Jiří; Richardson, David M.; Liebhold, Andrew M. 2024. **Global proliferation of nonnative plants is a major driver of insect invasions.** BioScience. 74(11): 770–781. https://doi.org/10.1093/biosci/biae088.

Invasions by nonnative insect species can massively disrupt ecological processes, often leading to serious economic impacts. Previous work has identified propagule pressure as important driver of the trend of increasing numbers of insect invasions worldwide. In the present article, we propose an alternative hypothesis—that insect invasions are being driven by the proliferation of nonnative plants, which create niches for insect specialists and facilitate their establishment outside their native ranges where their hosts are planted or are invasive. We synthesize mechanisms by which plant invasions facilitate insect invasions, macroecological patterns supporting the tight link between plant and insect invasions, and case studies of plant invasions having facilitated subsequent insect establishment. This body of evidence indicates that plant invasions are a major driver of insect invasions. Consequently, the benefits of limiting the spread of nonnative plants include averting the proliferation of nonnative insects and their spillover onto native plant species.

Branco, Manuela; Dokhelar, Théo; Brockerhoff, Eckehar G.; Liebhold, Andrew M.; Jactel, Hervé. 2024. **Widespread experimental evidence of Allee effects in insects: a meta-analysis.** Entomologia Generalis. 44: 765–778. https://doi.org/10.1127/entomologia/2024/2377.

During the last two decades there has been growing recognition of the importance of Allee effects in population dynamics and applied ecology. The Allee effect, that is decreased fitness at lower population densities, has been recognized as potentially playing an important role in the conservation of endangered species, in the practice of biological control, and the eradication of invasive species. Although a number of theoretical studies have been devoted to the role of Allee effects in the population dynamics of insects and other terrestrial arthropods, experimental evidence documenting Allee effects is still scarce. Here, we reviewed the literature reporting on density-dependent relationships in low-density populations and conducted a meta-analysis of 191 case studies to identify the occurrence of Allee effects and associated species traits. Allee effects are not rare in terrestrial arthropods, as they were reported in 47 percent of the cases we reviewed, comprising 46 out of 68 species. Ample examples exist for both demographic Allee effects (28 out of 74 cases cases), and component Allee effects (61 out of 117 cases). Insufficient mating success, cooperative feeding, and enemy escape were the three main mechanisms associated with Allee effects in terrestrial arthropods. Insufficient reproductive success was the mechanism with the highest proportion of related Allee effects (71 percent). Voltinism and host specialization were common species traits behind demographic Allee effects. Host specialists with univoltine life cycles tended to have stronger Allee effects. The high frequency of Allee effects in terrestrial arthropods reported here and the identified mechanisms behind them have important implications for the selection of management strategies.

Fenn-Moltu, Gyda; Liebhold, Andrew M.; Weber, Donald C.; Bertelsmeier, Cleo. 2024. **Pathways for accidental biocontrol: the human-mediated dispersal of insect predators and parasitoids.** Ecological Applications. 34: e3047. https://doi.org/10.1002/eap.3047.

Introductions of insect predators and parasitoids for biological control are a key method for pest management. Yet in recent decades, biological control has become more strictly regulated and less frequent. Conversely, the rate of unintentional insect introductions through human activities is rising. While accidental introductions of insect natural enemies can potentially have serious ecological consequences, they are challenging to quantify as their movements go largely unobserved. We used historical border interception records collected by the U.S. Department of Agriculture from 1913 to 2018 to describe the diversity of entomophagous insects transported unintentionally, their main introduction pathways, and trends in host specificity. There were 35,312 interceptions of insect predators and parasitoids during this period, representing 93 families from 11 orders, and 196 species from these families. Commodity associations varied, but imported plants and plant products were the main introduction pathway. Most interceptions originated with commodities imported from the Neotropical, Panamaian, and Western Palearctic regions. Among the intercepted species, 27 percent were found in material originating from more than one country. Two thirds of species were polyphagous host generalists. Furthermore, 25 percent of species had already been introduced intentionally as biological control agents internationally, and 4.6 percent have documented negative impacts on native biodiversity or human society. Most of the intercepted species that have not established in the United States are host generalists or have at least one known host species available. The unintentional transport of diverse natural enemy insects has the potential to cause substantial ecological impacts, both in terms of controlling pests through accidental biocontrol and disrupting native communities. Characterizing the insects being transported and their introduction pathways can inform biosecurity practices and management.

Gougherty, Andrew V.; Clipp, Hannah L. 2024. **Testing the reliability of an AI-based large language model to extract ecological information from the scientific literature.** npj Biodiversity. 3: 13. https://doi.org/10.1038/s44185-024-00043-9.

Artificial intelligence-based large language models have the potential to substantially improve the efficiency and scale of ecological research, but their propensity for delivering incorrect information raises significant concern about their usefulness in their current state. Here, we formally test how quickly and accurately a large language model performs in comparison to a human reviewer when tasked with extracting various types of ecological data from the scientific literature. We found the large language model was able to extract relevant data over 50 times faster than the reviewer and had very high accuracy (greater than 90 percent) in extracting discrete and categorical data, but it performed poorly when extracting certain quantitative data. Our case study shows that large language models offer great potential for generating large ecological databases at unprecedented speed and scale, but additional quality assurance steps are required to ensure data integrity.

Gougherty, Andrew V.; Klapwijk, Maartje; Liebhold, Andrew M.; Mech, Angela; Trombik, Jiří; Fei, Songlin. 2024. **Identifying the generalizable controls on insect associations of native and non-native trees.** Ecology and Evolution. 14(5): e11265. https://doi.org/10.1002/ece3.11265.

