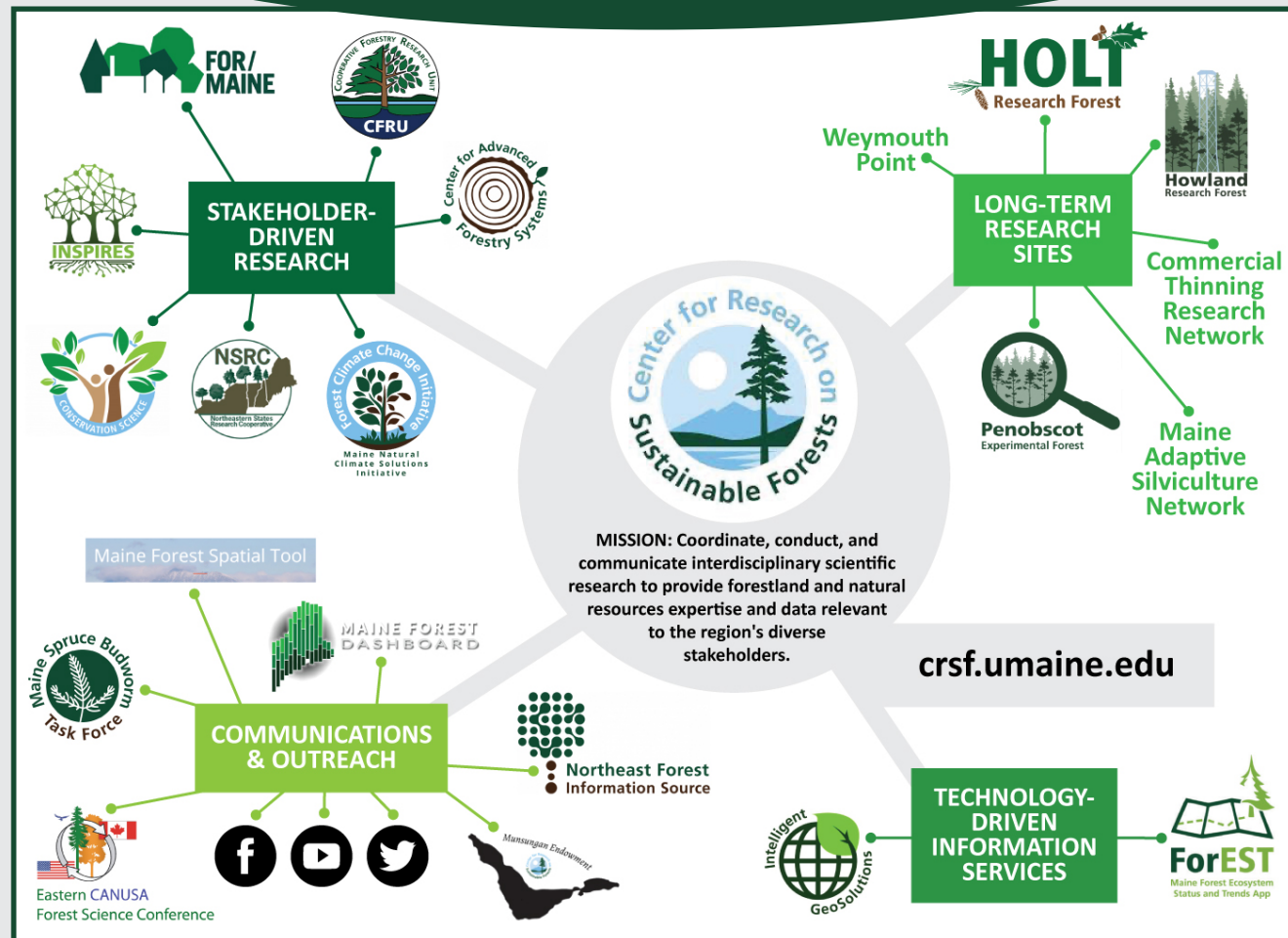


# Center for Research on Sustainable Forests

## 2022 Annual Report



Our mission is to conduct and promote leading interdisciplinary research on issues affecting the management and sustainability of northern forest ecosystems and Maine's forest-based economy.



The Center for Research on Sustainable Forests (CRSF) was founded in 2006 to build on a rich history of leading forest research and to enhance our understanding of Maine's forest resources in an increasingly complex world. The CRSF houses a variety of forest research programs and initiatives, including the Cooperative Forestry Research Unit (CFRU), Northeastern States Research Cooperative (NSRC), Forest Climate Change Initiative (FCCI), Intelligent GeoSolutions (IGS), Nature-based Tourism, and the National Science Foundation Center for Advanced Forestry Systems (CAFS). The CRSF continues to develop, integrate, and apply emerging technologies and informatics methods to address current and future issues to support the sustainable management of the region's natural resources.

### Center for Research on Sustainable Forests

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The Center for Research on Sustainable Forests (CRSF) entered its 16th year of existence this year and has been under my leadership since 2016. We are very excited to get back to almost business as usual and resume in-person events, particularly our very successful and popular Forest Climate Change Initiative's Science & Practice field tour series done in partnership with the Forest Stewardship Guild. These partnerships and events have greatly expanded the recognition and visibility of CRSF endeavors. We are excited to share our accomplishments from the past year in this report and to begin planning for the coming year.



As outlined these pages, CRSF has fully embraced the land grant university mission of research, education, and service. In terms of research, CRSF continues to led on multiple stakeholder-led research efforts including the Cooperative Forestry Research Unit (CFRU), Center for Advanced Forestry Systems (CAFS), Northeastern States Research Cooperative (NSRC), and the National Science Foundation Track 2 project entitled INSPIRES. CFRU, NSRC, and CAFS support stakeholder-led and approved research projects at the local-, regional-, and national-scales, respectively. These efforts provide invaluable forest research and continue to evolve with the times. For example, NSRC funded several Maine-based projects via its second-round of the Indigenous Forest Knowledge program, and I am truly delighted to continue to work with our Tribal partners to ensure that program remains active. Likewise, INSPIRES, which has been a large collaborative effort with the UNH and UVM, successfully completed its third year and moves into its final year of funding. Significant outcomes from INSPIRES will be prominently featured at the NSF National EPSCoR meeting in Portland Maine in November.

CRSF endeavors to support both undergraduate and graduate students through a variety of means. The CFRU resumed hiring summer student field crews who gain direct research experience by establishing and maintaining research installations on CFRU member lands throughout the state. CAFS received three supplemental grants (Research Experience for Undergraduates, Non-Academic Research Internships for Graduate Students [INTERN], and Skills Training in Advanced Research & Technology [START] with Monroe Community College in New York) that directly supported students. The CAFS START grant with the University of Maine at Fort Kent moved into its second year and continued to support undergraduates students there. The INTERN funding supported CRSF/CAFS MS student Ryan Smith, and allowed him to gain valuable professional training during a six-month internship with Seven Islands Land Company in Bangor. Over the summer, the START grant with Monroe Community College brought two students from upstate New York to Maine to engage in several ongoing CAFS-related research projects. These unique educational opportunities created by CRSF give students the skills and knowledge needed for future careers.

For service, CRSF Communications and Outreach Coordinator Meg Fergusson continued her outstanding efforts to better engage scientists, practitioners, and the general public on issues as well as outcomes relevant to CRSF. CRSF staff manage a variety of external websites in addition to our CRSF webpage: Maine Spruce Budworm Task Force, Northeast Forest Information Source, Maine Forest Dashboard, and New England Sustainability Consortium. In addition, we maintain numerous and rather active social media websites like Twitter, Facebook, and YouTube. Both the content and usage of these websites continue to grow through our strategic efforts for engagement. The combination of media platforms, e-newsletters, and direct interactions, particularly the Forest Climate Change Science & Practice webinar/field tour series, has been a great way to connect with a diverse audience and highlight the great research that CRSF is doing.

Overall, it has been yet another highly successful year in CRSF's history and I look forward to the year ahead.

*Aaron Weiskittel*  
AARON WEISKITTEL

Professor, Forest Biometrics & Modeling  
Director, Center for Advanced Forestry Systems





- ❖ Four-year Center review completed in early 2022 highlights how CRSF has grown significantly in its capacity and overall impact on multiple fronts, including research, outreach, and education. [The report](#) summarizes its successes and challenges to enhance our understanding of Maine’s forest resources in an increasingly complex world.
- ❖ Natural Climate Solutions analysis and findings for forest and agriculture practices final report and fact sheets published.
- ❖ Season 2 of the Forest Climate Change Science & Practice coupled lunch hour webinars with in-person field tours at Holt Research Forest, Schoodic Peninsula, Rangeley Lakes region, and Penobscot Experimental Forest.
- ❖ “Developing Priorities for Eastern White Pine Health and Management” symposium held in March 2022. Topics included white pine health issues, management of EWP in natural systems, and management of EWP at the rural/urban interface.
- ❖ Over the last 25 years Howland Forest has stored almost 3.5 tons of CO2 per acre each year, even though that timespan has included the warmest, wettest, and driest years in the last 125. Although the Howland Forest is maturing, it is storing on average a bit more carbon each year. Over the past year, three graduate and two undergraduate students gained training at Howland.
- ❖ Our [online web mapping system \(ForEST\)](#) was substantially restructured and the code base modernized to improve operability and stability. This project has prioritizes recruiting recent CS graduates as lead programmers with supportive mentoring by senior personnel.
- ❖ US Congress appropriated \$5 million in funding for the Northeastern States Research Cooperative (NSRC) for FY22.
- ❖ NSF awarded PI Weiskittel \$599,999 in supplemental funds to the INSPIRES T2 EPSCoR project (INSPIRES). The INSPIRES team will use the funding to build a strategic partnership with the Alabama Agricultural & Mechanical (AAMU) University, an Historically Black College and University (HBCU).
- ❖ The INSPIRES project supported a 4-day workshop/teacher’s tour at the Schoodic Peninsula to develop quantitative reasoning in context lessons for the classroom focused on forestry. Videos about the workshop produced for the CRSF YouTube playlist ([Inspires: Smart Data for Resilient Forests](#)).
- ❖ CRSF staff produced a series of [profiles of INSPIRES graduate students and researchers](#) on the project.
- ❖ The University of Eastern Finland, in collaboration with the University of Maine and the Michigan State University, presented a four-part webinar series focused on Forestry in Finland and the Northern United States.
- ❖ UMaine’s CRSF, lead site for the NSF-supported Industry/University Research Cooperative [Center for Advanced Forestry Systems \(CAFS\)](#), hosted an in-person industry advisory board meeting for 55 attendees in Snoqualmie, WA.
- ❖ FCCI Natural Carbon Solutions team released its final report [Forestry and Ag GHG Mitigation](#).
- ❖ Meg Fergusson, CRSF Communications & Outreach Coordinator, named University of Maine Outstanding Research Administrator for 2022.
- ❖ The Cooperative Forestry Research Unit (CFRU) staff hosted a faculty and student meet and greet to discuss research funding opportunities through the CFRU, while undergraduates were able to learn about summer field research opportunities.

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**Leslee Canty-Noyes, CRSF/CFRU Administrative Specialist**  
**Regina Smith, CFRU Communications & Outreach Specialist**

**Aaron Weiskittel, CRSF Director**  
**Professor, Forest Biometrics & Modeling**  
**Meg Fergusson, CRSF Communications & Outreach Specialist**

**Researchers & Collaborators from Partner Institutions**

**UMaine Faculty & Research Staff**

|  |   |   |
|--|---|---|
| Carol Adair, University of Vermont                                     | Kelly French, Maine TREE                                | Andrew Ouimette, University of New Hampshire                |
| Chad Babcock, University of Minnesota                                  | Adam Gibson, Acadia National Park/National Park Service | Michael Parisio, Maine Forest Service                       |
| Scott Bailey, Northeastern Soil Monitoring Cooperative                 | Alex Giffen, New England Forestry Foundation            | Christine Parrish, New England Forestry Foundation          |
| Kaitlyn Baillargeon, University of New Hampshire                       | Rich Grogan, Northern Borders Regional Commission       | Marek Petrik, University of New Hampshire                   |
| Karen Beeftink, University of Maine at Machias                         | John Gunn, University of New Hampshire                  | Ian Prior, Seven Islands Land Co.                           |
| Ethan Belair, The Nature Conservancy                                   | John Hagan, Our Common Climate                          | Joshua Puhlick, The Jones Center at Ichauway                |
| Aaron Berghahl, Maine Forest Service                                   | Chris Hennigar, University of New Brunswick             | Karin Rand, University of Vermont                           |
| Nicholas Brazee, Plant Disease Clinique Specialist, UMass              | Dave Hollinger, USDA Forest Service                     | Michael Reed, Tufts University                              |
| Elizabeth Burakowski, University of New Hampshire                      | Shaik Hossain, Alabama A&M University                   | Donna Rizzo, University of Vermont                          |
| Nicholas Butler, USDA NRCS   | Dave Houston, USDA Forest Service                       | Steve Roberge, Forest Extension Specialist, UNH             |
| Aimee Classen, University of Vermont                                   | Michael Jensen, Maine Forest Service                    | Brian Roth, SeedTree  |
| Alix Contosta, University of New Hampshire                             | Logan Johnson, Forest Stewards Guild                    | Shelby Rousseau, Rangeley Lakes Heritage Trust              |
| Bruce Cook, NASA GSFC  | Allison Kanoti, Maine Forest Service                    | Joe Roy, Maine DIFW   |
| Mindy Crandell, Oregon State University                                | Laura Kenefic, USDA Forest Service                      | Kathleen Savage, Woodwell Climate Research Center           |
| Andy Cutko, Maine Department of Agriculture, Conservation and Forestry | Stacy Knapp, Maine DEP                                  | Charles (Tat) Smith, University of Toronto                  |
| Anthony D'Amato, University of Vermont                                 | Greg Lawrence, Northeastern Soil Monitoring Cooperative | Brent Sohngen, The Ohio State University / Sylvan Acres LLC |
| Julie Davenport, Maine Forest Service                                  | Dawn Lemke, Alabama A&M University                      | Kevin Solarik, NCASI  |
| Dedrick Davis, Alabama A&M University                                  | Adrienne Leppold, Maine IF&W                            | Rebecca Stanley, Friends of Acadia                          |
| Bob DeForrest, Maine Coast Heritage Trust                              | David Lutz, Dartmouth College                           | Aaron Teets, Northern Arizona University                    |
| Luben Dimov, University of Vermont                                     | Amanda Mahaffey, Forest Stewards Guild                  | Neil Thompson, UM at Fort Kent                              |
| Tom Doak, Maine Woodland Owners  | Don Mansius, Maine Forest Service                       | Regina Toolin, University of Vermont                        |
| Mark Ducey, University of New Hampshire                                | Mary Martin, University of New Hampshire                | Rex Turner, Bureau of Parks and Lands                       |
| Steve Dunham, Maine DIFW   | Peter McKinley, The Wilderness Society                  | Tom Walker, Independent Contractor                          |
| Caren Dymond, Gov't British Columbia                                   | Stacy McNulty, SUNY ESF                                 | Jay Wason, University of Maine                              |
| Peter Ellis, The Nature Conservancy                                    | Bethany Muñoz Delgado, USDA Forest Service              | Jennifer Watts, Woodwell Climate Research Center            |
| Kenny Fergusson, Maine Forest Service                                  | Peter Nelson, Schoodic Institute                        | Mary Whelan, Rutgers University                             |
| Andrew Finlay, Michigan State University                               | Sarah Nelson, Appalachian Mountain Club                 | Ethel Wilkerson, Manomet Inc                                |
| Nicholas Fischelli, Schoodic Institute                                 | Laura Nickerson, University of New Hampshire            | Patricia Wohner, New Hampshire Audubon                      |
| Carol Foss, New Hampshire Audubon                                      | Robert Northington, Husson University                   | Chris Woodall, USDA Forest Service                          |
| Jane Foster, University of Vermont                                     | Daniel Obrist, University of Massachusetts, Lowell      | Zaixing Zhou, University of New Hampshire                   |
| Jereme Frank, Maine Forest Service                                     | Scott Ollinger, University of New Hampshire             |   |
|  | Carolann Ouellette, Office of Outdoor Recreation        |   |

|                                   |                              |                                      |
|-----------------------------------|------------------------------|--------------------------------------|
| Ali Abedi, faculty                | Daniel Hayes, faculty        | Franziska Peterson, faculty          |
| Kate Beard-Tisdale, faculty       | Holly Hughes, research staff | Parinaz Rahimzadeh-Bajgiran, faculty |
| Ken Bundy, tech programmer        | Sarah Jackson, postdoc       | Darren Ranco, faculty                |
| John Daigle, faculty              | Keith Kanoti, faculty        | Sam Roy, research staff              |
| Adam Daigneault, faculty          | John Lee, research staff     | Bruce Segee, research staff          |
| Sandra De Urioste-Stone, faculty  | Kasey Legaard, faculty       | Linda Silka, faculty                 |
| Leo Edmiston-Cyr, tech programmer | Brandon Lieberthal, postdoc  | Erin Simons-Legaard, faculty         |
| David Evanoff, research staff     | Sara Lindsay, faculty        | Marina Van der Eb, research staff    |
| Ivan Fernandez, faculty           | William Livingston, faculty  | Yaxing Wei, postdoc                  |
| Shawn Fraver, faculty             | Susan McKay, faculty         | Aaron Weiskittel, faculty            |
| Allison Gardner, faculty          | Angela Mech, faculty         | Larry Whitsel, research staff        |
| Hamish Greig, faculty             | Laura Millay, research staff | Jack Witham, research staff          |
| Anthony Guay, research staff      | Alessio Mortelliti, faculty  | Salimeh Yasaei Sekeh, faculty        |
| Torsten Hahmann, faculty          | Silvia Nittel, faculty       | Jing Yuan, faculty                   |
|                                   |                              | Jianheng Zhao, postdoc               |

**Student Researchers**  
*(degree sought in parenthesis)*

|  |   |                                      |
|--|---|--------------------------------------|
| <b>Graduate Students</b>                           | Sarah Rappaport (MSc), Contributor          | Nathaniel Burke, Research Assistant  |
| Alley Barry (MSc), Research Assistant              | Zoe Read (MSc), Research Assistant          | MacKenzie Conant, Research Assistant |
| Colby Bosely-Smith (MSc), Research Assistant       | Joey Reed (MSc), Research Assistant         | Elyse Daub, Summer Technician        |
| Valeria Briones (MSc), Contributor                 | Gabby Sherman (PhD), Research Assistant     | Jack Ferrara, Summer Technician      |
| Alyssa Campbell (MSc), Contributor                 | Alyssa Soucy (MSc), Research Assistant      | Joshua Goldsmith, Summer Technician  |
| MacKenzie Conant (MSc), Research Assistant         | Gabrielle Venne (MSc), Research Assistant   | Kasey Grass, Summer Technician       |
| Asha DiMatteo-LePape (MSc), Contributor            | Bishnu Wagle (PhD), Research Assistant      | Hateva Levesque, Summer Technician   |
| Luke Douglas (MSc), Research Assistant             | Stephanie Willsey (MSc), Research Assistant | Mckenna Mollner, Research Assistant  |
| Thomas Fennell (MSc), Research Assistant           | Gabriela Wolf-Gonzalez (MSc), Contributor   | Shane Peterson, Summer Technician    |
| Alex K. George (PhD), Research Assistant           | Logan Woodyard (MSc), Research Assistant    | Emily Roth, Summer Technician        |
| Brooke Hafford MacDonald (PhD), Research Assistant | enna Zukswert (PhD), Research Assistant     | Natalie Siwek, Research Assistant    |
| Jamin Johanson (PhD), Research Assistant           |   | Kyle Smelter, Summer Technician      |
| Jonah Levy (PhD), Research Assistant               | <b>Undergraduate Students</b>               | Augusta Stockman, Research Assistant |
| Zoe Lidstrom (MF), Research Assistant              | Kelsi Anderson, Summer Technician           | Madison Syer, Research Assistant     |
| Lucy Martin (MSc), Research Assistant              | Autumn Brann, Research Assistant            | Emily Tomak, Summer Technician       |
| Sylvia Noralez (PhD), Research Assistant           | Jackson Ashby, Summer Technician            |                                      |
|  | Molly Bogner, Research Assistant            |                                      |



During FY22 (July 1, 2021-June 30, 2022), CRSF researchers were awarded nearly \$1.8M in external grants to support their research, in addition to nearly half a million in support from CFRU members and \$220,572 in funding provided by gifts and internal support (see Table 1 for budget detail). 14 additional proposals were submitted during FY22 which, if awarded, could bring in more than \$2M in extramural funding. Awards over the past year came from the National Science Foundation, US Department of Agriculture, National Aeronautics and Space Administration, Maine Dept. of Inland Fisheries and Wildlife, and the Maine TREE Foundation.

Income supporting the center in FY22 came from programs administered by or that support CRSF/CFRU staff and general operations, student employees, and outreach efforts (Figure 1). Extramural grants received by CRSF scientists from outside agencies support specific research projects described in this report. CFRU cooperators contributed \$496,852 to support applied forestry research lead primarily by University of Maine System faculty.

Total extramural funding of the CRSF topped \$1.8 million in FY22. CRSF scientists were able to leverage their grant awards for an additional \$887,304 in funding. The majority

(greater than 80%) of the CRSF budget is allocated directly to the research described in this report, supporting CRSF projects and initiatives: CFRU, Howland Research Forest, INSPIRES NSF research, Northeastern States Research Cooperative, Penobscot Experimental Forest, Forest Climate Change Initiative, Nature-based Tourism, Intelligent GeoSolutions, and the CAFS NSF Industry/University Cooperative. The remaining funds support personnel salaries and operating costs, outreach (including webinars and meeting support), and student employees and tuition aid. We are proud of the strong number of personnel involved with the CRSF over the years and the number of outcomes related to their efforts (Table 2).

A key source of financial support for the CRSF is provided by the Maine Economic Improvement Fund (MEIF). The \$200,769 investment from MEIF helps to cover Director Weiskittel’s salary and fringe as well as the Center’s personnel and operating costs. MEIF funds helped to leverage a total \$3.19M from extramural and CRSF sources—a \$15.87 return on investment for every dollar of MEIF funding.

