Northeastern States Research Cooperative (NSRC) FY2021
USDA FS Award #: 21-DG-11242307-040

Interim Progress Report
Period ending December 31, 2025

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Administration and Information Transfer

The Northeastern States Research Cooperative (NSRC; https://nsrcforest.org/) is a research-granting program administered collaboratively by the USDA Forest Service Northern Research Station, the Rubenstein School of Environment and Natural Resources at the University of Vermont, the Department of Natural Resources and the Environment at the University of New Hampshire, the Center for Research on Sustainable Forests at the University of Maine, the State University of New York College of Environmental Science and Forestry, and the Hubbard Brook Research Foundation. NSRC's goal is to foster research that is relevant and beneficial to the people who live within the Northern Forest boundaries, work with its resources, use its products, visit it, and care about it.

The specific objectives of the NSRC are to:

1. Develop a multi-stakeholder platform for the Northern Forest to inform research priorities and recruit a strategic roster of funded research projects.
2. Support high priority scientific research through efficient research administration, data archiving and sharing, and annual financial and technical monitoring and reporting.
3. Share and foster dialogue regarding research findings and synthesis to stakeholders through multiple communication channels.

Between January 1 and December 31, 2025, NSRC:

- Rebranded and launched a new website: www.nsrcforest.org.
- Conducted outreach and communications activities to increase the visibility of NSRC with people who live within the Northern Forest boundaries, work with its resources, use its products, visit it, and care about it.
- Monitored and tracked all research and Indigenous Forest Knowledge Fund (IFKF) projects.
- Organized a special session at the 2025 Forest Ecosystem Monitoring Cooperative conference in Burlington, Vermont, highlighting research from NSRC projects to over 50 attendees.
- Presented and/or exhibited at the New York SAF, New England SAF, and the Northern Hardwood conference.

Summary of Progress

Objectives and tasks described in the NSRC 2021 proposal narrative are on schedule and described below.

Objective 1: Develop a multi-stakeholder platform for the Northern Forest to inform research priorities and recruit a strategic roster of funded research projects.

- External Advisory Committee (EAC) formed—Complete.
- EAC meets and recommends priorities for research—Complete.
- Successful Request for Proposals (RFP) process—Complete.
    - Research project awarded—Complete. In 2022, 11 grants were awarded totaling nearly $1.6 million of federal funding and close to $900K in matching funds. View all the projects on the NSRC website and in table 1 below.
    - IFKF projects awarded—Complete. In 2022, 3 grants were awarded totaling nearly $300K in funding. View all IFKF projects on the NSRC website and in table 1 below.

<u>Objective 2:</u> Support high priority scientific research through efficient research administration, data sharing, and annual financial and technical monitoring and reporting.

- Annual technical and financial reporting—Ongoing.
- Research outputs, to include scholarly and public-facing publications and activities—Ongoing. This award supported the development of 10 scholarly articles, 25 presentations, and 5 other communications materials during this reporting period (see "Products" below). Additionally, these research projects supported at least 9 graduate students, 14 undergraduates, and two undergraduate classes.
- Project data archived with the Forest Ecosystem Monitoring Cooperative (FEMC)—Ongoing. An NSRC collection with available data is accessible on the FEMC website.

<u>Objective 3:</u> Share and foster dialog regarding research findings and synthesis to stakeholders through multiple communication channels.

- Communications outputs—During the reporting period, this award supported a special session at the FEMC conference, print publications, press releases, and project specific communications materials.
- NSRC website with current list of projects, research outputs—Ongoing. During this reporting period, the website underwent a complete redesign and refresh.
- Engagement with partners and the public—Ongoing. Key partners include the USFS, the universities in the Northern Forest, and members of the EAC.

Table 1: Regional Research and Indigenous Forest Knowledge Fund projects funded through NSRC 2021 (*21-DG-11242307-040)*

PI / Institution	Lead Institution	Project Title	Project Status
General Fund NSRC 2021 Research Projects			
Bogan, Daniel	Siena College	Wildlife In The WUI: Investigating Forest Characteristics and Impacts on Mammalian Diversity in the Wildland-Urban Interface	Ongoing
Clark, Melissa	The Nature Conservancy	**Quantifying Changes in Forest Condition, Connectivity and Resilience in the Northeast Using Geospatial and Remotely Sensed Data	Complete
Coleman, Kimberly	SUNY Plattsburgh	**Trail Forks And Merges: Exploring Social Impacts from Recreational Mountain Biking in Northern Forest Communities	Complete
D'Amato, Anthony	University of Vermont	**Implementing Forest Adaptation Options for Northern Forest Ecosystems	Complete
Garnas, Jeff	University of New Hampshire	*Invasive Pest Effects on Tree Demographics Across the Northeastern US	Complete
Hicks Pries, Caitlin	Dartmouth College	Investigating The Role of Mycorrhizal Fungi in New England Forest Management	Ongoing
McCay, Tim	Colgate University	*Jumping Worm Invasion and Impact in the Northern Forest	Complete

Murphy, Christina	University of Maine	**Effects Of Timber Harvesting on The Wetland Ecology of Northeastern Lowland Forests	Complete
Rahimzadeh, Parinaz	University of Maine	*Eastern White Pine Health Monitoring Through Remote Sensing Assessment of Foliar Traits	Complete
Vadaboncoeur, Matthew	University of New Hampshire	Oak at the Edge: Investigating the Importance of Fire as a Tool in Oak Range Expansion	Ongoing
Wason, Jay	University of Maine	*Impacts Of Extreme Climate Events on Tree Regeneration in the Northern Forest	Complete
NSRC 2021 Indigenous Forest Knowledge Fund (IFKF) Projects			
Asbjornsen, Heidi	University of New Hampshire	Supporting Abenaki Stewardship of the Atlantic White Cedar Swamp Ecosystem	Ongoing
Daigle, John	University of Maine	*Building Stewardship Capacity: Protecting the Brown Ash of the Northern Forest	Complete
Simpson, Benjamin	Penobscot Nation	*Monitoring Moose and Other Culturally Important Wildlife on Penobscot Indian Nation Lands Using Remote Cameras	Complete

**Indicates the project finished during this reporting cycle. The final report for each research project is available in Appendix B.*

***Indicates the project concluded during a previous reporting cycle. The final report for each research project will be attached to the final award report.*

Collaboration with USDA Forest Service

Deahn DonnerWright serves as the Forest Service liaison with NSRC. She contributes expertise to all aspects of NSRC activities, including the development and implementation of research projects and IFKF research competitions, participation in the EAC as an observer, and coordination and management activities.

Next Reporting Period

Projects from this funding cycle will end on 6/30/2026. Four research projects are continuing into the Spring of 2026. During the next reporting period, NSRC will work on activities related to objectives 2 and 3 and ensure the successful completion of each research project. This annual report is composed of summaries of progress for the administration project, ongoing research projects, and IFKF projects.

Products

Scholarly Articles

1. Bascom, C., C. Fearer, A. Liebhold, R. Morin, S. Fei, and J. R. Garnas. Nearing submission (in revision). Trajectories of host tree demographics in the face of invasive forest threats.

2. Bascom, C., C. Fearer, A. Liebhold, R. Morin, S. Fei, and J. R. Garnas. (In preparation). Long-term impacts of nonnative pests and disease on forest biomass storage capacity mediated through shift in host tree demographic rates.
3. Das, P., Rahimzadeh-Bajgiran, P., Livingston, W., McIntire, C. D., & Bergdahl, A. (2024). Modeling forest canopy structure and developing a stand health index using satellite remote sensing. *Ecological Informatics*, 84, 102864. https://doi.org/10.1016/j.ecoinf.2024.102864
4. Legge, E.O., Fitch, A., Goldsmith, S., D'Amato, A., Evans, K., & Hicks Pries, C. (2025). Negative effects of belowground competition outweigh potential benefits of arbuscular mycorrhizal facilitation for seedling success in a managed temperate hardwood forest. *Canadian Journal of Forest Research*. 55,1-14. https://doi.org/10.1139/cjfr-2024-0259
5. Mrenna, Brigid, "Testing How Plant Traits Predict Survival of Northeastern U.S. Tree Seedlings Under Compounded Heat and Drought Stress" (2025). Undergraduate Honors Thesis.
6. Pinover, L., Butnor, J.R., Fisichelli, N., Murakamib, P., Rogers, N., Zhang, Y.J., and Wason, J. Earlier leaf out and loss of cold tolerance for northeastern U.S. trees in response to winter warming events and early springs. In advanced stages of preparation for submission in early 2026.
7. Pinover, L., Mrenna, B., Fisichelli, N., Rogers, N., Zhang, Y.J., and Wason, J. Higher risk of mortality for tree regeneration at warm range margins during compounded heat and drought. In advanced stages of preparation for submission in early 2026.
8. Pinover, Laura, "Impacts of Extreme Climate Events on Tree Regeneration in the Northern Forest" (2025). M.S. Thesis. *Electronic Theses and Dissertations*. 4233. https://digitalcommons.library.umaine.edu/etd/4233
9. Timalsina, S., Rahimzadeh-Bajgiran, P., Das, P., Meireles, J. E., & Bhattarai, R. (2024). Monitoring eastern white pine health by using field-measured foliar traits and hyperspectral data. *Sensors*, *24*(18), 6129. https://doi.org/10.3390/s24186129
10. Timalsina, Sudan, "Monitoring Eastern White Pine Health by Using Remote Sensing Assessement of Foliar Traits" (2024). Electronic Theses and Dissertations. 3982. https://digitalcommons.library.umaine.edu/etd/3982
11. Ton, K. (2025). Effects of silvicultural burns on *Quercus rubra* regeneration near its northern range limit (MSc Thesis). University of New Hampshire, Durham, NH. https://scholars.unh.edu/thesis/2005
12. Ton, K., Vadeboncoeur, M. A., Cleavitt, N., Powell, A., & Asbjornsen, H. (2026). *Effects of prescribed fire on Quercus rubra regeneration near its northern range limit.* Forest Ecology and Management, 606, 123565. https://doi.org/10.1016/j.foreco.2026.123565

Conferences and Presentations

1. Bascom, C., Liebhold, A., Morin, R., Fei, S., Fearer, C., & Garnas, J. R. (2025, January). *Changes in host demographic structure in the face of invasive forest pests* [Conference presentation]. 33rd United States Department of Agriculture Interagency Research Forum on Invasive Species, Annapolis, MD, United States.
2. Daigle, J. (2025). Oral presentation at Native Seed Conference.
3. Daigle, J. (2025). Pathways to Sustain Ash: Webinar and Field Tour Series (Forest Steward's Guild).
4. Daigle, J. (2025). *Pathways to Sustain Ash Series: The How-To of Ash Seed Preservation from Collection to Propagation.* Forest Stewards Guild.

5. Daigle, J. (2025). *Social Science in Ash Protection Work.* Colby College Seminar.
6. Daigle, J. (2025). APCAW Update Poster Session. Maine Land Conservation Conference.
7. Daigle, J. (2025). *Wabanaki Efforts to Preserve Brown Ash.* Yale Seminar.
8. Das, P., Rahimzadeh-Bajgiran, P., Livingston, W., McIntire, C. D., & Bergdahl, A. EWPHI: A Novel Eastern White Pine (EWP: *Pinus strobus*) Health Index Based on Remote Sensing Data, NESAF Conference; March 27-29, 2024; South Burlington, VT, USA.
9. Das, P. and Rahimzadeh-Bajgiran P., Remotely Sensed Estimation of Live Crown Ratio (LCR) for Eastern White Pine (EWP) Health Assessment", ASPRS 2024 Geo Week, February 11-13, 2024, Denver, CO, USA.
10. Edwards, M. J. Görres, T. S. McCay. (2025). Impacts of Invasive Earthworms on Soil
11. Invertebrate Communities. Northeastern Natural History Conference, April.
12. Franzoni, C., Marshall, A., Wilkins, L., Ciampitti, R., Jarrett, G., & Moore, G. (2025). *Are microplastics ubiquitous in freshwater wetlands? Examination of peat deposits in a remote Atlantic white cedar bog in Bradford, NH* [Poster presentation]. Undergraduate Research Conference, 26 April 2025, University of New Hampshire, Durham, NH.
13. Garnas, J. (2025). *Changes in host demographic structure in the face of invasive forest threats*. Seminar presentation, April 2025. Virginia Tech's Department of Forest Resources and Environmental Conservation faculty, staff, graduate students.
14. Hicks Pries, C. (2025). *How the mycorrhizal symbiosis shapes forests* [Invited presentation]. Vermont Woodlands Conference, Randolph, VT.
15. Mabrysmith, T., Morris, T., Tang, J., Saionz, W., Dobson, A., Dávalos, A., McCay, T. (2025). Greenhouse study of lumbricid and megascolecid invasive earthworm impact on seedling growth [Poster presentation]. NENHC, April.
16. Monroe, M., Liu, M., Fitch, A., & Hicks Pries, C. (2025). *Investigating the role of mycorrhizal fungi in carbon management after a timber harvest* [Poster presentation]. American Geophysical Union Meeting, New Orleans, LA.
17. Mrenna B, Pinover L, Fisichelli N, Rogers N, Zhang Y, and Wason J. *How do plant traits relate to the survival of tree seedlings under compounded heat and drought stress?* [Poster presentation], University of Maine Annual Student Symposium. Orono, Maine (April).
18. Simpson, B. (2025, June 23–27). *Finding our niche: An overview of moose management on Penobscot Nation tribal lands* [Conference presentation]. 9th International Moose Symposium, Östersund, Sweden. https://moosesymposium2025.se/programme/
19. Timalsina, S. and Rahimzadeh-Bajgiran P., Assessing White Pine Needle Damage (WPND) Impact on Eastern White Pine (EWP) Health through Modeling Foliar Traits using Remote Sensing Data, ASPRS 2024 Geo Week, February 11-13, 2024, Denver, CO, USA.
20. Ton K. (2025). North Atlantic Fire Science Exchange Student Webinar (YouTube).
21. Ton, K., Vadeboncoeur, M. A., Cleavitt, N., Powell, A., & Asbjornsen, H. (2025). *Effects of prescribed burning on Quercus rubra regeneration near its northern range limit in New Hampshire* [Poster presentation]. Society of American Foresters Annual Meeting, Hartford, CT, October 2025.
22. Vadeboncoeur, M. (2025). North Atlantic Fire Science Exchange Fall Mini-Symposium Presentation (YouTube).
23. Wason J, Grega M, and Pinover L. *How extreme weather events impact trees in Maine.* [Invited seminar], Dirigo Pines. Orono, Maine. (April).

24. Wason J, Grega M, and Pinover L. *How do heatwaves and drought events impact Maine's trees*. [Invited seminar], Maine Center for Research in STEM Education. Orono, Maine. (March).
25. Wason J, Grega M, and Pinover L. *How do heatwaves and drought events impact Maine's trees* [Invited seminar], Forest Society of Maine. Bangor, Maine. (February).

Other Products

1. Asbjornsen, Heidi. Research Outreach Page.
2. News Article – Portland Press Herald: Native seeds preserved, protected to counter surging invasives
3. Ton, K., Vadeboncoeur, M. A., Cleavitt, N., & Asbjornsen, H. (2025). *Northern red oak regeneration in burned and unburned stands in the White Mountain National Forest, New Hampshire, USA, 2023–2024 ver 1*. Environmental Data Initiative. https://doi.org/10.6073/pasta/f488d29e300ce386fd6c99920e2d5f3b
4. (Rahimzadeh) IEEE Maine January 2025 Newsletter
5. (Rahimzadeh) Interview done in September 2025 by Hubbard Brook Research Foundation

Ongoing Research Projects

Wildlife in the WUI: Investigating Forest Characteristics and Impacts on Mammalian Diversity in the Wildland-Urban Interface

Principal Investigator: Daniel Bogan (Siena University; dbogan@siena.edu)

Summary of Progress in 2025

A rebudgeting and no-cost extension were negotiated in 2025. The interdisciplinary research team made progress developing additional geospatial analyses to evaluate land use change using historical maps (USGS Topographic Maps) and modern LiDAR, expanding the ability to evaluate land use change beyond the 1990-2020 Wildlife-Urban Interface (WUI) period. Nearly all forests in New York, particularly in the WUI, are second-growth forests subject to ongoing successional dynamics. Forests and wildlife populations may be influenced by patterns of early forest conversion and trends in expanding housing development. Research assistants evaluated the U.S. Census Bureau's changes to the quantitative definition of urban areas at the census block and tract level, which may influence land use designations and the WUI framework. Research forests and biological field stations were examined across New York and the Northeast USA for potential wildland study sites. Given the rapid expansion of Artificial Intelligence (AI), the project team investigated AI applications to expedite analyzing camera-trap data and wildlife species identification. AddaxAI (https://addaxdatascience.com/addaxai/) was identified as a frontrunner based on cost, consistent results, and ease of use. Although AI applications expedite photo analyses, human review, particularly for low-confidence identifications remains necessary for quality control.

Figure 1. Camera-trap surveys not only record species presence, but also capture important seasonal behaviors such as this male Eastern wild turkey (Meleagris gallopavo) strutting during spring breeding season.

Figure 2. Camera-trap surveys not only record species presence, but also capture important seasonal behaviors such as this male Eastern wild turkey (Meleagris gallopavo) strutting during spring breeading season

Problems or Changes

Field seasons faced two challenges: lack of field technicians and public land access. The team continues to work toward obtaining private land access and student recruitment is on the rise as a new cohort looks to gain field and computer-based research experience. Strategies are being implemented to contact landowners in time for the upcoming field 2026 season.