Trees growing outside their native geographic ranges often exhibit exceptional growth and survival due in part to the lack of co-evolved natural enemies that may limit their spread and suppress population growth. While most non-native trees tend to accumulate natural enemies over time, it remains uncertain which host and insect characteristics affect these novel associations and whether novel associations follow patterns of assembly similar to those of native hosts. Here, we used a dataset of insect–host tree associations in Europe to model which native insect species are paired with which native tree species, and then tested the model on its ability to predict which native insects are paired with which non-native trees. We show that native and non-native tree species closely related to known hosts are more likely to be hosts themselves, but that native host geographic range size, insect feeding guild, and sampling effort similarly affect insect associations. Our model had a strong ability to predict which insect species utilize non-native trees as hosts, but evolutionarily isolated tree species posed the greatest challenge to the model. These results demonstrate that insect–host associations can be reliably predicted, regardless of whether insect and host trees have co-evolved, and provide a framework for predicting future pest threats using a select number of easily attainable tree and insect characteristics.

Gougherty, Andrew V.; Walters, Ashley D.; Prasad, Anantha; Peters, Matthew P.; Matthews, Stephen N.; DeMerchant, Ian. 2024. **Climate, host abundance and spread: unravelling the drivers of forest pest distributions in North America.** Journal of Biogeography. 51(12): 2498–2511. https://doi.org/10.1111/jbi.15004.

Forest pathogens, insect pests and parasitic plants are among the most important disturbance agents in forested ecosystems. Understanding where pests occur and where they might occur in the future will be important for understanding their impacts on host trees, and planning for future pest outbreaks. Here, we develop and implement a framework to predict the contemporary distributions of 26 pest species that accounts for climate, host abundance and, for non-native species, their spread on the landscape. We show that pest distributions can be predicted primarily by climatic variables. The abundance of individual host trees had only minor explanatory power, but the summed total of host abundance frequently had greater importance—suggesting forest composition and the relative frequency of hosts and non-hosts place strong limits on pest distributions. Non-native pests were strongly impacted by the distance from their original discovery location in North America, which tended to interact with climate variables—suggesting most non-native pests are not yet at equilibrium with their potential climatic ranges in North America. This work helps to clarify the generalized controls on pest distributions and provide a framework for predicting pest distributions in future climates.

Isitt, Rylee; Liebhold, Andrew M.; Turner, Rebecca M.; Battisti, Andrea; Bertelsmeier, Cleo; Blake, Rachael; Brockerhoff, Eckehard G.; Heard, Stephen B.; Krokene, Paal; Økland, Bjørn; Nahrung, Helen F.; Rassati, Davide; Roques, Alain; Yamanaka, Takehiko; Pureswaran, Deepa S. 2024. **Asymmetrical insect invasions between three world regions.** NeoBiota. 90: 35–51. https://doi.org/10.3897/neobiota.90.110942.

The geographical exchange of non-native species can be highly asymmetrical, with some world regions donating or receiving more species than others. Several hypotheses have been proposed to explain such asymmetries, including differences in propagule pressure, source species (invader) pools, environmental features in recipient regions, or biological traits of invaders. We quantified spatiotemporal patterns in the exchange of non-native insects between Europe, North America, and Australasia, and then tested possible explanations for these patterns based on regional trade (import values) and model estimates of invader pool sizes. Europe was the dominant donor of non-native insect species between the three regions, with most of this asymmetry arising prior to 1950. This could not be explained by differences in import values (1827 to 2014), nor were there substantial differences in the sizes of modeled invader pools. Based on additional evidence from literature, we propose that patterns of historical plant introductions may explain these asymmetries, but this possibility requires further study.

Kinsley, Amy C.; Bajcz, Alex W.; Haight, Robert G.; Phelps, Nicholas B.D. 2024. **Facilitating effective collaboration to prevent aquatic invasive species spread.** Biological Conservation. 290(12): 110449. https://doi.org/10.1016/j.biocon.2024.110449.

Aquatic invasive species threaten ecosystem health, serving as a major challenge for conservation efforts worldwide. Invasive species easily move across jurisdictional boundaries that may each have diverse management approaches, leading to management mosaics in which each manager's actions impact those of neighboring jurisdictions. Here, we investigate the potential impact of collaborations between counties in Minnesota in managing four aquatic invasive species (Eurasian watermilfoil, spiny waterflea, starry stonewort, and zebra mussels), with a focus on evaluating the efficiency of county-led prevention programs. We aimed to identify potential collaboration networks, each representing a group of counties with a relatively high number of potentially infested boats moving between them and describe the connections within those groups using social network analysis. We found that collaboration networks formed by ranking reciprocal connections amongst counties yielded efficiency gains over a non-collaborative or county-focused approach but were still less efficient than a state-wide approach. This study presents an analytical framework for identifying collaborations based on aquatic invasive species dispersal pathways that may increase the efficiency of interjurisdictional prevention efforts.

Liebhold, Andrew M.; Turner, Rebecca M.; Bartlett, Charles R.; Bertelsmeier, Cleo; Blake, Rachael E.; Brockerhoff, Eckehard G.; Causton, Charlotte E.; Matsunaga, Janis N.; McKamey, Stuart H.; Nahrung, Helen F.; Owen, Christopher L.; Pureswaran, Deepa S.; Roques, Alain; Schneider, Scott A.; Sanborn, Allen F.; Yamanaka, Takehiko. 2024. **Why so many Hemiptera invasions?** Diversity and Distributions. 30: e13911. https://doi.org/10.1111/ddi.13911.