Figure 1. Sources of CRSF Income

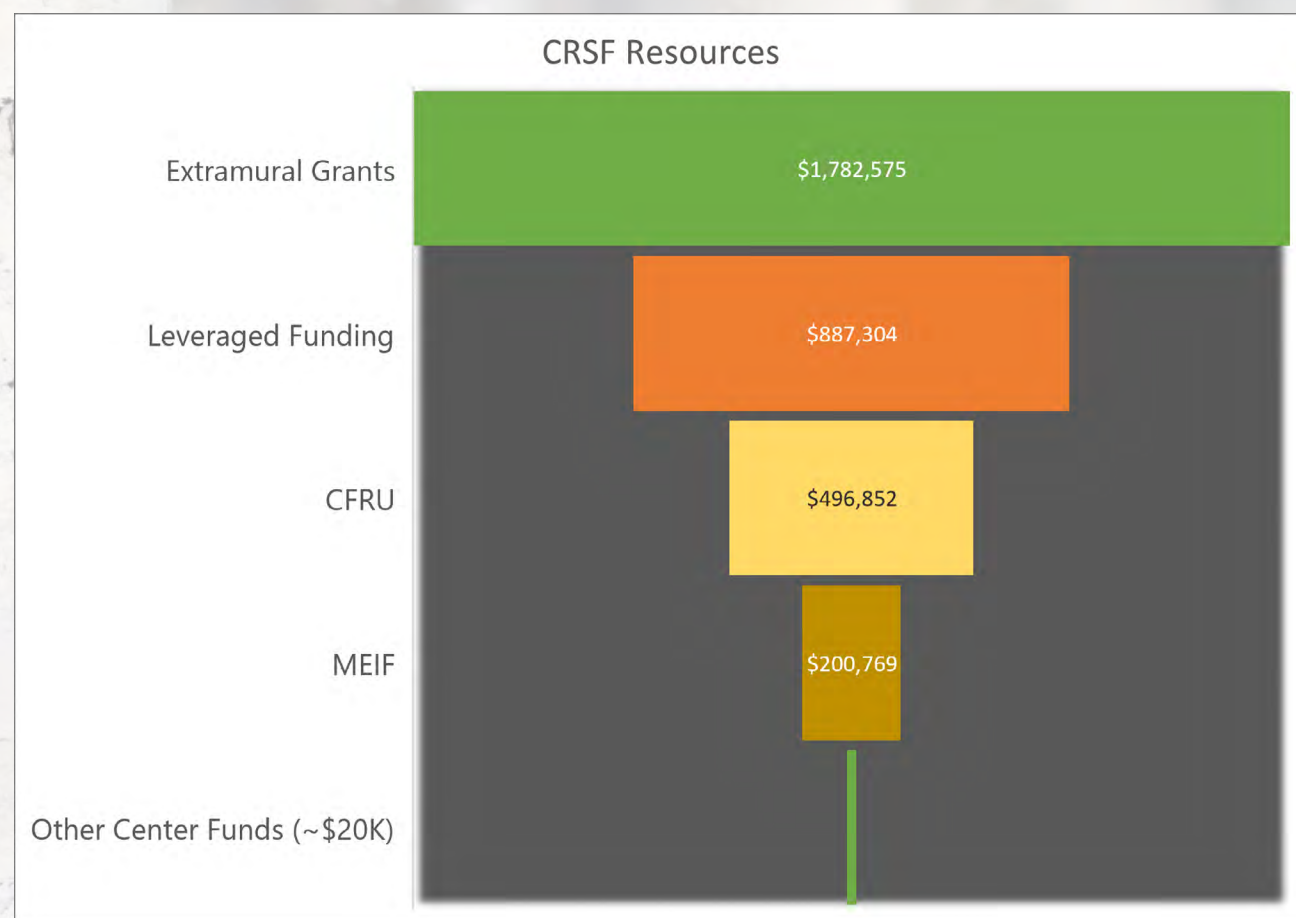


Table 1. Breakdown of CRSF Income

|  |                    |
|--|--------------------|
| Direct Funding (external grants)       | \$ 1,782,575       |
| CFRU Contributions                     | \$ 496,852         |
| MEIF                                   | \$200,769          |
| Gifts (CRSF Gift Fund, Munsungan Fund) | \$19,803           |
| Leveraged Funding                      | \$887,304          |
| <b>Total</b>                           | <b>\$3,387,303</b> |

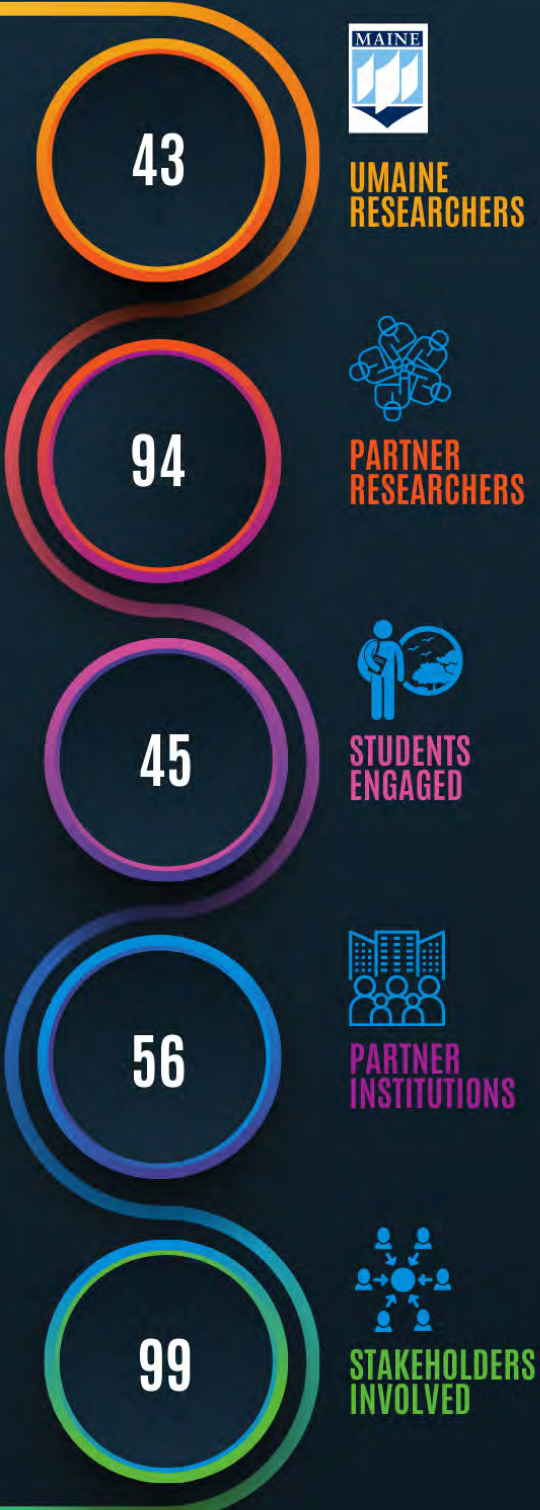
Table 2. CRSF Outcomes, 2018-2022

| FY           | # of Research Outcomes | # of Involved Students | # of Involved Faculty | \$ of External Funding | # of Website Views |
|--------------|------------------------|------------------------|-----------------------|------------------------|--------------------|
| 2018         | 50                     | 17                     | 37                    | \$1,094,728            | 20,140             |
| 2019         | 105                    | 65                     | 48                    | \$708,803              | 15,154             |
| 2020         | 94                     | 45                     | 60                    | \$4,897,463            | 13,404             |
| 2021         | 88                     | 31                     | 35                    | \$2,205,545            | 32,746             |
| 2022         | 42                     | 51                     | 29                    | \$3,166,731            | 47,637             |
| <b>Total</b> | <b>379</b>             | <b>209</b>             | <b>209</b>            | <b>\$12,073,270</b>    | <b>164,375</b>     |

Note. Covid-19 pandemic significantly impacted years 2020-2022.



# CRSF COLLABORATION



## Cooperative Forestry Research Unit Members

- Acadia Forestry, LLC
- Appalachian Mountain Club
- Baskahegan Company
- Baxter State Park, SFMA
- BBC Land, LLC
- Clayton Lake Woodlands Holding, LLC
- The Conservation Fund
- David B. Field
- Downeast Lakes Land Trust
- EMC Holdings, LLC
- Fallen Timber, LLC
- Forest Society of Maine
- The Forestland Group, LLC
- Fresh Timber, LLC
- Frontier Forest, LLC
- Hancock Forest Management
- Huber Engineered Woods, LLC
- Irving Woodlands, LLC
- Katahdin Forest Management, LLC
- LandVest
- Maine Bureau of Parks & Public Lands Mosquito, LLC
- The Nature Conservancy
- New England Forestry Foundation
- North Woods Maine, LLC
- Prentiss and Carlisle Company, Inc.
- Rangleley Lakes Heritage Trust
- Robbins Lumber Company
- Sandy Gray Forest, LLC
- Sappi North America
- Seven Islands Land Company
- Si Balch
- Solifor Timberland, Inc.
- St. John Timber, LLC
- Sylvan Timberlands, LLC
- Tree-Star Timberlands, Inc.
- Wagner Forest Management
- Weyerhaeuser

Partnerships are a key strength and focal area of CRSF. The research center has numerous deep relationships with a variety of academic and non-academic partners throughout Maine, the region, and the US. This is primarily achieved by the numerous initiatives that operate within CRSF under Dr. Weiskittel's leadership. Strong ties have been achieved with the University of Maine at Fort Kent and the recent NSF START grant. The Center maintains direct working relationships with over 30 different organizations through the CFRU, including state agencies, NGOs, private landowners, and forestry service providers.

Regionally, the NSF INSPIRES Track 2 involves collaborations with Dartmouth College, the University of New Hampshire, and the University of Vermont. The Northeastern States Research Cooperative involves working relationships with the Hubbard Brook Foundation, the State University of New York, the University of New Hampshire, and the University of Vermont. Nationally, CRSF's leadership of NSF's Center for Advanced Forestry Systems involves partnerships with over 80 unique federal, state, NGOs, or private entities throughout the US as well as direct relationships with six universities (Oregon State University, North Carolina State University, Purdue University, University of Georgia, University of Idaho, and the University of Washington).

CRSF is recognized as a key partner both locally and nationally because of these diverse and deep connections to a variety of organizations. In addition to regular collaboration with UMaine School of Forest Resources Scientists, CRSF researchers have engaged with more than 40 collaborators and stakeholders throughout the year.

### Stakeholder / Partner Institutions

- |  |   |  |
|--|---|--|
| Acadia National Park                               | Maine Dept of Environmental Protection                      | Schoodic Institute at Acadia National Park                   |
| Adirondack Ecological Center                       | Maine Dept of Inland Fisheries & Wildlife                   | Seven Islands Land Company                                   |
| American Forest Management                         | Maine Office of Outdoor Recreation                          | State University of New York                                 |
| AmeriCorp  | Maine Outdoor Heritage Fund                                 | Stephen Phillips Memorial Preserve Trust                     |
| Appalachian Mountain Club                          | Maine Research Reinvestment Fund                            | The Nature Conservancy                                       |
| Baxter State Park                                  | Maine Timberlands Charitable Trust                          | The Ohio State University                                    |
| BBC Land, LLC                                      | Maine TREE  | UMaine Cooperative Forestry Research Unit                    |
| Blue Hill Heritage Trust                           | Manomet Inc.  | UMaine Dept. of Ecology & Environmental Sciences             |
| Canadian Wood Fibre Centre                         | Michigan State University Forest Carbon and Climate Program | UMaine School of Forest Resources                            |
| Forest Carbon for Commercial Landowners            | NASA Goddard  | UMaine School of Wildlife, Fisheries, & Conservation Biology |
| Forest Stewards Guild                              | NASA GSFC   | UMaine Wheatland Geospatial Lab                              |
| Friends of Acadia                                  | National Council for Air and Stream Improvement             | Umbagog National Wildlife Refuge                             |
| Garden Club of America                             | National Council for Air and Stream Improvement             | University of Maine at Fort Kent                             |
| Government of British Columbia                     | NCASI   | University of Maine Presque Isle                             |
| Hubbard Brook Research Foundation                  | New England Forestry Foundation                             | University of Massachusetts, Lowell                          |
| Huber Resources                                    | Northeast Wilderness Trust                                  | University of Minnesota                                      |
| J.D. Irving Limited                                | Northeastern Soil Monitoring Cooperative                    | University of New Hampshire                                  |
| Landvest   | Northern Arizona University                                 | University of New Hampshire Extension                        |
| Maine Agricultural and Forest Experiment Station   | Northern Borders Regional Commission                        | University of Vermont  |
| Maine Bureau of Parks and Lands                    | Oregon State University                                     | US Fish & Wildlife   |
| Maine Coast Heritage Trust                         | Penobscot Valley Chapter of Maine Audubon                   | USDA Forest Service  |
| Maine Dept of Agriculture, Conservation & Forestry | Rangleley Lakes Heritage Trust                              | Woodwell Climate Research Center                             |
|  | Rutgers University  |  |





**Maine Forest Climate Change Science & Practice Webinar & Field Tour Series**  
Addressing Forest Climate Change in Maine

How will Climate Change impact the different forest types found in Maine? Join the University of Maine's Forest Climate Change Initiative and the Forest Stewards Guild as we try to answer this question in a series of webinars and tours that focus on specific forest types found throughout the state. This series is building on the success of our 2020 Science and Practice Forum and 2020-2021 Science & Practice Webinar Series.

**Session 1: Penobscot Experimental Forest**  
Webinar: Wednesday, October 27, 2021  
Field Tour: Friday, October 29, 2021

**Session 2: Holt Research Forest**  
Webinar: Wednesday, December 1, 2021  
Field Tour: Friday, December 3, 2021

**Session 3: Schoodic Institute**  
Webinar: Wednesday, February 23, 2022  
Field Tour: Thursday, February 24, 2022

**Session 4: Rangeley Lakes Heritage Trust**  
Webinar: Wednesday, April 27, 2022  
Field Tour: Friday, April 29, 2022

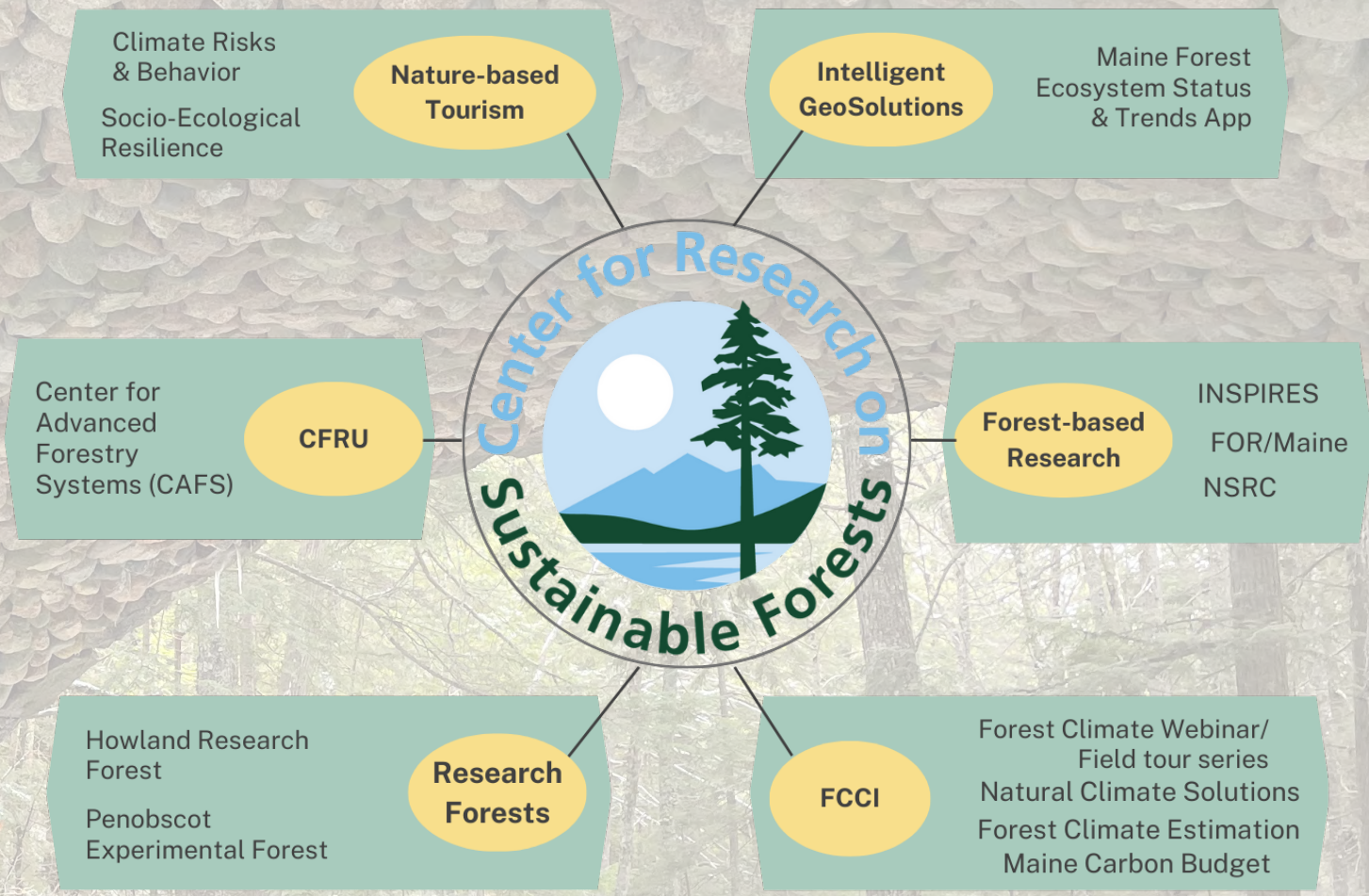
**Session 5: To Be Announced**

To register, visit: [crsf.umaine.edu/fcci-webinars](https://crsf.umaine.edu/fcci-webinars)

The CRSF greatly benefits from ongoing support from our Munsungan and CRSF gift funds. These accounts support outreach and communication efforts and enable us to interact effectively with partners and stakeholders in the state and region. During the 2021-22 academic year, the Munsungan Endowment made it possible for CRSF to expand the FCCI Science and Practice webinar series to include field tour at locations throughout the state, where science-based panelists discussed how climate change will impact the forest types found in Maine. Gifts to the CRSF fund benefit student researchers and special projects on forest-related issues.

CRSF's programs and initiatives are integral to the mission of the Center, and focus research efforts on forest ecosystems, human interactions, and economies around the state and beyond. The following pages contain detailed project reports that showcase these efforts. Degrees sought by student research assistants are noted in parenthesis.

**Programs & Initiatives**







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 research goals are to sponsor research to sustain the health of northern forest ecosystems and communities, develop new forest products, and to improve forest biodiversity management. NSRC also supports an Indigenous Forest Knowledge Fund (IFKF) to address structural inequities in opportunity for Indigenous youth in forest research and invest in the cultural and intellectual sovereignty of Tribal forest traditions, alongside other forms of applied forest research.

For the 2021-22 funding cycle, NSRC awarded a total of 15 grants totaling nearly \$2.5 million of federal funding and close to \$1.1 million of matching funding. The four Maine-based projects address a broad range of concerns related to climate impacts on tree regeneration, using remote sensing to assess Eastern White Pine health, protecting brown ash, and impacts of forestry operations on wetland ecosystems.

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

John Daigle, Professor of Forest Recreation, UMaine School of Forest Resources, will promote Tribal priorities through the production of management guides that offer management recommendations for addressing Emerald Ash Borer (EAB). These guides will help to inform management by Tribal Nations, foresters, loggers, and landowners working to address EAB in the northern forest. This project will use landowner and manager perceptions on ash best management practices, and the cultural significance of ash to guide our education and outreach.

**Effects of Timber Harvesting on the Wetland Ecology of Northeastern Lowland Forests**

Christina A. Murphy, USGS ME Cooperative Fisheries and Wildlife Research Unit, will study the impacts of forestry operations on wetland ecosystem, areas recognized for their important roles in supporting water quality, biodiversity, and as critical habitat for wildlife of conservation concern. This study will inform sustainable management and prepare stakeholders for questions regarding ecological tradeoffs in management of intermittent waters throughout Northern Forest lowlands.

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

Parinaz Rahimzadeh-Bajgiran, Assistant Professor of Remote Sensing, UMaine School of Forest Resources, will incorporate remote sensing tools using aerial and satellite imagery to assist white pine needle damage (WPND) field and aerial monitoring efforts. This work will provide objective and spectrally explicit observations across large regions over time as part of short- and long-term efforts to monitor and mitigate negative impacts of WPND damage.

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

Jay Wason, Assistant Professor of Forest Ecosystem Physiology, UMaine School of Forest Resources, is to determine how tree regeneration in the Northern Forest will respond to extreme drought, heat, and midwinter warming events to better inform forest management. Two experiments that will simulate novel future extreme climate conditions using sapling trees of 10 Northern Forest tree species will help identify forest tree species that are best and least adapted to future extreme climate events and the physiological characteristics that promote resistance and resilience to extreme climate change.



Founded in 1975, the CFRU is one of the oldest industry/university forest research cooperatives in the United States. The CFRU is composed of member organizations representing almost 8.2 million acres of Maine's forestland, including private and public forest landowners, wood processors, conservation organizations, and other private contributors. Research by the CFRU seeks to solve the most important problems facing the managers of Maine's forests. The CFRU adapted and shifted as needed under the pandemic, moving to virtual meeting formats and adjusting fieldwork efforts. A number of new research projects moved forward, and membership supported the establishment of a spruce budworm L2 processing facility. Details on CFRU research can be accessed on the [CFRU webpage](#), with related video content on the new [CFRU YouTube channel](#).