Plans for 2026

Winter 2026

- Hire research assistants for the 2026 field season.
- Implement Public Outreach Campaign.
- Hire multiple Siena undergraduates to assist the study.
- Continue to seek additional funding to support continued and expanding ongoing research through internal (e.g., Center for Undergraduate Research and Creative Activity; *link*) and external sources (e.g., Catskill Science Collaborative *link*).

March–June 2026

- Conduct field studies following the stratified sampling protocol selecting locations in all three WUI change classes: old-WUI (pre-1990), new-WUI (1990-2020) and non-WUI (forested) lands. This involves the original plans to conduct camera-trap wildlife (mammal) surveys, estimate small mammal abundance and diversity, measure site characteristics at each study location for quantitative analyses and comparison with USFS FIA data.

July 2026

- Analyze data, prepare summary reports, and final report to NSRC.

With Additional Funding and Support:

- Draft manuscripts for publication
- Continue public outreach to disseminate study findings
- Present results at regional conferences (Northeast Natural History Conference, or Northeast Association of Fish & Wildlife Agencies) and international conferences (Annual Meetings of The Wildlife Society and Ecological Society of America)

Collaboration or Alignment with USFS, Partners, or the Public

The Wildlife in the Wildland-Urban Interface research project continues to be a direct collaboration with USFS Northern Research Station staff. The team includes co-PIs Rachel Riemann, M. Phil., Dr. Nancy Sonti, Dr. Miranda Mockrin, and Dr. Jonathan Knott. This interdisciplinary study is an expansion of research initiated by the USFS collaborators (Sonti et al. 2023) and incorporates wildlife surveys and ongoing research examining the response of wildlife across the urban-wildland landscape gradient. The project benefits from the shared interest of investigating habitat fragmentation and urbanization of the northern forest ecosystems by leveraging expertise in geospatial data and modeling of forest change, mapping and analyzing growth of the Wildland-Urban Interface, sampling wildlife populations through non-invasive and direct capture methods, human-wildlife interactions, and science dissemination and community engagement.

Investigating the Role of Mycorrhizal Fungi in New England Forest Management

Principal Investigator: Caitlin Hicks Pries (Dartmouth College, caitlin.hicks.pries@dartmouth.edu)

Summary of Progress in 2025

A research paper titled "Negative effects of belowground competition outweigh potential benefits of arbuscular mycorrhizal facilitation for seedling success in a managed temperate hardwood forest" in the *Canadian Journal of Forest Research*, and manuscript development was led by former undergraduate thesis student Eva Legge. A second publication is undergoing revisions to be included in *Ecological Applications* and is being led by a former PhD student, Amelia Fitch. Soil samples collected in 2024 were analyzed to compare to pre-harvesting treatment soils collected in 2020. Soil samples are used to quantify how harvesting affected soil carbon and nitrogen pools in particulate and mineral-associated fractions within AM and EcM-dominated forest stands. Samples were fractionated and analyzed on an elemental analyzer for carbon and nitrogen. Leaf samples were analyzed from study plots for ^{15}N on an isotope ratio mass spectrometer for an offshoot project investigating how plant sources of nitrogen are affected by location within harvest plots and the legacy of AM or EcM-dominated forest stands (Figure 3).

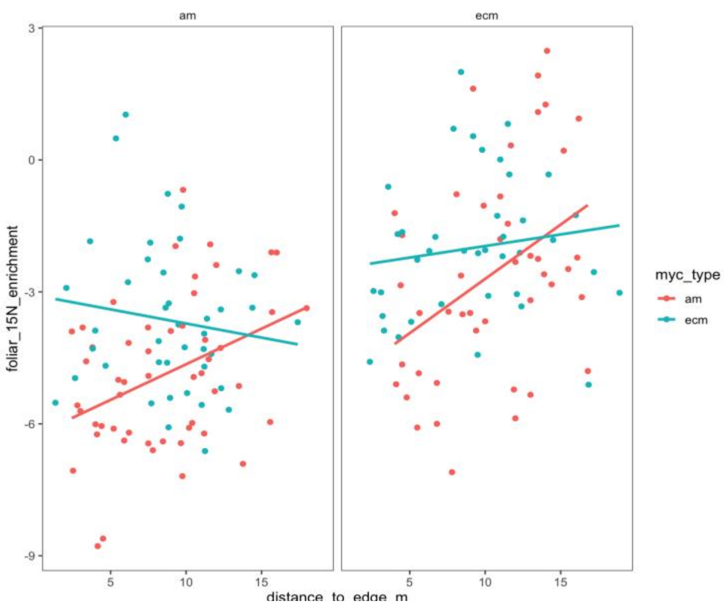

Figure 3. After two years of growth (202 -2023), AM seedling foliar 15N isotope enrichment (leaf - soil 15N) increased with distance from harvested gap edges. These preliminary results suggest that AM seedlings closer to live trees obtain more of their nitrogen.

Plans for 2026

- Finish revisions of the manuscript for Ecological Applications and resubmit.
- Complete CN analysis of soil fractions and analyze the data for a potential paper.
- Analyze the leaf ^{15}N data and prepare a manuscript on how plant sources of nitrogen differ with location in harvested plots and mycorrhizal type.

Collaboration or Alignment with USFS, Partners, or the Public

Research was shared on two occasions at conferences. A presentation titled "How the mycorrhizal symbiosis shapes forests" was given at the Vermont Woodlands Conference, and a poster titled "Investigating the role of mycorrhizal fungi in carbon management after a timber harvest" was presented by Matthew Monroe (Figure 4), undergraduate student, at the 2025 American Geophysical Society meeting.

Presentations, Posters and Products

- Legge, E.O., Fitch, A., Goldsmith, S., D'Amato, A., Evans, K., & Hicks Pries, C. (2025). Negative effects of belowground competition outweigh potential benefits of arbuscular mycorrhizal facilitation for seedling success in a managed temperate hardwood forest. *Canadian Journal of Forest Research*. 55,1-14. https://doi.org/10.1139/cjfr-2024-0259
- Monroe, M., Liu, M., Fitch, A., & Hicks Pries, C. (2025). Investigating the role of mycorrhizal fungi in carbon management after a timber harvest [Poster presentation]. American Geophysical Union Meeting, New Orleans, LA.
- Hicks Pries, C. (2025). How the mycorrhizal symbiosis shapes forests [Invited presentation]. Vermont Woodlands Conference, Randolph, VT.

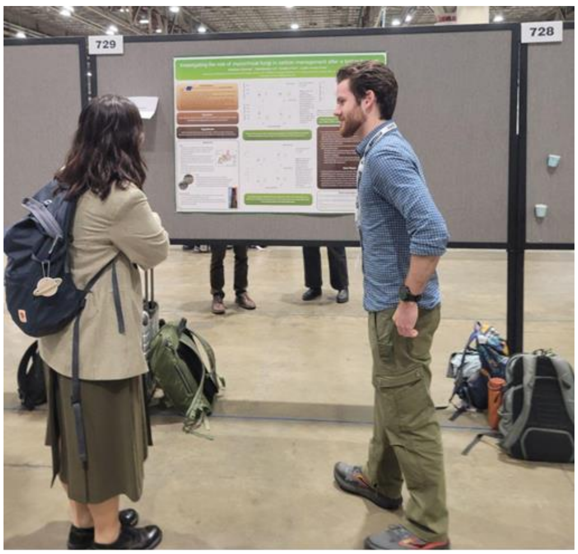

Figure 4. Dartmouth undergraduate, Matthew Monroe, presents his research on how mycorrhizal type affects the soil carbon response to timber management at the 2025 AGU Fall Meeting in New Orleans

Figure 5. The particulate soil fraction (>53 microns) being rinsed off a sieve, separating the soil into particulate and mineral-associated fractions to understand how these different soil carbon pools are affected by timber harvesting in arbuscular and

Oak at the Edge: Investigating the Importance of Fire as a Tool in Oak Range Expansion

Principal Investigator: Matthew Vadeboncoeur (University of New Hampshire, matthew.vadeboncoeur@unh.edu)

Co-Principal Investigators: Natalie Cleavitt, Cornell University; Khanh Ton, University of New Hampshire (MSc Student), Heidi Asbjornsen, University of New Hampshire; Andy Fast, UNH Cooperative Extension

Summary of Progress in 2025

Data Collection & Analysis

- Completion of mycorrhizal colonization analyses of field-collected root samples from oak seedlings.
- Collection of increment cores from two NH forest stands dominated by mature red oak as case studies of the relationship between historic fires and oak regeneration.
- Analysis of foliar C:N ratios as well as stable isotope ratios of carbon and nitrogen as possible indicators of N availability, photosynthetic capacity, intrinsic water-use efficiency, and rooting depth.
- Decommissioning of study sites—removal of stakes and tags in compliance with research permits.
- Statistical analyses and interpretation of all data.

Communications and Outreach

- North Atlantic Fire Science Exchange Student Webinar and presentation at the fall Mini-Symposium.
- Presentation at UNH Graduate Research Symposium and National SAF meeting.
- Completion of a MS thesis.
- Article accepted for *Forest Ecology and Management.*
- Submission of data collected for this project to a public data archive.

Problems or Changes

Extensive review comments on a manuscript submitted to *Forest Ecology and Management* required a large time effort but resulted in improvements to the statistical analysis and communication of results in a relevant silvicultural context. Tree core collection has proceeded at two of the three case study sites earlier identified as meeting study criteria, both on privately owned conservation land in New Hampshire. Undergraduate student Zach Hooper is analyzing tree cores as a senior project.

Plans for 2026

Data collection and analysis

- Analysis of red oak age structure, growth history, and fire history at two case study stands

- Finish decommissioning of study sites

Communications and outreach

- Archive a post print of the accepted article at scholars.unh.edu with an embargo date set to comply with the publisher's copyright agreement.
- Presentation of analysis of stands with historic fires at the UNH Undergraduate Research Conference
- Explore additional venues for communication to foresters and landowners

Collaboration or Alignment with USFS, Partners, or the Public

This project was motivated by conversations with John Neely, retired USFS, about prescribed fires that had been implemented on the White Mountain National Forest (WMNF) and USFS scientists and managers have been engaged throughout the project to align research direction with the needs of the stakeholders. Including: John Neely (retired), Mariko Yamasaki (retired), Nicholas Jeros, James Innes, and Erin Lane. Erin is a former fire ecologist of the WMNF, making her an invaluable resource for fitting our findings in with the past fire management activities and management needs of this landscape. Currently, Erin works at both the USDA Climate Hub and the North Atlantic Fire Science Exchange (NAFSE), two important communities for outreach and engagement. Nicholas Jeros and James Innes are currently involved in forest management and implementing prescribed fire on the WMNF. Neely and Yamasaki are now retired but were involved in planning and implementing the prescribed burns being studied, and in motivating the current study. In 2025, feedback from Lane, Neely, and Yamasaki led to substantial improvements in our manuscript that is now published in *Forest Ecology and Management.*

Figure 6. Zach Hooper (UNH undergraduate) collects an increment core at the base of a red oak to determine its age and growth history at a site in Marlow, NH which burned in 1941. Photo by Matt Vadeboncoeur, October 2025.

Presentations, Posters and Products

- North Atlantic Fire Science Exchange Student Webinar (YouTube).
- North Atlantic Fire Science Exchange Fall Mini-Symposium Presentation (YouTube).
- UNH Graduate Research Symposium
- Ton, K. (2025). Effects of silvicultural burns on *Quercus rubra* regeneration near its northern range limit (MSc Thesis). Department of Natural Resources, University of New Hampshire, Durham, NH. https://scholars.unh.edu/thesis/2005
- Ton K, Vadeboncoeur MA, Cleavitt N, Powell A, Asbjornsen H. (2026). Effects of prescribed fire on Quercus rubra regeneration near its northern range limit. *Forest Ecology and Management.* 606: 123565. https://doi.org/10.1016/j.foreco.2026.123565

- Ton, K., M.A. Vadeboncoeur, N. Cleavitt, and H. Asbjornsen. (2025). Northern red oak regeneration in burned and unburned stands in the White Mountain National Forest, New Hampshire, USA, 2023-2024 ver 1. Environmental Data Initiative. https://doi.org/10.6073/pasta/f488d29e300ce386fd6c99920e2d5f3b
- Ton K, Vadeboncoeur MA, Cleavitt N, Powell A, Asbjornsen H. (2025). Effects of prescribed burning on *Quercus rubra* regeneration near its northern range limit in New Hampshire [Poster presentation]. Society of American Foresters Annual Meeting, Hartford, CT, October 2025.

Figure 7. A shelterwood was initiated on the WMNF in Benton, NH in 2014, and a light-moderate prescribed burn followed in 2018. Limited mortality of canopy oaks resulted, but most survived. Oak seedling regeneration (foreground) was much greater in stands that were burned than those that were not, but the long-term success of this cohort remains to be seen. Photo by Matt Vadeboncoeur, October 2025.

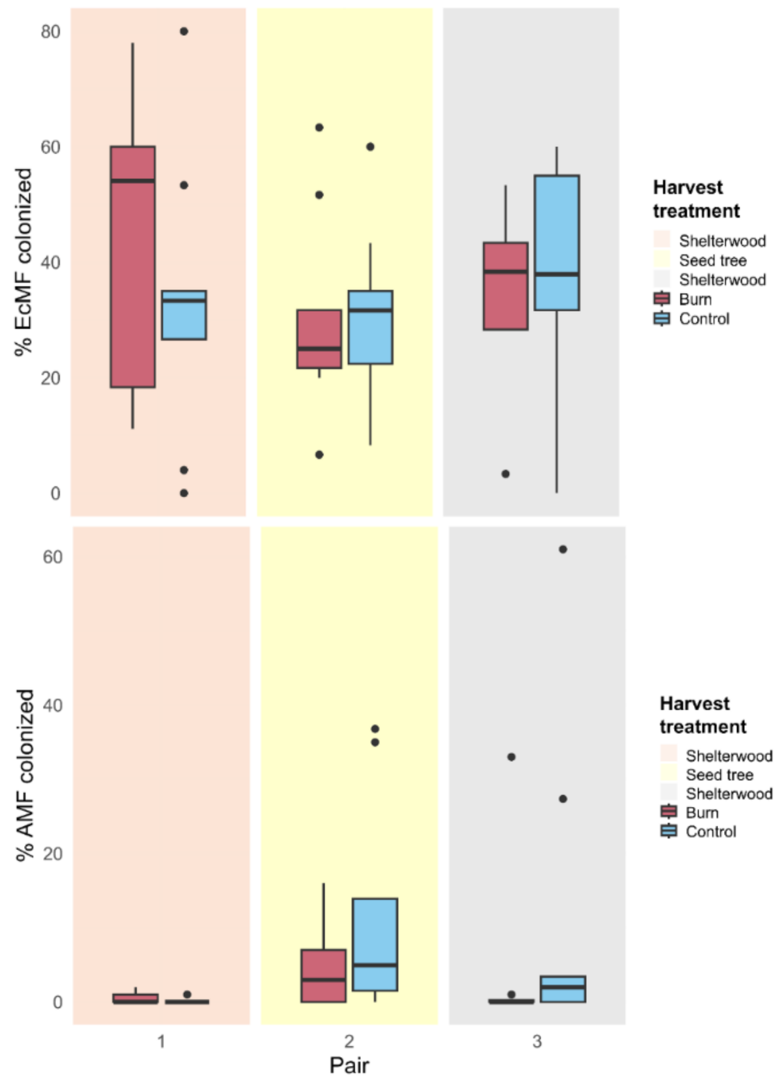

Figure 8. a) Ectomycorrhizal fungal colonization of Q. rubra seedling root tips expressed as percentage of root tips colonized. b) Arbuscular mycorrhizal fungal colonization of Q. rubra seedling roots expressed in percentage of first- and second-order root length colonized. For both panels, error bars = ±1 SE. There were no significant differences in oak seedling colonization rates between burned and unburned stands. Colonization of oak seedlings by both types of mycorrhizal fungi are quite low compared with northern hardwood species in this region, they are comparable to ranges observed in other studies of Q. rubra seedlings.

Supporting Abenaki Stewardship of the Ecologically Rare and Culturally Important Atlantic White Cedar Swamp Ecosystem

Principal Investigator: Heidi Asbjornsen (University of New Hampshire, heidi.asbjornsen@unh.edu)

Summary of Progress in 2025

Piezometers were installed and indicated a significant influence of drought on saturation levels of Bradford Bog in each of the experimental treatment sites (control, open canopy, closed canopy). Results may be correlated to low seeding recruitment in 2025 and may have also influenced soil water chemistry where no significant differences were found for pH or redox potential. A seedling growth analysis was completed, and preliminary results show significant relationships with microclimate variables, whereas seedling density did not. Mean seedling height increased significantly with daytime light availability showing that seedlings grow taller in plots with higher light levels. Height showed a positive relationship with daytime temperature in models including both predictors, although temperature alone was not a significant predictor. Stem diameter increased with both daytime light and daytime temperature, suggesting the growth of American White Cedar (AWC) seedling stems is influenced by both parameters. Seedling density did not vary significantly with either daytime light or temperature, indicating that microclimate variables have little effect on AWC seedling abundance. Analysis of vegetation diversity did not differ significantly among the experimental treatments. However, closed canopy areas tended to have slightly higher vegetation diversity, although the difference was not statistically significant, suggesting that vegetation composition may play a more critical role than diversity alone in influencing the AWC regeneration. Finally, despite the bog's remote location, microplastics contamination was found in each sediment core obtained and across all treatment types. However, there are no data to immediately support that the presence of microplastics influences AWC seedling recruitment or success.