The Hemiptera is the fifth-largest insect order but among non-native insect species is approximately tied with the Coleoptera as the most species-rich insect order (Hemiptera comprise 20 percent more species than in world fauna). This over-representation may result from high propagule pressure or from high species invasiveness. Here, we assess the reasons for over-representation in this group by

analyzing geographical, temporal and taxonomic variation in numbers of historical invasions. We assembled lists of historical Hemiptera invasions in 12 world regions, countries or islands (Australia, Chile, Europe, New Zealand, North America, South Africa, South Korea, Japan and the Galapagos, Hawaiian, Okinawa and Ogasawara Islands) and border interception data from nine countries (Australia, Canada, European Union, United Kingdom, Hawai'i, Japan, New Zealand, South Korea, USA mainland and South Africa). Using these data, we identified hemipteran superfamilies that are historically over-represented among established non-native species, and superfamilies that are over-represented among arrivals (proxied by interceptions). We also compared temporal patterns of establishments among hemipteran suborders and among regions. Across all regions, patterns of over- and under-representation were similar. The Aphidoidea, Coccoidea, Aleyrodoidea, Cimicoidea and Phylloxeroida were over-represented among non-native species. These same superfamilies were not consistently over-represented among intercepted species indicating that propagule pressure does not completely explain the tendency of some Hemiptera to be over-represented among invasions. Asexual reproduction is common in most over-represented superfamilies and this trait may be key to explaining high invasion success in these superfamilies. We conclude that both propagule pressure and species invasiveness are drivers of high invasion success in the Sternorrhyncha suborder (aphids, scales, whiteflies) and this group plays a major role in the exceptional invasion success of Hemiptera in general. The high historical rates of invasion by Sternorrhyncha species provide justification for biosecurity measure focusing on exclusion of this group.

Nguyen, Hoa-Thi-Minh; Chu, Long; Liebhold, Andrew M.; Epanchin-Niell, Rebecca; Kean, John M.; Kompas, Tom; Robinson, Andrew P.; Brockerhoff, Eckehard G.; Moore, Joslin L. 2024. **Optimal allocation of resources among general and species-specific tools for plant pest biosecurity surveillance**. Ecological Applications. 34(3): e2955. https://doi.org/10.1002/eap.2955.

This paper proposes a surveillance model for plant pests that can optimally allocate resources among survey tools with varying properties. While some survey tools are highly specific for the detection of a single pest species, others are more generalized. There is considerable variation in the cost and sensitivity of these tools, but there are no guidelines or frameworks for identifying which tools are most cost-effective when used in surveillance programs that target the detection of newly invaded populations. To address this gap, we applied our model to design a trapping surveillance program in New Zealand for bark and wood-boring insects, some of the most serious forest pests worldwide. Our findings show that exclusively utilizing generalized traps proves to be highly cost-effective across a wide range of scenarios, particularly when they are capable of capturing all pest species. Implementing surveillance programs that only employ specialized traps is cost-effective only when these traps can detect highly damaging pests. However, even in such cases, they significantly lag in cost-effectiveness compared to generalized trap-only programs due to their restricted coverage. When both generalized traps and specialized traps are used in an integrated surveillance program, the total expected cost generally diminishes when compared to programs relying on a single type of trap. However, this relative reduction in total expected cost is only marginally larger than that achieved with generalized trap-only programs, as

long as highly damaging species can be detected by generalized traps. The proportion of specialized traps among the optimal required traps fluctuates based on several factors, including the relative pricing of generalized traps and specialized traps, pest arrival rates, potential damage, and, more prominently, the coverage capacity of generalized traps. Our analysis suggests that deploying generalized traps extensively across landscapes appears to be more cost-effective in areas with either very high or very low levels of relative risk density, potential damage, and arrival rate. Finally, specialized traps are less likely to be required when the pests that are detected by those tools have a higher likelihood of successful eradication because delaying detection becomes less costly for these species.

Sambaraju, Kishan R.; Srivastava, Vivek; Barker, Brittany S.; Keena, Melody A.; Ormsby, Michael D.; Carroll, Allan L. 2024. **Editorial: forest insect invasions—risk mapping approaches and applications.** Frontiers in Insect Science. 4: 1378061. https://doi.org/10.3389/finsc.2024.1378061.

Forests around the globe are facing unprecedented threats from biotic and abiotic factors that challenge the overall health of ecosystems and potentially contribute to climate warming through positive feedback to atmospheric carbon dioxide. Presently, some of the greatest challenges pertain to the rapid spread and resulting tree mortality caused by non-native forest insects. Increased global trade and more favorable climates due to climate change have facilitated the establishment of non-native forest insects in new areas where conditions were previously unsuitable for their growth and survival. The lack of co-evolutionary history between native trees and invasive insects, combined with the absence of natural enemies in the invaded habitats, has allowed aggressive non-native forest insects to rapidly colonize or kill trees and expand their invaded range in a short period of time.

Schafstall, Nick; Dobor, Laura; Baldo, Marco; Liebhold, Andrew M.; Rammer, Werner; Honkaniemi, Juha; Hlásny, Tomáš. 2024. **Assessing the effect of invasive organisms on forests under information uncertainty: the case of pine wood nematode in continental Europe.** Forest Ecosystems. 11: 100226. https://doi.org/10.1016/j.fecs.2024.100226.

Forests worldwide are experiencing increasingly intense biotic disturbances; however, assessing impacts of these disturbances is challenging due to the diverse range of organisms involved and the complex interactions among them. This particularly applies to invasive species, which can greatly alter ecological processes in their invaded territories. Here we focus on the pine wood nematode (*Bursaphelenchus xylophilus*), an invasive pathogen that has caused extensive mortality of pines in East Asia and more recently has invaded southern Europe. It is expected to expand its range into continental Europe with heavy impacts possible.