**Research Projects**

**SILVICULTURE & MANAGEMENT**

- ❖ Identifying Opportunities for Improving Small-Diameter Tree Harvesting Strategies, Logistics, and Market Diversification
- ❖ Long-Term Outcomes of Beech Bark Disease on the Penobscot Experimental Forest
- ❖ Strategies for Altering Species Composition in Stands with American Beech and Beech Bark Disease on the Maine Adaptive Silviculture Network

**HABITAT & BIODIVERSITY**

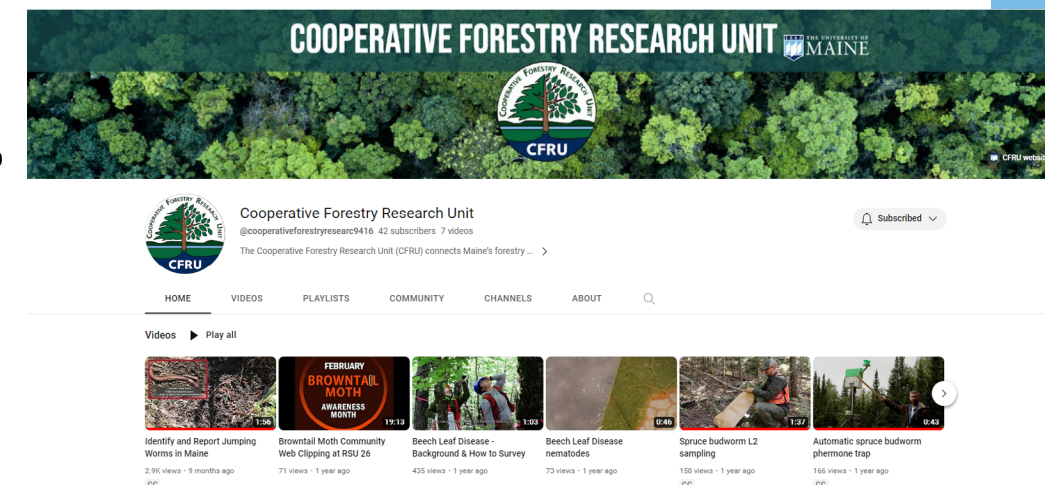
- ❖ Rusty Black Bird Use of Commercial Spruce-Fir Forests in Northern New England
- ❖ Thirty Years of Change in Commercial Forest Management and Implications for Bird Conservation in Maine (1992–2022)
- ❖ Watershed Scale Drivers of Temperature and Flow of Headwater Streams in Northern Maine
- ❖ Quantifying the Ecological and Economic Outcomes of Alternative Riparian Management Strategies

**INVENTORY & GROWTH MODELING**

- ❖ Assessing and Monitoring Soil Productivity, Carbon Storage, and Conservation on the Maine Adaptive Silviculture Network
- ❖ Measurements, Models, and Maps: Toward a Reliable and Cost-Effective Workflow for Large-Area Forest Inventory from Airborne LiDAR Data
- ❖ Spruce Budworm L2 Monitoring Program in Maine
- ❖ Interdisciplinary Spatial Modeling

**YouTube Videos**

Spruce Budworm L2 Sampling  
 Browntail Moth Community Web Clipping • Beech Leaf Disease Identifying Jumping Worms in Maine • Spruce Budworm



nsrcforest.org

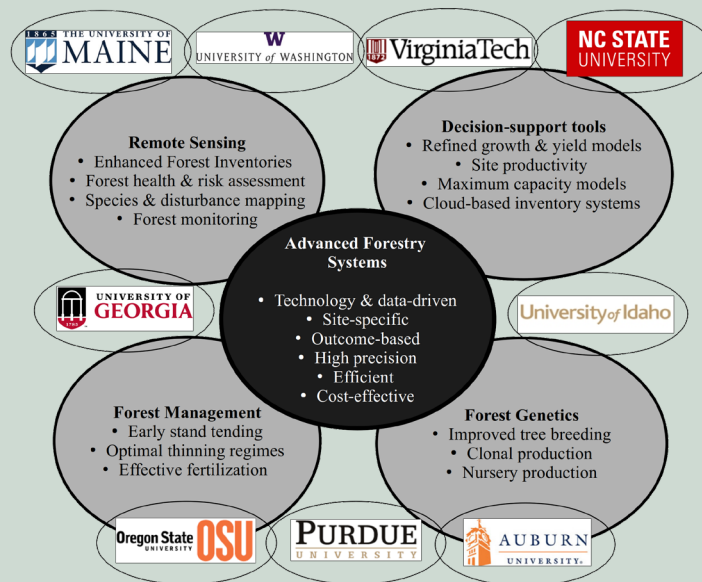
umaine.edu/cfru





The Center for Advanced Forestry Systems (CAFS) is a National Science Foundation Industry University Cooperative Research Center that serves as a national organization for R&D relevant to the forest industry. The University of Maine became the lead site for CAFS in 2016, with the program being led by Dr. Aaron Weiskittel. IN FY22, CAFS was supported by \$3.7M in contributions from 84 primary and secondary industry members across 7 sites.

This year we were able to get back to business as usual with our first in-person Industry Advisory Board (IAB) meeting since June 2019. Nearly 60 site directors, industry representatives, and researchers attended the IAB and field tour. It was a delight to be back in the Pacific Northwest and the inspiring forests of towering Douglas-fir. Although the virtual world made organizing and hosting large meetings like the CAFS IAB relatively easy, the in-person venue made meaningful interactions and open discussions more accessible. Further, it is important for both CAFS researchers and industry members to see the different challenges each region actually faces on the ground. IAB members and researchers greatly benefited from hosts University of Washington, Washington Department of Natural Resources, and Manulife Global for their great help on putting on an engaging field tour of the region.

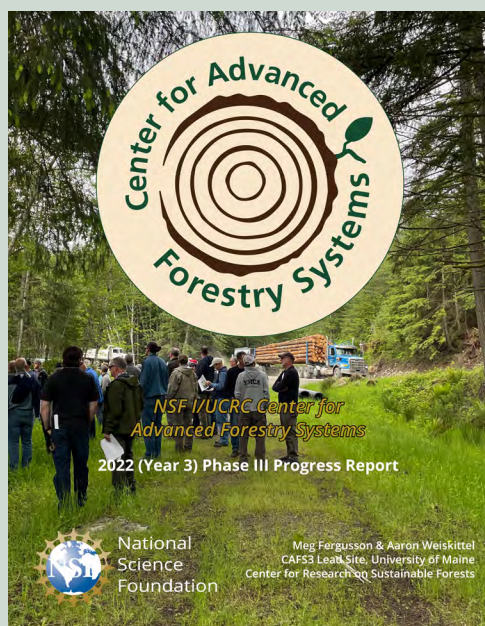


Current research happening within CAFS is exciting, highly collaborative, and forward thinking, particularly as new and powerful technologies continue to emerge. Our IAB-approved research projects continue to grow yet they all still embrace and address critical knowledge gaps or needs identified in the technology/research roadmap that was developed in 2019. Particular research areas like remote sensing and small area estimation are among topics the IAB would like to

see addressed through collaborative research projects in the remaining two years of Phase 3. This feedback and knowledge will help prioritize future collaboration and projects to ensure successful outcomes that can help launch CAFS following NSF's support. This is a true team effort and continuing to create the opportunity for effective industry-university collaboration is critical.

CAFS members sites are University of Maine, North Carolina State University, Oregon State University, Purdue University, University of Georgia, University of Idaho, and University of Washington. In FY22, the University of Maine at Fort Kent, Montgomery Community College, and Monroe Community College collaborated with member sites thru NSF START grants.

Detailed project reports can be accessed via the CAFS annual reports on the [CAFS website](#).



## CAFS Highlights

- CAFS projects address national and regional technological challenges with research questions aimed at specific multiple spatial and temporal scales, including molecular, cellular, individual-tree, stand, and ecosystem levels.
- CAFS research personnel includes 7 site directors, 19 faculty, and 17 researcher scientists across the country
- CAFS projects engaged, trained, and mentored 8 post docs, 12 PhD students, 22 Masters students, and 17 undergraduates.

### IN-PERSON IAB MEETING

- Held in Snoqualmie, WA, in June 2022
- 46 industry members and researchers attended in person; additional 14 joined remotely
- Held in conjunction with the National Council for Air and Stream Improvement (NCASI) Biometrics Working Group
- Full day of expanded project updates (see summaries in this report) and industry-researcher interaction
- Presentation and discussion on the substantial erosion of forest resource R&D capacity over past several decades and 2020-21 summit on strengthening R&D for US forests and forest products
- NSF supplemental funding opportunities (INTERN and START projects)

### RESEARCH PRIORITIES

- Forest Modeling & Decision-Making Tools
- Effective Use of Remote Sensing Technologies
- Improved Silvicultural Practices
- Incorporation of Advanced & Emerging Technologies
- Synthesis of Regional Datasets

### FIELD TOUR

- Operational LiDAR/Digital Forestry on Manulife Lands
- Federation Forest State Forest: History & Habitat, Digital Soils Mapping
- WA DNR Installation: Digital inventory, Early Stand Management

### NCASI AFFILIATION

- 28% of CAFS members are also NCASI members
- Provide synergistic partnerships and leverage key resources and expertise
- Improve coordination across the sector





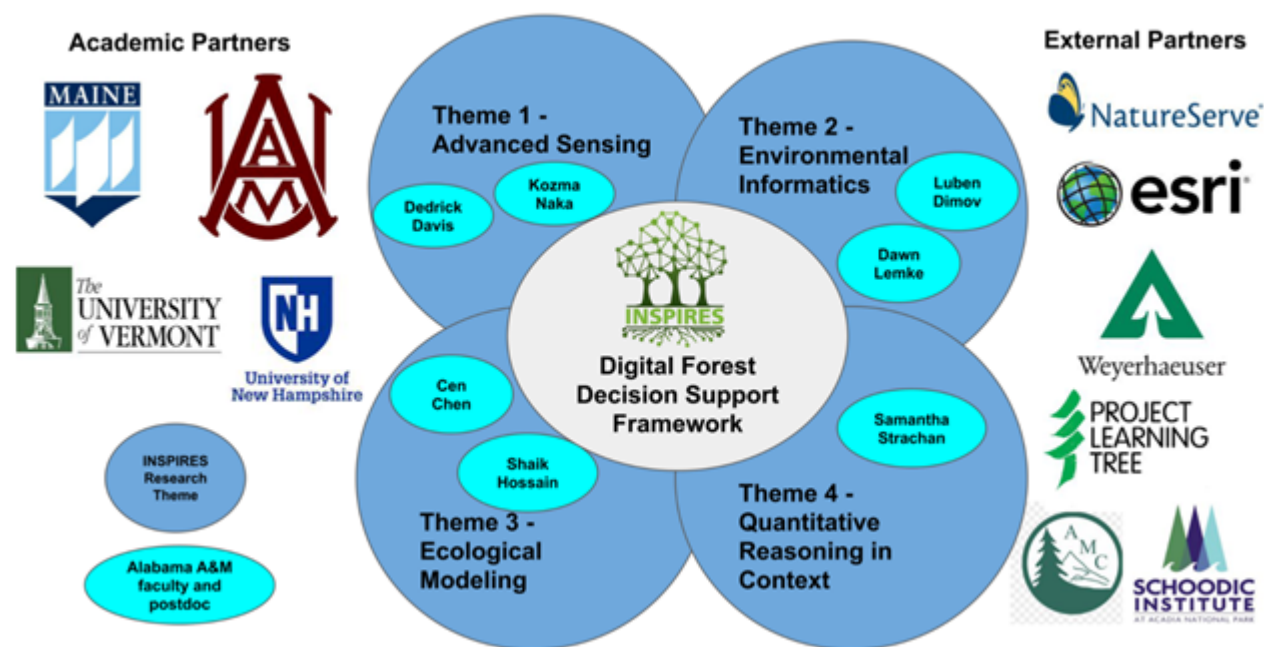
The **Leveraging Intelligent Informatics and Smart Data for Improved Understanding of Northern Forest Ecosystem Resiliency (INSPIRES; Smart Data for Resilient Forests)** project is an interjurisdictional partnership between research and higher educational institutions in Maine, New Hampshire, Vermont, and Alabama A&M University supported by the National Science Foundation EPSCoR Track 2 program.

In Year 3, with \$599,999 in new supplemental funding from NSF, the INSPIRES team began a strategic partnership with AAMU, an Historically Black College and University (HBCU). This partnership will add a diversified perspective as well as specific scientific expertise and talent to the multi-

institution, multi-state endeavor.

Primary goals for Year 3 were to continue visiting field research sites, strategically deploying wireless sensors for climate data acquisition across the four jurisdictions, targeting remote sensing acquisitions, completing ecological model parameterization and calibration for predicting regional forest dynamics, and refining mentoring and student participation. Project leaders continue to directly engage stakeholders and project partners to gain input and feedback on research objectives, to identify opportunities for leveraging existing long-term data collections, and to develop collaborative relationships around the four INSPIRES research themes. In addition, an important focus of Year 3 was strategically evaluating project sustainability efforts and assessing key project wrap-up needs, particularly potential synthesis outcomes. This was mostly centered around focused efforts on synthesis publications, future proposals, and stakeholder engagement.

### Fostering Ecosystem Resiliency Through Harnessing Big Data



Effective stakeholder engagement remains a high priority for INSPIRES. In Year 3, virtual and in-person outreach events featured INSPIRES participants and highlighted ongoing research. In particular, Theme 4 continues to unite teachers and INSPIRES researchers to foster forest research and data acquisition partnerships, hosting numerous high school science teachers from around the region for a field visit to support integration of Quantitative Reasoning in Context (QRC) using forestry science and research at the Schoodic Institute in Maine.

### Highlights

- ⇒ Year 3 theme research activities of the INSPIRES project focused on the continued refinement and deployment of environmental sensors at strategic locations throughout the region (Theme 1), providing regional estimates of key forest canopy traits (e.g. foliar nitrogen, photosynthetic capacity) at high resolution (30-m) using field collected data and remote sensing platforms (Theme 2), initiating the construction of a general digital framework for a multi-model comparison to understand model strengths and weaknesses (Theme 3), and continuation of engagement as well as recruitment of high school science teachers to better integrate project elements into hands-on curricular activities (Theme 4).
- ⇒ AAMU's long-term research field site at Paint Rock will be a key focal area of collaboration and leverage numerous ongoing INSPIRES efforts and has already led to a new collaborative proposal submitted to NSF.
- ⇒ The INSPIRES team currently involves 82 individuals with the majority being faculty from the four states (45; ME = 19, NH = 12, VT = 8, AL = 4), bolstered by undergraduate/graduate students (21), post-doctorate researchers (2), and professional staff (14).
- ⇒ A 3-day INSPIRES in-person team retreat in May 2022 featured a field tour, informal group meetings, and all-team discussion to envision the future beyond the project end.
- ⇒ Project semi-annual virtual retreat in January featured a team science facilitator who conducted team-building exercises to address specific challenges and pathways to the success of the project and promote the communication of common goals and successful project outcomes, particularly joint publications and proposals.
- ⇒ Ongoing engagement of project stakeholders and partners for input and feedback on research objectives, to secure access to research sites and identify potential new experimental sites, to identify opportunities for leveraging existing long-term data collections, and to develop collaborative relationships around the INSPIRES themes.
- ⇒ Key project stakeholders include Federal partners like the US Forest Service, NGOs like the Appalachian Mountain Club, Schoodic Institute, or Second College Grant, and private forest landowners like The Nature Conservancy, Seven Islands Land Company, and Weyerhaeuser Company.



⇒ Outputs: 12 (8 published; 3 in press; 1 under review) peer-reviewed articles, 1, conference proceedings, 3 data/model/technology products, and 10 presentations (3 by early-career faculty, 2 by trainees).

⇒ Through May 2022, 8 research proposals requesting \$23,733,100 were submitted with 2 awarded (\$818,197) and \$22,714,987 pending.

⇒ Theme 4 leaders convened teachers from Maine and Vermont at Acadia's Schoodic Institute with researchers Alix Contosta, Liz Burkowski and Peter Nelson (video of the collaboration and research goals available via YouTube). These workshops unite teachers and INSPIRES researchers to foster forest research and data acquisition partnerships.





The FCCI team is a collaboration of interdisciplinary scientists from the University of Maine's School of Forest Resources, School of Food & Agriculture, and Climate Change Institute, and from the Schoodic Institute at Acadia National Park and the Appalachian Mountain Club. In October 2020, FCCI teamed with the Forest Stewards Guild to develop and host a year-long webinar series focused on climate change and forest health, recreational use, forest management, biodiversity and pests, as well as the role of carbon and greenhouse gases.

For 2021-22, the FCCI-FSG hosts expanded the webinar series format by adding half-day field tours focused on the four primary forest types in Maine: spruce-fir, oak-pine, coastal spruce-fir, and mixed hardwood to complement the webinars. The webinars provided an overview of the topics and issues faced at each site: including those related to the intersection of climate adaptation and site-specific biodiversity. Webinars allowed time for Q&A and to showcase field tour specifics. The four webinars engaged more than 300 attendees from the university, public, conservation, and private forest sectors in discussion and Q&A sessions; we 108 individuals participated in the field tours. Videos of each session are available via the CRSF YouTube channel.



### UMaine's Forest Climate Change Initiative and Forest Stewards Guild: Season 2

Project Leads: Aaron Weiskittel & Meg Fergusson, UMaine Center for Research on Sustainable Forests; Amanda Mahaffey & Logan Johnson, Forest Stewards Guild

The FCCI's collaboration with the Forest Stewards Guild to address Climate Change impacts in Maine's forests began with the Science and Practice forum in Orono in February 2020, where forest scientists and managers gathered to identify the highest priority concerns around climate change in Maine's forests. Following that event, the FCCI and Guild kicked off a monthly webinar series to catalyze scientist-manager discussions about climate change research, grow Maine's forest climate adaptation community of practice, and be a resource for the Maine Climate Council about Maine's forest and climate change. The first season of the Forest Climate Change Science & Practice series featured nine lunch-hour webinars that spanned topics from carbon budgets to forest biodiversity and species shifts. Season 2 took a new approach—coupling lunch-hour webinars followed by half-day field tours. This new hybrid model provided the ideal balance between information sharing and in-depth discussions in the field, with each session focused on a specific forest type in Maine.

#### Spruce-fir (inland) at the Penobscot Experimental Forest (PEF)

The second season began with a focus on the spruce-fir (inland) forests at the PEF, a research forest jointly managed by UMaine and the US Forest Service. This webinar and field tour featured USFS Research Scientist Laura Kenefic, UMaine Forest Manager Keith Kanoti, UMaine wildlife faculty Alessio Mortelliti, and Maine Forest Service District Forester Kenny Fergusson.

Webinar participants learned about the decades of research at the PEF. The field tour focused on how different management techniques lead to vastly different results in the woods, with stops covering selection cutting and commercial clearcuts, shelterwood with and without thinning, and a strip clear cut. Discussions ranged from how viable each method would be for landowners, future forest stand development and what conditions make a forest more resilient to climate change and enhance carbon storage, and how adaptability is key to changing winter conditions.

#### Oak-Pine (coastal) at the Holt Research Forest

The following webinar focused on the Holt Research Forest in Arrowsic, Maine. The Holt Research Forest, owned by the Maine Timber Research & Environmental Education Foundation (Maine TREE), is a long-term forest research and monitoring site launched in 1983. Two timber harvests have taken place in that time, with the most recent occurring one growing season before the tour in the winter of 2020/21. This session featured longtime Holt Research Forest scientist Jack Witham, consulting forester Barrie Brusila, Maine TREE Programs and Outreach Coordinator Kelly French, and Maine Forest Service District Forester Shane Duigan.

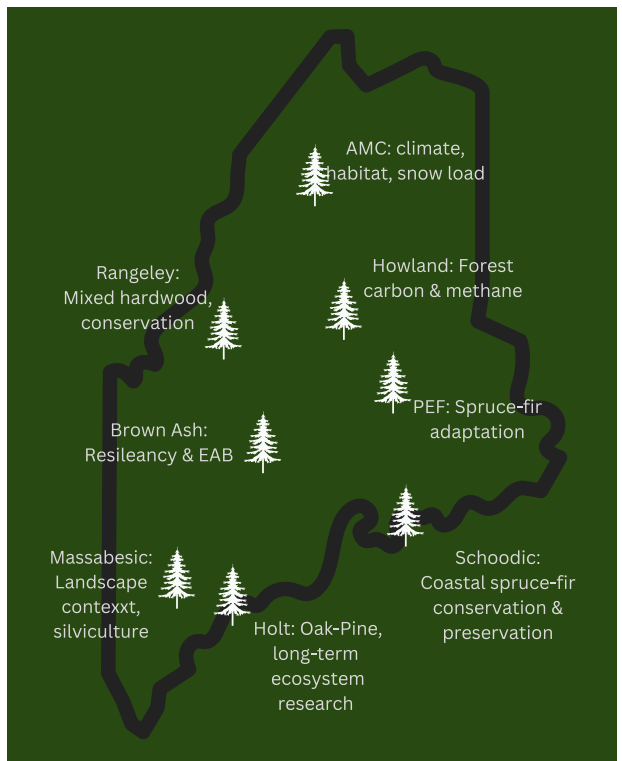
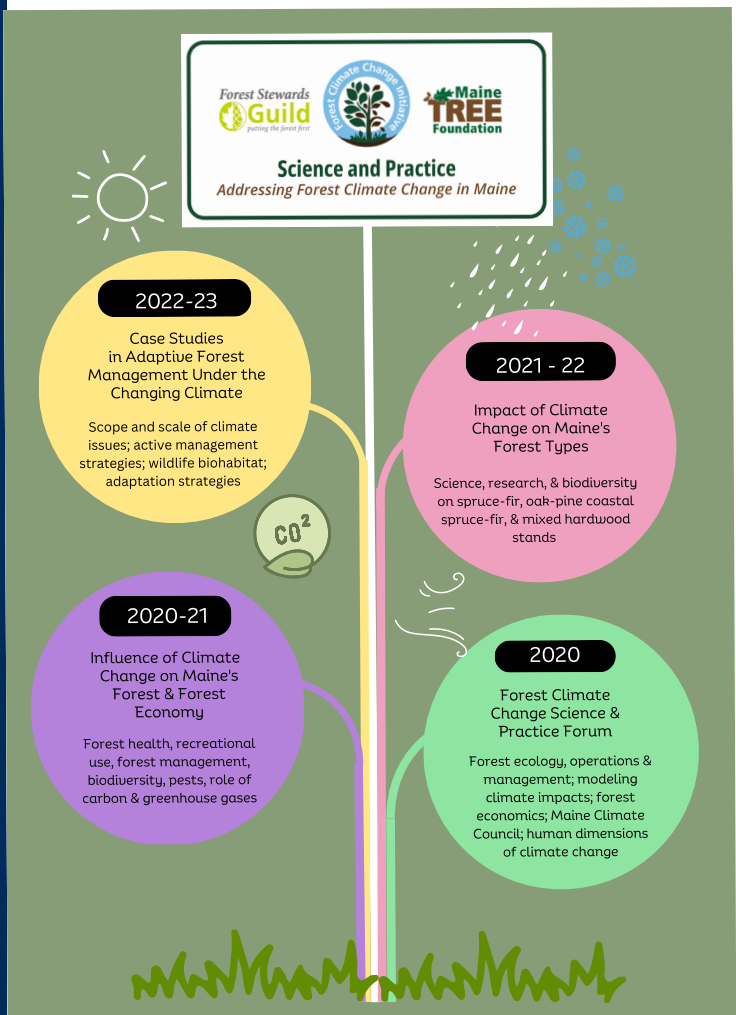
The webinar featured key findings during the nearly 40 years of continuous monitoring. The field tour took participants on a loop around the recently harvested research grid. It included stops at unharvested control areas, canopy gaps created during the harvest, a stream crossing location, and a recently installed deer exclosure. The discussions ranged from the effects of deer herbivory on regeneration to the importance of microclimates and climate-adapted plantings.