Figure 9. Graduate student, Reece Ciampitti, measuring forest floor metrics in Bradford Bog (left) and a vigorous AWC seedling in a closed canopy plot (right).

Problems or Changes

Two monitoring parameters have been added since the initiation of the project, including 1) assessing bog sediment for microplastic contamination, and 2) obtaining tree cores for assessing variation in growth over time for mature AWC in study plots.

Plans for 2026

Field & Lab Tasks

- Redeploy piezometers, light sensors, and temperature sensors.

- Gather seedling recruitment metrics in all experimental plots.
- Sample pore water chemistry during site visits.
- Analyze microbiome samples of tree cores (including amplification and DNA extractions). Sequencing will follow.
- Measure growth rings of tree cores.

Science Communication & Publishing Tasks

- Plan and host a workshop with project partners to present results and discuss management applications.
- Present results at local and regional scientific conferences, including the upcoming New England Society of American Foresters conference in Portland, ME.
- Finish preparations of microplastic results manuscript and submit for review.

Collaboration or Alignment with USFS, Partners, or the Public

The project has engaged with collaborators across stakeholder groups interested in the conservation, restoration, and management of Bradford Bog, and site walks were conducted with project partners and community members in 2024 and 2025. A working group meeting of project partners and community members was facilitated on April 2, 2025 and had 11 attendees. Presentations were given by project co-investigators and Reece Ciampitti, graduate student. Stakeholders engaged can be seen in the table below.

Table 2. Stakeholders engaged in the research project.

Name	**Affiliation**	**Role**
Michael Andrews	Adjacent landowner and Member of The Society for the Protection of NH Forests	Co-PI, Advisor
William Gould	Canoe Maker and Eastern Forest Cultural Advisory, Department of Cultural and Historic Resources, Nulhegan Band of the Coosuk Abenaki Nation (NB-CAN)	Co-PI, Advisor
Brooks McCandlish	Forester, Bradford, NH	Advisor
Brian Chenevert	Tribal Historian, Director Cultural and Historic Preservation Department; NB-CAN citizen	Advisor
Alexander Cotnoir	NB-CAN citizen	Advisor
Ann Eldridge	Bradford Conservation Commission	Advisor
Sherry Gould	Special Project Coordinator, Cultural and Historic Preservation Department, NB-CAN	Advisor
Ausbon Sargent	Land Preservation Trust	Advisor
Chief Don Stevens	Chief, NB-CAN	Advisor

Presentations, Posters and Products

- Franzoni, C., Marshall, A., Wilkins, L., Ciampitti, R., Jarrett, G., and G. Moore. (2025) Are Microplastics Ubiquitous in Freshwater Wetlands? Examination of Peat Deposits in a Remote Atlantic White Cedar Bog in Bradford, NH [Poster presentation]. Undergraduate Research Conference, 26 April 2025, University of New Hampshire, Durham, NH.
- A summary of the research project can be seen on the website Research Outreach Page.

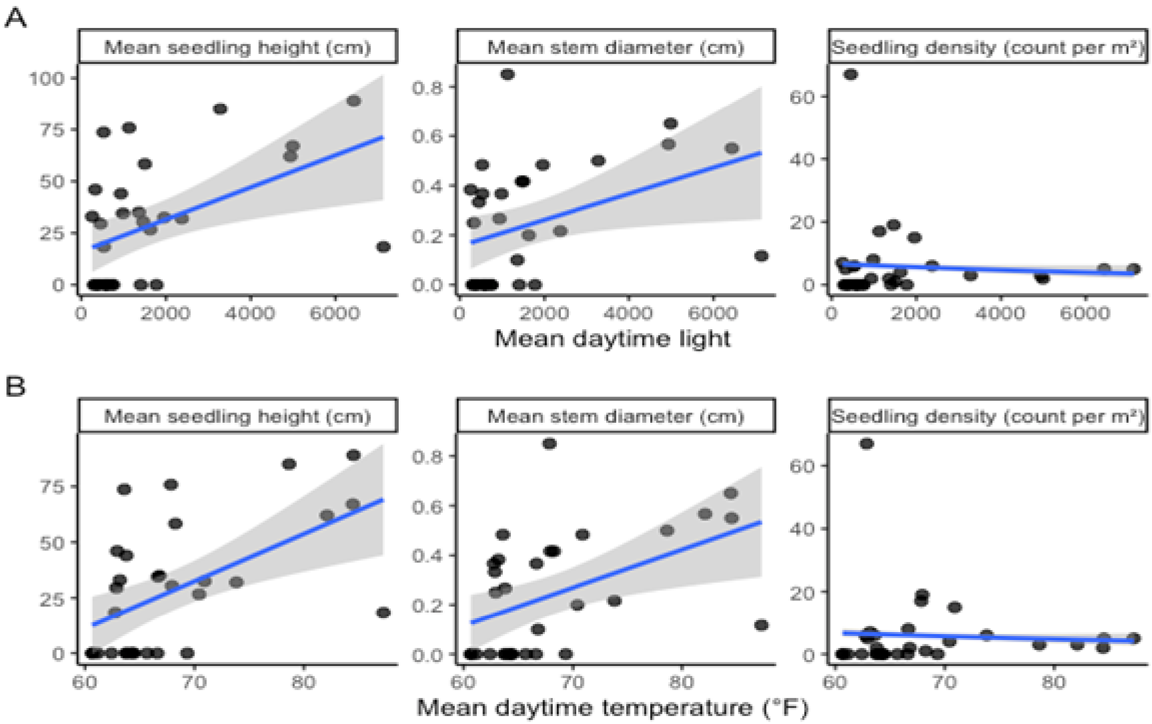

Figure 10. Relationships between daytime light (A) and mean daytime temperature (B) and Atlantic white cedar seedling density, height, and stem diameter across plots. Points show plot-level means; lines represent fitted regression models (Poisson GLMs for density,

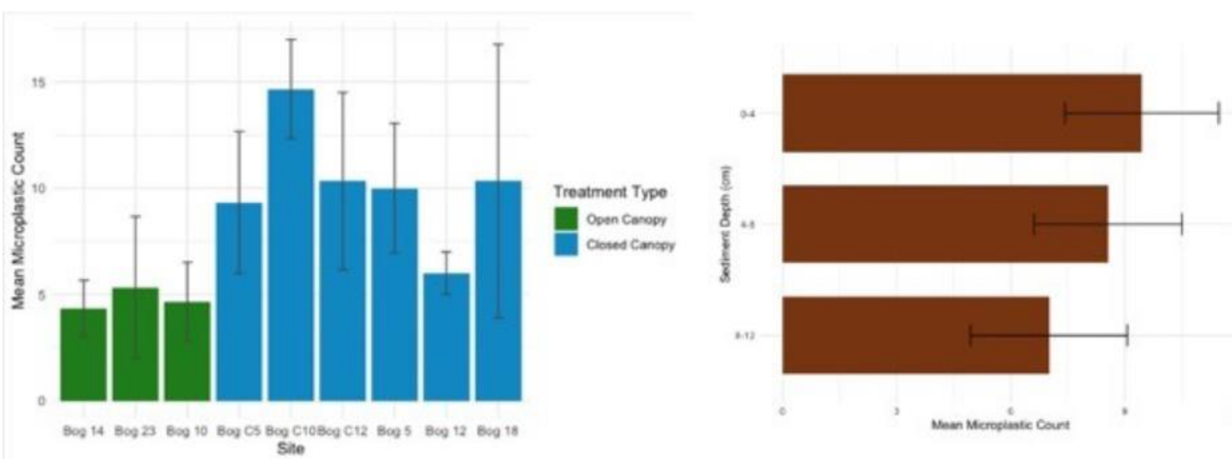

Figure 11. (Left) Average microplastic count by sample site and color corresponding to treatment type with standard error bars. (Right) Mean microplastic count by each of the three sediment depth intervals with standard error bars.

Appendix B: Final Reports

Building Stewardship Capacity: Protecting the Brown Ash of the Northern Forest

Principal Investigator: John Daigle (University of Maine; jdaigle@maine.edu)
Co-Principal Investigators: Tyler Everett (University of Maine; tyler.everett@maine.edu), Emily Francis (University of Maine; emily.t.francis@maine.edu), Anthony D'Amato (University of Vermont; awdamato@uvm.edu), Suzanne Greenlaw (University of Maine; suzanne.greenlaw@maine.edu), Amanda MahaNey (U.S. Fish and Wildlife Service; amanda_mahaNey@fws.gov), Darren Ranco (University of Maine; darren.ranco@maine.edu), Nathan W. Siegert (U.S. Forest Service; nathan.w.siegert@usda.gov)

Project Outcomes

This project established experimental silvicultural sites in brown ash wetland forests across the northern region to serve as a baseline for current and future management in response to Emerald Ash Borer (EAB; *Agrilus planipennis*) in the region. Using social science methods, the project documented foresters' and loggers' perspectives on EAB management and explored Wabanaki Tribal Nations' cultural perceptions and acceptability of various adaptive management strategies for addressing EAB on Tribal lands.

Project Summary

This project was an interdisciplinary initiative that integrated physical sciences, social sciences, and Indigenous knowledges to protect *Fraxinus nigra* (*Wisqoq*, brown ash), a tree of immense cultural, ecological, and economic importance. With the continued spread of the non-native EAB, which has caused near-total mortality in some ash-dominated forests, this project responded to an urgent need for coordinated stewardship—particularly in the northeastern U.S., where some of the last unaffected ash forests remain. Nearly 98% of Maine's forests are privately owned, meaning the decisions of foresters, loggers, and landowners play a critical role in shaping EAB response. For Wabanaki Tribal Nations, whose cultural lifeways and practices—including basketry—are intertwined with brown ash, understanding and influencing forest management across jurisdictions is vital. The project had three main components. First, it established four silvicultural trial sites—two in central Maine and two in northern Maine—based on ash density, accessibility, land-use stability, and proximity to known EAB infestations. Each site contained control and treatment plots using strip and patch harvests informed by Wisconsin DNR research, with pre- and post-treatment vegetation and EAB monitoring via fixed-radius plots, panel traps, and trap trees. Second, a Theory of Planned Behavior–based survey of foresters and loggers, deployed via industry listservs using Dillman methodology, provided insight into behavioral intentions and management trends. Preliminary analysis shows many respondents are both harvesting most ash ahead of EAB and reserving select trees, with the latter being more common. Attitudes were the strongest predictor of behavioral intention, while subjective norms showed weak or negative influence. Third, community meetings with the Mi'kmaq Nation and the Passamaquoddy communities of Sipayik and Indian Township used storytelling videos to explore adaptive management strategies, accompanied by shared meals and discussions. Transcriptions of meetings were analyzed thematically and shared with participants for member checking. Data sovereignty for these Tribal Nations was honored by only sharing data deemed appropriate by participants with a public

audience. Major outcomes include a first-of-its-kind silvicultural baseline for brown ash wetland forests, foundational data on professional practices in ash management, and documented Tribal perspectives on culturally appropriate EAB response strategies. Together, these elements create actionable knowledge for preserving ash across the diverse landownership mosaic of the Northern Forest. This project established partnerships—particularly with Tribal Nation natural resource departments and conservation organizations—that will be essential to future regional collaboration. It also catalyzed broader outreach efforts through the Ash Protection Collaboration Across Wabanakik (APCAW), offering a critical platform for protecting ash during this period of ecological and cultural urgency

Background and Justification

The EAB is a non-native insect from Southeast Asia that first arrived on Turtle Island (North America) in the mid-to late 1990s but was not officially detected until 2002. Since then, it has spread rapidly across the continent, causing near-total mortality in some ash-dominated forests. EAB poses significant ecological, economic, and cultural threats—especially in the Northeast, where some of the last remaining unimpacted ash forests in North America are found. In the past two decades, researchers have made considerable progress in understanding how to manage these forests in response to EAB. However, in present day Maine, where approximately 98% of land is privately owned, forest management is often shaped by the actions and values of private landowners, as well as the foresters and loggers they employ. This context raises critical concerns for Wabanaki Tribal Nations, whose cultural lifeways—including traditional brown ash basketry—are deeply tied to the health and survival of brown ash trees. In response, the APCAW Lab at the University of Maine—guided by the priorities of its Tribal Nation partners—has undertaken this project to better understand the trajectory of ash forest management across private and Tribal lands. The project addresses two urgent gaps: first, a lack of information on how foresters and loggers currently approach EAB on private lands; and second, limited silvicultural knowledge specific to brown ash wetland forests in the Northeast, particularly on Tribal lands. To address these gaps, the project established experimental silvicultural sites to serve as baseline data for managing brown ash forests now and into the future. Additionally, it created a series of educational videos outlining a range of EAB management strategies—including silviculture, biological control, insecticide treatment, seed collection and propagation, enrichment planting, youth engagement, and cultural material preservation. These videos were shared during “Brown Ash and Emerald Ash Borer Community Meetings” with Wabanaki Tribal communities to understand varying levels of cultural support for different adaptive management strategies. The insights gathered will help inform decision-making by Tribal forestry and natural resource departments in their ongoing efforts to steward these culturally vital forests.

Methods

In alignment with the Indigenous methodological principles described by Tachine, Yellow Bird, and Cabrera (2016) in “Sharing Circles: An Indigenous Methodological Approach for Researching With Groups of Indigenous Peoples,” this project utilized an adapted form of sharing circles to engage Wabanaki communities in culturally grounded dialogue on adaptive management strategies for addressing EAB impacts on Tribal lands. Known as the “Brown Ash and Emerald Ash Borer Community Meetings,” two gatherings were held—one with the Mi’kmaq Nation and a joint meeting with the Passamaquoddy Tribe at Pleasant Point (Sipayik) and Indian Township—

at locations chosen by the communities themselves to ensure accessibility and comfort. Each meeting included a shared meal prepared by lead researcher Mr. Everett and featured nine pre-recorded storytelling videos to spark discussion on topics including cultural significance of brown ash, Tribal youth involvement, silviculture, genetic resource preservation, biological and chemical EAB control, data sovereignty, and integrative strategies. Meetings were intentionally limited to approximately 10 participants to maintain a respectful, safe space for open sharing. Audio from each session was recorded and transcribed, with transcriptions returned to participants for member-checking to ensure accuracy and respect for shared knowledge; these transcriptions were then thematically analyzed based on discussion following each video. A report was created for each community summarizing key themes, and where permitted by the communities, findings were incorporated into a final, in-progress public-facing guide intended to help non-Tribal entities (e.g., private landowners, land trusts, and government agencies) integrate Tribal cultural values into their own EAB response strategies. This aspect of study received approval and oversight from the University of Maine Institutional Review Board (IRB) to ensure ethical compliance with human subjects' research standards. The survey of foresters and loggers in Maine was designed using the Theory of Planned Behavior (Ajzen, 1991) to assess attitudes, subjective norms, and perceived behavioral control related to ash management behavior in response to EAB. To maximize reach and response rates, the survey was distributed across multiple forestry and conservation listservs using Dillman's Tailored Design Method (Dillman et al., 2014), which included a structured email sequence: a primer email, an initial outreach message, and three subsequent follow-up solicitations. The instrument was developed and administered using Qualtrics survey software, and the collected data were analyzed using SPSS statistical software. This aspect of study received approval and oversight from the University of Maine Institutional Review Board (IRB) to ensure ethical compliance with human subjects' research standards. Four study site locations were selected for silvicultural trials based on the presence of high brown ash (*Fraxinus nigra*) stem density, site accessibility, potential for long-term land use stability (i.e., minimal risk of land sale or conversion away from forest cover), and proximity to known emerald ash borer (EAB, *Agrilus planipennis*) infestations. Sites were distributed across the state of Maine, with two in central Maine (Readfield and Farmington) and two in northern Maine (Frenchville and Garfield). At each location, a 2-acre rectangular study block was established in an area of high brown ash density. These blocks were subdivided into three 0.66-acre treatment plots: one untreated control plot and two experimental plots implementing either strip harvest or patch harvest silvicultural treatments. The harvest designs—along with strip widths and patch sizes—were adapted from the Wisconsin Department of Natural Resources' bottomland hardwood silvicultural trials (WDNR Resource). In the strip harvest treatment, two parallel strips (either 6- or 9-meters wide) were cut, spaced 20 meters apart. In the patch harvest treatment, three circular gaps (either 6.5- or 9- meter radii) were harvested around high-quality basket-grade brown ash trees, which were later donated to Wabanaki Tribal artisans. Vegetation was inventoried before and after treatment using nested plot sampling. A 350-m^2 fixed-radius plot was used to measure overstory trees, with a 9.29-m^2 subplot nested inside for saplings and recruits. Three 5-m^2 plots were used to sample advanced regeneration, and three 1-m^2 microplots captured seedling data. To monitor EAB presence, three purple panel traps—one per 0.66-acre block—were deployed during each growing season to estimate adult beetle abundance. Additionally, one trap tree per study site (n = 4) was felled and peeled annually (2023 and 2024) to directly quantify larval densities, yielding a total of eight trap trees over the course of the study.