Given the unknown dynamics of pine wood nematode in continental Europe, we reviewed laboratory and field experiments conducted in Asia and southern Europe to parameterize the main components of pine wood nematode biology and host-pathogen interactions in the Biotic Disturbance Engine, a model designed to implement a variety of forest biotic agents, from fungi to large herbivores. To simulate dynamically

changing host availability and conditions, the Biotic Disturbance Engine was coupled with the forest landscape model iLand. The potential impacts of introducing pine wood nematode were assessed in a Central European forest landscape (40,928 hectares), likely within pine wood nematode's reach in future decades.

A parameter sensitivity analysis indicated a substantial influence of factors related to dispersal, colonization, and vegetation impact, whereas parameters related to population growth manifested a minor effect. Selection of different assumptions about biological processes resulted in differential timing and size of the main mortality wave, eliminating 40 to 95 percent of pine trees within 100 years post-introduction, with a maximum annual carbon loss between 1.3 and 4.2 percent. Pine wood nematode-induced tree mortality reduced the Gross Primary Productivity, increased heterotrophic respiration, and generated a distinct legacy sink effect in the recovery period. This assessment has corroborated the ecological plausibility of the simulated dynamics and highlighted the need for new strategies to navigate the substantial uncertainty in the agent's biology and population dynamics.

Weber, Megan M.; Gupta, Angela.; Phelps, Nicholas B.D.; Jensen, Douglas A.; Venette, Robert C. 2024. **Invasive species common names: working towards more inclusive invasive species education and outreach.** The Journal of Extension. 62(3): 11. https://open.clemson.edu/joe/vol62/iss3/11.

Invasive species harm natural and managed ecosystems. Awareness and management of these species depends on effective education and outreach. Traditional common names, including those with geographic references, for many invasive pests may perpetuate slanderous terms or stigmatize people from that place. To create more inclusive invasive species educational materials, the University of Minnesota Extension's Invasive Species Community of Practice developed guidelines for selection of common names. Suggested names were shared with others involved in invasive species communications, leading to broader adoption. These guidelines may be useful to others who struggle to find descriptive, non-alienating common names for invasive species.

Yamanaka, Takehiko; Turner, Rebecca M.; Bertelsmeier, Cleo; Blake, Rachael E.; Brockerhoff, Eckehard G.; Nahrung, Helen F.; Pureswaran, Deepa S.; Roques, Alain; Seebens, Hanno; Liebhold, Andrew M. 2024. **International imports and climatic filtering drive compositional variation in non-native insect establishments.** Diversity and Distributions. 30(7): e13844. https://doi.org/10.1111/ddi.13844.

Invasions of non-native insects can have substantial impacts on agriculture, forestry, human health and biodiversity with considerable economic and environmental consequences. To understand the causes of these invasions, it is important to quantify the relative influence of principal drivers such as international imports and climatic effects. To evaluate the relative contributions of various factors in explaining global variation in numbers of non-native insect establishments in different world regions, we conducted two multivariate regression analyses to quantify temporal changes in family-level composition and native ranges of established non-native species in several world regions. There were temporal changes in the family-level composition of non-native species assemblages. Prior to 1900, invasions were dominated by scale insects,

subsequently shifting to a more diverse set of species, except in North America, which had relatively small compositional change over time compared to other regions. Spatial and temporal variation in the composition of established species was associated with differences in the origin of imports and climatic factors, each explaining 26.3 percent and 27.4 percent of the total variation, respectively. The analysis of native ranges of non-native species indicated that there was no consistent temporal variation across all regions. Established species in New Zealand were predominantly native to Australasia and species in North America and Chile were mainly from Europe. Non-native species in Europe mainly originated from the Nearctic region while those in Japan and Australia generally originated from multiple regions. Climatic factors in the destination regions had a primary effect (66.3 percent) on variation in the native range of established species, although imports also had substantial effects (45.4 percent). Geographical variation in climate and imports act together as drivers of establishment success for non-native insects in all six regions.

SOILS AND FOREST HEALTH

Adams, Mary Beth; Rau, Benjamin M.; Peterjohn, William T.; Fowler, Zach; Kelly, Charlene. 2024. **Long-term treatments alter acidification, fertility and carbon in soils of the Fork Mountain long-term soil productivity experiment.** Soil Science Society of America Journal. 88(4): 1027–1044. https://doi.org/10.1002/saj2.20691.

Historical atmospheric acidic deposition resulting from the combustion of fossil fuels may alter the pools of important nutrients and base cations in sensitive forest soils. This raises concern that chronic acidic deposition, particularly when coupled with intensive forest biomass harvesting, may diminish long-term soil fertility, forest productivity, and carbon storage potential. To address these concerns, the Fork Mountain long-term soil productivity experiment was initiated in 1996 at the Fernow Experimental Forest, West Virginia. The replicated experimental design consists of 16 plots (0.2 hectares) that receive one of four treatments: (1) whole-tree harvesting (removal of all aboveground biomass); (2) whole-tree harvesting plus ammonium-sulfate fertilization; (3) whole-tree harvesting plus ammonium-sulfate fertilization plus dolomitic lime; and (4) untreated reference plots. We present forest floor and soil chemistry responses after approximately 25 years of treatment and evaluate the temporal changes to illuminate these results. Soil acidification has occurred, and base cation movement through the soil profile was observed, with effective cation exchange capacity increasing slightly in the deepest soil horizon by the end of the 25 years. However, some of our hypotheses were not supported. In particular, soil carbon did not increase over time with fertilization and soil acidification but was mainly altered by whole tree harvesting, as were other nutrients. Dolomitic lime provided some amelioration of acidification, but surprisingly, most of the changes in base cations appeared to be the results of magnesium, not calcium, likely due to greater tree requirements and uptake of calcium.