#### Spruce-Fir (coastal) at the Schoodic Peninsula

Coastal spruce-fir forests on the Schoodic Peninsula provided the third topic. Schoodic Peninsula sits just north of Mount Desert Island and features the only portion of Acadia National Park on the mainland. During this session, participants heard from Schoodic Institute President & CEO Nick Fisichelli and Forest Ecology Director Peter Nelson, along with Maine Forest Service District Forester Michael Jensen, Maine Department of Inland Fisheries & Wildlife (DIFW) Regional Biologist Steve Dunham, and Maine Coast Heritage Trust Project Manager Bob DeForrest.

crsf.umaine.edu/forest-climate-change-initiative

crsf.umaine.edu/forest-climate-change-initiative



Detailed information on past and future webinars and field tours can be accessed online:  
**FCCI Forest Climate Change Webinar & Field Tour Series**



The webinar highlighted Nelson's work using remote sensing to monitor forest health and wildlife connectivity on the peninsula. In the field, DeForrest led the group along trails of the Forbes Pond Preserve, a Maine Coast Heritage Trust property on the peninsula, where conversations ranged from silviculture and recreation management to the value of ecological features such as lichen and coarse woody material. The group made their way to Frazer Point in Acadia National Park, where Fisichelli described the peninsula's recent history and forest practices, and guided attendees through an older spruce-fir forest managed to increase recreational opportunities.

**Mixed Hardwoods in the Rangeley Lakes Regions**

The final session of the series focused on mixed hardwood ecosystems in Western Maine's Rangeley Lakes region. The Rangeley lakes region is unique for its mixed-hardwood forests and the range of partnerships and ownerships in the region working in concert to steward the forest resource. The session featured Rangeley Lakes Heritage Trust (RLHT) staff, including David Miller (Executive Director), Shelby Rousseau (Deputy & Stewardship Director), and Jason Latham (Natural Resource Specialist), Christine Parrish and Alec Giffen of the New England Forestry Foundation, Walker Day of Seven Islands Land Company, Joe Roy a Private Lands Wildlife Biologist for Maine DIFW, and Julie Davenport as Maine Forest Service's District Forester.

To set the stage for the field tour and highlight partnerships, the panelists provided a landscape-level perspective of forest management and conservation in the region before focusing on hardwood management in a changing climate. During the final field tour, participants visited lands owned by the RLHT, where attendees viewed varying stages of hardwood forest development, including recently harvested areas and areas where harvesting hasn't recently occurred. This property provided a strong example of uneven-aged forest management in hardwood systems. Discussions where harvesting hasn't taken place recently focused on managing for diversity and carbon. When visiting a recently harvested site, conversations shifted to the importance of having a skilled workforce.

**Building a Community of Practice**

Each session provided an opportunity to build the climate change community of practice. The addition of field tours during this second season created a new avenue to develop the community by providing an opportunity for in-depth discussions about the challenges managers face in the woods. The field tours also provided a vehicle for informal conversations and connections while traveling from field site to field site, and of course, over lunch with friends in the field. The varying backgrounds of the participants amplified the benefit of these connections during each session. From government agencies at the federal and state level to conservation nonprofits and land management companies, everyone on the field tours played the role of teacher and student, bringing their unique perspectives to the conservation.

**Key Themes**

Many subthemes emerged from the primary theme of climate change. Each panel highlighted the impacts and disturbances on sites such as windthrow, insects and diseases, and other climate-related impacts that influence management decisions. Wildlife also emerged as a key theme throughout the series. Changing forest conditions change how wildlife use the forest, and forest connectivity is essential for providing forest corridors for all types of wildlife. Finally, each session specifically focused on communicating with landowners about climate change. Maine Forest Service District Foresters joined each panel and field tour to discuss their experience talking with landowners who have climate change on their minds. Engaging landowners is critical to addressing climate change in Maine's forests at a scale that makes a difference.

USFS Research Forester Laura Kenefic posed the most important consideration during the first session: "The treatments we visit have varying carbon storage, adaptation, and climate and market resilience outcomes. An approach that is good for one objective is not necessarily good for others. How do we balance these competing demands, and what are the tradeoffs?" As it often is in forestry, the answer is: "it depends."

The NCS Initiative was formed to evaluate the potential of alternative NCS to decrease greenhouse gas (GHG) emissions through management in forestry and agriculture. Alternatives include reforestation, planting of fast-growing tree species, and extended rotations in forests as well as no-till cultivation, cover cropping, and capturing methane from manure on farms. In particular, researchers are assessing land management strategies for Maine's farms and working forests that will optimize future carbon sequestration rates and how the price of carbon influences the outcome



**Maine Natural Climate Solutions Initiative**

*Project Lead: Adam Daigneault, Associate Professor of Forest Ecology, University of Maine*

*Project Personnel: Ivan Fernandez, Co-PI; Aaron Weiskittel, Co-PI; Daniel Hayes, Co-PI; Erin Simons-Legaard, Research Assistant Professor; Jinheng Zhao; Postdoctoral Researcher*

*Student Research Assistants: Zoe Lidstrom (MF), Logan Woodyard (MS), Joey Reed (MS)*

Maine's working landscape can play an important part in Maine's GHG mitigation strategy, but the most cost-effective and impactful practices are relatively unknown. This research has several distinct components. First, we combine economic and biophysical methods to identify the mitigation potential for several natural climate solutions (NCS) practices in Maine, ranging from modified timber harvesting to timber stand improvement in forests and no-till, biochar and cover cropping on farms. Estimates of GHG sources and sinks at different carbon prices and implementation levels have been developed. Second, we engage with stakeholders to gauge the degree that these NCS practices could be implemented, identifying the most valued options and critical impediments (e.g., cost, policy, technology) to implementation. Stakeholders include large forest landowners to small and diversified family farms. Third, we developed alternative scenarios to estimate uncertainty in NCS mitigation potential under a range of alternative climatic, policy, and socio-economic futures. These pathways are likely to impact key components of natural and working lands such as land productivity, desired management practices, global and local commodity prices, and land use (e.g., development). Fourth, we incorporate our expert knowledge of forest carbon modeling to develop decision support tools for policymakers to conduct their own NCS mitigation analyses. Collectively, this research will accelerate the implementation of NCS in Maine and other states with similar goals and land management systems.

**Objectives & Approach**

- ⇒ Conduct a benchmark analysis of NCS practices that are applicable to Maine, including their cost and GHG mitigation/C sequestration potential.
- ⇒ Identify cost-effective and efficient opportunities to implement Natural Climate Solutions in Maine



- Work with farmers and foresters to identify technical, financial, and policy barriers to implementing NCS on Maine's land
- Support the work of the newly formed Maine Climate Council (MCC) and Governor Mills' executive order for Maine to be carbon neutral by 2045.
- Construct and disseminate decision support tool for policymakers to engage in and conduct their own NCS analyses, with emphasis on modeling Eastern US forest ecosystems.
- Develop an outreach plan for project partners to engage with policymakers, forest landowners and farmers.

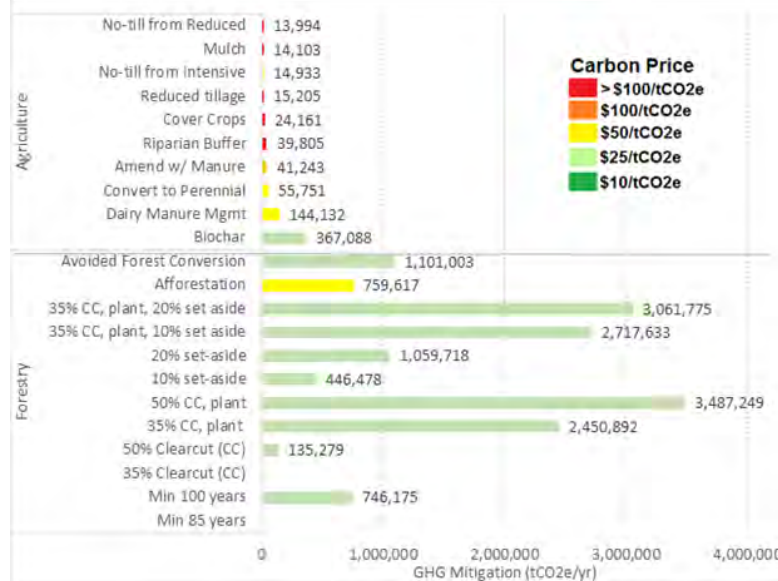


Figure 1. Total annual Maine forest and agriculture mitigation by NCS practice (MtCO<sub>2</sub>e/yr)

### Highlights & Key Findings

- Final analyses have been conducted for several forest and agricultural practices. Forestry practices are generally cheaper to implement than agricultural practices, and other sectors of the economy (e.g., electricity, transportation)
- The revised findings have estimated that Maine's forests<sup>1</sup> could sequester an additional 0.1 to 5.3 million tons of carbon dioxide equivalent per year (MtCO<sub>2</sub>e/yr). The most effective practices were found to be a) increasing clearcutting area and replanting with spruce, and b) extending the average age of a stand that can be harvested from 50 to 85 or 100 years. Implementing these practices would cost about \$4 to \$79 million per annum, equivalent to \$10 to \$20/tCO<sub>2</sub>e (Figure 1).
- A key concern of implementing forest NCS are that some practices (e.g., extended rotation and set asides) can result in reduced harvests, that can result in leakage (i.e., increased harvests elsewhere to meet wood demand) and/or a decline in the state forest products sector. Accounting for this, we find that it is still possible to harvest timber at historical levels and still increase forest carbon sequestration by nearly 1.0 MtCO<sub>2</sub>e/yr through a mix of silvicultural treatments ranging in harvest and management intensity.

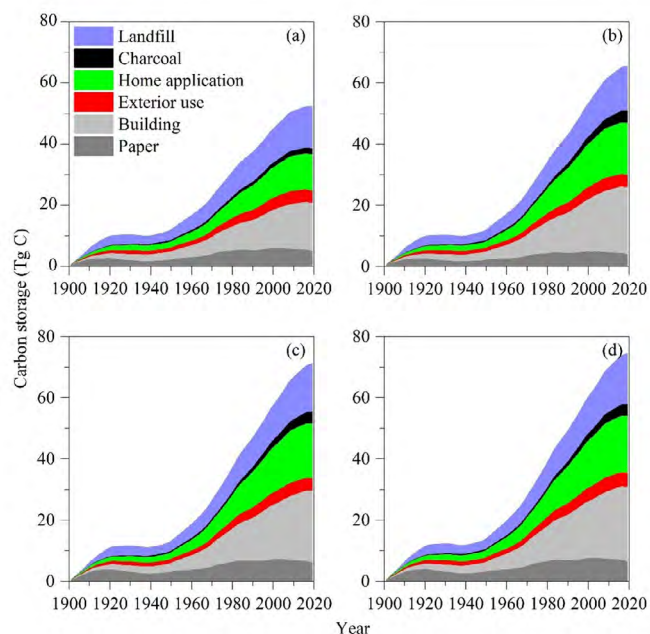


Figure 2. Range of scenario estimates for total HWP carbon storage in each carbon pool created by Maine harvests, 1901 - 2019 (Source: Li et al., 2022)

Looking specifically at the climate mitigation potential for harvested wood products (HWPs), we estimate that can sequester 1.6-2.5 MtCO<sub>2</sub>e/yr, with the range dependent on the types of products are made. This is equivalent to 9-13% of Maine's current GHG emissions (Figure 2).

We find that the use of no harvest set asides is an important component of enhancing forest carbon sequestration across the state. If historical harvests are held constant, and intensive forestry (e.g., clearcut and planting) is conducted

at a relatively large scale, then the increase in harvest and management intensity in one part of the landscape could allow for more than 2 million more acres of set aside reserves in Maine's northern forest, thereby resulting in more diverse wildlife habitat and increased forest carbon (Figure 3).

- We estimate that doing NCS practices on Maine's agricultural lands could reduce the state's GHG emissions by 0.01 to 0.57 MtCO<sub>2</sub>/yr. Jointly implementing practices for the agricultural sector is estimated to cost \$18.9 million/yr or \$33/tCO<sub>2</sub>e. Consequently, this analysis showed that Maine's agricultural sector has the potential to be carbon neutral or even be net-negative as a sector (Figure 1).
- Most climate mitigation studies estimate that carbon prices should be \$40 or more. This suggests that Maine NCS practices should be cost-competitive.
- For context, Maine's forests have sequestered an average of 12 MtCO<sub>2</sub>e/yr over the past decade, equivalent to removing about 70% of the state's GHG emissions, while Maine's agricultural sector has emitted about 0.4 MtCO<sub>2</sub>e/yr.

### Outcomes

- NCS analysis and findings have been summarized and distributed via a July 2021 Final report and factsheets published on the Maine NCSI website.
- Findings have been presented during more than a dozen stakeholder meetings held across the state, including several webinars. This has created a lot of discussion in Maine and beyond about how our modeling framework can contribute to policymaking.
- Results have been used to support the Maine Climate Council's "Maine Won't Wait" Climate Action Plan, and Governor's Forest Carbon Program Task Force.
- Shared socioeconomic pathway-based scenarios developed and conducted. Results included in final report.
- Analysis has identified that cost-effective mitigation can be achieved, especially in the forest sector, particularly when compared to GHG mitigation costs in other sectors of the economy (e.g., electricity generation, transportation).
- We have identified cost-effective forest management options that increase forest carbon sequestration but also maintain a steady flow of wood supply, thereby a win-win for Maine's environment and forest economy.

### NCS Research Components

- Mitigation Analysis.** Combine economic and biophysical methods to identify the mitigation potential for NCS practices in Maine, ranging from modified timber harvesting to timber stand improvement to no-till, biochar and cover cropping. We have initially identified 10 forestry and 6 agricultural practices to evaluate.
- Stakeholder Input.** We solicited feedback via focus group discussions and surveys about the findings developed in #1. This helps us better understand whether practices we estimate as cost-effective might work in the real world. Stakeholders included large forest landowners, conservation land managers, family forest owners, large commercial farmers from key Maine commodities (e.g., potatoes, lowbush blueberries), small-scale diversified farmers, and dairy farmers.
- Alternative Pathways.** We couple findings from components 1 and 2 with the development of alternative scenario pathways to estimate potential uncertainty in NCS mitigation potential under a range of climatic, policy, and socio-economic futures. These pathways will impact key components of natural and working lands (NWL) such as land productivity, desired management practices, global and local commodity prices, and land use (e.g., development).
- Decision Support.** We utilize UMaine's knowledge of forest carbon modeling to develop and disseminate a decision support tool for state-level policymakers to conduct their own forest carbon modeling assessments. The report and tool synthesizes the current state of carbon modeling, lists the names and attributes of a range of models that can be applied in eastern US forests, and provides a framework for selecting the most appropriate tool to use based on user knowledge, modeling resources, and policy questions.



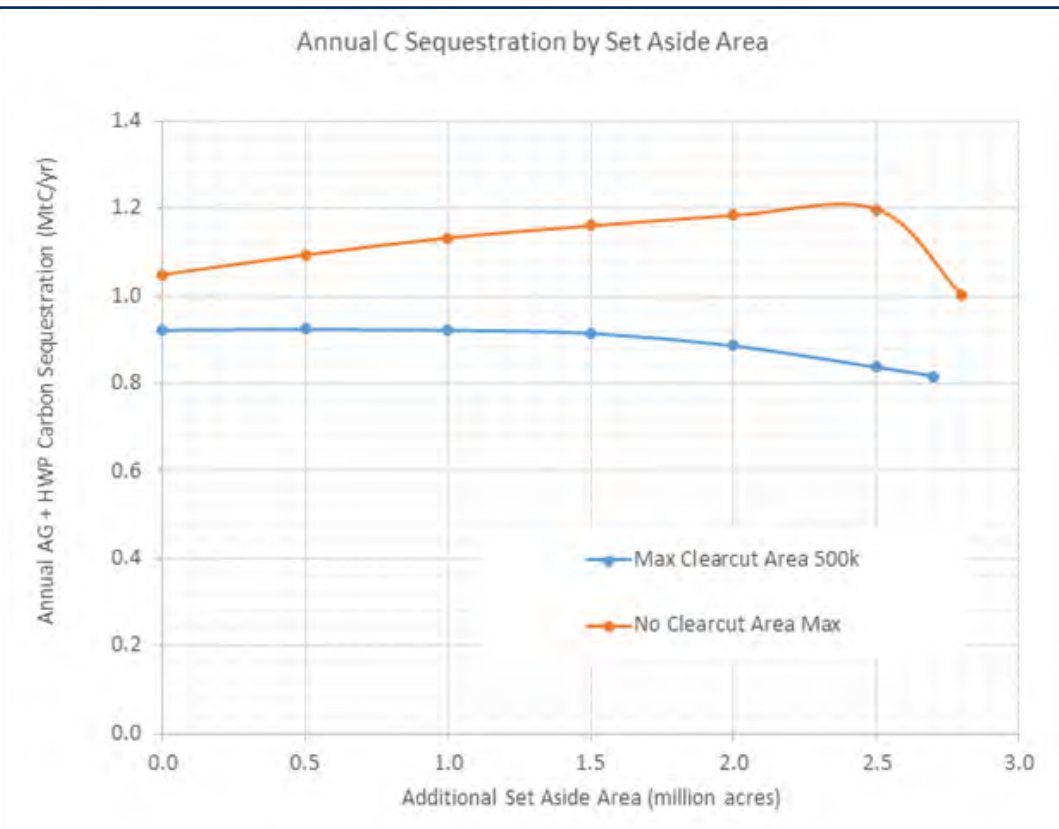


Figure 3. Forest carbon sequestration potential from set aside forest reserves under alternative clearcut and plant restrictions

- ⇒ Framework has been expanded to include more silvicultural practices and a more integrated biophysical-economic modeling methodology.
- ⇒ Several formal and informal partnerships and collaborations have been developed based on the efforts of the Maine NCSI.

**Significant Challenges**

Covid 19 limited our ability to conduct in-person farmer and forester focus groups and engage in stakeholder outreach. We have largely conducted virtual meetings instead.

Interest in utilizing our modeling and expertise to conduct NCS analyses has grown in the past year, which requires expanded capacity. We have recently added a full time post-doctoral researcher, Jianheng Zhao, to assist with the work related to this initiative.

Collaborators/stakeholders interested in the initiative have held up some analyses related to the NCSI due their constant scrutiny of model assumptions and results. This has resulted in the delay in finishing projects and/or inefficient use of resources due to having to conduct additional sensitivity analyses to 'prove' that our framework is appropriate.

**Future Plans & Opportunities**

- ✦ Draft manuscripts on NCS analysis
- ✦ Release final carbon model decision support tool
- ✦ Explore opportunity to do multi-model comparisons



The University of [Maine Forest Carbon Economy \(UMaine FORCE\)](https://umaine.edu/force) is a university-wide multidisciplinary initiative that brings together university, industry, government, and community collaborators to advance and communicate state-of-the-art research on forest carbon capture, storage, accounting, and policy in an increasingly complex and dynamic environmental, social, and political landscape to improve forest ecosystems, quality of life, and the social and economic well-being of the people of Maine and beyond.

**The FORest Carbon Estimation (FORCE) Project: Mapping GEDI-derived Forest Structure Metrics in the U.S. and Canada with Plot-based Inventory and Multimodal Remote Sensing Data in a Hierarchical Spatial Modeling Framework**

*Project Lead: Daniel Hayes, Associate Professor of Geospatial Analysis & Remote Sensing*

*Project Personnel: Aaron Weiskittel, Co-PI; Andrew Finlay, Michigan State University; Chad Babcock, University of Minnesota*

*Student Research Assistants: Sylvia Noralez (PhD)*

The major goal of our "GEDI-FORCE" project is to use spaceborne LiDAR measurements as the basis of a spatial modeling approach to develop maps of forest structural attributes required for assessing aboveground carbon stocks and their estimation uncertainty. This will be accomplished with multi-dimensional 30m, wall-to-wall map products with quantified pixel-level uncertainty. The spatial modeling framework will be developed, applied and compared over the study domain from 42oN to the northern extent of GEDI acquisitions (51.6oN), and west from northern Minnesota east to the Canadian Maritime Provinces. The models will use plot data from the national forest inventory networks of both the U.S. and Canada. The data products developed by this project will allow researchers to address current and emerging scientific questions on carbon cycling in forest ecosystems that have implications from regional to global scales.



## Objectives & Approach

The objectives for the project's first year were focused on establishing the investigator team and building the collaboration process; learning the tools required to search for and download GEDI data; visualizing and exploring the spatial locations of available GEDI data collections and their attributes over our study domain; and analyzing GEDI data against other remote sensing and ground information for geolocation accuracy and correlation to land cover and metrics of forest structure.