Key Findings/Accomplishments

Preliminary analysis of forester and logger survey data shows that many respondents are engaging in both management behaviors of harvesting all or a majority of ash or reserving select ash (including merchantable ash) ahead of EAB, with reserving ash being more common. Or respondents engaging in either behavior, attitudes ranked highest among the Theory of Planned Behavior constructs for influencing behavioral intention. However, perceived behavioral control also showed a positive correlation with behavioral intention for most respondents, while subjective norms had a weak, neutral, or negative correlation. Further interpretation of these results could help to improve education and outreach on ash best management practices for supporting ash preservation into the future. Community meetings provided insight into the perceptions of Wabanaki Tribal Nation communities and will prove pivotal in crafting EAB response plans that align with perceptions moving forward. It's likely that as EAB infestation continues, there will be a need to further explore these various adaptive management options with the Tribal Nation communities and observe how perceptions change over time. For the silvicultural trials, a robust data set from permanent plots across the four study sites creates a baseline to further explore regeneration outcomes for strip and patch harvest silvicultural prescriptions in ash management in the face of EAB. In this short time, logistical considerations for executing these types of silvicultural prescriptions in brown ash wetland forests are now far better understood and can be shared with the broader forestry community. The four study sites can also serve as platforms for future research implementing adaptive management options beyond silviculture, such as enrichment planting, insecticide treatments, biological controls, and seed collection.

Implications and Applications in the Northern Forest Region

This project represents a foundational step forward in the application of silviculture within brown ash wetland forests—a forest type critical to both ecological integrity and cultural survival in the Northern Forest region. By establishing the first set of experimental silvicultural trials specifically tailored to these ecosystems, the project provides an essential reference point for future management efforts in similar forest types threatened by the EAB. Beyond field experimentation, the research generated valuable social science insights through a regional survey of foresters and loggers, shedding light on how private land management is currently being shaped in response to EAB. The community meetings with Wabanaki Tribal Nations brought cultural and community-based perspectives into clearer focus, ensuring that any future forest management planning can be better aligned with Tribal priorities and values—especially as forests span across Tribal, private, and public ownership. Importantly, this project fostered broad partnerships among Tribal Nation natural resource departments and conservation organizations operating throughout the Northern Forest Region. These collaborations were instrumental in elevating Tribal voices in a policy and practice landscape where they are too often underrepresented. One major outcome of this partnership-building was the formation and growth of the APCAW lab group at the University of Maine, a Tribal-led research collaborative born, in part, from the synergy of this project. APCAW served as a critical hub for education and outreach in 2023 and 2024, offering programming that reached over 900 participants and deepened public engagement with the issue of ash preservation. Together, the silvicultural trials, community engagement, and behavioral survey components of this project build a comprehensive platform for cross-boundary learning and collaborative forest management that will be vital in the coming years as the Northern Forest continues to respond to the growing EAB threat.

Future Directions

Looking ahead, future work building on this project will continue to deepen the understanding of effective and culturally appropriate responses to EAB across the Northern Forest region. The established silvicultural trial sites over a long-term research platform to monitor brown ash regeneration outcomes under different harvesting prescriptions and can now serve as testbeds for additional adaptive management strategies such as enrichment planting, insecticide treatment, biological control, and seed collection. These interventions can be trialed and refined in ways that account for ecological variability, cultural relevance, and logistical feasibility—ultimately producing a more nuanced toolkit for land managers navigating EAB impacts. The baseline data collected in this project will also enable longitudinal analysis as EAB continues to spread across the region, helping researchers and forest managers evaluate which interventions offer the best chances for sustaining brown ash in a changing landscape. Equally important is the continuation and expansion of Tribal community engagement and inter-agency collaboration. Future directions include returning to Wabanaki Nation communities to revisit adaptive management strategies through a series of follow-up community meetings, allowing participants to reflect on and revise perspectives as on-the-ground EAB conditions evolve. There is also a need to explore the critical but often overlooked relationship between private forest landowners and the foresters and loggers they hire to manage their land. While the current survey provides insight into professional practices and perceptions, it is unclear to what extent landowners are aware of or open to a wider range of adaptive management options such as enrichment planting, biological control, or seed conservation. These conversations may not be occurring unless foresters and loggers are initiating them, suggesting a significant opportunity to bridge knowledge gaps and align landowner intentions with forest health best practices in the face of EAB. Continued education and outreach through the APCAW will help ensure that knowledge generated from both Western science and Indigenous knowledge systems is widely accessible. This work also highlights the importance of fostering meaningful relationships between Tribal Nations, private landowners, conservation groups, and forest professionals to create shared goals in managing ash forests. As brown ash faces increasing pressure from EAB, facilitating conversations that connect cultural values, scientific insights, and landowner agency will be vital. The future of ash in the Northern Forest may well depend on how effectively we can engage all stakeholders in collaborative, informed, and culturally respectful forest stewardship.

Products

Peer-reviewed publications

- D'Amato, A. W., Orwig, D. A., Siegert, N. W., MahaNey, A., Benedict, L., Everett, T., Daigle, J., Johnson, L., Catanzaro, P., & Cusack, C. (2023). Species preservation in the face of novel threats: Cultural, ecological, and operational considerations for preserving tree species in the context of non-indigenous insects and pathogens. Journal of Forestry, 121(5–6), 470–479. https://doi.org/10.1093/jofore/fvad024
- D'Amato, A. W., Orwig, D. A., Siegert, N. W., MahaNey, A., Benedict, L., Everett, T., Daigle, J., Johnson, L., Catanzaro, P., & Cusack, C. (2023). Towards tree species preservation: Protecting ash amidst the emerald ash borer invasion in the Northeast. Journal of Forestry, 121(5–6), 480–487. https://doi.org/10.1093/jofore/fvad025

Research/technical Reports

- Catanzaro, P., D'Amato, A., Orwig, D., Siegert, N., Benedict, L., Everett, T., Daigle, J., & MahaNey, A. (n.d.). Managing New England forests threatened by Emerald Ash Borer. Massachusetts Land Trust Coalition.

Theses

- Dr. Emily Francis-Lamore - Understanding private landowners involvement, knowledge sharing, and social networks in conservation of brown ash in the face of emerald ash borer

Conference presentations (including workshops and posters).

- National Adaptation Forum – Brown Ash and Emerald Ash Borer 2022
- National Native Seed Conference 2023
- Maine Society of American Foresters Annual Meeting -Building Stewardship Capacity Lightning Talk 2022
- Maine Society of American Foresters Annual Meeting –Tribal Forestry Panel 2024
- National Native Seed Conference 2025

Seminars / webinars / workshops / field tours

- Common Ground Fair – APCAW Presentation 2022
- Maine Forest Service Annual Training – Ash Preservation Presentation 2022
- United South and Eastern Tribes Inc. Forest and Wetland Webinar Training Series – Adaptive Management in Brown/Black Ash Wetland Forests -2022
- Maine Bureau of Parks and Lands Ash Inventory Training 2022
- Northeast Forest Pest Council Meeting – Brown Ash and Emerald Ash Borer Panel 2023
- Maine Land Trust Network Ash Forest Field Trip 2023
- Introduction to the Ash Protection Collaboration Across Wabanakik 2023
- APCAW Identifying and Inventorying Ash Forests Workshop #1 2023
- APCAW Emerald Ash Borer and Ash Resilience Research 2023
- APCAW Identifying and Inventorying Ash Forests Workshop #2 2023
- APCAW Why Collect Ash Seed? 2023
- APCAW Office Hours 2023
- Maine Land Trust Network Annual Meeting – APCAW Introduction 2023
- Common Ground Fair - APCAW Presentation 2023
- Akwesasne Basket Makers Gathering 2023
- Maine Audubon Annual Plant Sale – APCAW Introduction Presentation 2023
- Caring for Maine's Brown Ash Resource in the Face of Emerald Ash Borer – Webinar and Field Tour 2023
- Sustaining Ash Partners Network Kick-ON Webinar 2024
- APCAW Talk at the Museum of the White Mountains 2024
- Scarborough Library talk: Emerald Ash Borer in Maine and the Current State of Ash Trees 2024
- APCAW's - Future of Brown Ash Meeting 2024
- Common Ground Fair – APCAW Presentation 2024
- Colby College Seminar – Social Science in Ash Protection Work 2024
- Yale Forest Forum on Tribal Forestry – Wabanaki Efforts to Preserve Brown Ash 2024

- Sebasticook Regional Land Trust Annual Meeting 2024 – Keynote Speaker on APCAW Efforts
- United South and Eastern Tribes – Native American Heritage Month – Ash Basketry and Emerald Ash Borer Presentation 2024
- Pathways to Sustain Ash: Webinar and Field Tour Series (Forest Steward's Guild) 2025
- Forest Stewards Guild Pathways to Sustain Ash Series: The How-To of Ash Seed Preservation from Collection to Propagation 2025
- Colby College Seminar – Social Science in Ash Protection Work 2025
- Maine Land Conservation Conference – APCAW Update Poster Session 2025
- Yale Seminar – Wabanaki Efforts to Preserve Brown Ash 2025

Other tangible products (videos, websites, databases, interviews, etc.).

- APCAW Webpage
- News Article – Portland Press Herald: Wabanaki tribes, scientists take drastic steps to save ash trees from invasive beetles
- News Article – Portland Press Herald: Native seeds preserved, protected to counter surging invasives
- News Article – Maine Bureau of Parks and Lands Ash Inventory Training 2022
- Forest Stewards Guild - Guild Student Feature: Tyler Everett 2022
- Intertribal Timber Council – IFMAT IV Student Spotlight 2023
- News Article - Yessenia Funes | Indigeneity - Tribes Unite in Defense of Culture and Forests

Student Involvement

Category	Name	Degree Sought
Post-Doctoral	Emily Francis Lamore	
Professional	Tom Newell, Neil Thompson	
Graduate Students	Tyler Everett, Ella McDonald	PhD, Masters
Undergraduate Students	University of Main Fort Kent Silviculture Class	Bachelors
Summer Students	Sydney Cyr	High School Diploma

Partners & Collaborators

University of Maine School of Forest Resources, Ash Protection Collaboration Across Wabanakik, The Nature Conservancy of Maine, United States Forest Service, Maine Forest Service, University of Vermont, Forest Stewards Guild, Maine TREE Foundation, Maine Bureue of Parks and Lands, Maine Inland Fisheries and Wildlife, USDA APHIS, Brown Ash Task Force, Saint Regis Mohawk Tribe, Wabanaki Youth in Science, Penn State – Schatz Center for Tree Molecular Genetics, University of Maine at Fort Kent, Wild Seed Project, Maine Indian Basket Makers Alliance, Maine Department of Agriculture Conservation & Forestry, First Light, Maine Land Trust Network, Mi'kmaq Nation, Passamaquoddy Tribe at Pleasant Point ,Sipayik, Passamaquoddy Tribe at Indian Township, Passamaquoddy Forestry Department, Penobscot Nation, Houlton Band of Maliseet Indians, Monitoring and Managing Ash, Forest Products Council, CFRU, Forest Society of Maine, New England Society of American Foresters, Society of American Foresters – Maine Division, Trust to Conserve Northeast Forestland, Professional Logging Contractors of Maine, Maine Organic Farmers and Gardeners Association – Low

Impact Forestry, Maine Woodland Owners, New England Regional Council on Forest Engineering, Gulf of Maine Research Institute, Maine Audubon.

Geographic Location of Project

a. Garfield, ME (46°36'56.9"N 68°28'28.7"W)
b. Frenchville, ME (47°17'01.9"N 68°25'06.2"W)
c. Readfield, ME (44°21'31.9"N 69°53'37.5"W)
d. Farmington, ME (44°41'19.3"N 70°06'51.2"W

Leveraged Funding

Source	**Amount**	**Direct/In-Direct**
USDA State, Private, and Tribal Forestry	$300,000.00	Direct
The Nature Conservancy	$50,000.00	Direct

Invasive Pest Effects on Tree Demographics Across the Northeastern US

Principal Investigator: Jeff Garnas (University of New Hampshire, jeff.garnas@unh.edu)
Co-Principal Investigators: Andrew Liebhold (US Forest Service, Morgantown, VA, andrew.liebhold@usda.gov, Co-PI), Randy Morin (US Forest Service, York, PA, randall.s.morin@usda.gov, Co-PI), Songlin Fei (Purdue University, West Lafayette, IN, sfei@purdue.edu, Co-PI)

Project Highlights

How a non-native forest pest affects the structure of its host is dependent on the biology and epidemiology of the pest as well as the biology of the host. Overall, the forests of the Northeast remain resilient as long-term carbon sequestration continues as a result of a non-native pest activity.

Project Summary

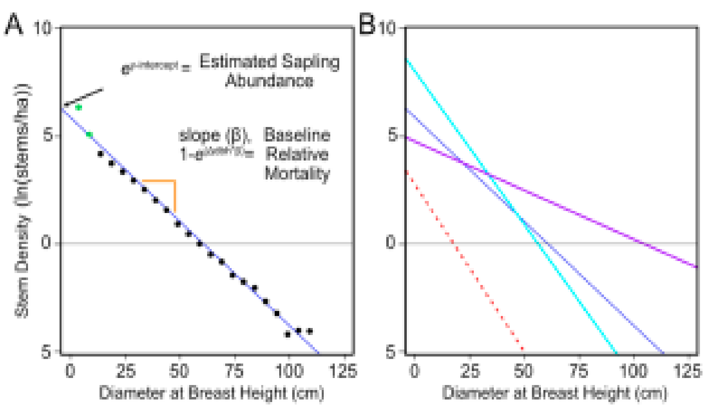

Figure 12. De Liocourt's Law Models Structure of a Forest A) De Liocourt's Law based on a hypothetical forest stand. The natural-log transformed stem density of trees larger than 5 in (12.7 cm, black dots) have a nearly linear relationship, through which a linear regression may be drawn (blue line). The slope of this line (orange bracket) is then used to calculate the Baseline Relative Mortality (BRM). The antilog of the y-intercept is the Estimated Sapling Abundance (ESA). B) Hypothetical changes in the structure of a forest. Solid dark blue line: original structure. Dashed red line: ESA decrease, BRM increase. Solid light blue line: ESA and BRM both increase. Solid purple line: ESA and BRM both decrease.

The degree to which nonnative forest threats are altering carbon storage capacity is a key component of market viability and long-term sustainability of large-scale carbon sequestration efforts. Additionally, landscape-scale assessment of the impacts of introduced insects and disease (and other forest threats) on demographic structure have the potential to shed light on management approaches that could ultimately lead to a healthier forest that is more diverse in size structure and species composition, with consequences for stability and resilience in the face of novel biotic and abiotic threats, including those linked to changing environmental conditions. To make determinations on changes in structure and carbon sequestration, the project utilized estimates generated by the US Forest Service's Forest Inventory and Analysis (FIA) program. Healthy forests at a sufficient spatial scale will have a geometric reduction in stem density by size class, known as an inverse-J distribution. De Liocourt's Law is the description of two key parameters that can be easily estimated from the log-linear fit of this stem density distribution: baseline relative mortality (BRM) from the slope, and estimated sapling abundance (ESA) from the intercept. Using FIA remeasurement cycles, changes in BRM and ESA were tracked through time, coupled them with empirical estimates of mortality and sapling density, as well as determine if changes in structure are predictive of aboveground carbon (Figure 12B). Understanding the current demographic trajectory of the Northeastern forests, and specifically within the context of host species demography changing as a function of invasive pests, can inform management practices as to maximize the efficiency of carbon sequestration in forests.

Background and Justification

The NSRC states have been repeatedly infested by non-native pests and pathogens since the turn of the 19th century. And yet, the region's forests have proved resilient in most cases. Widespread mortality of one species has generally been followed by a compensatory response by mid- and understory trees. It is therefore characteristic of this region that forests change, often dramatically in the face of novel invasive threats, but remain forests. Yet, fully understanding how demographic and compositional shifts in our forests impact growth, yield, and carbon storage capacity along with a suite of ecosystem services, in both the short and long term, is of critical importance. These estimates have high value given the importance of forest structure and composition to economic, ecological, and aesthetic value of forests as well as to informing emerging carbon markets in the region. Focusing on each forest insect and disease threat of historical and ongoing importance to NSRC states also allows for explicit consideration of how region-specific mitigation strategies (i.e., diseased tree removal, pre-emptive stand harvest or salvage operations, or other intervention) are likely to influence densities and demography in the future forest. Additionally, the recognition of the establishment of novel equilibria that might be suboptimal from a carbon storage or ecosystem services perspective could lead to different forest management approaches that focus less on pest management and more specifically on pushing forests toward more desirable stable states.

Methods

This project required generating customized SQLite code to directly query a local copy of the FIA database. An important aspect to the queries was to optimize the geographic scale from which the estimates were generated. Aa semi-automated pipeline was developed by which counties that share a common pest infestation duration (binned approximately by decade) were pooled together to have 50-300 host-tree-species-positive FIA plots. This allowed for geospatial replicates in most cases, while ensuring structural distribution was of sufficient quality. Code developed would take "county clusters" and automatically write SQLite code to query the FIA database. For each county cluster, estimates were obtained for stem number across size classes, empirical mortality across size classes, and aboveground biomass (which can then be converted to carbon), both in total and across size classes. This method was used to develop demographic estimates for 2010 and 2020 for host tree species, all species within the cluster, and all non-host species. The custom-built code for this pipeline will be made available upon publication of the findings in a peer-reviewed journal or earlier upon request.