Benalcazar, Paul.; Kolka, Randall; Diochon, Amanda C.; Schindelbeck, Robert R.; Sahota, Tarlok; McLaren, Brian E.; Stanovick, John. 2024. **Predictive soil health indicators across a boreal forest to agricultural conversion gradient.** Agricultural & Environmental Letters. 9(1): e20123. https://doi.org/10.1002/ael2.20123.

A changing climate offers new opportunities to expand agriculture in northern latitudes, and understanding forest-to-agriculture land conversion impacts is critical to ensure soil sustainability. Using the Comprehensive Assessment of Soil Health framework, we identified a minimum suite of indicators with little collinearity to reliably predict soil impacts during the conversion of boreal forest to agriculture and a time since conversion gradient (forest, less than 10 years, less than 10 and more than 50 years, and more than 50 years since conversion). We sampled paired forest and agricultural sites and used multiple linear regression to assess 16 indicators and found four- and six-indicator models predicted the Comprehensive Assessment of Soil Health score with varying but reasonable accuracy depending on conversion class. Organic matter, water aggregate stability, and pH were consistent predictors across all classes, as well as one or more micronutrients. The Comprehensive Assessment of Soil Health framework appears to be more suitable for agricultural soils and as time since conversion proceeds.

Mejía, Gisselle A.; Groffman, Peter M.; Avolio, Meghan L.; Bratt, Anika R.; Cavender-Bares, Jeannine; Grijseels, Noortje H.; Hall, Sharon J.; Heffernan, James; Hobbie, Sarah E.; Lerman, Susannah B.; Morse, Jennifer L.; Narango, Desiree L.; Neill, Christopher; Padullés Cubino, Josep; Trammell, Tara L.E. 2024. **Woody plant-soil relationships in interstitial spaces have implications for future forests within and beyond urban areas.** Ecosystems. 27(2): 185-206. https://doi.org/10.1007/s10021-023-00881-x.

Relatively unmanaged interstitial areas at the residential–wildland interface can support the development of novel woody plant communities. Community assembly processes in urban areas involve interactions between spontaneous and cultivated species pools that include native, introduced (exotic or non-native) and invasive species. The potential of these communities to spread under changing climate conditions has implications for the future trajectories of forests within and beyond urban areas. We quantified woody vegetation (including trees and shrubs) in relatively unmanaged "interstitial" areas at the residential–wildland interface and in exurban reference natural areas in six metropolitan regions across the continental USA. In addition, we analyzed soil nitrogen and carbon cycling processes to ensure that there were no major anthropogenic differences between reference and interstitial sites such as compaction, profile disturbance or fertilization, and to explore effects of novel plant communities on soil processes. We observed marked differences in woody plant community composition between interstitial and reference sites in most metropolitan regions. These differences appeared to be driven by the expanded species pool in urban areas. There were no obvious anthropogenic effects on soils, enabling us to determine that compositional differences between interstitial and reference areas were associated with variation in soil nitrogen availability. Our observations of the formation of novel communities in interstitial spaces in six cities across a very broad range of climates suggest that our results have relevance for how forests within and beyond urban areas are assessed and managed to provide ecosystem services and resilience that rely on native biodiversity.

Yesilonis, Ian; Placella, Sarah; Csuzdi, Csaba; Szlavecz, Katalin. 2024. **Changes in remnant forest soils and earthworm communities over two decades.** Applied Soil Ecology. 202: 105534. https://doi.org/10.1016/j.apsoil.2024.105534.

Long-term urban soil studies provide details of how urban soils develop over time. Urban soils are affected by regional and local pressures related to air pollution and introduced species such as earthworms and vegetation, which can affect change within relatively short periods of time. In Baltimore, forest soils of an urban–rural gradient were re-sampled, and it was found that, over two decades, calcium concentration and pH had increased. These forest soils are habitats for populations of earthworms, which feed on the leaf litter and, consequently, locally alter the forest floor. Given the profound impact that earthworms have on soil properties, changes in soil chemistry were examined to determine any relation to shifts in earthworm community composition and abundance, with a special focus on the invasive jumping worms. To answer this question, earthworm assemblages in urban, suburban, and rural forest patches were sampled in 2002 and 2020. Species biomass and density were determined and then compared to samples collected at the same locations. In 2020, mean biomass and density varied between 91 and 33 grams per square meter, and 388 and 12 individuals per square meter, respectively. The results indicate statistically significant correlations between soil properties (pH, calcium, leaf litter depth, and bulk density) and earthworm abundance within a given year. However, changes in soil properties were independent of changes in earthworm species or abundance. The dynamics of earthworm assemblages appear to be different in urban forests than rural ones, with rural forests containing more jumping worms than urban ones, which uniquely affects the forest ecosystems.

GENERAL FOREST HEALTH

Conrad, Anna O.; Villari, Caterina; Bonello, Pierluigi. 2024. **A workflow for metabolomics of forest tree biotic stress response and applications for management.** In: António, C., ed. Monitoring forest damage with mass spectrometry-based metabolomics methods. Hoboken, NJ: John Wiley & Sons: 109–126. Chapter 5.

Trees are exposed to a variety of stressors over their lifetimes. To survive and thrive under diverse conditions, they have evolved a suite of defenses, which confer resistance or tolerance to most biotic and abiotic stressors. Even though disease (or insect pest infestation) is the exception and not the rule, pests and pathogens have had and continue to have a profound impact on the health of forests globally. This is especially true for invasive and/or non-native pests and pathogens and, more recently, for native pests and pathogens whose range or virulence has changed because of climate change. Any estimate of the impact of pests and pathogens on forests is likely conservative and an underestimate of the actual impact on forests and the communities that rely on them. The incidence of non-native insects (and pathogens) continues to increase every year, and increased tree mortality within just the United States is predicted in 63 percent of forest land due to non-native insect pests and pathogens. Over the last 100 years, invasive pests and pathogens have functionally eradicated or decimated multiple forest tree species in local populations or across species ranges. Examples of impacted forest tree species include, but are not limited to, chestnut (chestnut blight), pines (white pine blister rust and mountain pine beetle), ash (emerald ash borer and ash dieback), and tanoak, oaks, and larch (sudden oak death and Ramorum blight).