## Highlights & Key Findings

We can report important progress in year one across all of these project objectives. First, University of Maine investigators (PI Hayes, co-PI Weiskittel) have developed new partnerships with colleagues at Michigan State University (co-PI Andrew Finley) and University of Minnesota (co-PI Chad Babcock). We have added two graduate students whose thesis or dissertation research will focus on this project, and will contribute to the larger GEDI Science Team mission. Both Eliot Shannon (M.S., MSU, advised by Finley) and Sylvia Noralez (PhD, UMaine, advised by Hayes) began their graduate programs in September 2021. Over the past year, the investigator team has held regular, monthly meetings on Zoom to discuss research strategies and other project business. Since September, PI Hayes has held more frequent (biweekly) meetings with Shannon and Noralez to work on data collection and analysis, along with other specific project tasks. One or more of the investigator team has attended all monthly science team meetings, as well as the annual meeting in November.

We have developed our workflow for data analysis for this project, primarily using Python and R tools for subsetting GEDI data and extracting their attributes, while also visualizing GEDI and other various data sets on the Google Earth Engine. We have now downloaded and extracted all available version 2 GEDI data for our 'pilot' study sites, namely Petawawa Research Forest (Ontario) and Acadia Research Forest (New Brunswick), along with the two NAFD / Cohen-CMS project areas of interest in Minnesota and Maine. Additionally, we have assembled several other data sets for these study areas, both remote sensing (e.g. Landsat, Sentinel-2) and in situ measurements. For the Maine study area, we have airborne LiDAR data for comparison, including two recent acquisitions with G-LiHT in 2017 and 2021.

We made initial comparisons of forest height metrics acquired from GEDI and ICESat-2 against G-LiHT and in situ measurements for select areas in Maine (Fig. 1). We are developing methods

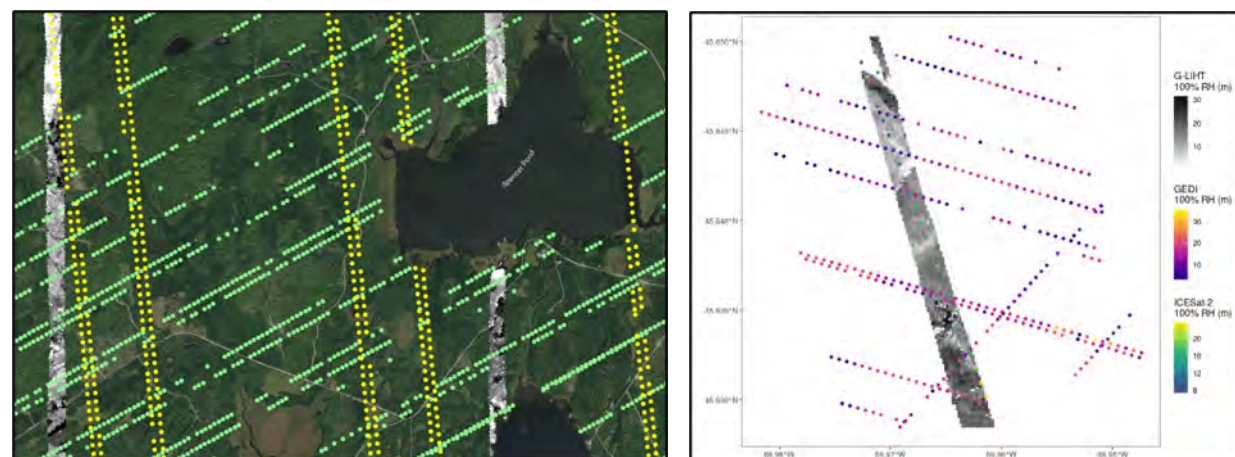


Figure 1. GEDI (green) and ICESat-2 (yellow) day and night data over a portion of the Maine CMS area with G-LiHT tracks shown in grayscale.

to identify coincident observations using a spatial buffer and Gaussian resolution adjustment to overcome the differences in sampling strategies among the data sources and to provide direct comparison of the height metrics. We also compared the overall distributions of the metrics over forests at both local and regional scales to investigate the characteristics of each data source's measurements in different scenarios (forest types, terrain types, disturbance histories, etc.).

Our direct accuracy assessments of spaceborne forest height metrics vs. G-LiHT provide valuable information for forest biomass uncertainty quantification using data from multiple sources integrated through the Bayesian spatial joint modeling framework. Key findings from this analysis include: · Good geolocation accuracy is critical for the GEDI collections in order for modeling with spatial covariates from other remotely-sensed data sources. The GEDI data show a bimodal distribution in relative height metrics where shots are collected in non-forest or recently disturbed areas (Fig. 2). GEDI shows good relationships in RH90 and RH100 coincident with G-LiHT, with high R-sq (0.68 and 0.67) and no apparent bias (Fig. 2). GEDI detects changes in relative heights (e.g., RH95) over transects from mature forest to harvested areas.

## Significant Challenges

While progress has been made and the results look promising, our analysis is for only a limited area of our larger study region. Initial progress for our work was slowed primarily due to waiting for the release of the corrected version 2 of the GEDI L2A data. Our initial analysis also brings to light some potential data issues including where filtering for nighttime-only GEDI and ICESat-2 collections greatly reduces the amount of available data (loss of 93% for GEDI, loss of 83% for ICESat-2). Furthermore, negative RH values for GEDI are present in some cases for low RH (RH < ~ 60m), while ICESat-2 and G-LiHT are limited to positive RH values only. This is a known issue with interpretation of the RH Metrics in the GEDI L2A data set where: "the lower RH metrics (e.g., RH10) will often have negative values, particularly in low canopy cover conditions. This is because a relatively high fraction of the waveform energy is from the ground 3 and below elev\_lowestmode." We will continue to investigate the prevalence of this issue in our study sites and analyses, and report on the particular conditions where these negative values exist. Potential solutions could come from applying different mask layers to remove true non-forest areas from our analysis, and adjusting RH metrics based on low canopy situations and recent disturbances.

## Future Plans & Opportunities

We plan to continue carrying out our spaceborne and airborne LiDAR data analyses with in situ data from inventory plot networks across the broader study region. The results from these

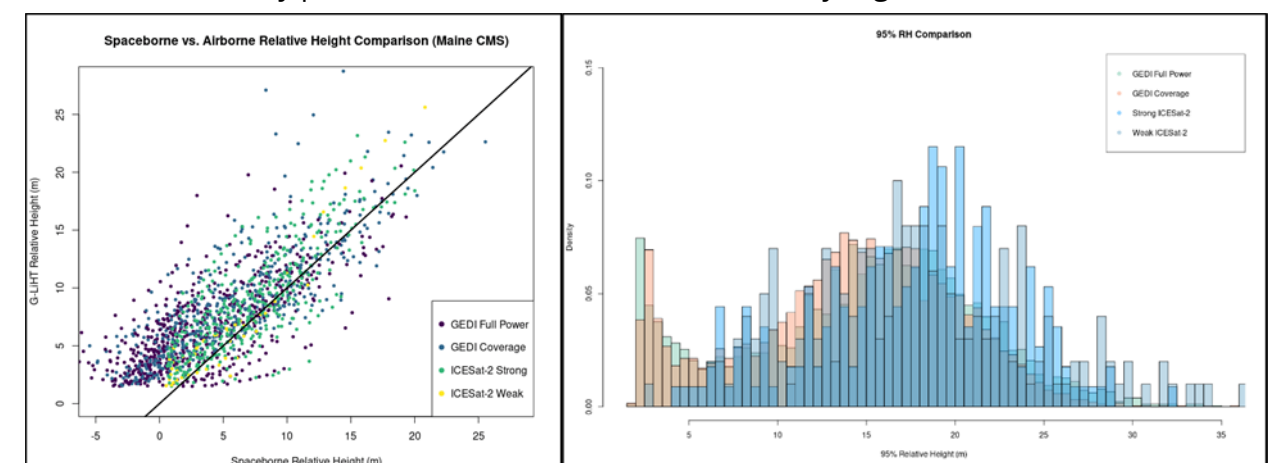


Figure 2. Coincident spaceborne lidar relative height measurements compared with airborne G LiHT metrics. Metrics compared include RH 10, 20, 30, 40, 50, 60, 70, 80, 90, 100.



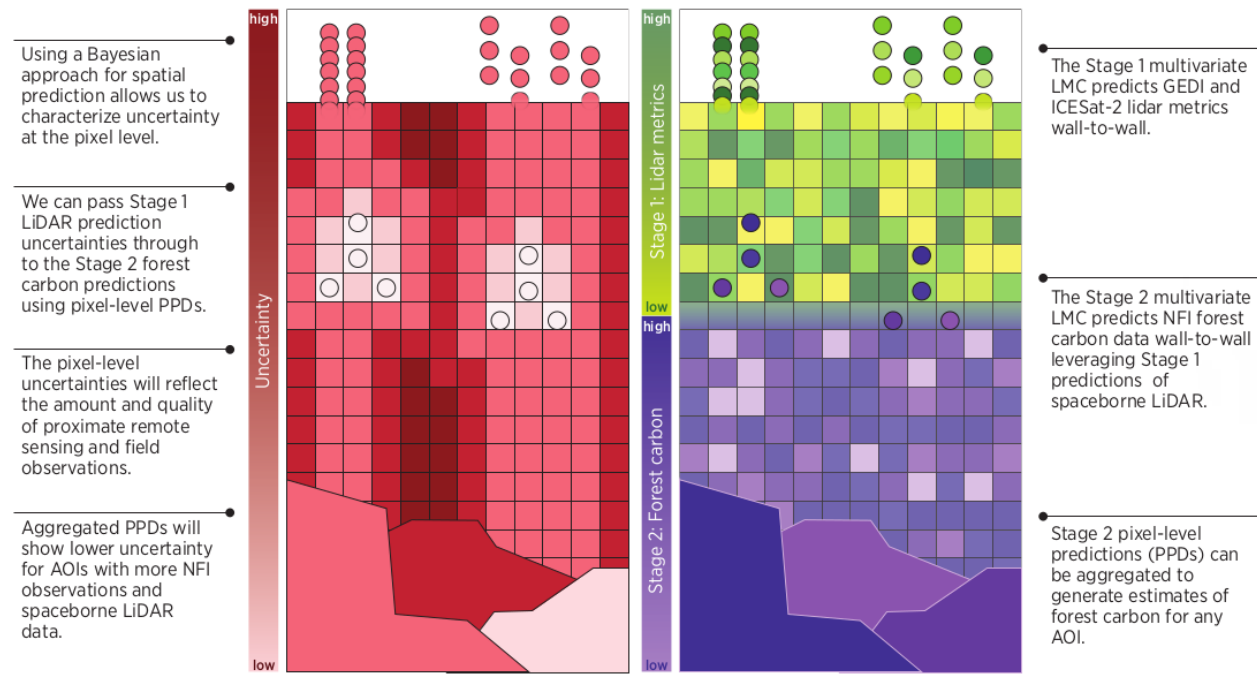


Figure 3. Modeling framework for estimating wall-to-wall forest carbon with pixel-level uncertainty.

analyses will inform the spatial modeling process, pixel-level uncertainties in mapping forest biomass, and broader research questions around remote sensing of forest carbon. Specifically, our next steps are to:

- Implement a gaussian resolution adjustment to better compare G-LiHT and spaceborne LiDAR data.
- Perform similar comparisons at other intensive study areas in the temperate-boreal ecotone using available airborne and GEDI data.
- Investigate the statistical relationship among coincident LiDAR observations at the profile level (i.e., analyzing finer-resolution RH metrics).
- Introduce coincident plot level data to compare airborne and GEDI LiDAR data with in situ measurements at intensive study areas.

These research activities will build toward the development of a two-stage modeling approach to (1) map wall-to-wall predictions of GEDI metrics that are then used to (2) predict forest structural 4 variables (e.g. biomass) based on field-based calibration plots (e.g., US FIA and Canadian provincial inventory data). At each stage, the joint regression model predicts a set of dependent variables (e.g. height and canopy cover metrics) with a multivariate spatial random effect, effectively filling in missing data between GEDI orbital tracks. The models are calibrated using Bayesian inference to allow for the propagation of uncertainty through to the prediction of pixel-level forest carbon (Fig. 3). From here, we will create wall-to-wall forest carbon predictions with pixel-level uncertainty to provide the ability for local-to-regional quantification of forest carbon.

## Supporting Stakeholder Data Requirements for Decision-Making in Managed Forests: A Landscape Model-Data Framework for High Resolution Carbon Accounting and Uncertainty Estimation

*Project Lead: Daniel Hayes, Associate Professor of Geospatial Analysis & Remote Sensing*

*Project Personnel: Erin Simons-Legaard, Co-PI; Kasey Legaard, Co-PI, Aaron Weiskittel, Co-PI; Anthony Guay, Senior Personnel; Yaxing Wei, Postdoc*

Managing forests for climate benefits requires monitoring, reporting, and verification (MRV) systems for quantifying—and assessing the uncertainty in—stocks and transfers within and among the major forest carbon pools. The UMaine investigator team is partnering with colleagues in the US Forest Service, Canadian Forest Service, and NASA’s Goddard Space Flight Center to develop an MRV system that tracks the stocks and fluxes among all of the major carbon pools in the managed forest sector at the regional, cross-national scale. The model-data framework leverages several NASA assets and remote sensing sources, from analyzing disturbance metrics from the historical Landsat record to modeling forest structure and plant traits from new data acquisitions with Goddard’s LiDAR-Hyperspectral-Thermal (G-LiHT) imaging system. These data, along with field observations from long-term research sites complemented with new plot data collection, are being used to initialize, parameterize, and validate mechanistic model development with LANDIS-II and CLM. Stakeholder engagement is a major focus of this project’s activities, and we are working with partners in forest industry and public land management agencies to address decision-making tools for various scenarios considering climate change, shifts in management activities, and potential disturbances like spruce budworm.

### Objectives & Approach

We are organizing our initial research tasks and other project activities around the following objectives: Working with stakeholders to co-produce the MRV data products and scenarios required for carbon accounting and decision making; Building an accounting framework by integrating remote sensing data within LANDIS-II; Producing map estimates and projections of regional forest carbon dynamics; and Conducting uncertainty assessment of both remote sensing and modeling outputs, and communicating and addressing these uncertainties with the user community.

### Highlights & Key Findings

- We have engaged with stakeholders early in the project through different venues and specific activities. We introduced the larger NASA CMS Science Team to our partnership with the State of Maine and their use of forest carbon data for their biennial greenhouse gas reporting for the Maine Climate Council’s action plan. Maine CMS project Co-PI Weiskittel is a member of the Governor’s Scientific and Technical Subcommittee for implementation of this plan. He also served on the advisory panel for the Maine Science



and Technology statewide strategic plan where forest carbon and the need to better monitor conditions was highlighted. In conjunction with this work, members of our team released “version 1” estimates of Maine’s state-level carbon budget (<https://crsf.umaine.edu/forest-climate-change-initiative/carbon-budget/>). Our primary stakeholder partner on this effort, Stacy Knapp from the Maine Department of Environmental Protection and inventory manager for the Bureau of Air Quality, presented and participated in the stakeholder panel at NASA CMS Science Team Meeting & Applications Workshop in November 2021. We have also engaged with forest industry practitioners and state land agency personnel on our work, including presenting on proposed CMS activities to the Cooperative Forestry Research Unit (CFRU) in January 2022 and New England Region Council on Forest Engineering (NERCOFE) in April 2022, as well as organized and held a hands-on workshop for LiDAR forest inventory at the New England Society of American Foresters annual meeting in March 2022.

- ⇒ We have made good first year progress with respect to collection and development of remote sensing data to support model initialization and calibration. In August 2021, we partnered with project collaborator Bruce Cook to conduct a G-LiHT campaign over several study areas in Maine for a repeat acquisition of 2017 and 2012 data. We are using these data sets to support biomass model calibration and mapping for these areas, and developing methods for canopy height model change ( $\Delta$ CHM) detection using repeat LiDAR. We are demonstrating the application of this approach with the development of a comprehensive, spatially-explicit assessment of the carbon budget of the University’s forest and associated properties (notably, the Penobscot Experimental Forest, Demeritt Demonstration Forest, and Howland Research Forest). To upscale these assessments, we are using the G-LiHT acquisitions to co-locate and validate LiDAR metrics generated using data from the Global Ecosystem Dynamics Investigation (GEDI), which will ultimately provide regional-scale biomass maps for initialization of our CMS models under development.
- ⇒ We have also taken significant steps toward the application of multi-objective ML for the production of forest disturbance time series. Our multi-objective approach provides the unique capability of simultaneously minimizing both omission and commission error, controlling prediction bias through time while achieving very high disturbance detection accuracy. These methods require extensive training data, and we have therefore invested significant effort in developing software to support rapid development of reference data. During this first project year, we have completed a lightweight, online reference labeling web tool similar to TimeSync in concept but with a simpler, more efficient user interface geared exclusively to the labeling of abrupt disturbance. We are currently working to integrate this disturbance detection approach into our species ML workflows to more accurately identify and mask recently disturbed areas from species predictions.
- ⇒ In Year 1 we began development of a ca. 2000 map of initial forest conditions in preparation for using LANDIS-II to “hindcast” (2000-2020) carbon dynamics across the Maine study site. This area was previously established in the Cohen et al. (“CMS-2013”) study, and corresponds to Landsat P12/R28. Previously developed maps of per species predictions of relative abundance were combined with disturbance information provided by a Landsat-derived disturbance time series (1973-2000). The resulting preliminary classification provides per-pixel (30m) identification of dominant tree species and forest disturbance class (regenerating or mature). Forest age will be refined based on time since disturbance for regenerating forest and assigned to mature forest using established imputation techniques informed by FIA plot data and LiDAR-derived canopy height. Once initialized for the Maine study site, we will integrate disturbance data from Landtrender (2000-2020) into the Land Use Change + extension to LANDIS-II to model the effects of harvesting on carbon dynamics.

### Outcomes

- ⇒ Our project participants have supported the activities of NASA’s CMS Science Team (ST) over our first project year. We have been represented at all monthly ST meetings since even before the start of the grant funding (July 1st 2021).
- ⇒ UMaine project personnel have been actively participating in all CMS working groups, with the exception of Methane: Stakeholders (Guay), Flux & MRV (Hayes), Biomass (Weiskittel), and Uncertainty (Legaard). PI Hayes presented for and participated in the Stakeholder panel session at the annual CMS ST meeting.
- ⇒ Over the first year, we have recruited for additional project participation through postdoc hiring and student assistantships. We have hired Xinyuan Wei as postdoc scientist funded on this project, with a start date of May 1st 2022. Dr. Wei will support all phases of technical development around modeling and model-data assimilation for this project.
- ⇒ We have hired a field crew of forestry students to collect LiDAR / remote sensing calibration plot data throughout various study sites in Maine over summer 2022.

### Significant Challenges

Data collection, quality control, formatting, and general analysis readiness; software/code development, computing resources, and model set up.

### Future Plans & Opportunities

For the second project year (7/1/2022 - 6/30/2023), we plan to continue carrying out research and stakeholder activities across all of our project objectives. We will continue with the development of the remote sensing data products to calibrate models for mapping biomass and other plant traits for model parameterization. An important activity in Year 2 will be to take an initial look at estimates and uncertainty in our new biomass maps that are now coming on-line. These have been developed and verified mostly independently, and here we plan to compare these various map estimates against related products such as the GEDI L4B Gridded Biomass data set. The field crew along with project investigators plan to measure around 100 plots during summer 2022, being a combination of re-measured existing (including the previous CMS project study area in northwestern Maine) and newly established plots (locally in the PEF and University Forest). We will map forest harvest using Landsat between 2020 and 2022 to update the disturbance maps and estimate the associated carbon transfers. We will use this “book-keeping” framework in the state-wide carbon budget to compare with LANDIS, and as a regional accounting estimate for top-down vs. bottom-up assessments. We will on-board and mentor the newly-hired postdoc, Xinyuan Wei, who will focus on model set up and calibration of CLM-FATES to simulate forest conditions in our study area. Over Year 2, we plan to set up site parameterizations for Harvard Forest, Hubbard Brook, and Howland). We also plan to bring on a PhD graduate research assistant to support this work. Over summer 2022, we will develop and organize our first CMS-sponsored, regional stakeholder workshop. This will be an opportunity to share our CMS project’s initial ideas and findings with a large audience of stakeholders who will participate in discussions to guide the development of the data and tools that can address their needs for decision-making. The draft agenda for a one-day, facilitated workshop is attached here as an appendix. We have developed an initial invitation list that lists over 100 potential participants, with more to be added. They represent a range of stakeholders, from forest industry and state agencies to GIS professionals and teachers.





## Fostering Forest Landscape Planning

**Project Lead:** Erin Simons-Legaard, Research Assistant Professor

**Project Personnel:** Kasey Legaard, Co-PI; Aaron Weiskittel, Co-PI; Leo Edmiston-Cyr, Technical Programmer; Kenneth Bundy, Technical Programmer

Widespread outbreaks of forest insects and land management responses to reduce risk and minimize economic loss can have long term impacts on forest productivity and ecosystem services. The most widespread of the budworm species, which causes more tree damage than any other insect in North America, is eastern spruce budworm. Budworm outbreaks can last years, and population indicators suggest the current outbreak will soon spread from Canada to Maine. Our goal is to provide the science-based information forest managers need to reduce risk of budworm damage, without compromising important ecosystem services through innovative use of machine learning, U.S. FIA plot data, remote sensing and forest landscape modeling. Projections will evaluate interactions between outbreak intensity, forest management and climate change across a study area that encompasses nearly all the northeastern U.S. forestland most likely to impacted during the oncoming budworm outbreak.