Key Findings/Accomplishments

The findings of this research provide a direct demonstration of how the demographic trajectory of Northeastern forests affects carbon sequestration (Table 3) as well as produce a conceptual model that can inform management practices going forward (Figure 13). By calculating the difference in BRM, ESA, and aboveground carbon from 2010 and 2020, the project team stablished demographic trajectories at the county cluster level across the Northeastern forests. Invariably, across all pathosystems studied, the demographic trajectory of data aggregated across all species fell within the green polygon shown in Figure 13. Further, all trajectories existed

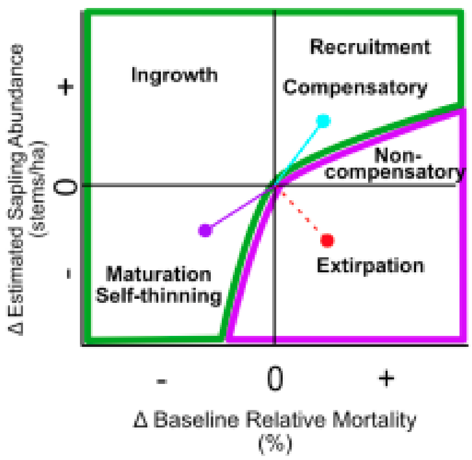

Figure 13. The change in De Liocourt-derived demographic rates of mortality and sapling abundance can be plotted against each other as illustrated. When the trajectory of a county cluster is within the magenta-outlined polygon, aboveground carbon decreases. Conversely, trajectories in the green polygon sequester carbon. Light blue, purple, and red lines correspond to demographic trajectories described in Fig. 12. T1 is the center of the plot, with T2 represented by the ball at the end of each trajectory.

along a line between maturing/self-thinning and compensatory recruitment, presumably reflecting the age of the stand. Younger stands would be undergoing recruitment (an increase in BRM and compensatory increase in ESA) while older stands would be maturing and self-thinning (decrease in both ESA and BRM). These results are considered both a conceptual validation of the method and model as well as allowing to conclude that the Northeastern forests have proved resilient in the face of invasive pests. Interrogating tree species that are hosts to invasive pests elucidated demographic trajectories that can result in the loss of carbon sequestration (Figure 13, magenta polygon). Indeed, increases in BRM without a sufficiently compensatory increase in ESA result in a net loss of aboveground carbon. Similar outcomes occur when ESA decreases without sufficient decreases in BRM. An increase in BRM and decrease in ESA, which occurs locally for hemlock and ash, invariably results in a loss of sequestered carbon. The summary of stand trajectories for host tree species appears in Table 3. A land manager wishing to maximize carbon sequestration rates can utilize this framework to direct the demographic trajectories of their forests. The results of this work are currently written in a manuscript and is expected to go out for peer review this summer.

Implications and Applications in the Northern Forest Region

One of the goals of this project was to understand how changes in the demographic structure (i.e. size class distribution profile) of trees affect carbon sequestered in the form of live aboveground biomass. Such understanding is critical for carbon market infrastructure, as well as helping Northeastern states accomplish atmospheric carbon mitigation goals. The implication of this work would be that landowners can survey the structure of their managed forest and understand what measures need to be taken to adjust demographic rates to maximize carbon sequestration. Indeed, using allometric equations provided by the forest service, changes can be modeled in live carbon stocks for given scenarios of demographic change.

Pathosystem/ pest common name	Pest/Pathogen	Host	Trend of Baseline Relative Mortality (%/decade)		Trend of Estimated Sapling Abundance (stems/ha/decade)		Trend of Aboveground Carbon Sequestration (tonnes/ha/decade)	
			Non-infested	Longest Infested	Non-infested	Longest Infested	Non-infested	Longest Infested
Beech Bark Disease	*Cryptococcus fagisuga* + *Neonectria spp.* fungus	*Fagus grandifolia* (American beech)	+ 1.13	+ 2.94	+ 1.27	+ 41.1	+ 0.400	+ 0.06
Hemlock Woolly Adelgid	*Adelges tsugae*	*Tsuga spp.* (Hemlock species)	- 2.27	+ 0.101	- 4.97	+ 1.27	+ 0.47	+ 0.07
Emerald Ash Borer	*Agrilus planipennis*	*Fraxinus spp.* (Ash species)	- 0.51	- 0.74	+ 3.22	- 29.6	+ 0.36	- 3.60
Spongy Moth	*Lymantria dispar dispar*	*Quercus spp.* (Oak species)	- 1.25	- 2.52	- 11.7	- 22.8	+ 1.93	+ 3.45
Chestnut Blight	*Chruphonectria parasitica*	*Castanea dentata* (American chestnut)	N/A	- 6.75	N/A	-0.07	N/A	- 0.002
Butternut Canker	*Ophiognomonia clavignignenti-juglandacearum*	*Juglans cinerea* (Butternut)	N/A	+ 0.75	N/A	-0.02	N/A	- 0.006

Future Directions

This work focused on demographic changes that were the result of hypothesized effects of non-native pests on host mortality rates. However, there are other questions we would like to ask considering the northern forests through the lens of De Liocourt's Law:

- Are there predictable patterns of demographic disequilibrium as one moves from stands with high percent basal area of a species to low? (e.g., demographic patterns across range of a tree species)
- There is a predictable inverse relationship between aboveground biomass and baseline relative mortality when data are aggregated across all species, but not when considering a specific species or genus. This observation generates several questions:
    - When considering all species in a given geographic region, what factors determine the equilibrium between demography and biomass? In practice, is this equilibrium ever realized or is it a theoretical point that is unattainable due to disturbance?
    - What is the minimum number of species needed to reconstitute the inverse relationship seen across all species?
    - What factors limit the inverse relationship from forming within a species?

The Northern forests have a diverse patchwork of land use history and species composition. How does the demographic trajectory of a stand vary by land use history and species composition?

Products

Conference presentations (including workshops and posters).

- Bascom, C., Liebhold, A., Morin, R., Fei, S., Fearer, C., & Garnas, J. R. (2025, January). *Changes in host demographic structure in the face of invasive forest pests* [Conference presentation]. 33rd United States Department of Agriculture Interagency Research Forum on Invasive Species, Annapolis, MD, United States.
- Garnas, J. R., Bascom, C., Liebhold, A., Morin, R., Fei, S., & Fearer, C. (2024). *Invasive pest effects on tree demographics and equilibrium carbon storage capacity across the northeastern United States* [Conference presentation]. International Union of Forest Research Organizations (IUFRO), Stockholm, Sweden.
- *Human-introduced pests have variable effects on forest demography* [Poster presentation]. (2024, July). Gordon Research Conferences: Unifying Ecology Across Scales.

Seminars/Webinars/Workshops/Field Tours

- Changes in host demographic structure in the face of invasive forest threats. Seminar presentation, April 2025. Virgina Tech's Department of Forest Resources and Environmental Conservation faculty, staff, graduate students
- Changes in forest structure resultant from human-introduced pests and pathogens, Seminar Talk, March 2024, University of New Hampshire's Department of Natural Resources and the Environment

Pending Article Submissions

- Bascom, C., C. Fearer, A. Liebhold, R. Morin, S. Fei, and J. R. Garnas. Nearing submission (August 2025). Trajectories of host tree demographics in the face of invasive forest threats.
- Bascom, C., C. Fearer, A. Liebhold, R. Morin, S. Fei, and J. R. Garnas. In preparation anticipated submission in October 2025). Long-term impacts of nonnative pests and disease on forest biomass storage capacity mediated through shift in host tree demographic rates.

Student Involvement

Category	Names	Degree Sought
Post-Doctoral	Carrie Fearer Carlisle Bascom Jr.	N/A
Graduate Students	Samatha Tower	PhD

Partners/Stakeholders/Collaborators

- Jeff Garnas (University of New Hampshire, Department of Natural Resources and the Environment)
- Carrie Fearer (Virginia Polytechnic Institute and State University; VTech),
- Department of Forest Resources and Environmental Conservation)
- Carlisle Bascom (University of New Hampshire, Department of Natural Resources and the Environment)
- Andrew Liebhold (US Forest Service)
- Randy Morin (US Forest Service)
- Songlin Fei (Purdue University, Department of Forestry and Natural Resources

Geographic Location

This project included no fieldwork. Computations covered all counties in the eastern United States that contained one or more of the following species: beech, ash, hemlock, oak, chestnut or butternut. All counties in NY, VT, NH, and ME were included in this research.

Leveraged Funding

Source	Amount	Direct/In-Direct
United States Forest Service	$57,250	Direct

Jumping Worm Invasion and Impact in Northern Forest

Principal Investigator: Timothy S. McCay (Colgate University, tmccay@colgate.edu)
Co-Principal Investigators: Andrea Dávalos, SUNY Cortland, mariaandrea.davalos@cortland.edu), Annise Dobson (Yale School of the Environment, annise.dobson@yale.edu), Josef Görres (University of Vermont, josef.Gorres@uvm.edu), Bradley Herrick, University of Wisconsin-Madison Arboretum, Kyle Wickings (Cornell College of Agriculture and Life Sciences, kgw37@cornell.edu)

Project Outcomes

Effects of jumping worms were documented at seventeen sites in the Northern Forest of New York and Vermont. Biomass of jumping worms was negatively associated with growth of sugar maple seedlings, and abundance of many types of invertebrate animals that live in leaf litter and soil.

Project Summary

Jumping worms are invasive exotic annelids that are very abundant and change soil properties in the Upper Midwest and Northeast regions. Jumping worms had been observed in natural forested environments of the Northern Forest, but the extent and impacts of invasion were unknown. Therefore, a network of natural resource professionals and interested amateurs in the region was established and trained to monitor and report jumping worm populations. Additionally, seventeen sites in the Adirondacks and Vermont with varying levels of jumping worm and European earthworm invasion were established. The invasion of the Northern Forest by jumping worms is extensive. Some areas invaded by jumping worms do not apparently support European earthworms, suggesting that jumping worms are invading areas not previously colonized by exotic earthworms or that jumping worms outcompeted European earthworms at these sites (Laushman et al. 2018). Abiotic factors (e.g., soil chemistry, climate) in the Northern Forest that will prevent jumping worm expansion and unknown.

The impact of jumping worms at study sites was measurable in terms of soil chemistry, soil biodiversity, litter biodiversity, and seedling survival. More magnesium (Mg) was found in soils that were invaded by jumping worms. This might reflect the action of earthworms near the surface, without deep-soil-dwelling earthworms to move Mg to deeper soil levels (Resner et al. 2015). Jumping worm biomass was negatively associated with certain soil and litter arthropods, including springtails and oribatid mites. These changes likely reflect the redistribution of carbon to deeper levels of the soil.

Jumping worm biomass was negatively associated with sugar maple growth at sites (Figure 13). This adds to growing concern about how jumping worms might affect regeneration of sugar maple, especially during dry years. A positive effect of European earthworm survival of sugar maple and oak seedlings was found, underscoring the differences between jumping worms and European lumbricid earthworms (Chang et al. 2021). European species may improve seedling survival by accelerating nutrient cycling without the potentially desiccating effect of their castings.

The large and expanding range of jumping worms in the Northern Forest is cause for concern. Their biological effects are similar to those effects seen with European invasive earthworms but differ in ways that are consistent with their ecological habit. They are found near the soil surface, and create granular castings that poorly retain moisture. Future work will aim to better understand how jumping worm invasions in the Northern Forest unfold and whether impacts change in a predictable way over time.

Background and Justification

Invasive earthworms are widely recognized as a challenge to previously glaciated portions of North America (Hendrix and Bohlen 2002). They accelerate decomposition, reducing leaf litter and changing habitat for a variety of plants, animals, and microbes. In particular, they can threaten biodiversity and regeneration (Bohlen et al. 2004). The colonization of the Northern Forest by native North American earthworms and European invasive species has been modest compared to other regions, but invasive jumping worms have begun moving into the region. These species are different in many ways from European invasive earthworms and early evidence suggested that they may invade forests previously unaffected by European species.

Jumping worms are invasive earthworms of the family Megascolecidae with Asian provenance. Sixteen species from this family are found in North America, but in the Northern Forest, three species are of particular importance: *Amynthas agrestis*, *A. tokioensis*, and *Metaphire hilgendorfi* (Chang et al. 2021). These species have been present in the United States since at least the late 1940s but have only become conspicuous in the last few decades. Although frequently a pest of gardens, jumping worms have demonstrated the ability to move from gardens and other anthropogenic habitats into mature, undisturbed forests. Invasion by jumping worms represents a "second wave" of earthworm invasion, following the invasion of North America by European earthworms. Therefore it is important to assess the invasibility of Northern Forests to jumping worms and quantify potential effects while this invasive process is still in an incipient stage.

Methods

The project aimed to better understand the current extent of colonization of the Northern Forest by jumping worms, the potential for future expansion within this ecosystem, and the anticipated impact of invasion.

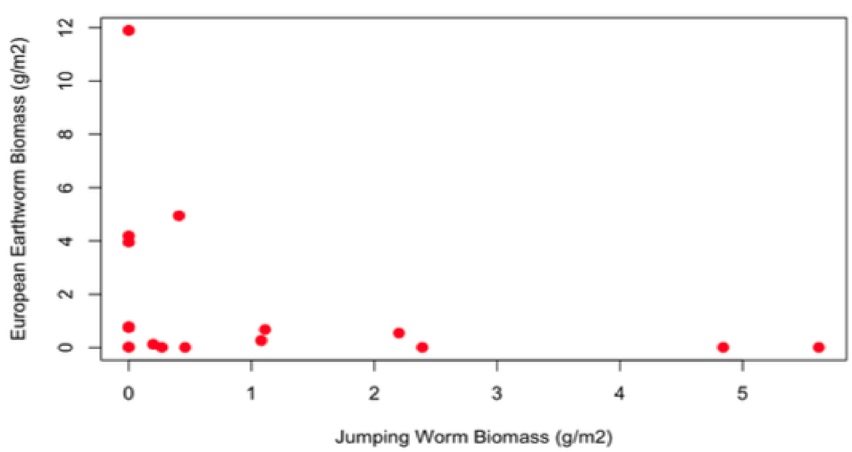

Figure 14. Relationship between jumping worm and European (lumbricid) earthworm abundance at seventeen sites in the Northern Forest.

Early Detection. A series of workshops was used to establish a network of natural resource professionals in the Northern Forest. Members of this network were trained in the identification and sampling of these pests (McCay et al. 2020), and sampling materials were sent to members of the network.

Impact. Seventeen sites with varying levels of invasion by jumping worms and European earthworms were established in the northern forests of Adirondack Park and Vermont. Soil parameters were measured, soil and litter invertebrate abundance, and the survival of growth of planted sentinel seedlings. Although the sites were initially selected to represent the gradient in jumping worm abundance in the region, it was found that they also captured a wide range in abundance of European invasive earthworms as well (Figure 15). These gradients were not positively related to one another. Therefore, the approach of comparing the abundance of both jumping worms and European earthworms with response variables was adopted.

Key Findings/Accomplishments

The study documented the increased expansion of jumping worms into the Northern Forest of the US and Canada. A network of natural resource professionals and interested citizens is now documenting new records of jumping worms when they are encountered. The expanding distribution of jumping worms suggests that ongoing incursion is not prevented by the abiotic context (soil chemistry, climate) of the Northern Forest. The study suggests that all management units of the Northern Forest are possibly susceptible to new invasions and should act to prevent new introductions. Mulch used in landscaping and gardening is apparently a major avenue for introduction and should be avoided if possible (Bellitürk et al. 2015). The use of jumping worms as fishing bait is currently disallowed in New York, and the study suggests that other states restrict this activity as well.

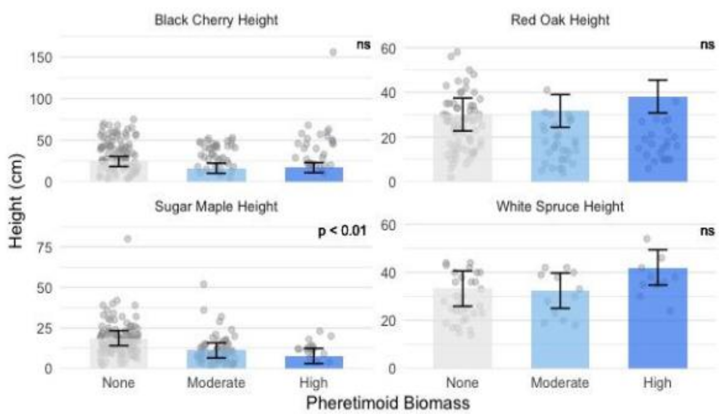

Figure 15. Relationship between abundance of prostigmatid mites and the abundance of European and jumping worms at 17 sites in the Northern Forest.

Measured parameters of soil chemistry (Ca, K, Mg, P, Al, Cu, Fe, Mn, Na, S, Zn) were largely unrelated to the abundance of either jumping worms or European earthworms, with the exception of soil magnesium. Soil Mg was positively related to dry weight biomass of jumping worms at the study sites ($r = 0.7$, $p = 0.03$). It is hard to know whether this might be a consequence or cause of jumping worm invasion. However, others (Resner et al. 2015) have found that surface-dwelling earthworms can increase the abundance of Mg at the surface, probably by accelerating litter decomposition. This accumulation can be short-lived, however, if deep-soil-dwelling earthworms colonize, which can lead to losses. Jumping worms

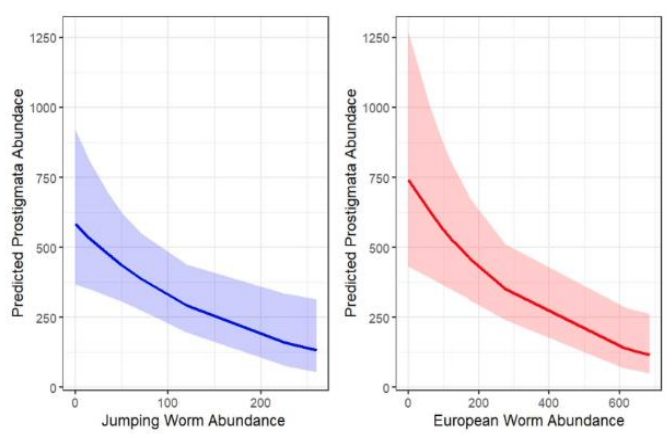

Figure 16. Relationship between height change of the three sentinel seedling species and the abundance of jumping worms at 17 sites in the Northern Forest.

are surface dwelling, and in the absence of other earthworm species may cause a temporary accumulation of Mg near the surface.