The impacts of pests and pathogens are widespread, from economic losses to loss of forest ecosystem services and negative outcomes for human health. For example, emerald ash borer, which was first identified in the early 2000s, is estimated to have killed tens of millions of ash trees in the eastern United States. In areas of emerald ash borer infestation, increased human mortality from cardiovascular illness has been reported. Impacts have also been felt in the housing industry, where emerald ash borer infection negatively impacted home values in one midwestern United States city. These studies do not even include more direct impacts, such as costs of forest management for the treatment, removal, or replacement of susceptible ash trees. Wide-reaching impacts are not exclusive to the emerald ash borer. Similar impacts have been observed or estimated for other pathogens and pests of trees across wildlands and urban landscapes.

To counter biotic threats, trees possess a suite of defenses that act directly and/or indirectly on the attacking pest or pathogen, and range from physical defenses, including bark and lignin, to chemical defenses, such as phenolics and terpenoids. These defenses can be general or specific for a given organism and can be produced constitutively (pre-infection) or induced following infection. The reason why invasive and non-native pests and pathogens have been particularly problematic is because affected tree species lack a co-evolutionary history with them, so the pests and pathogens have no co-evolved natural enemies. Thus, the suite of defenses that the novel host possesses is unable to prevent infection or minimize adverse impacts to tree health, ultimately, resulting in higher-than-normal levels of mortality of impacted host tree species, often across larger spatial scales.

In this chapter, we focus on the role of metabolite defenses in forest tree responses to biotic stress. Within this context, we describe a workflowfor use in metabolomics studies of forest tree-pest/pathogen interactions. Applications for the workflow as well as considerations for applying it across scales, from individual trees to landscapes, are also discussed. Finally, case studies from multiple tree-pathogen and pest systems are presented, including oak (sudden oak death and European oak leafroller), ash (emerald ash borer and ash dieback), and pine (Diplodia tip blight and mountain pine beetle).

Crocker, Susan J., ed. 2024. **Proceedings of the 2022 Forest Inventory and Analysis (FIA 2022) science stakeholder meeting: grow. adapt. regenerate—monitoring and responding to global change to promote resilient and productive forests.** Gen. Tech. Rep. NRS-225. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 102 p. https://doi.org/10.2737/NRS-GTR-225.

The Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service, implements the Nation's only comprehensive inventory of forest resources across all ownerships. Through its continuous forest monitoring, FIA provides strategic-level information necessary to evaluate the status and changing trends in forest resources and the sustainability of forest management practices; FIA data serve as the foundation for a broad array of scientific studies. These proceedings report findings from invited and contributed presentations and posters from the 15th biennial Forest Inventory and Analysis Science Stakeholder Meeting (FIA

2022, formerly known as the Forest Inventory and Analysis Symposium). Hosted by the Northern Research Station's FIA program, the conference was held virtually November 14 through 17, 2022. Topics were based on the theme "Grow. Adapt. Regenerate: Monitoring and Responding to Global Change to Promote Resilient and Productive Forests" and included landscape change, remote sensing, ecocultural resources and people, forest disturbance, understory vegetation and invasive plants, and monitoring changes in forest composition. These proceedings include 15 papers and extended abstracts, a list of papers published in a special issue of Frontiers in Forests and Global Change, the conference program, and the titles of poster presentations.

Gormanson, Dale D.; Hemmer, Bryan J.; Gallion, Daniel J.; Albright, Thomas A.; Butler, Brett J.; Crocker, Susan J.; Garner, James D.; Goff, Thomas C.; Kurtz, Cassandra M.; Lister, Tonya W.; Morin, Randall S.; Nelson, Mark D.; Riemann, Rachel; Schanning, Sjana; Walters, Brian F.; Westfall, James A.; Woodall, Christopher W. 2024. **Indiana forests 2018: summary report.** Resour. Bull. NRS-132. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 34 p. [plus interactive report]. https://doi.org/10.2737/NRS-RB-132.

This summary report provides an overview of findings from the fourth full annualized inventory of Indiana forests based on data collected from 2012 to 2018. Indiana has nearly 4.9 million acres of forest land with an average of 442 trees (at least 1.0-inch in diameter) per acre. Hardwoods are the dominant tree species in Indiana. Forest land is dominated by the oak-hickory forest-type group, which occupies 72 percent of the total forest land area (3.5 million acres). Live tree volume averages 2,240 cubic feet per acre. Growing-stock net growth exceeds removals resulting in a growth-to-removals ratio of 2.2, meaning that timberland is accumulating volume. Fragmentation and parcelization, aging forest cover, as well as threats from native and non-native plants and pests are major issues that will impact the future of Indiana's forests. Information from the National Woodland Owner Survey and the Timber Products Output studies are also presented in this summary document. A detailed interactive report is available at https://doi.org/10.2737/NRS-RB-132-INT, and supplemental information, including (1) tables summarizing quality assurance, (2) a core set of tabular estimates for a variety of forest resources, and (3) user and database guides for P2 and P2+ protocols, can be accessed at https://doi.org/10.2737/NRS-RB-132.

Gougherty, Andrew V.; Davies, T. Jonathan. 2024. **Evolutionary history of host trees amplifies the dilution effect of biodiversity on forest pests.** PLOS Biology. 22(2): e3002473. https://doi.org/10.1371/journal.pbio.3002473.