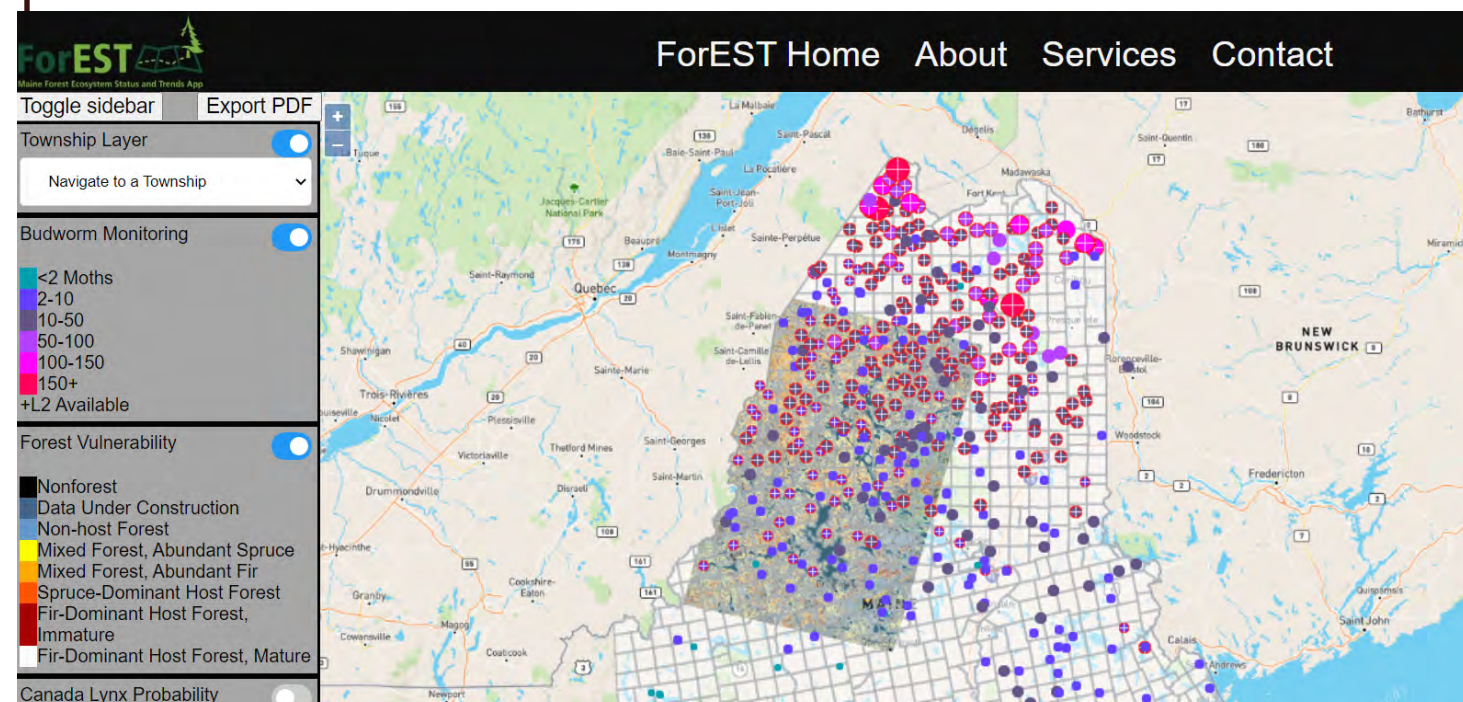
### Objectives & Approach

1. Determine the local and landscape conditions that influenced forest susceptibility to defoliation during the last outbreak of spruce budworm, using historic field plot data and satellite imagery.
2. Identify forest conditions that promote the early establishment of local budworm populations, using contemporary population monitoring data and satellite imagery.
3. Evaluate tradeoffs among ecosystem services and uncertainty associated with alternative strategies to mitigate risk based on susceptibility vs. vulnerability, in the context of ongoing climate change and outbreak uncertainty.
4. Increase local and regional adaptive capacity using a Participatory GIS approach and online mapping system.

*Major Activities in Year 2 primarily focused on Objectives 2 and 3*

**Objective 2 :** Since 2014, moth counts have been recorded 1+ years at more than 560 locations and 7 consecutive years at a subset of 245 locations. In Year 2 we used the subset of monitoring locations with long term records, also including L2 counts in 2020 and 2021, in cluster and regression analyses. Clustering identified groups of locations associated with developing trends in average moth counts (increasing, decreasing, stable, variable) and regression analyses were used to develop predictive models of moth or L2 count. We were particularly interested in evaluating the effect(s) of landscape position relative to the local terrain (average elevation, orientation, and exposure), to better understand, for example, if certain landscape conditions (e.g., fir hill vs fir bog) had higher susceptibility to immigrating moths.

**Objective 3 :** Forest landscape models (FLMs) are increasingly being used for decision support in forest management settings because they are better suited to simulating forest response to novel conditions than traditional growth-and-yield models. In Year 2 we calibrated the Biological Disturbance Agent extension for LANDIS-II using species-specific information derived from the historic GIS dataset about how tree mortality rates were affected by budworm defoliation. We then modelled the interactive effects of budworm-induced tree mortality and forest management (with and without pre-salvage) on forest dynamics and future forest conditions mid-century (ca. 2050).



### Highlights & Key Findings

#### Objective 2

- After two large in-flights from outbreak zones in neighboring QC in July 2019, average moth count quadrupled between 2018 ( $x = 19.8$ ) and 2019 ( $x = 66.2$ ) and remained high ( $x = 36.3$ ) in 2020.
- K-means clustering ( $n = 5$ ) of the 138 location with complete moth records and 2020/2021 L2 observations was able to explain ~60% of the variability in the time series of average moth counts. The majority of locations ( $n = 100$ ) fell into one of two groups with stable trends of mostly lower than average counts. The next largest group ( $n = 19$ ) identified locations where moth counts have been consistently increasing since 2016, all of which were within ~60 miles of Maine's northern border with Canada.
- In addition to latitude and longitude average moth count in 2019 was also a significant predictor of moth count in 2020, which may suggest local population growth has become positive in many areas independent of in migration. Among the terrain variables we considered, elevation was marginally significant ( $P = 0.052$ ) and had a negative effect on moth count.
- The majority of sites continued to have zero L2 larvae detected, but incidence rates in 2020 (23%) and 2021 (30%) were notably higher than 2014-2019 (3-9%). As with average moth counts, latitude had a positive relationship with L2 count. There was also positive correlation both between average moth count in 2020 and L2 count in 2021 (0.41) and between 2020 L2 count and 2021 L2 count (0.6).

#### Objective 3

- In the absence of a budworm outbreak, projections suggest northern Maine would continue to be a carbon sink over the next 40 years (2020-2060). As a result, total live aboveground biomass (total AGB) would steadily increase at a rate of ~1% per year across all forest types.
- Simulations suggest that if the current outbreak spreads to Maine, presumably within the next 10 years, budworm-induced tree mortality during the outbreak period would result in a 3-7%



decline in AGB of host species with the greatest declines occurring in areas of high-risk forest where relative abundance of balsam fir is greater than 75%. Results further suggest that host species abundance in those areas would recover after approximately 40.

- ⇒ Simulation outcomes of the interactive effects of pre-salvage on AGB dynamics were dependent on whether pre-salvage harvesting was modeled 1) as additive to current harvest levels during the outbreak period or 2) as a reallocation of current harvest levels. If annual harvest rate increased, for example, from 2% under BAU to 3% with pre-salvage during a 10-year outbreak period, simulations suggest decline of host species AGB would increase to 11% in high-risk forest. In contrast, if total harvest level was maintained through reallocation of BAU harvest area to pre-salvage change in host species AGB would be comparable to predictions without pre-salvage (i.e., 7% decline).
- ⇒ Simulations further suggest a longer term effect of pre-salvage harvesting (and assuming no intensive management such as herbicide application) would be higher conversion rates from spruce-fir forest to mixed forest.

**Outcomes**

In Year 2 we welcomed an early-career computer scientist (CS) into our interdisciplinary team, who is providing expertise in technical programming and advanced math. Through their involvement with this project they are gaining domain knowledge about application of geospatial technologies, artificial intelligence, and software development in the context of risk mapping and natural resource management. Also in Year 2, another early-career team member led a substantial restructuring and modernization of the code base to improve operability and stability of our online web mapping system (ForEST). Since its start, this project has prioritized recruiting recent CS graduates as lead programmers with supportive mentoring by Senior Personnel. Project management and mentoring plans include regular meetings for updates and strategic planning and flexible work schedules to meet diverse needs. In Year 2, we also recruited a recent graduate from the Wildlife, Fisheries, and Conservation Biology program who will be working with members of the Spruce Budworm Task Force and leading the effort to assemble information for a new map of sensitive areas.

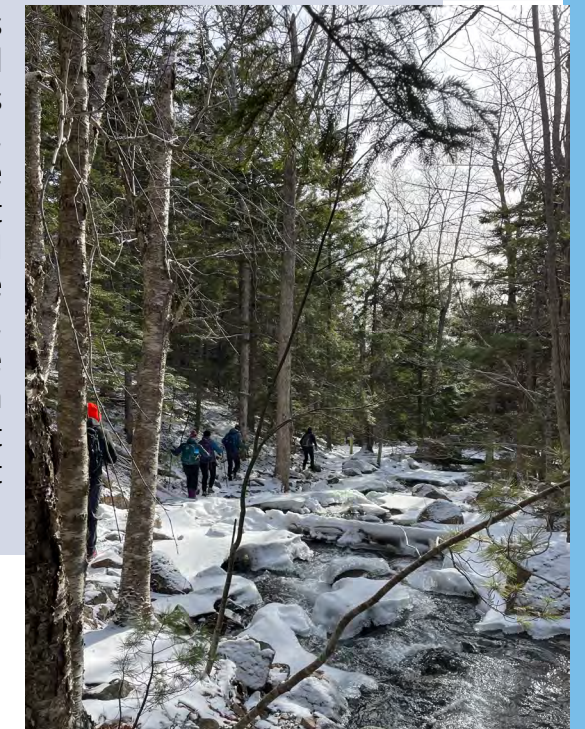
**Significant Challenges**

Student recruitment was a primary challenge to project progress in Year 2.

**Future Plans & Opportunities**

- ⇒ In Year 3, We will finalize our analyses describing patterns of budworm population establishment and growth. Analyses will include a final round of regression modeling using available moth and L2 data, and application of an unsupervised machine learning algorithm referred to as a self-organizing map (SOM) to spatially predict risk of budworm defoliation. We will also complete statewide mapping of the contemporary (ca. 2022) distributions of budworm host tree species.
- ⇒ Projections completed in Year 2 assume the continuation of current climate; in Year 3 we will incorporate the effects of climate change on tree regeneration, competition, and growth into our final scenario analysis. In addition to budworm-induced tree mortality, we will also include the effects of defoliation on tree productivity to better understand the how the impeding budworm outbreak will influence aboveground carbon sequestration and storage.
- ⇒ We will continue to update and expand the maps in ForEST. Maps of forest vulnerability, balsam fir abundance, and lynx habitat will be updated to current (ca. 2022) conditions and expanded to be wall-to-wall statewide, and we will be developing a new map to identify sensitive areas where the use of salvage harvesting or insecticidal spray should be limited or avoided. We will offer an outreach workshop (hybrid) with ForEST end users to solicit feedback about system updates and to form a steering committee to inform future development.

The Nature-Based tourism program engages students and researchers in geospatial, economic, and social science analyses to develop solution-driven approaches to climate change. Natural resource-based economies, such as forestry and tourism, play a vital role in the culture, quality of place, and economic development of Maine’s rural communities, as well as in the overall economy of the state. Dr. Sandra De Urioste-Stone continues to lead our Nature-Based Tourism program, with ongoing research into the impacts of climate change on land cover and management, and a timely project on the pandemic’s impacts on local tourism and its effect on the vitality and well-being of tourism-dependent communities.



**Forest Socio-Ecological Resilience**

*Project Lead: Sandra De Urioste-Stone, Associate Professor of Nature-based Tourism*

*Project Personnel: Parinaz Rahimzadeh-Bajgiran, Co-PI; Aaron Weiskittel, Co-PI; Adam Daigneault, Co-PI*

*Student Research Assistants: Alyssa Soucy (MSc), Brooke Hafford MacDonald (PhD), Nathaniel Burke (undergrad), MacKenzie Conant (undergrad), Madison Syer (undergrad)*

*Survey Participants: Maine Woodland Owners; Cooperative Forestry Research Unit members*

Maine’s rural communities and natural resources-based industries rely heavily on the products and services provided by forest ecosystems. Given the complexity of the state’s forest systems, with transition forests in early and mid-successional stages resulting from prior disturbances, the influence of climate change should be more evident than in other regions. Hence, the importance of this research to address the impacts of climate change on land cover and management. Our research will enhance the resilience of forest socio-ecological systems (SES) by integrating geospatial, economic, and social science analyses, and developing solutions-driven approaches to climate change.

Our study contributes to USDA-AFRI’s goals to promote science driven solutions, conduct engaged research, increase adaptive capacity of forest SES to climate variability, and foster reduction of greenhouse gas emissions. The study utilizes a transdisciplinary approach to develop generalizable models for effective climate change adaptation and mitigation.



## Objectives & Approach

Our research aims to develop and validate an integrated framework to assess and enhance the resilience of forest SES to climate change. We pursue this through four targeted research objectives

Objective 1: Assess forest resources industry stakeholder awareness of climate variability and consequences on the landscape and ecosystem services, perceptions of vulnerability of forest SES, and land management decisions in response to climate change.

Objective 2: Link stakeholder perceptions of consequences of climate change with simulated and remote sensing derived changes of forest condition.

Objective 3: Use an integrated modelling framework to quantify and map the potential physical and socio-economic effects of climate change, forest policy, and landowner adaptation to these pressures on forest composition, structure, and health at a spatial resolution relevant to managers and other stakeholders.

Objective 4: Jointly identify best management strategies to increase socio-ecological resilience of forest systems and opportunities to enhance ecosystem services along the forest supply chain.

## Highlights & Key Findings

- ⇒ A short online questionnaire with Maine forest industry stakeholders was conducted to understand policy facilitators and barriers to implementing climate change adaptation strategies. The instrument also enquired about climate change information needs.
- ⇒ A spatially explicit vulnerability assessment model (VAM) was developed to map the vulnerability of Maine's forest sector to climate change by combining biophysical and social indicators of exposure, sensitivity, and adaptive capacity.

## Outcomes

- ⇒ Created a transdisciplinary team of researchers to integrate social and biophysical data relevant to stakeholders.
- ⇒ Trained four undergraduate students and three graduate students in how to conduct social science research (strategies to conduct rigorous, reliable, and ethical studies) and spatial analysis efforts.
- ⇒ Increased capacity of faculty and students to effectively work across disciplines and expand collaboration with stakeholders in the state.

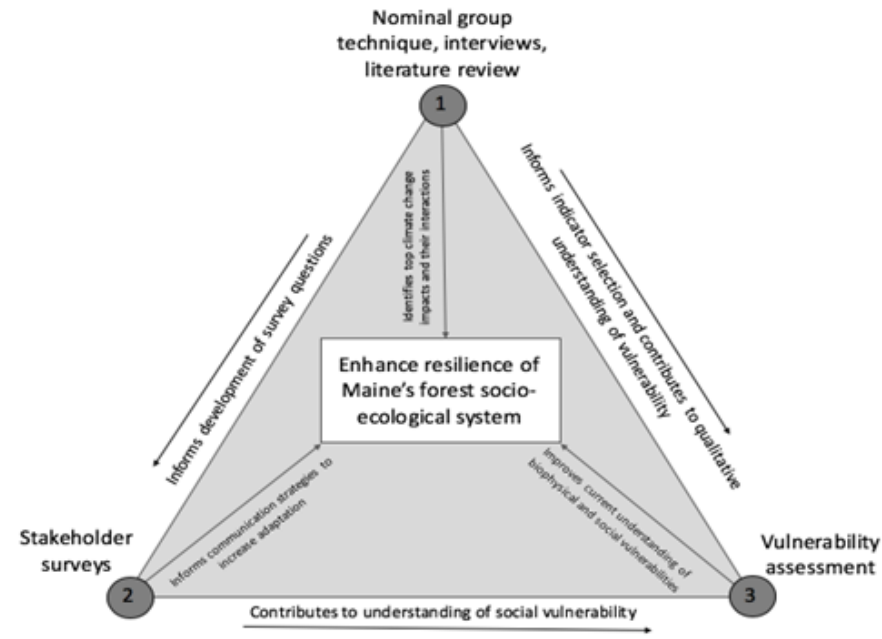


Figure 1. Research process (figure developed by A. Soucy).

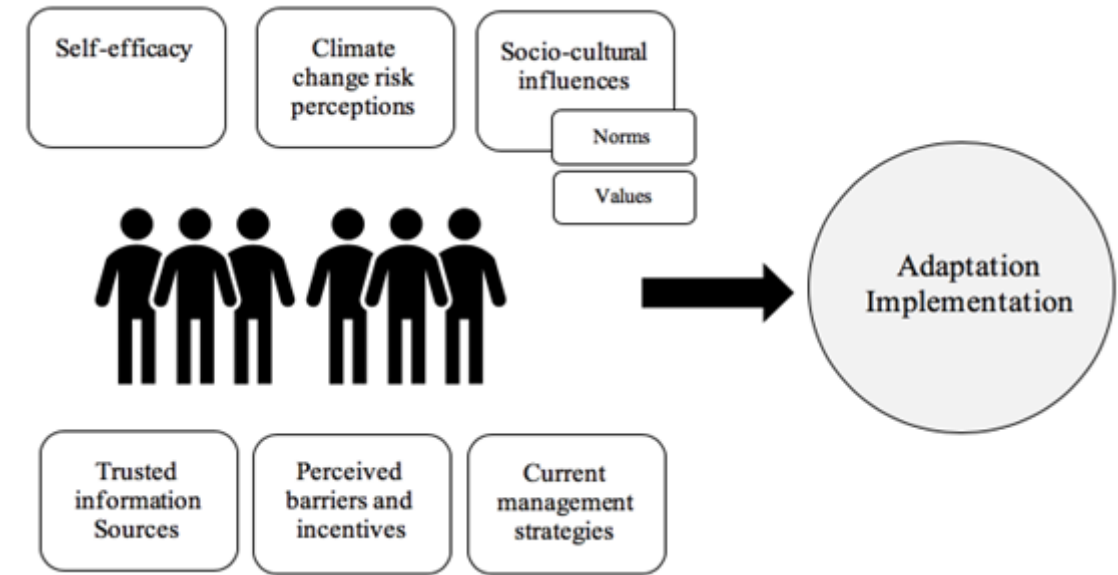


Figure 2. Important factors to consider when communicating to forest stakeholders about climate change adaptation implementation (figure developed by A. Soucy).

- ⇒ The lead graduate student developed and distributed three infographics to share study results with industry stakeholders (i.e., members of the CFRU, small woodlot owners, and other partners in Maine). Results have also been shared online, and through multiple workshops.
- ⇒ Increased capacity of students and faculty to develop effective science communication tools.
- ⇒ Developed a novel Vulnerability Assessment Model of climate change impacts that integrates biophysical and socio-economic data. Model was tested and validated for the State of Maine.
- ⇒ Four graduated master's students who contributed to the project are now working for Woodwell Climate Research Center, Americorp, and (two) U.S. Fish & Wildlife.

## Future Plans

Continue to develop ideas for future research proposals and collaborations.

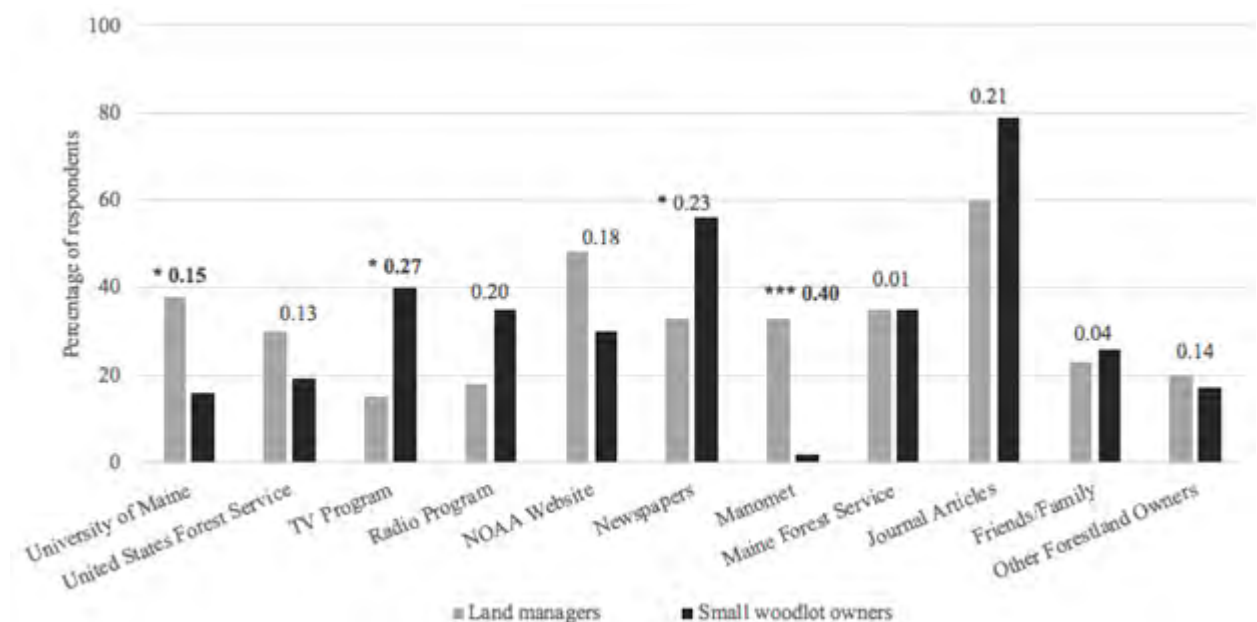


Figure 3. Sources of climate information for stakeholder groups according to survey responses. Significance level (\* p value < 0.05; \*\* p value < 0.01; and \*\*\* p value < 0.001) and Cramer's V for chi-square test results for the two stakeholder groups (figure developed by A. Soucy).



## Community Resilience in a Time of Crisis: Lessons from the COVID-19 Pandemic

*Project Lead: Sandra De Urioste-Stone, Associate Professor of Nature-based Tourism*

*Project Personnel: Sarah Jackson, Co-PI; John Daigle, Co-PI; Karen Beeftink, Co-PI; Allison Gardner, Co-PI; Brandon Lieberthal, Co-PI; Linda Silka, Co-PI*

*Student Research Assistants: Lucy Martin (MSc), Gabrielle Venne (MSc), MacKenzie Conant (MSc), Molly Bogner (undergrad), Natalie Siwek (undergrad), Augusta Stockman (undergrad), Mckenna Mollner (undergrad)*

Tourism supports the economies of numerous rural communities in Maine, and the COVID-19 pandemic has presented major challenges to the vitality and well-being of these communities through limitations posed on travel and tourism business operations. This project used social science surveys to explore how the pandemic influences visitor travel decisions; and epidemiological modeling to retrospectively assess the vulnerability of rural, tourism-dependent communities to COVID-19 transmission. The project brings together researchers and practitioners from tourism and outdoor recreation, rural planning, social and community psychology, disease ecology, and mathematics.