The sentinel seedlings used in the study revealed contrasting effects of European and jumping worms in the Northern Forest. European earthworms were positively associated with survival of sugar maple ($p < 0.05$) and red oak ($p < 0.01$) seedlings in the field; whereas jumping worms were negatively correlated with growth rate of sugar maple ($p < 0.01$; Fig. 2). This adds to the accumulating anecdotal evidence that jumping worms may pose a threat to sugar maple regeneration in the Northern Forest, at least during dry seasons (O'Keefe and McCulloh, 2021).

Among leaf-litter invertebrates, jumping worm abundance was negatively associated ($p < 0.05$) with the abundance of springtails, which are small arthropods that primarily eat soil fungi (Fig. 3). Invasive earthworms often cause a decrease in soil fungi because of the redistribution of carbon to deeper soil layers (Dempsey et al. 2011). Interestingly, though, the study found that jumping worm biomass was not correlated with leaf decomposition rate at the study plots. Thus, the mechanism of effect remains unclear.

European earthworm abundance was negatively associated ($p < 0.05$) with the abundance of prostigmatid mites, tiny arachnids with diverse diets, and with oribatid mites, which are important litter decomposers. European invasive earthworm biomass was positively related, as expected, to leaf decomposition rate at the study plots.

No invertebrate groups were positively associated with jumping worm or European earthworm abundance. There is abundant evidence that earthworms can affect food webs and biodiversity in the Upper Midwest and Northeast (e.g., McCay and Scull 2019). We expect that expansion of jumping worms in the Northern Forest may lead to decreased biological diversity in these ecosystems as well.

Implications and Applications in the Northern Forest Region

The partnerships that the project has established and the training programs that the study team has conducted have increased the capacity of both professionals and amateur naturalists in the Northern Forest to detect and report jumping worms. Work with iMapInvasives (imapinvasives.org) has supported and will continue to support this platform as a repository for these data. This network stands as a continuing resource for individuals who want to have sites examined or earthworms identified.

Apparently, no portion of the Northern Forest is immune to colonization by jumping worms. Indeed, the study documented jumping worms in many new locations outside of direct anthropogenic influence. Managers within the region must be prepared for the public relations, ecological, and economic problems that may result from jumping worm colonization and abundance.

The study found evidence that the ecological effects of jumping worms may be different from the effects of European invasives. Indeed, jumping worms are very different from existing lumbricid earthworms in the Northeast (Chang et al. 2021). Given that jumping worms have shown the ability to displace European earthworms (Laushman et al. 2018), managers should consider steps to prevent jumping worm introduction, even if their management units are currently colonized by European species.

Of particular concern are the effects of jumping worms on sugar maple seedlings. The study found evidence that jumping worms can negatively affect the growth rate of these seedlings, and others have reported data suggesting a negative effect on seedlings during dry periods (O'Keefe and McCulloh, 2021). This topic requires further research given the profound implications of a decrease in sugar maple in the Northern Forest.

Future Directions

Given the present difficulty of eradicating jumping worms from an ecosystem once they are established, it is important to consider steps toward mitigating their negative impacts. Additionally, a better understanding is needed of how jumping worm invasion interacts with other stressors, such as white-tailed deer overabundance, to influence tree regeneration and biodiversity in the Northern Forest.

The research team intends to continue monitoring the sentinel seedlings at the impact plots and, at 5-year intervals, to reexamine forest-floor biological diversity. Experience in other regions indicates that jumping worm populations can be extremely variable, and the investigators remain uncertain about the environmental factors that correlate with invasion intensity. Long-term study of these plots can help clarify how invasions may proceed in the Northern Forest and what factors influence jumping worm populations.

Products

Conference Papers

- Edwards, M. J., Görres, J., & McCay, T. S. (2025, April). *Impacts of invasive earthworms on soil invertebrate communities* [Conference presentation]. Northeastern Natural History Conference.
- Mabrysmith, T., Morris, T., Tang, J., Saionz, W., Dobson, A., Dávalos, A., & McCay, T. S. (2025, April). *Greenhouse study of lumbricid and megascolecid invasive earthworm impact on seedling growth* [Poster presentation]. Northeastern Natural History Conference (NENHC).
- McCay, T. S., Pedzich, S., Xie, C., & Tang, J. (2023, March). *Response of forest-floor food web to peregrine earthworms in the American Northeast* [Poster presentation]. Third Global Soil Biodiversity Conference, Dublin, Ireland.
- McCay, T. S., Frank, K. M., Hurst, A. S., Kim, M., Lerner, R. E. B., & Tang, J. (2024, April). *Movement behavior, isotopic niche, and population dynamics of invasive jumping worms in northeastern forests* [Conference presentation]. Northeastern Natural History Conference.

Seminars, Webinars, Workshops

- During the term of this award, the investigators of this project have delivered approximately 40 public seminars, webinars, and workshops related to the work with jumping worms.

Student Involvement

Category	**Name**	**Degree Sought**

Professionals	Abigail Allen (Lab Technician, Cornell)	
Graduate Students	Madalynn Edwards (Vermont)	PhD
Undergraduate Students	Caroline Barnhart (Colgate), Kayelah Brown (SUNY Cortland), Azaria Laster (SUNY Cortland), Adam Limoges (Colgate), Teagan Mabrysmith (Colgate), Tilly Morris (Colgate), Sophie Pedzich (Colgate), Wilbur Saionz (Colgate), Joy Tang (Colgate)	BA/BS
Summer Students	Nathan Apfel (Yale), Caroline Barnhart (Colgate), Kayelah Brown (SUNY Cortland), Adam Limoges (Colgate), Tilly Morris (Colgate), Xavier Murrell (Yale, University of Connecticut), Sophie Pedzich (Colgate), Ian Robinson (Yale, Southern Connecticut State University), Joy Tang (Colgate)	BA/BS

Partners/Stakeholders/Collaborators

(Organizations directly supporting the investigators) Biological Science Department, SUNY Cortland; Department of Biology, Colgate University; Department of Entomology, Cornell University; Department of Environmental Studies, Colgate University; University of Vermont Department of Agriculture, Landscape, and Environment; University of Wisconsin - Madison Arboretum; Yale School of the Environment

(Organizations with which we have partnered in this work) Adirondack Park Invasive Plant Program, City of Montpelier Vermont, Green Mountain Audubon Center, iMapInvasives.org, Lake George Land Conservancy, New York State Department of Environmental Conservation, Shelburne Farms, Vermont State Park.

Geographic Location

Vermont Sites	LAT.	LONG.
Audubon, Heavily Jumping Worm (JW) Invaded	44.3469	-72.9958
Audubon, Lightly JW Invaded	44.3471	-72.9952
Camel's Hump I State Park Invaded	44.3613	-72.8468
Camel's Hump I State Park Uninvaded	44.3607	-72.8473
Camel's Hump II State Park Invaded	44.3693	-72.8793
Camel's Hump II State Park Uninvaded	44.3664	-72.8828
Hubbard Park Heavily Invaded	44.2676	-72.5747
Hubbard Park Less-heavily Invaded	44.2674	-72.5750
Shelbourne Farms Invaded	44.4108	-73.2486
Shelbourne Farms Uninvaded	44.3921	-73.2640
Adirondack Sites		
Gull Bay I Heavily invaded	43.7325	-73.4560
Gull Bay I Lightly invaded	43.7328	-73.4555
Gull Bay II Invaded	43.7355	-73.4584
Gull Bay II Uninvaded	43.7353	-73.4576
Roger's Rock Park Lakeside Invaded	43.7944	-73.4759
Roger's Rock Park Upland Invaded	43.7888	-73.4897
Roger's Rock Park Upland Uninvaded	43.7915	-73.4961

Leveraged Funding

Source	**Amount**	**Direct/In-Direct**
Colgate University	$37,800	Direct
Colgate University	$1,656	Direct
Colgate University	$22,728	In-kind (PI summer salary)

Colgate University	$29,442	In-kind (foregone indirect and F&A)
SUNY Cortland	$8,851	In-kind (summer salary)
Yale University	$17,125	In-kind (PI salary)
Yale University	$19,545	Direct

Eastern White Pine Health Monitoring through Remote Sensing Assessment of Foliar Traits

Principal Investigator: Parinaz Rahimzadeh (University of Maine, parinaz.rahimzadeh@maine.edu)
Co-Principal Investigators:
Jose Eduardo Meireles (University of Maine, jose.meireles@maine.edu), Aaron Bergdahl (Maine Forest Service, Aaron.Bergdahl@maine.gov)

Project Outcomes

- White pine needle damage (WPND) impact studies using satellite remote sensing are challenging as the top canopy often remains unaltered, whereas the lower canopy experiences higher damage, yellowing, and premature needle defoliation. This work established a foundation for further application of remote sensing for Eastern White Pine (EWP) health monitoring and early detection of WPND and showed that leaf-level hyperspectral data are capable of detecting WPND.
- The live crown ratio (LCR) in EWP serves as a key health indicator and can be used as a proxy for susceptibility of EWP to WPND. This study generated the leaf area index (LAI) map and a novel spatial layer of LCR at landscape scale using a combination of satellite data and ground observations. Then the predicted LAI and LCR were integrated with canopy height and stand density data to develop a novel health index map for EWP.

Project Summary

Eastern white pine (*Pinus strobus* L.; EWP), an economically and ecologically important tree species in Northeastern forests, has been subject to shift in habitat and disturbance regime over the past two centuries making this species prone to several pests and pathogens and dieback. In recent years, white pine needle damage (WPND) has been the most significant threat to EWP during growing season and is expected to become more severe (in symptoms and occurrence). Remote sensing tools using aerial and satellite imagery provide a unique opportunity to assist WPND field and aerial monitoring efforts by providing objective and spectrally explicit observations across large regions over time. In this project we conducted two research projects at two different scales to evaluate the application of remote sensing data for EWP health assessment with the focus on WPND detection and monitoring. We first evaluated the application of hyperspectral data and foliar traits (chlorophyll (Chl), nitrogen (N), and equivalent water thickness (EWT)) for WPND detection. The field data were collected over a period of six weeks from the start of June 2022 in Bethel, Maine. Results indicated that the model based solely on remotely sensed spectral vegetation indices (SVIs) can be used with high accuracy for disease classification into asymptomatic and symptomatic classes. The study also highlights that the commonly measured traits may not be optimal for the detection of WPND.

In the second study, we generated the LAI map and a novel spatial layer of LCR at landscape scale using a combination of satellite data and ground observations. We conducted field surveys to collect plot-level (10 m × 10 m) data in four eastern EWP-dominated sites in the state of Maine. The plot-level data were used to develop regression models for LAI and LCR estimation using microwave (Sentinel-1) and optical (Sentinel-2) remote sensing data. Furthermore, the predicted LAI and LCR were integrated with canopy height and stand density to develop a novel health index map for EWP. The resulting health index map successfully delineated patches representing various EWP health categories. *Forestry practitioners and decision-makers can use the derived health index map and intermediate spatial data layers (LAI and LCR) to guide stand management.*

Background and Justification

EWP, an economically and ecologically important tree species in New England, faces widespread disease and decline due to the exacerbation of native and previously harmless pathogens. Over the last 15 years, WPND has emerged as the most significant threat to EWP during the growing season throughout Northeastern forests. As WPND outbreaks are expected to become more severe (in symptoms and occurrence), it is important to evaluate potential synergistic monitoring solutions. Recent experience under the COVID-19 pandemic also emphasized the need to have remote monitoring tools as many field and aerial campaigns were canceled or postponed for safety reasons.

Methods

Leaf-level analysis:

Efforts were made to detect WPND using the leaf samples collected in 2022 from an EWP-dominated site in Bethel, Maine. The field-measured foliar traits such as nitrogen (N), chlorophyll (Chl), and equivalent water thickness (EWT) and collected reflectance data from fresh green foliage (hyperspectral signature) were used for WPND detection. The hyperspectral signature was used to derive multiple spectral vegetation indices (SVIs). The random forest (RF) machine learning model was applied to classify the non-symptomatic and symptomatic samples based on field-measured foliar traits, remotely sensed-derived SVIs, and a combination of the two.

Landscape-level analysis:

In summer 2023, additional field data were collected for a landscape-level study in four EWP-dominated stands in Maine (Auburn, Bethel, Demeritt, and Davis). The plot-level (10m×10m) ground data on LAI, LCR, canopy density, tree height, and tree density were recorded in 48 plots. Repetitive LAI was collected for 28 plots (in Bethel and Demeritt) using the LiCOR 2200 TC plant canopy analyzer from May to August 2023. The field data were used to develop regression models (using the RF algorithm) and predict parameters at the landscape level using optical (Sentinel-2) and microwave (Sentinel-1) satellite images. Two novel spatial layers on the LCR and LAI were prepared at 10 m spatial resolution. The predicted LAI and LCR maps were integrated with canopy height and stand density data to develop a novel health index map for EWP.

Key Findings/Accomplishments

Leaf-level analysis:

The field-measured N content showed a significant difference ($p<0.05$) between non-symptomatic and symptomatic samples; however, no significant difference was observed in field-measured Chl and EWT content. The RF machine learning model was applied to classify the non-symptomatic and symptomatic samples based on field-measured foliar traits, remotely sensed-derived SVIs, and a combination of the two. The RF model based on only remotely sensed SVIs indicated the highest overall accuracy of 87% (Table 1). This project was published in a peer-reviewed journal. Please see Section 8.

Table 1: Results of RF classification of symptomatic and asymptomatic samples.

Variables (Only Traits)	Accuracy (%)	Kappa
EWT+Chl+N_{mass}+Fluorescence	70.0	0.38
N_{mass}+Fluorescence	66.7	0.33
EWT+N_{mass}+Fluorescence	66.7	0.30
EWT+Chl+N_{area}	66.7	0.21
LMA+Chl+N_{area}+Fluorescence	63.3	0.25
EWT+Chl+N_{area}+Fluorescence	63.3	0.25
LMA+Chl+N_{mass}+Fluorescence	60.0	0.20
EWT+Chl+N_{mass}	60.0	0.10
Variables (Only Spectral Vegetation Indices)		
NDNI+GNDVI+NDVI+REP+$NDWI_{1240}$	86.7	0.68
NDVI+NDNI+$NDWI_{1240}$+REP	80.0	0.52
NDNI+NDVI+$NDWI_{1240}$	73.3	0.40
NDNI+NI_Wang+NI_Ferwerda	66.7	0.15
Variables (Traits and Spectral Vegetation Indices)		
NDVI+NDNI+$NDWI_{1240}$+REP+N_{mass}+Chl+EWT	76.7	0.46
NDVI+NDNI+$NDWI_{1240}$+N_{area}+Chl+EWT	73.3	0.44
NDVI+NDNI+$NDWI_{1240}$+N_{mass}+Chl+EWT	73.3	0.43
NDNI+NI_Wang+NI_Ferwerda+$NDWI_{1240}$+N_{mass}+Chl+EWT+Fluorescence	70.0	0.42
NDVI+NDNI+$NDWI_{1240}$+REP+N_{area}+Chl+EWT	70.0	0.38
NDVI+NDNI+REP+N_{area}+Chl+EWT	70.0	0.38
NDNI+NI_Wang+NI_Ferwerda+$NDWI_{1240}$+N_{area}+Chl+EWT	70.0	0.31
$NDWI_{1240}$+N_{mass}+Chl+EWT+Fluorescence	66.7	0.30
$NDWI_{1240}$+N_{area}+Chl+EWT+Fluorescence	66.7	0.30
$NDWI_{1240}$+N_{mass}+Chl+EWT	66.7	0.25
$NDWI_{1240}$+N_{area}+Chl+EWT	66.7	0.21
NDNI+NI_Wang+NI_Ferwerda+N_{mass}+Chl+EWT	63.3	0.29
NDNI+NI_Wang+NI_Ferwerda+$NDWI_{1240}$+N_{mass}+Chl+EWT	63.3	0.20

Landscape-level analysis:

The developed novel EWP map is shown in Figure 1. The unhealthy EWP stands are recorded in 7 % of the total EWP-dominated area, while moderately healthy trees are recorded in 70 %, and healthy in 23 % of the area. The unhealthy stands are seen in the western part, whereas most of the healthy stands are observed in the southern and western regions. This project was published in a peer-reviewed journal.