Biodiversity appears to strongly suppress pathogens and pests in many plant and animal systems. However, this "dilution effect" is not consistently detected, and when present can vary strikingly in magnitude. Here, we use forest inventory data from over 25,000 plots (more than 1.1 million sampled trees) to quantify the strength of the dilution effect on dozens of forest pests and clarify why some pests are particularly sensitive to biodiversity. Using Bayesian hierarchical models, we show that pest prevalence is frequently lower in highly diverse forests, but there is considerable variability in the magnitude of this dilution effect among pests. The strength of dilution was not closely

associated with host specialization or pest nativity. Instead, pest prevalence was lower in forests where co-occurring tree species were more distantly related to a pest's preferred hosts. Our analyses indicate that host evolutionary history and forest composition are key to understanding how species diversity may dilute the impacts of tree pests, with important implications for predicting how future biodiversity change may affect the spread and distribution of damaging forest pests.

Haack, Robert A.; Petrice, Toby R.; Davidson, Robert L.; Acciavatti, Robert E. 2024. **Changes in ground beetle (Coleoptera: Carabidae) species assemblages after removal of red pine (*Pinus resinosa*) overstory on dry sand prairie sites in Michigan.** The Great Lakes Entomologist. 57(1–2): 4. https://doi.org/10.22543/0090-0222.2487.

Ground beetle (Coleoptera: Carabidae) species assemblages were studied at sites on the Huron-Manistee National Forests in Newaygo County, Michigan. The goal was to monitor changes in carabid diversity on areas where mature red pine (*Pinus resinosa* Sol. ex Aiton) was removed during the 1996–1997 winter and compare with carabid diversity at nearby natural dry sand prairie sites, natural oak-pine barrens, and uncut red pine stands. The red pine had been planted on dry sand prairie sites during 1940–1950. Sampling with pitfall traps occurred during May–August in both 1996 and 1997, but only July–August in 1999. Overall, 16,259 carabid specimens were collected, representing 92 species of which one was a new state record for Michigan: *Dicaelus furvus furvus* Dejean. Of the 92 species, 27 were collected in the uncut red pine stands, 41 in the natural dry sand prairie sites, 28 in the natural oak-pine barrens, and 77 in the clearcut areas. Of all 41 species collected in the dry sand prairie sites, 27 (66 percent) of these were collected in the clearcut sites in 1997, 30 (73 percent) in 1999, and 34 (81 percent) for both years combined. Carabid abundance peaked in June in the red pine and oak-pine sites, compared with August for the clearcut sites. Non-metric multidimensional scaling (NMDS) ordination indicated considerable overlap in the carabid composition for the red pine and oak-pine collections, but more distinct assemblages for the dry sand prairie and clearcut sites. Of the 92 species, 41 (45 percent) were significant indicator species for a particular habitat.

Morin, Randall S.; Albright, Thomas A.; Butler, Brett J.; Caputo, Jesse; Crocker, Susan J.; Goff, Thomas C.; Kurtz, Cassandra M.; Lister, Tonya W.; Nelson, Mark D.; Riemann, Rachel; Schanning, Sjana; Walters, Brian F.; Westfall, James A.; Woodall, Christopher W. 2024. **West Virginia forests 2018: summary report.** Resour. Bull. NRS-133. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 34 p. [plus interactive report]. https://doi.org/10.2737/NRS-RB-133.

This report summarizes the third full annualized inventory of West Virginia forest land. The inventory was conducted from 2012 to 2018 by the Forest Inventory and Analysis program of the U.S. Department of Agriculture, Forest Service, Northern Research Station in cooperation with the West Virgina Division of Forestry. West Virginia has nearly 12 million acres of forest land with an average of 507 trees (at least 1.0-inch in diameter) per acre. Hardwoods are the dominant tree species in West Virginia. Forest land is dominated by the oak/hickory forest-type group, which

occupies 73 percent of the total forest land area (8.8 million acres). Sound tree volume of live trees averages 2,775 cubic feet per acre. Growing stock net growth exceeds removals resulting in a growth to removals ratio of 2:1, meaning that timberland is accumulating volume. Fragmentation and parcelization, aging forest cover, as well as threats from native and non-native plants and pests are major issues that will impact the future of West Virginia's forests. Information from the National Woodland Owner Survey and the Timber Products Output studies are also presented in this summary document. For further information about the FIA program, including methods and raw data, please visit the National FIA program website. A detailed interactive report is available at https://doi.org/10.2737/NRS-RB-133-INT, and supplemental information, including (1) tables summarizing quality assurance, (2) a core set of tabular estimates for a variety of forest resources, and (3) user and database guides for P2 and P2+ protocols, can be accessed at https://doi.org/10.2737/NRS-RB-133.

Nowak, David J. 2024. **Understanding i-Tree: 2023 summary of programs and methods.** Gen. Tech. Rep. NRS-200-2023. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 103 p. [plus 14 appendixes]. https://doi.org/10.2737/NRS-GTR-200-2023.

i-Tree is a suite of computer software tools developed through a collaborative public-private partnership. These tools are designed to assess and value the urban forest resource, understand forest risk, and develop sustainable forest management plans to improve environmental quality and human health. This report provides details about the underlying methods and calculations of these tools, as well as their potential limitations. Also discussed are the history of i-Tree, its future goals, and opportunities to facilitate new science and international collaboration.

Rutledge, Annamarie; Brandt, Leslie A.; Peters, Matthew P.; Baroli, Madeline J.; Foen, Fai; Harrington, Anita; Grantham, Katherine. 2024. **Detroit region urban forest vulnerability assessment and synthesis: a report from the Urban Forestry Climate Change Response Framework.** Gen. Tech. Rep. NRS-218. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 172 p. https://doi.org/10.2737/NRS-GTR-218.