### Objectives & Approach

Objective 1. Measure visitor motivations and travel behaviors to travel to/within Maine.

What factors influence visitor decisions to travel to/within Maine during the pandemic? Which place attributes have attracted visitors and which have served as barriers to considering Maine as a tourism destination during the pandemic?

Objective 2. Identify correlations between environmental, sociodemographic, economic, and political variables and high transmission of COVID-19 in Maine towns .

Hypothesis 1. Initially, transmission was highest in urban areas of Maine, and human population density and network connectivity were the best predictors of transmission risk.

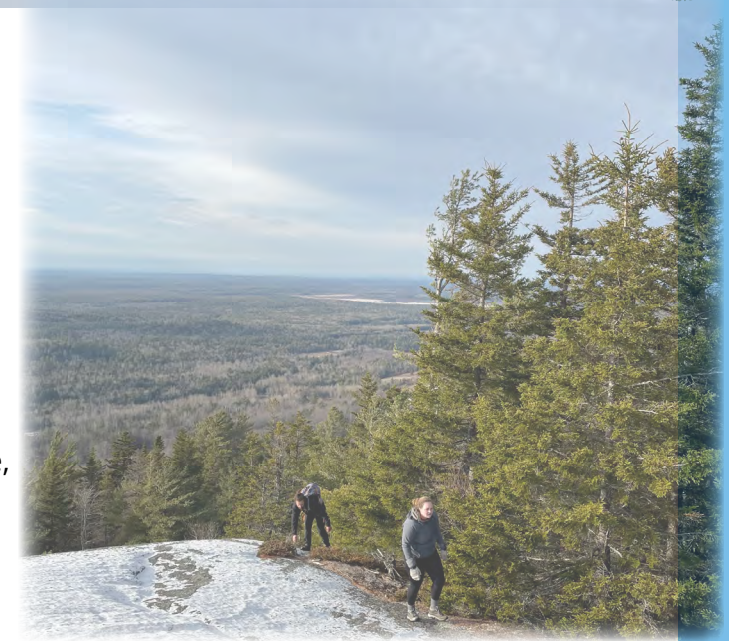
Hypothesis 2. High transmission later shifted into rural communities, with peaks less severe but more sustained over time, and economic dependence on tourism became the best predictor.

Our research uses a combination of primary and secondary data. Three surveys will measure visitor motivations and travel behaviors by using primarily close-ended questions to assess travel behavior, health risk perceptions, knowledge and experience with COVID-19, sources of information, and evaluation of destination attributes. The second component includes a statistical model to identify economic, political, environmental, and demographic variables that are strongly correlated to town-level transmission rates over time. Predictor data was aggregated from the American Community Survey, U.S. Census, and state economic reports.

### Highlights & Key Findings

#### Data Collection

- ↪ In October-November 2021 we conducted an online survey of Maine out-of-state visitors from Massachusetts, New Hampshire, New York, Connecticut, Vermont, Rhode Island, Pennsylvania, North Carolina, and Florida. The effort resulted in 410 responses currently being analyzed.
- ↪ We are currently conducting a mixed-mode visitor survey at Acadia National Park. To date we have intercepted over 1,400 visitors on site, and have received over 400 responses to the online self-administered survey.
- ↪ An online survey of Maine outdoor recreationists is currently under development in collaboration with the Bureau of Parks and Lands.
- ↪ COVID-19 mitigation strategies in early 2020 were motivated primarily by economic and political factors, not by science-driven estimates of risk. As a result, U.S. counties that took COVID-19 less seriously, especially rural counties with an economic reliance on tourism, suffered greater epidemic spread in the summer of 2020.
- ↪ A 2021 survey of out-of-state visitors to Maine found that trust in information sources, experience and concerns about the pandemic, and several protective and travel behaviors varied depending on political affiliation.



### Outcomes

- ↪ Created a transdisciplinary team of researchers to integrate social and biophysical data relevant to stakeholders.
- ↪ Trained four undergraduate students and four graduate students in how to conduct social science research (strategies to conduct rigorous, reliable, and ethical studies).
- ↪ Increased capacity of faculty and students to effectively work across disciplines and expand collaboration with stakeholders in the state.

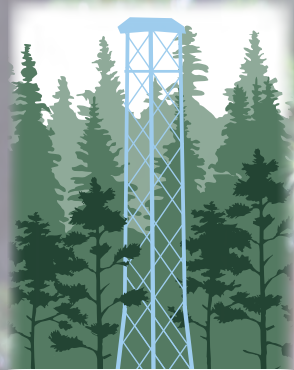
### Significant Challenges

The pandemic posed challenges for data collection in 2021, which led to changing the mode of data collection (online survey), and delayed in person surveying to summer 2022.

### Future Plans & Opportunities

- ↪ Finalize data collection for 2022.
- ↪ Launch an outdoor recreation survey for Maine residents in fall 2022.
- ↪ Analyze survey data.
- ↪ Submit one biophysical manuscript in fall 2022, and at least one social science manuscript in spring 2023.
- ↪ Developing ideas for future research proposals and collaborations.





**Howland**  
Research Forest

**H**owland Research Forest is owned by the Northeast Wilderness Trust and operated by CRSF faculty and staff, in collaboration with the US Forest Service, Northern Research Station. Howland is a long-term research site focusing on fluxes of carbon dioxide, methane, water, and energy, as well as other terrestrial processes, to better understand the forest carbon cycle, particularly in response to climate change. Howland is a founding member site and one of the current core sites of the AmeriFlux network, and it boasts the second longest-running carbon dioxide flux tower in the United States, dating back to 1996 (the longest belonging to Harvard Forest). These decades of data provide a time series long enough for robust analyses of relationships between carbon fluxes and various environmental variables.

**P**rimarily funding to support day-to-day activities at Howland originates from the U.S. Department of Energy, AmeriFlux Program, and the US Forest Service. Past funding and collaborations include NASA, NOAA, EPA, and the Woods Hole Research Center (now Woodwell Climate Research Center). The CRSF continues to support an active research program at Howland focused on ecosystem productivity, carbon cycling, remote sensing, climate change, and more. Such research allows us to address additional questions complementary to the core AmeriFlux mission, thereby expanding the project's reach and scope.

## Carbon Cycle Research at the Howland Forest, Maine

*Project Lead: Shawn Fraver, Associate Professor of Forest Ecology, University of Maine*

*Project Personnel: Dave Hollinger, USDA Forest Service; John Lee, Research Associate; Holly Hughes, Research Assistant*

*Student Research Assistants: Zoe Read (MS), Alley Barry (MS), Colby Bosely-Smith (MS), Elyse Daub (BS), Kasey Grass (BS)*

The AmeriFlux network is a nationwide set of research sites measuring fluxes of CO<sub>2</sub>, methane, water, energy, as well as other terrestrial processes, to quantify the forest carbon cycle and the response of terrestrial ecosystems to climate and disturbance. The Howland Research Forest, Maine, is one of the Core Sites of the AmeriFlux program. The general expectations for Core Sites include providing high quality continuous data with long-term duration, participating cooperatively in the network, and being responsive to Department of Energy requests.

### Objectives & Approach

The primary objective of this project is to support ongoing AmeriFlux-related activities at the Howland Research Forest, Maine, including (1) providing overall technical support for the CO<sub>2</sub> flux, meteorological, soil flux, and ecological activities, (2) assisting with sensor calibration, telecommunications, flux calculations, data processing, and ecological measurements, (3) ensuring adequate communication between the University of Maine and Forest Service personnel regarding project status, (4) sharing data freely with the AmeriFlux Management Project, and (5) providing general upkeep and safety of the Howland Forest site, including liaising with the Howland Forest landowner. These objectives are met through the work of two Research Associates, John Lee and Holly Hughes. In addition, the infrastructure and continuous, long-term data at Howland Forest provide an ideal framework for graduate student research, which is conducted through the School of Forest Resources, University of Maine.

### Highlights & Key Findings

- The Howland Forest site has had continuous atmosphere-forest canopy CO<sub>2</sub> flux data since 1996, and additional environmental measurements added since then.



*M.S. student Zoe Read measuring CO<sub>2</sub> flux from a decaying spruce log at the Howland Research Forest, Maine. Photo: Shawn Fraver.*



- ⇒ Over the last 25 years Howland Forest has stored almost 3.5 tons of CO<sub>2</sub> per acre each year, even though that timespan has included the warmest, wettest, and driest years in the last 125.
- ⇒ Although the Howland Forest is maturing, it is storing on average a bit more carbon each year.

**Outcomes**

Trained three graduate and two undergraduate students; advanced partnerships with colleagues at the US Forest Service (Northern Research Station), Woodwell Climate Research Center, University of Massachusetts, Rutgers University, and Northern Arizona University.

**Future Plans & Opportunities**

We expect to begin a project focusing on methane fluxes at the Howland Forest.



The PEF is home to collaborative long-term silviculture and ecology research by the Forest Service and the University of Maine. The CRSF has partnered with the Forest Service to maintain their large-scale silviculture experiments across 1,000 acres of the PEF. This work includes the Management Intensity Demonstration (1950 to present), Compartment Management Study (1952 to present), Biomass (Whole-Tree and Stem-Only) Harvesting Study (1964 to present), Precommercial Thinning x Fertilization Study (1976

to present), and Silvicultural Rehabilitation Study (2008 to present). In addition to collaborating on data collection, analysis, and presentation or publication of the results of PEF research, the Center has supported Forest Service research data and archive management leading to the publication of permanent sample plot data from many studies. The PEF is also the location of a Smart Forest network installation, linking wireless sensor data collection across sites.

Researchers from the U.S. Forest Service and Center for Research on Sustainable Forests are collaborating to continue and expand research on lowland cedar, with a focus on the ecology, ecophysiology, and silviculture of this species in cedar-dominated swamps and seeps. Remeasurements of harvested and control stands are used to determine effects of management on ecological characteristics of cedar stands and the potential of silviculture for sustainable use. Additional efforts at the PEF include the dissemination of findings from the beech bark disease tolerance study, and generating new management guidelines for practitioners and science delivery products for students and the public, with a focus on northern conifer silviculture, carbon storage, and forest health.

PEF staff hosted the CRSF's inaugural Forest Climate Change Initiative webinar and field tour series in October 2021. Nearly 30 forestry professionals joined USFS Research Scientist Laura Kenefic, UMaine Forest Manager Keith Kanoti, UMaine wildlife faculty Alessio Mortelliti, and Maine Forest Service District Forester Kenny Fergusson to discuss forest climate adaptation and management options on the spruce-fir forest ecosystem at the PEF, including wildlife impacts and implications for both large and small forest landowners.



*Photo by Regina Smith.*



# Global Timber Modelling Approach to Estimating Regional Forest Carbon Leakage

*Project Lead: Adam Daigneault, E.L. Giddings Associate Professor of Forest Policy & Economics, UMaine School of Forest Resources*

*Student Research Assistant: Logan Woodyard, MSc*

*Partners: Brent Sohngen, The Ohio State University/Sylvan Acres LLC; Peter Ellis, The Nature Conservancy; Ethan Belair, The Nature Conservancy*

TNC is exploring the potential leakage impacts from implementing forest carbon sequestration projects across the globe. Quantifying leakage from a specific project or region requires modeling impacts on forest product markets timber supply, forest management, and carbon in both standing forests and harvested wood products. To quantify the potential impacts in various forested areas/regions around the world, we used the Global Timber Model (GTM). GTM is forward-looking dynamic optimization model of forests and land use, which accounts for forest growth, management, and harvests in more than 300 forest ecosystems across 16 regions of the globe from present day through 2200. The model's objective function maximizes the net present value of total economic surplus in timber markets, capturing decadal changes in landowners' decision-making based on market and biophysical conditions. The final analysis estimated carbon and harvest leakage rates from 29 forest types modeled across 16 regions of the globe.

## Objectives & Approach

This research used the existing 16-region delineation of GTM to measure region- and practice-specific carbon and harvest leakage rates using the following methods:

- ⇒ Run model out to 2200 based on historical trends in forest stocks and socioeconomic drivers to quantify 'baseline' timber harvest, area, and forest carbon levels at the decadal level;

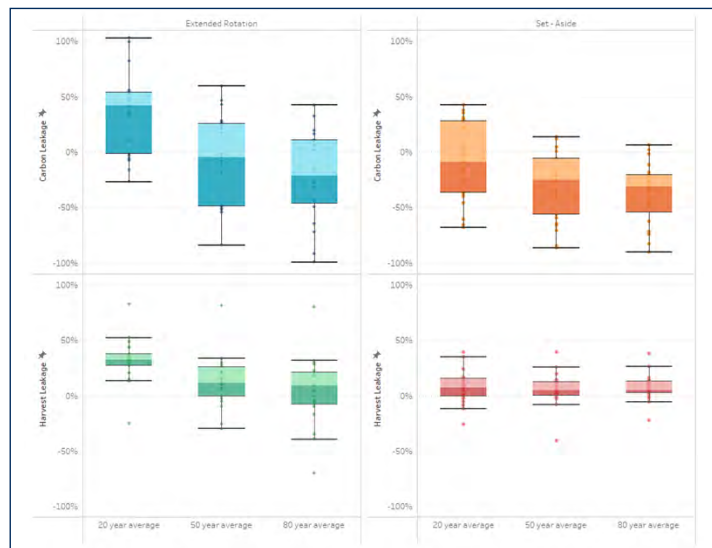


Figure 1. Range of carbon and harvest leakage estimates by carbon project over 3 measurement periods (note: outliers with leakage rates +/- 100% removed from sample)

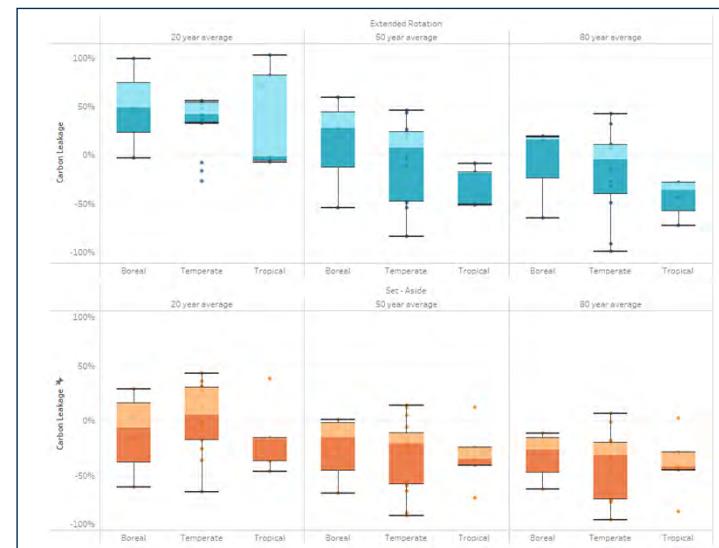


Figure 2. Carbon leakage estimates by carbon project type and forest ecosystem. (note: outliers with leakage rates +/- 100% removed from sample)

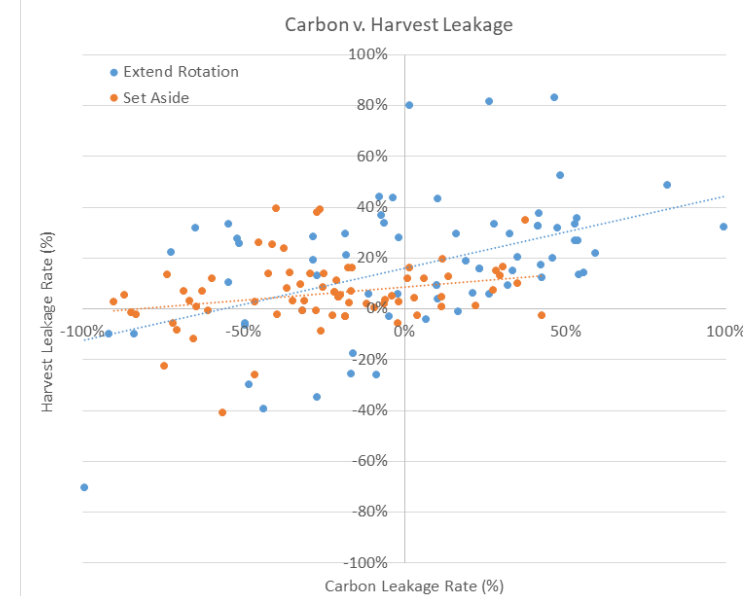


Figure 3. Scatterplot of carbon and harvest leakage estimates by carbon project type. (note: outliers with leakage rates +/- 100% removed from sample)

- ⇒ Model a set of scenarios that individually impose specific forest carbon management practices (i.e., deferred harvest and permanent set asides) on at least one forest type in each of the 16 regions, but leave all other regions to follow the baseline assumptions;

- ⇒ Calculate the difference in harvest and forest carbon in each region of the globe to estimate the 'leakage' rate;

- ⇒ Conduct sensitivity analysis to assess how leakage rates can vary across key assumptions (e.g., percent total forest area enrolled in forest carbon project, length of time to quantify leakage over), and

- ⇒ Synthesize and present leakage estimates in absolute and percentage terms via regional look up tables that vary leakage by carbon management practice and year.

## Highlights & Key Findings

- ⇒ Quantifying carbon and timber leakage for all 29 forest type combinations in our study results in a wide range of estimates for both metric across project type, forest type, and estimation period.
- ⇒ Interestingly, there are several instances where imposing forest carbon project in the manner that was modeled in GTM (i.e., specifying a given area enrolls in the project, while the rest of the world does not have any carbon program or policy imposed on them) can result in negative leakage (i.e., gross global carbon or harvests increase by even more than the project estimate).
- ⇒ Carbon leakage rates for deferred harvests average 40%, have a median of 7% and range from -226% to +2582%. For set asides, C leakage averages -27% (i.e., negative leakage), has a median of -25%, and ranges from -213% to +276%.
- ⇒ In terms of harvest leakage, deferred harvests have a mean leakage rate of 32%, with a median of 21% and ranges from -421% to +944%, while set asides have a mean harvest leakage rate of 8%, a median of 5%, and a range from -112% to +100%.
- ⇒ Leakage rates typically decline with the length of the estimation period (Figure 1). This is because the estimate is accounting for more time that it takes non-project forests to respond to the policy, specifically the global price increases associated with a reduction in project area harvests.
- ⇒ Leakage rates are typically lower for set aside projects than deferred harvest projects, again because there is a larger market signal that induces more investment outside of the project area.
- ⇒ Harvest leakage rates are often higher than carbon leakage rates, likely because some of the reductions in harvests in the carbon project area shift to more productive (i.e., economically) efficient areas of the globe.



- ⇒ Average and median carbon leakage rates are generally lower in forests located closer to the tropics compared to the poles (Figure 2).
- ⇒ Harvest and carbon leakage rates are somewhat correlated (Figure 3). The two leakage metrics for extended rotation scenarios had a correlation coefficient of +0.48, while estimates for the set aside scenarios had a correlation of +0.25.

#### Future Plans & Opportunities

- ✦ Present findings to TNC and other interested stakeholders (carbon market developers and participants)
- ✦ Continue to refine the modeling and analysis to determine the key drivers of the variance in leakage rates across the globe.
- ✦ Draft and submit peer reviewed manuscript with project collaborators, including TNC.



## *Landowner Engagement Improves Eastern White Pine (EWP) Resilience and Value in a Changing Environment*

*Project Lead: William H. Livingston, Associate Professor*

*Project Personnel: Steve Roberge, UNH Forest Extension Specialist, Co-PI; Nicholas Brazee, UMass Pland Disease Clinique Specialist, Co-PI*

Eastern white pine (EWP) is a major component of eastern forest with over 186 million mbf (15 billion ft<sup>3</sup>) in 25 states. The species responds extremely well to management if densities are kept low. Managing stand densities can also ameliorate losses due to increasing threats from drought, fungal pathogens, and insect pests. Unmanaged stands can suffer mortality over 50%. Outreach products to be developed for improving EWP management production includes a symposium, online Eastern White Pine Management Institute, updated field manual, workshops, fact sheets, and videos.

#### **Objectives & Approach**

- ⇒ Develop new and innovative outreach products and delivery approaches for engaging natural resource professionals and landowners to understand eastern white pine health issues and how to minimize risks.
- ⇒ Involve stakeholders from rural communities and from the rural/urban interface to address concerns and implement strategies to improve the health and sustainability of eastern white pine.
- ⇒ **Symposium:** There will be a symposium on “Developing Priorities for Eastern White Pine Health and Management” in March 2022 (delayed from 2021). Topics will include health issues, management of EWP in natural systems, and management of EWP at the rural/urban interface. Speakers will be experts on EWP health and professionals who have extensive experience in managing EWP.
- ⇒ **Eastern White Pine Management Institute:** The EWPMI will be organized based on a web site hosted by UNH. The web site will host downloadable print resources (field manuals, fact sheets, videos), calendar of events (workshops, EWP topics at other professional meetings, webinars), membership list, and online training. Stakeholders can register with the institute to keep track of training records and earning of continuing education credits needed for various licenses.
- ⇒ **Field Manual:** Based on feedback from the symposium the Field Manual for Management of EWP in New England (Livingston, et al., 2019) will be revised. Descriptions of risks can be improved as needed, and new sections for management can be included such as use of gaps for regeneration, use of fire in stand establishment, and special needs for managing shade trees.
- ⇒ **Fact Sheets:** Based on feedback from the symposium, fact sheets will be developed on insect pests, infectious diseases, environmental stresses, and management.
- ⇒ **Field Workshops:** Two field workshops will be organized for summer/fall in 2022. One workshop will focus on issues for natural forest stands of EWP and will primarily target land managers and consulting foresters. A second workshop another will focus on issues for EWP in managed landscapes and will primarily target arborists and landscape managers. The agenda for the workshops will be determined by the feedback from the March 2022 symposium. The workshops will provide opportunities to learn how to recognize signs and



symptoms of health problems and basic strategies to minimize risks and promote health.