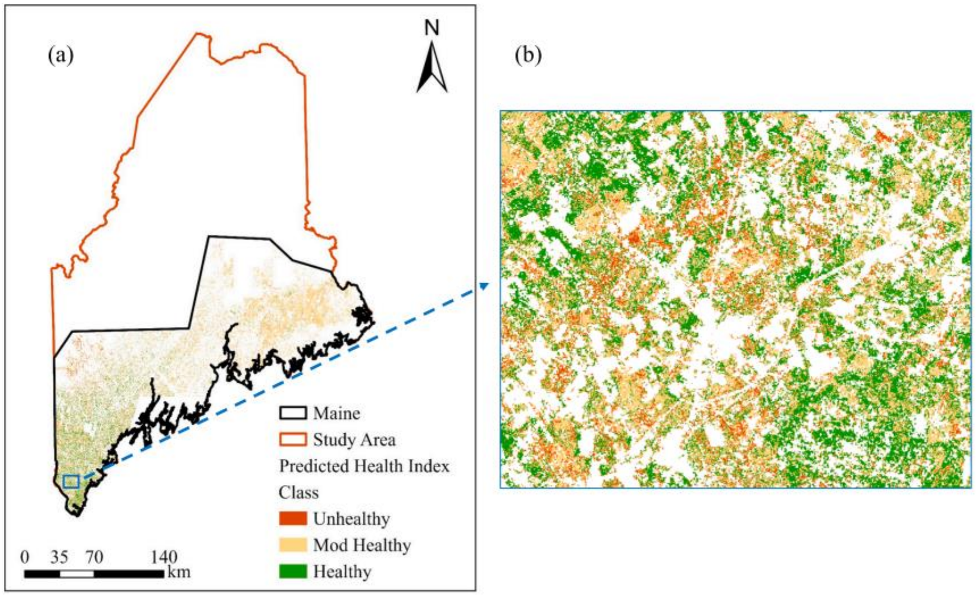

Figure 17. Eastern white pine (EWP) stand health index map for (a) southern Maine, USA, and (b) Magnified area

Implications and Applications in the Northern Forest Region

<u>WPND project:</u> Overall, the results from the spectral analysis presented in this work are promising and may help identify other field-measured traits that could be potentially better indicators of EWP health. Moreover, the developed approach and best SVIs identified in this study can be applied or tested with suitable satellite data, such as Landsat and Sentinel-2, for landscape-level WPND impact studies.

<u>EWP health index project:</u> Forestry practitioners and decision-makers can use the derived health index map and intermediate spatial data layers (LAI and LCR) to guide stand management. The developed framework can potentially be applied to other coniferous and broadleaved species for remote sensing-based LCR estimation and forest health assessment upon further studies and verification.

Partners/Stakeholders/Collaborators

Collaborations or partnerships established: In this project, we closely collaborated with USFS and Maine Forest Service in the past three years and our products were designed to be directly used for EWP health monitoring by USFS and Maine Forest Service (MFS). Forest pathologists Dr. Isable Munck, Dr. Cameron McIntire (USFS, New Hampshire), and Aaron Bergdahl from the MFS, Augusta were actively involved in the project. Aaron Bergdahl helped us with identifying appropriate sampling locations acting as a mediator between the forest landowners in summer 2022 and 2023 field seasons. He helped us with data collection and reviewed the techniques that we were using. He also provided feedback on our study results. Similarly, Drs. Isabel Munck and Cameron McIntire supported the project by providing feedback on our preliminary results. Dr. Isabel Munck was also on the advising committee of a graduate student who was working on WPND project. Dr. José Eduardo (Dudu) Meireles, Associate Professor at the University of Maine (UMaine), helped us with spectral data collection and data processing. Our collaborators periodically joined the research discussions and reviewed the data processing methodology. Dr. William Livingston also from SFR, UMaine supported this project through regular discussion and supervision of the methods that have been applied. We published two peer-reviewed articles from this work where above scientists were co-authors.

Future Directions

We are currently working on expanding the EWP health map for other Northern regions through a different project.

Products

Peer-Reviewed publications

Das, P., Rahimzadeh-Bajgiran, P., Livingston, W., McIntire, C. D., & Bergdahl, A. (2024). Modeling forest canopy structure and developing a stand health index using satellite remote sensing. *Ecological Informatics*, 84, 102864. https://doi.org/10.1016/j.ecoinf.2024.102864

Timalsina, S., Rahimzadeh-Bajgiran, P., Das, P., Meireles, J. E., & Bhattarai, R. (2024). Monitoring eastern white pine health by using field-measured foliar traits and hyperspectral data. *Sensors*, *24*(18), 6129. https://doi.org/10.3390/s24186129

Theses

Timalsina, Sudan, "Monitoring Eastern White Pine Health by Using Remote Sensing Assessement of Foliar Traits" (2024). Electronic Theses and Dissertations. 3982. https://digitalcommons.library.umaine.edu/etd/3982

Conference Presentations

Das, P., Rahimzadeh-Bajgiran, P., Livingston, W., McIntire, C. D., & Bergdahl, A. EWPHI: A Novel Eastern White Pine (EWP: *Pinus strobus*) Health Index Based on Remote Sensing Data, NESAF Conference; March 27-29, 2024; South Burlington, VT, USA.

Das, P. and Rahimzadeh-Bajgiran P., Remotely Sensed Estimation of Live Crown Ratio (LCR) for Eastern White Pine (EWP) Health Assessment", ASPRS 2024 Geo Week, February 11-13, 2024, Denver, CO, USA.

Timalsina, S. and Rahimzadeh-Bajgiran P., Assessing White Pine Needle Damage (WPND) Impact on Eastern White Pine (EWP) Health through Modeling Foliar Traits using Remote Sensing Data, ASPRS 2024 Geo Week, February 11-13, 2024, Denver, CO, USA.

Other Tangible Products

- IEEE Maine January 2025 Newsletter (https://r1.ieee.org/maine/wp-content/uploads/sites/29/Beacon_January25.pdf)
- Interview done in September 2025 by Hubbard Brook Research Foundation

Student Involvement

Category	**Names**	**Degree Sought**
Post-Doctoral	Dr. Pulakesh Das	N/A

Graduate Students	Sudan Timalsina Garima Yadav	MS
Summer Students	Rajeev Bhattarai	PhD

Monitoring Moose and Other Culturally Important Wildlife on Penobscot Nation Lands Using Remote Cameras

Principal Investigator: Benjamin Simpson (Penobscot Nation Department of Natural Resources, benjamin.simpson@penobscotnation.org)
Co-Principal Investigators: Nina Kappel, Graduate Student, University of Maine Department of Wildlife, Fisheries, and Conservation Biology, nina.kappel@maine.edu; Sabrina Moreno, Assistant Professor, University of Maine Department of Wildlife, Fisheries, and Conservation Biology, sabrina.morano@maine.edu; Therese Donovan, Assistant Unit Leader, USGS Vermont Cooperative Fish and Wildlife Research Unit, University of Vermont, tdonovan@uvm.edu; Alexej Sirén, Postdoctoral Researcher, Vermont Cooperative Fish and Wildlife Research Unit, University of Vermont, alexej.siren@uvm.edu; Laurence Clarfeld, Postdoctoral Researcher, Vermont Cooperative Fish and Wildlife Research Unit, University of Vermont, laurence.clarfeld@uvm.edu

Project Outcomes

Preliminary data suggests that hair loss patterns observed during remote surveys reflect patters that have been observed in prior captive studies of hair loss due to winter tick infestation, indicating that cameras can be an effective tool to monitor moose population on the landscape.

Project Summary

The purpose of this project was to develop a multi-species monitoring program using remote cameras to track population trends of moose and other wildlife species found on Penobscot Nation (PN) lands. This project will help PN sustain healthy populations of wildlife to protect cultural traditions and also serve as an educational tool to engage tribal members and preserve Penobscot culture. 70 cameras across 7 tribal properties were set using an established protocol for monitoring wildlife in the region. The camera data were collected seasonally by PN staff using Survey123, and managed, stored, and analyzed using AMMonitor. The camera images were tagged to species to allow for population monitoring of multiple wildlife species. Hair loss was also assessed as a proxy for winter tick infestation on moose. Hair loss was characterized for moose using a quadrant system which allowed for assessment in cases where

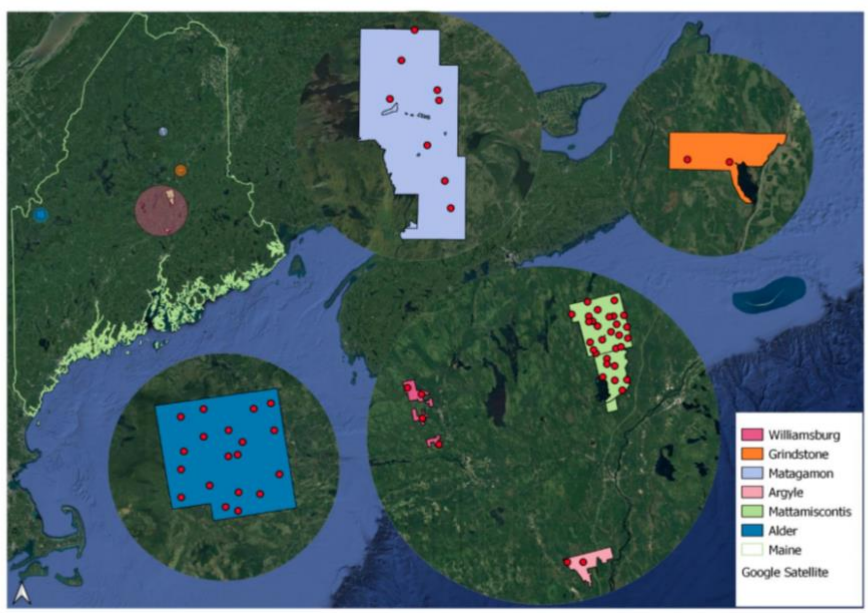

Figure 18. Camera locations across Tribal Trust lands. Created by Nina Kappel.

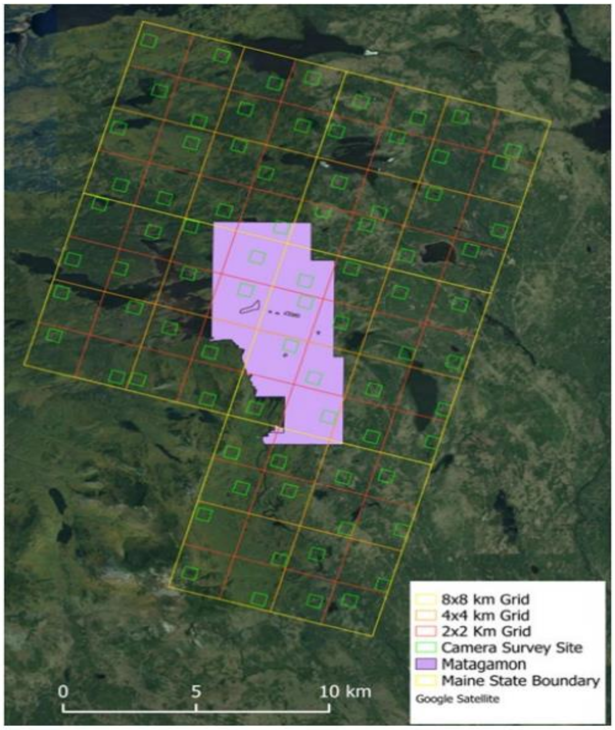

Figure 19. Non-overlapping nested grid used to select camera survey sites overlaid across the Matagamon property.

incomplete views of the animal occurred. Hair loss patterns were identified through time that were consistent with infestation and hair loss in captive animals. Variation in patterns of hair loss across tribal lands was identified. These results indicate that cameras can be an effective tool for monitoring infestation rates on moose populations across a geographic range. Hair loss scores plus environmental data and forest composition will be used to evaluate the impacts of ticks on moose occupancy. These results can aid in moose management on tribal lands and be used to solicit advice from tribal members on important variables for other species. The AMMonitor framework will be used to evaluate annual occupancy outputs and integrate the decision making approach of the PN to inform any changes in management for wildlife on Tribal lands and the larger Northern Forest landscape.

Background and Justification

The PN has sole jurisdiction over 129,000 acres of land in Maine. The PN manages these lands for the cultural activities of tribal members. One major priority is to conserve and manage wildlife as many species are culturally important and a source of food. Moose (*Alces alces*) are the most important game species for the PN. However, recent declines in regional populations due to winter ticks (*Dermacentor albipictus*) have caused concern among the Tribe. In response to these threats, the PN has implemented aerial surveys to estimate moose populations. However, aerial surveys are costly and not a viable long-term monitoring solution. Remote cameras are a cost-effective and robust method for monitoring moose and other wildlife species in the region. They provide abundant data and can be used to engage tribal members with wildlife on PN lands.

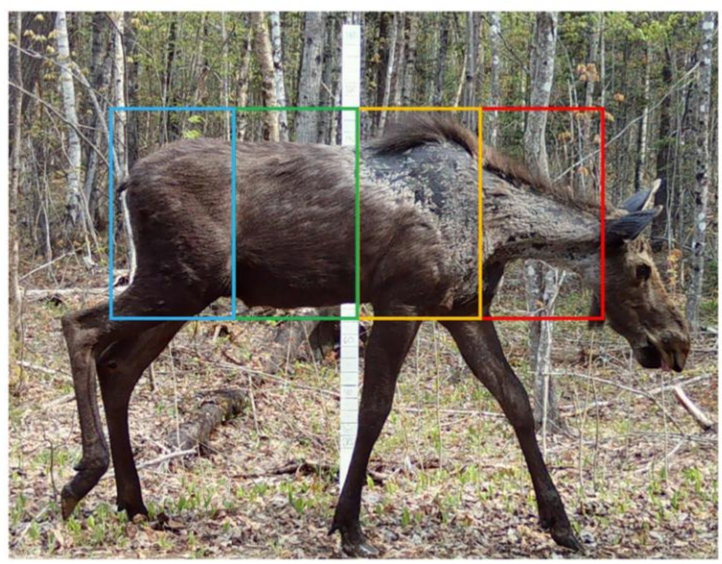

Figure 20. Quadrants of the body used to estimate winter tick induced hair loss. Each quadrant is given a hair loss score (e.g. N/A,No Hair Loss Detected, < 5% of hair damaged, 6-25% of hair damaged, 26-50% of hair damaged, 51-75% of hair damaged ,76-100% of hair damaged)

Methods

Camera survey sites were selected using non-overlapping and nested grids ranging from 2x2 km,4 x 4 km, and 8 x 8 km in size overlaid across 7 tribal properties. To improve detection probability for multiple species, cameras were set along game trails in 500 x 500 m patches of either mature or young forest available within the 4 x 4 km grids. The 76 cameras that were deployed during the 2023-2024 season were monitored. A secondary camera check was performed during summer of 2024 where SD cards were collected and processed. A total of 98,627 unique images were uploaded to AMMonitor over the course of the project to date. New images from the secondary check were annotated with species identification information by an additional 35 undergraduate students as part of the Wildlife-Habitat Relationships course. Any remaining images were processed by a trained team of undergraduate volunteers. Following species identification, the team of trained volunteers quantified hair loss assessment using a novel quadrant scoring system for images where moose were detected during the initial round of species identification tagging (Figure 20). Only images where a moose is upright, image taken during the winter tick season (Jan 1st - May 15th), and where at least one full quadrant of the body visible were considered for quadrant scoring. Additionally, during this step, images that were misclassified as moose by prior volunteers were reclassified and supplementary information about individual animals' age and sex were also recorded.

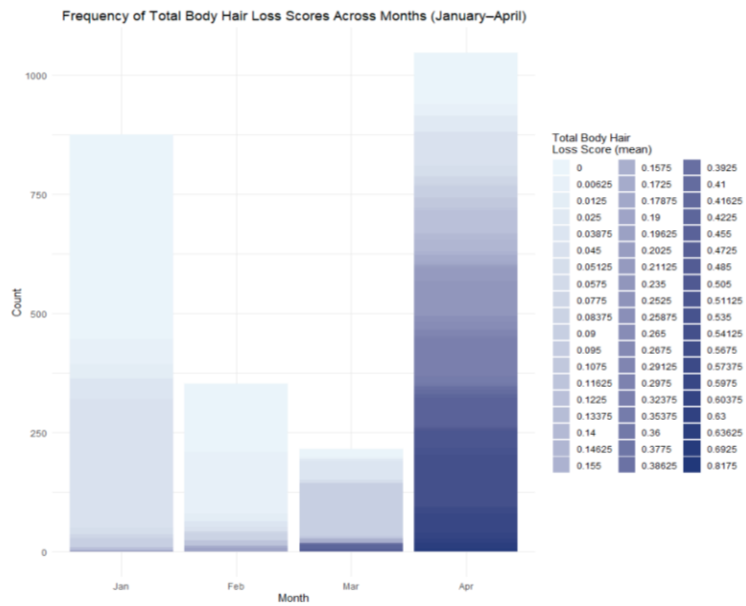

Figure 21. A stacked bar chart showing the frequency of median hair loss estimates across months where winter tick induced hair loss is observable.

Key Findings

Just under 100,000 images have been uploaded to AMMonitor and annotated by the team of students and volunteers. Over 30 different taxa have been observed, including approximately 42,000 unique detections (a unique detection being defined as a unique image of an animal) of moose, 8,000 unique detections of white-tailed deer (*Odocoileus virginianus*), and 1,500 detections of black bear (*Ursus americanus*). Furthermore, while not as numerous, we also had several detections of Canada Lynx (*Lynx canadensis*), a federally listed species. Through the species identification processing, 98,627 raw images resulted in 43,733 moose annotations (the number of moose annotations reflects individual animals detected within an image; thus, this number is greater than just the number of images where at least one moose was observed). Of these moose observations 4,953 included at least one moose that was visible enough to be given a full body quadrant assessment, while 6,415 moose observations were only suitable for partial tagging. Exploratory data analysis suggests that the patterns of hair loss observed using camera survey images reflects patterns that have been observed in experimental studies using captive moose that were exposed to winter tick. Observations of hair loss peaked in April (Figure 20) with quadrants closer to a moose's head showing more variation in the amount of hair loss observed (Figure 21). Furthermore, variation in hair loss severity across the 7 tribal properties was observed.