As the climate changes over the 21st century, the people, trees, and green spaces of Detroit, Michigan will face physical, biological, health, and indirect impacts. This assessment evaluates the vulnerability of the urban forest in the Detroit region. We synthesized and summarized information on the contemporary landscape, provided information on past climate trends and projected future climates, and illustrated climate impacts on a range of topics. We used models of habitat suitability for trees native to the Detroit area and used projected shifts in plant hardiness zones and heat zones to understand how less common native species, nonnative species, and cultivars are projected to tolerate future conditions. We also assessed the adaptability of planted and naturally occurring trees to stressors that are not included in habitat suitability models such as drought, flooding, wind damage, and air pollution.

The summary of the contemporary landscape identifies major stressors currently threatening urban trees and natural areas in the Detroit region. Major current threats to

the urban forest in the region include urban heat islands, invasive species and diseases, vacant land, soil and water contamination, air pollution, and social and economic inequality. Detroit has been warming at a rate of about 0.4 degrees Fahrenheit per decade since 1960 and the average temperature is projected to increase by 5 to 13 degrees Fahrenheit by the end of the century compared to the mean for 1980 through 2009. Precipitation in Detroit has been increasing by 0.95 inch per decade since 1960 and spring precipitation is projected to increase, while other precipitation projections vary by season and climate scenario. Extreme heat and heavy precipitation events are expected to increase in intensity and become more frequent. By the end of the century, Detroit is projected to shift from hardiness zone 6 to 7 or 8, and from heat zone 5 to a zone between 7 and 9, depending on the climate change scenario.

Species distribution modeling of native trees projects that suitable habitat will decrease for about a third of the tree species, increase for 13 percent of species, and remain stable for 13 percent of species, while 26 percent of native species evaluated for habitat suitability may be able to gain suitable habitat. In terms of adaptive capacity for planted or developed conditions, 27 percent of native species evaluated received a high adaptability score, 57 percent received a medium adaptability score, and 16 percent received a low adaptability score. For natural areas (both native and naturalized), 45 percent of species received a high adaptability score, 46 percent received a medium adaptability score, and 9 percent received a low adaptability score. Under the low climate change scenario, most Detroit tree species (51 percent) fell into the low-moderate vulnerability category. However, more species received higher vulnerability ratings under the high climate change scenario; 14 percent were categorized as low vulnerability, 21 percent as low-moderate vulnerability, 20 percent as moderate vulnerability, 35 percent as moderate-high vulnerability, and 10 percent as high vulnerability. These projected changes in climate and their associated impacts and vulnerabilities will have important implications for urban forest management, including the planting and maintenance of street and park trees, equity and environmental justice efforts, and long-term planning from partnerships to green infrastructure.

FOREST HEALTH RESEARCH SUMMARIES (ROOTED IN RESEARCH)

Fisher, Cherie LeBlanc; Nowak, David; Greenfield, Eric; Ellis, Alexis. 2024. **Threats to urban forests in the United States.** Rooted in Research Issue 45, December 2024. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 2 p.

Urban forests—trees within an urban area—provide substantial environmental and economic benefits, such as air purification, temperature regulation and energy savings, water absorption, and improved public health. However, these forests face multiple and overlapping threats that could reduce their capacity to deliver these benefits. Understanding threats to urban forests is critical for planning and implementing strategies that sustain urban forest health.

USDA Forest Service, Northern Research Station. 2024. **Deer exclusion fences help hybrid chestnut seedlings thrive.** Rooted in Research Issue 37, August 2024. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 2 p.

American chestnuts (*Castanea dentata*) were once abundant in the eastern United States, until the non-native diseases chestnut blight fungus and ink disease devastated their numbers in the 19th and 20th centuries. By the 1950s, American chestnuts were functionally extinct, meaning that the species no longer plays a viable role in the ecosystem. Today, 10 percent of the original population remains, and most trees are small sprouts that often die young.

USDA Forest Service, Northern Research Station. 2024. **Loggers and foresters: vital voices for forest health research.** Rooted in Research Issue 29, April 2024. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 2 p.

Recognizing the involvement of various stakeholders in managing pests, diseases, and forest disturbances is critical for managing forest health. Although there has been substantial focus on the biological and ecological aspects of forest health in the peer-reviewed literature, there is a significant gap in understanding the human dimensions of forest health, especially from the perspective of foresters and loggers. These two groups—foresters, who write silvicultural prescriptions, and loggers, who implement them—are vital but understudied participants.

USDA Forest Service, Northern Research Station. 2024. **A new decision support tool for preventing the spread of aquatic invasive species.** Rooted in Research Issue 26, March 2024. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 2 p.

Every time a watercraft moves from one lake to another, it could potentially carry an aquatic invasive species (AIS) attached to the exterior, in bilge water, or in bait buckets. Aquatic invasive species can cause ecological and economic damage by degrading water quality, which in turn can harm fisheries, native species, and human health. Invasive species may also interfere with human use of lakes and lead to lower property values. Eradicating aquatic invasive species from an infested waterbody is nearly impossible, so water managers typically focus on prevention through inspection.

USDA Forest Service, Northern Research Station. 2024**. Tracking emerging infectious diseases that threaten forests.** Rooted in Research Issue 39, September 2024. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 2 p.

Around the world, emerging infectious diseases are affecting tree populations and changing forest communities. More widespread and severe in recent decades, these diseases harm native plant populations and the health of commercially available plants used in landscaping, agriculture, and forestry. One of the more extreme examples is chestnut blight, which killed most of the American chestnut trees in North America between 1900 and 1950.

Northern Research Station
https://research.fs.usda.gov/nrs