Implications and Applications in the Northern Forest Region

Initial findings suggest that it is possible to detect changes in patterns of hair loss observed through camera surveys. A change in the variation in winter tick induced hair loss across the winter tick season (January–April) was observed, with the greatest variation observed at the end of the winter tick in April. These preliminary results show promise in utilizing remote cameras in detecting instances of winter tick induced hair loss and further potential in understanding how hair loss severity may vary spatially and temporally. Winter tick distribution is believed to be driven largely by moose movement during the questing and drop off periods, therefore understanding potential landscape drivers of severe hair loss during the drop off period may help us identify the hotspots facilitating future outbreaks. Since tribal lands are managed with longer harvest intervals than commercially managed forests our work may inform how moose impacted by winter tick use these older forests and if stand age is associated with hair loss severity.

Future Directions

Hair loss data collected will continue to be analyzed, with a focus on understanding the relationship between tick induced hair loss and moose presence on tribal lands. The next steps will focus on understanding the impacts of tick-induced hair loss on moose occupancy. Additionally, examination if specific habitat conditions such as stand age, site, or landcover type are associated with varying levels of hair loss severity will be conducted. Because camera surveys are not species specific, future research can focus on using this data set to understand other species of interest to the tribe including other large mammals like black bear or white-tailed deer. Additionally, these camera surveys also captured images of uniquely marked collared individuals, which presents a unique opportunity to potentially make estimates about moose population size.

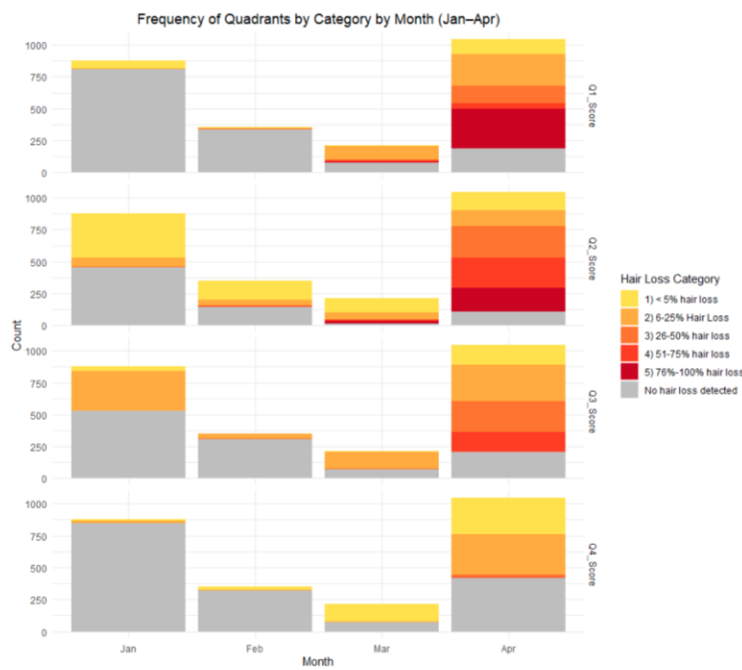

Figure 22. A stacked bar chart showing the frequency of hair loss observations of varying severity in different body quadrants across the months where winter-tick induced hair loss is observable

Products Delivered

- Kappel, N. S. (2024, May 14). *Assessing moose distribution and impacts of winter tick using remote camera surveys* [Oral presentation]. 42nd Annual National Conference of the Native American Fish and Wildlife Society, Wyoming, United States of America.

https://www.nafws.org/wp-content/uploads/2021/04/2024-National-Conference-Agenda-4.5.2024.pdf

- Kappel, N., Morano, S., Simpson, B., & Siren, A. (2024, May 13–16). *Evaluating moose–winter tick dynamics utilizing remote cameras on Penobscot Nation lands in Maine* [Conference presentation]. North American Moose Conference and Workshop, Utah, United States.
- Morano, S., Kappel, N., & Carovillano, C. (2023, December 13–14). *Moose habitat ecology and Maine forests* [Invited presentation]. Northeast Moose Meeting: Moose Research in the Northeast U.S. and Eastern Provinces of Canada, Sherbrooke, Quebec.
- Simpson, B., Kappel, N., Morano, S., & Siren, A. (2024, May 13–16). *Evaluating moose–winter tick dynamics utilizing remote cameras on Penobscot Nation lands in Maine* [Conference presentation]. 41st Annual Native American Fish and Wildlife Society National Conference, Prairie Island Indian Community, Welch, Minnesota. https://www.nafws.org/wp-content/uploads/2021/04/2024-National-Conference-Agenda-4.5.2024.pdf
- Simpson, B. (2025, June 23–27). *Finding our niche: An overview of moose management on Penobscot Nation tribal lands* [Conference presentation]. 9th International Moose Symposium, Östersund, Sweden. https://moosesymposium2025.se/programme/

Student Involvement

Category	Names	Degree Sought
Graduate Students	Nina Kappel	MS
Undergraduate Students	Brendan McGowan Courtney White Amber Smilen	WLE-BS

Undergraduates were included in this work by incorporating photo tagging as an activity in a Wildlife-Habitat Relationships course (~40 students) in the spring of 2024 and 2025. During this course students assisted with species identification of raw images.

Additionally, a team of (~5) undergraduate volunteers was developed that participated in species identification and hair loss assessment. As part of this project, an outreach program for the Penobscot Nation's tribal school was developed. Students practiced identifying different species in the Penobscot language using images collected from camera surveys. This activity was tied to a larger lesson about wildlife conservation as a whole and the role citizen science plays in understanding the natural world.

Partners/Stakeholders/Collaborators

Sabrina Morano, Assistant professor. Department of Fisheries, Wildlife and Conservation Biology, University of Maine, Grad Student Advisor

Geographic Location

Tribal Property	Lat, Long	Acres
Alder Stream	45.256196°, -70.639692°	23,503
Argyle	45.075070°, -68.717989°	7,105
Mattamiscontis/T2R8	45.445999°, -68.666012°	32,235

Lakeville/T3R1	45.268330°, -68.137585	14,453
Matagamon	46.170705°, -68.787684°	7,131
Grindstone	45.746285°, -68.512486°	5,300
Williamsburg	45.365396°, -69.101677°	4,419
Total		**94,146**

Leveraged Funding

Source	Amount	Direct/In-Direct
University of Maine	$4,000	Direct
University of Maine	$42,000	Direct

Impacts of Extreme Climate Events on Tree Regeneration in the Northern Forest

Principal Investigator: Jay Wason (University of Maine, jay.wason@maine.edu)
Co-Principal Investigators: Nicholas Fisichelli (Schoodic Institute at Acadia National Park, nfisichelli@schoodicinstitute.org), Nicole Rogers (Maine Forest Service, nicole.s.rogers@maine.gov), Yongjiang Zhang (University of Maine School of Biology and Ecology and Xishuangbanna Tropical Botanical Garden, yongjiang.zhang@maine.edu)

Project Outcomes

- Combined heat and drought events have outsized impacts on tree seedling survival, particularly for trees near their warm range-margins.
- Compared to deciduous species, evergreen tree seedlings advanced their leaf-out timing and lost cold tolerance more rapidly in response to winter warming events.

Project Summary

The likelihood of extreme climate events that impact trees is increasing in both summer and winter. However, it is unclear how forest managers should plan for the impacts of extreme climate events that significantly impact forest structure and composition. The goal of this project is to determine how tree regeneration in the Northern Forest will respond to extreme drought, heat, and winter warming events to better inform forest management decision making. Two separate experiments were conducted with planted seedlings of tree species common to the Northern Forest. In the first, more than 760 tree seedlings were planted in containers across 6 locations in Maine and built custom chambers to expose them to heat, drought, and combined heat and drought. In the second, 300 tree seedlings were exposed to 6 different winter and spring warming treatments and tracked their phenology and growth. Overall, it was found that the combined heat and drought treatment caused the largest reduction in seedling survival, particularly for tree species that were near their warm range-margins. The study also found that compared to seedlings of deciduous species, seedlings of evergreen species were more sensitive to warming events leading to advanced leaf-out timing and a loss of cold tolerance. Combined, these results demonstrate the profound effects of extreme events on tree regeneration. They highlight the opportunity for managers to consider management that

Figure 23. Conducting Measurements inside of one of the heat and drought chambers.

minimizes exposure to extreme events, particularly for species already near their warm range-margin or that are known to be sensitive to these abiotic changes. Managers can also consider how potential exposure to these extreme events can encourage a managed or unmanaged shift towards a new species composition.

Background and Justification

Extreme climate events such as heat, drought, and winter warming are expected to increasingly affect trees in the Northern Forest (Coble et al. 2017; Vose et al. 2019). Although adaptive management is widely recommended, uncertainty remains about how managers should incorporate climate variability and extremes into forest planning because their impacts are not well understood (Moss et al. 2024; Breigenzer et al. 2024). This gap is critical, as theory and empirical evidence indicate that extreme events, particularly compounded extremes, rather than gradual mean warming, are likely to drive major forest change (Jackson et al. 2009; Mitchell et al. 2014). Preparing for these potentially high-impact events is essential, as they are expected to occur sooner and could cause disproportionate ecological damage.

Recent events illustrate these risks. Sustained summer drought and extreme heat in 2020 negatively affected tree growth and physiology, and such conditions can lead to mortality, especially in Northern Forest species with limited historical exposure (Coble et al. 2017; Wason et al. 2018; Barry et al. 2024). Drought and heat reduce photosynthesis through stomatal closure, disrupt water transport, and amplify stress when occurring together (Barry et al. 2024; Choat et al. 2018; Grossiord 2020). Outside the growing season, midwinter warming events can prematurely trigger phenology, increasing vulnerability to refreezing and contributing to decline (Bourque et al. 2005; Ladwig et al. 2019). Tree regeneration may be particularly sensitive to these extremes, underscoring the need for experimental approaches that simulate future conditions. This knowledge will allow managers to anticipate regeneration failures, promote stress-tolerant species, and guide transitions in forest composition toward species better adapted to future climate extremes.

Figure 24. Collecting samples for estimates of cold tolerance.

Methods

Overall, the project proceeded as originally planned. For the first study, across 6 sites in the Northern Forest, more than 760 seedlings of ten tree species (red maple, sugar maple, paper birch, American chestnut, red oak, balsam fir, red spruce, red pine, white pine, and eastern red cedar) were planted in 76 40-L containers in spring of 2023 (one seedling of each species per container). At each site, the 12 to 16 containers were split among control, heat, drought, and heat × drought treatments and treatments were applied using custom-built chambers in July of 2024.

Environmental conditions, growth, survival, and physiology were tracked throughout the study. For the second study, 300 tree seedlings were planted of the same 10 species in individual 7.5-L containers in spring 2023. In February through April of 2024, a range of warming treatments were implemented by bringing containerized seedlings into a greenhouse at different points in the season and for different lengths of time before returning them back outdoors. Cold tolerance as well as the subsequent timing of bud burst and leaf out for each tree was tracked, and growth and survival was measured the following summer.

Key Findings/Accomplishments

Study #1: Heat and drought

Key results

- Across all species, drought partly reduced survival but heat × drought reduced survival the most.
- Northern species that were near their warm range-margin had the greatest reductions in survival.
- If seedlings survived, their growth that year was not impacted.
- Rather than plant traits, the species' climate niche was most closely associated with survival patterns: species from warmer climates generally had higher survival.

Management implications

- Management that reduces exposure to heat (e.g., maintain partial canopy cover) or drought (e.g., maintaining drought safe sites like deadwood substrate) can dramatically reduce the risk of mortality from a compounded stress event.

Study #2: Winter warming

Key results

- Warming treatments advanced leaf out between 5 and 41 days compared to controls.
- Leaf-out timing was best predicted by photoperiod (length of days) for deciduous trees and thermal time (exposure to warm temperatures) for evergreen trees.
- Cold tolerance was reduced for most species by 5 to 29 °C after only two weeks of warming.
- Most species did not experience cold damage, likely due to an unusually warm late winter and spring, further emphasizing the need for this research.
- Changing phenology did not impact total growth during the following growing season.

Management implications

- Managers can expect that winter warming events may have relatively modest impacts on tree regeneration unless warming events are followed by extreme cold that damages sensitive tissues.

Implications and Applications in the Northern Forest Region

The management implications, detailed in the previous section, have been part of the communication strategy throughout the later stages of the grant as results were coming in (see Products Delivered section, below). An extensive team of collaborators contributed to and benefited from participating in this project. Collaborating organizations hosted research sites, participated in data collection, attended annual meetings, and helped co-develop project goals and outcomes.

Future Directions

Emphasis on monitoring tree seedlings in forest inventories and documenting how environmental stressors contribute to changes in growth and survival. Particularly important in mixed forests and transition zones between forest types. Continued and expanded monitoring of tree phenology and extreme events is needed to expand results into a forest setting.

Products

Peer-reviewed publications

- Pinover, L., Butnor, J.R., Fisichelli, N., Murakamib, P., Rogers, N., Zhang, Y.J., and Wason, J. Earlier leaf out and loss of cold tolerance for northeastern U.S. trees in response to winter warming events and early springs. In advanced stages of preparation for submission in early 2026.
- Pinover, L., Mrenna, B., Fisichelli, N., Rogers, N., Zhang, Y.J., and Wason, J. Higher risk of mortality for tree regeneration at warm range margins during compounded heat and drought. In advanced stages of preparation for submission in early 2026.

Research/technical Reports

- Mrenna. B., Pinover, L., Fisichelli, N., Rogers, N., Zhang Y.J., and Wason, J. "Future Forests: Heat and Drought Impacts on Tree Regeneration in Maine" 2-page outreach document for landowners.

Theses

- Pinover, Laura, "Impacts of Extreme Climate Events on Tree Regeneration in the Northern Forest" (2025). M.S. Thesis. *Electronic Theses and Dissertations*. 4233. https://digitalcommons.library.umaine.edu/etd/4233
- Mrenna, Brigid, "Testing How Plant Traits Predict Survival of Northeastern U.S. Tree Seedlings Under Compounded Heat and Drought Stress" (2025). Undergraduate Honors Thesis.
- LaCasse, Casandra, "Phenological Response of Northeastern Tree Species to Midwinter Warming Events" (2024). Undergraduate Capstone Project.

Conference Papers

- Pinover, L., Butnor, J., Murakami, P., Rogers, N., Zhang, Y., & Wason, J. (2024, December). *Impacts of early springs and winter warming events on spring phenology and cold tolerance among temperate and boreal tree species* [Oral presentation]. Forest Ecosystem Monitoring Cooperative Annual Meeting, Burlington, Vermont.

Conference presentations (including workshops and posters).

- Mrenna, B., Pinover, L., Fisichelli, N., Rogers, N., Zhang, Y., & Wason, J. (2025, April). *How do plant traits relate to the survival of tree seedlings under compounded heat and drought stress?* [Poster presentation]. University of Maine Annual Student Symposium, Orono, Maine.
  Award: Dr. Susan J. Hunter Presidential Research Impact Award.

Seminars/Webinars/Workshops/Field Tours

- Wason, J., Pinover, L., Pollard, K., Harriman, J. W., Gellman, R., Rogers, R., & Bosley-Smith, C. (2025, July). *Conservation challenges and management decision making in Maine's coastal forests* [Field tour and workshop]. Surry Forest, Surry, Maine.

- Wason, J., Grega, M., & Pinover, L. (2025, April). *How extreme weather events impact trees in Maine* [Invited seminar]. Dirigo Pines, Orono, Maine.
- Wason, J., Grega, M., & Pinover, L. (2025, March). *How do heatwaves and drought events impact Maine's trees* [Invited seminar]. Maine Center for Research in STEM Education, Orono, Maine.
- Wason, J., Grega, M., & Pinover, L. (2025, February). *How do heatwaves and drought events impact Maine's trees* [Invited seminar]. Forest Society of Maine, Bangor, Maine.
- Wason, J., & Pinover, L. (2024). *Tree responses to winter warming events* [Undergraduate instructional module]. Semester-long module developed and delivered for ~45 first-year forestry students; included data collection and final reports.
- Wason, J., Pinover, L., Mrenna, B., & Hilli, C. (2024, June). *Forests and climate change* [Field workshop]. Greenville Field and Forest Day, Greenville, Maine.
- Wason, J., MacDonald, E., & Pinover, L. (2024, May). *Assisted migration of Maine's forests: Insights from experimental planting studies in Maine* [Invited seminar]. Maine Organic Farmers and Gardeners Association.

Other tangible products (videos, websites, databases, interviews, etc.).

- "Planting for the future". YouTube video produced by the University of Maine specifically focused on our project. https://www.youtube.com/watch?v=MJg_RxFglKA&t=1s

Student Involvement

Category	Names	Degree Sought
Graduate Students	Laura Pinover	MS Forest Resources
Undergraduate Students	Brigid Mrenna Cassandra LaCasse	BS Ecology and Environmental Sciences BS Biology

Partners/Collaborators/Stakeholders

Forest Society of Maine, Piscataquis County Soil and Water Conservation District, The University of Maine School of Forest Resources, The University of Maine Roger Clapp Greenhouses, The Maine Agricultural and Forest Experiment Station, The Blue Hill Heritage Trust, Newell Family Tree Farm, the Schoodic Institute, The Greenville Consolidated School, the Maine Forest Service, and The US Forest Service Northern Research Station.

Geographic Location

Heat and drought study planting locations:

- 45.43604465146681, -69.59265824033066
- 45.218807940757976, -69.18753739076469
- 44.90430665121276, -68.65976449609686
- 44.63464236120767, -69.28312794835954
- 44.53140716421763, -68.57839213131545
- 44.33863095246385, -68.06036360065417

Location of winter warming experiment

- 44.89701217624736, -68.66915376472006

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Source:	Amount	**Direct/In-Direct**
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