- ⇒ **Webinars:** Webinars will be used to both supplement the field workshops and to provide outreach education on a range of subjects to natural resource and tree care professionals. A subset of webinars will be based on topics covered by the field workshops for those who could not attend. Additional webinars will expand on topics in greater detail and utilize regional experts in their respective fields.
- ⇒ **Videos:** Professional photographers will be used to record symposium and field workshop events to create about 20 minutes of video. Some additional field shots will be made to supplement what is recorded in the scheduled meetings. The professional recordings will be used to create interest in the EWPMI institute goals and resources. Recordings of symposium talks, workshops, and webinars will also be provided.

### Highlights & Key Findings

- ⇒ The Eastern White Pine Management Institute Website is now active.
- ⇒ A 2 part Eastern White Pine Management Symposium was held past spring. The first part of the symposium consisting of 9 presentations was held in conjunction with the Annual Meeting for the New England Society of American Foresters on March 23-24, 2022, in Portland, Maine.
- ⇒ The second part of the Symposium was held in the Manchester/Concord area of New Hampshire on June 23-24 with 5 presentations and 3 field workshops.



### Outcomes

Speakers for the symposium came from Wisconsin, North Carolina, Virginia, Massachusetts, New York, New Hampshire, and Maine. The ability to get people involved in eastern white pine management and health talking with each other represents an opportunity to learn from each other.

### Significant Challenges

The COVID experience has fully disrupted plans for the project; the symposium was delayed 2 years and had to be split. Also, the contract for the videographer could not be completed until summer 2022. The resulting delays has made it not practical to complete a symposium proceedings for the project.

### Future Plans & Opportunities

In place of the symposium proceedings, the EWPMI web site will assemble case studies of eastern white pine management from throughout it's range. The information requested will be similar to what is used for NSRC subsidy requests plus market information. The resulting product will be a source for current ideas on how to manage eastern white pine utilizing experience from across a range of conditions.

An assistantship will allow a non-thesis graduate student to work on outreach publications for eastern white pine. The focus will be developing on outreach publication on white pine weevil, on eastern white pine's response to climate changes, and an update to the Field Manual on Eastern White Pine Health and Management in New England.

## *A Resilience Indicators Approach to Ensuring Equitable, Objective, and Continued Investment in Northern Border Communities*

**Project Lead:** Adam Daigneault, Associate Prof of Forest Policy and Economics

**Project Personnel:** Aaron Weiskittel, Co-PI; Jianheng Zhao, Postdoc Researcher

**Student Research Assistants:** Gabby Sherman (PhD), Joey Reed (MS)

The Northern Border's economy depends heavily on the health and sustainable management of its forest. In fact, the relative contribution of forested lands to the gross domestic product for most counties in the four-state Northern Border Region is among the highest in the United States (4-5%). The abundance of forestland in the Region can be a blessing and a curse because many rural communities are primarily dependent on a single ecosystem service and the tax revenue that related industries provide. Several communities in the Region have been dependent on a single industry for decades, facing hardship when markets shift and demand is reduced (e.g., mill closures), leading to crises of economy, culture, and identity (e.g., new manufacturing, recreation). Furthermore, the region's forest faces increasing pressures from land use change, shifts in ownership, and invasive pests and other environmental stressors. This research project uses a mixed methods approach to measure and enhance the socio-economic resilience of forest-dependent communities across the Northern Border Region. To ensure equitable, objective, and transparent investment in the region's rural communities – focusing on a path towards continued prosperity in the region – we are undertaking a multi-state approach to develop, quantify, and track a broad set of resilience indicators.

### Objectives & Approach

1. Use publicly available data to construct a time series of quantitative socio-economic resilience indicators for all communities located within the Northern Border Region;
2. Analyze household data to from 'distressed' areas of the Region to assess both the current perceptions and future aspirations of residents and visitors in these specific communities;
3. Conduct statistical analyses to compare the resilience indicators collected for these communities against other regions of the U.S. with similar issues and geographies to identify the most relevant metrics for benchmarking and building socio-economic resilience;
4. Integrate steps 1-3 into a framework of pathways that the Region's rural communities can take to build resilience and promote economic development. This building of this framework will be iterative, incorporating feedback obtained through community meetings, factsheets, and an interactive map that could be linked with the NBRC's map of the Region on the website.

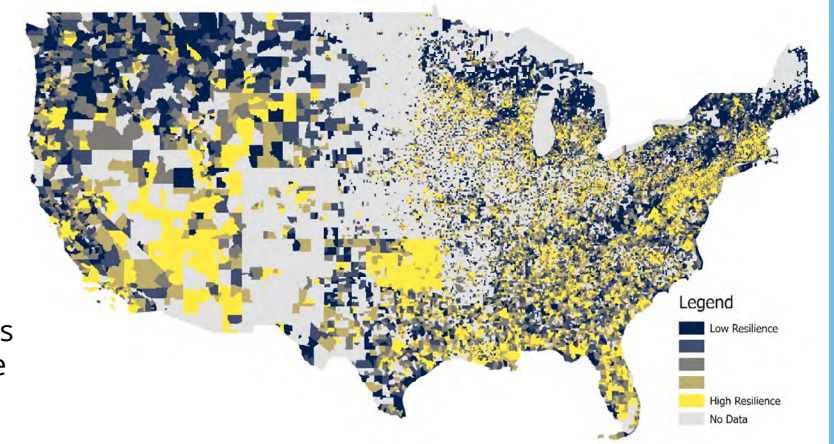


Figure 1. Total socioeconomic resilience index for United States communities (2018)



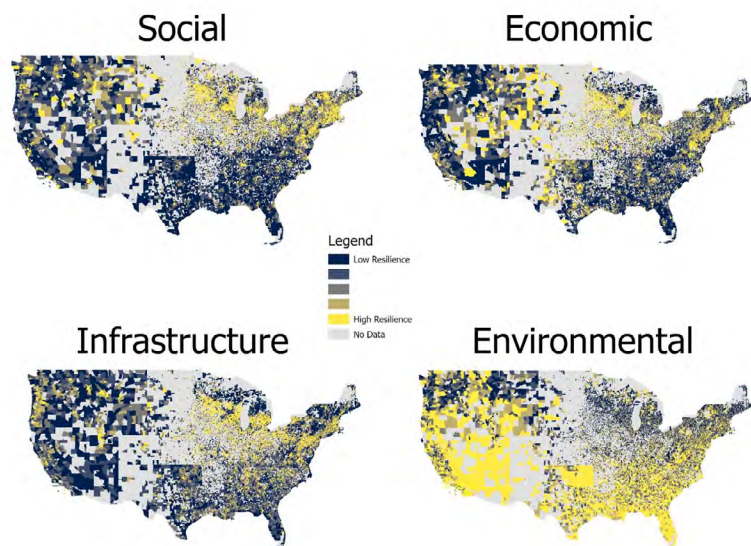


Figure 2: Individual socioeconomic resilience indices for United States communities (2018), a) social, b) economic, c) infrastructure, and d) environmental.

### Highlights & Key Findings

There has been noticeable progress over the past year. First, we have produced revised estimates for 24 resilience metrics for more than 1,000 communities across the Northern Border region, as well 21,286 communities across the United States. Resilience indices were estimated for total socioeconomic resilience (Figure 1) and four separate components of that index that evaluated social, economic, infrastructure, and environmental resilience (Figure 2). Statistical tests indicated that urban communities have higher overall resilience scores than rural areas, however rural places have statistically significant social resilience scores. Comparing across areas that are deemed to be naturally resource

dependent communities (NRDC, i.e. 8-20% or more of employment in natural resource sector), we find that NRDCs were less resilient overall than non-NRDC communities. However the difference in resilience scores was larger for Urban/Rural divide than the NDRC/Non-NDRC delineation.

Second, we revised our analysis based on a statewide survey to evaluate Maine resident perceptions on community resilience, natural resource industries, and socio-economic impacts of Covid-19 in Summer 2020. The results of the survey (n=503) reveal a somewhat pronounced divide amongst Maine residents in terms of their relationships to their communities. On the one hand, rural respondents' perceptions of community functionality tended to imply a sense of comradery amongst residents as well as accessibility to local elected officials. In essence, rural residents, as compared to urban residents, appeared to signal a sense of security in their social and political capital. Meanwhile, urban residents tended to more favorably regard their community's ability to attract new business and maintain economic diversity. Conversely, their reported faith in the trustworthiness and consideration of local representatives, and the tendency of their communities' residents to collaborate in times of hardship was less pronounced. As such, it may be stated that urban dwelling respondents have assessed their communities' access to financial capital to be greater than that of social and political, relative to rural counterparts. A journal article summarizing and discussing the results is currently under review.

Third, we modified the Maine questionnaire and used it to conduct region-wide resilience survey of 12 communities across four states in the northern border region. Communities were selected based on input from project collaborators, NBRC, and other stakeholders interested in the effect of economic development investment on resilience. The survey was conducted from October - December and received 711 completed responses. We are currently in the process of qualitatively and quantitatively analyzing results, which will be completed by September 2022. Preliminary analysis indicates that the top reported assets in surveyed communities are natural and social capital, while the top challenges are built and financial capital (Figure 3). Examples of top assets include natural resource amenities, land and open spaces, recreation opportunities, and the people in the community. Top built and financial challenges include housing, jobs, business sustainability, taxes, and roads/transportation.

### Outcomes

- Identified socioeconomic resilience indicators to support, grow, and diversify Northern Forest rural economies.

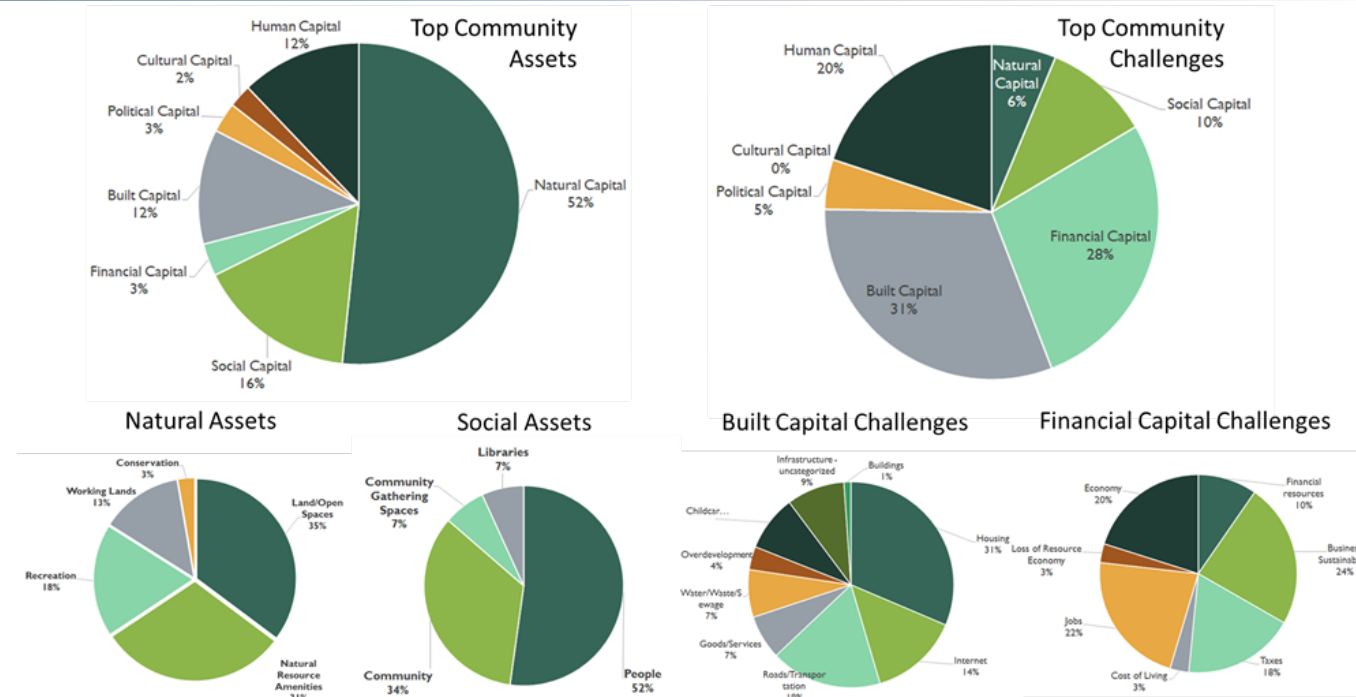


Figure 3: Reported community assets and challenges for NBRC region survey respondents (n=711)

- Developed partnerships with researchers and other stakeholders that are committed to improving the cultural, economic, and civic future of the Northern Border Region.
- Developed framework for engaging with stakeholders in natural resource dependent communities to better understand their needs and uses of socio-economic and ecological resilience indicators.
- Designed and enumerated Northern Border regional socioeconomic resilience survey (n=711) in 12 communities across 4 states (ME, NH, VT, NY).
- Directly involve graduate and undergraduate student researchers to build their personal and professional development.
- Presented interim findings to NBRC in June 2022.

### Significant Challenges

Covid-19 has limited our ability to conduct focus groups and engage in stakeholder outreach. We shifted in person and virtual outreach efforts to 2022.

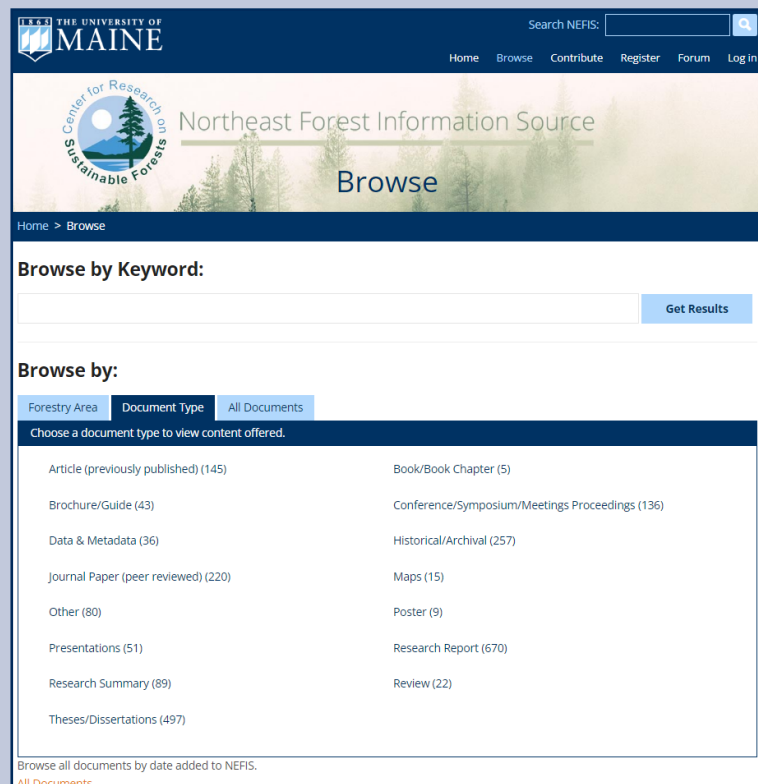
### Future Plans & Opportunities

- Continue with activities, as laid out in the work plan/approach discussed above with focus on completion by October 2022.
- Continue collaboration for community outreach and dissemination of project findings to turn knowledge into action.
- Refine quantitative indicators and analyze drivers of increased/decreased resilience across the Northern Border region using latest (2020) data.
- Summarize findings in project report and webinar.



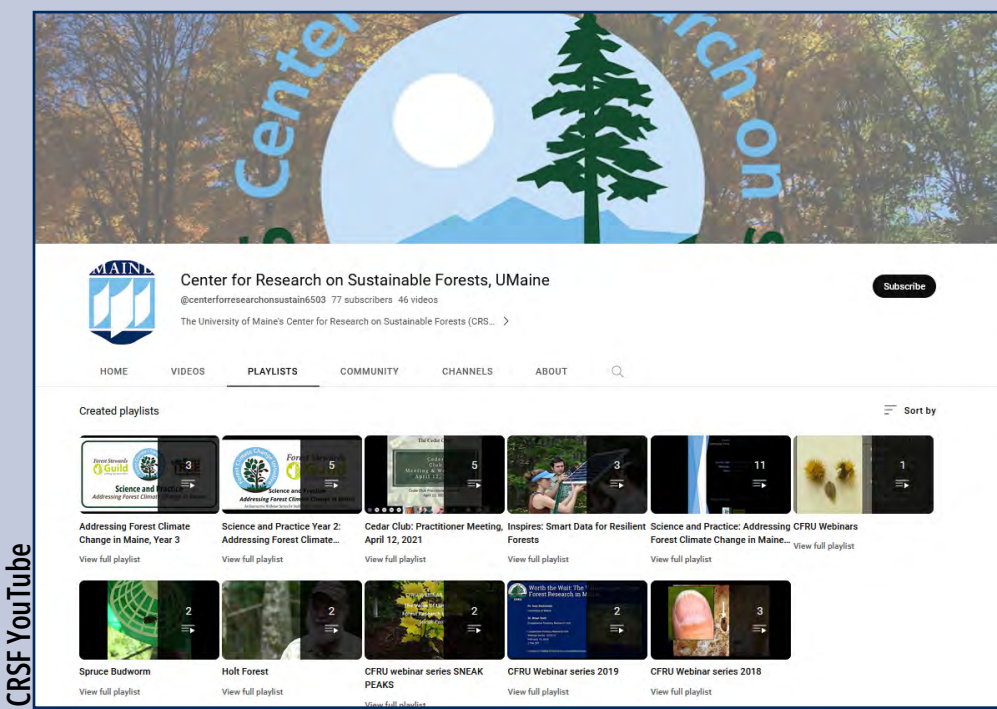
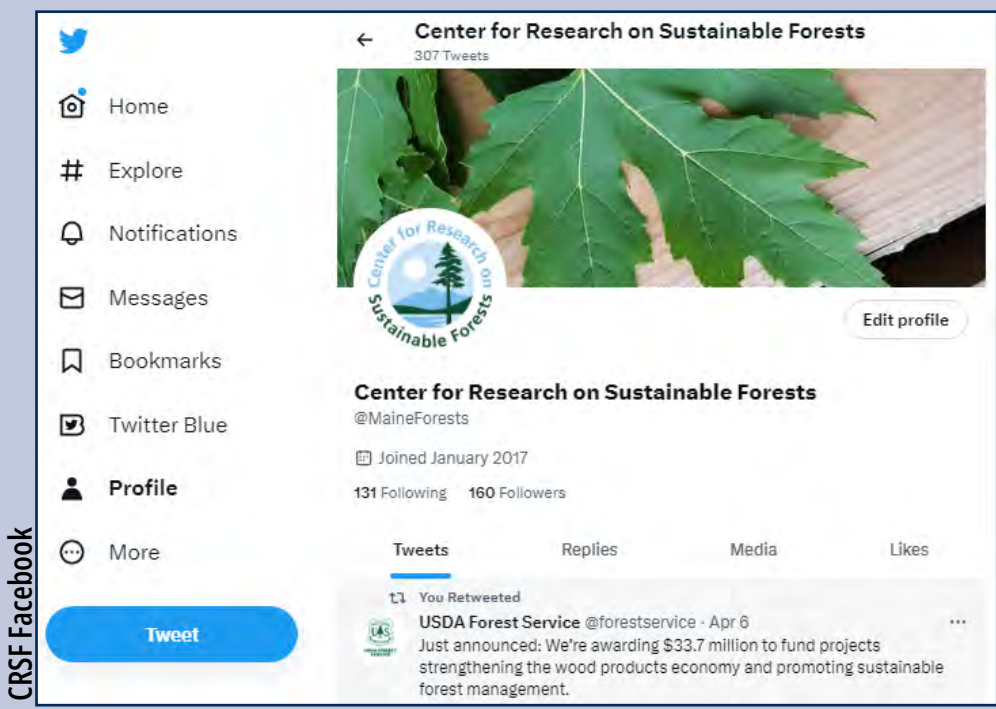
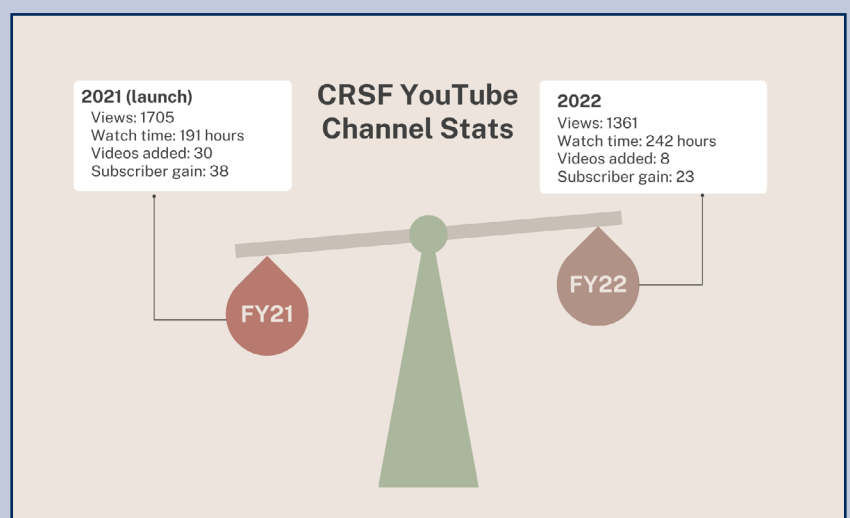
CRSF staff endeavor to make forest science research conducted under our programs and initiatives readily accessible to researchers, scientists, stakeholders, policymakers, and the public in clear and understandable ways. We embrace social media as part of that strategy. In addition to our social media, we continue to maintain and grow the Northeast Forest Information Source (NEFIS) web portal, an open-source online portal for applied forestry information.

**CRSF and NEFIS websites**



**Website/Social Media Links**

- CRSF Website
- CFRU Website
- CRSF UMaine Facebook
- CRSF Twitter: @MaineForests
- NEFIS research portal
- Spruce Budworm website
- Spruce Budworm Facebook







CRSF engages graduate and under-graduate students in a variety of scenarios: data analysis, research assistants, field crews, workforce development, office support, website support, and computer coding, to name a few. The pandemic has been especially difficult for graduate students due to the challenges of adjusting to new environments with limited support and high isolation. Although the majority of the undergraduates affiliated with CRSF are studying in the School of Forest Resources, we also have student involvement from several departments across campus: EES, PRT, WLB, Zoology,

Engineering, and Computer Sciences. In many cases, particularly CFRU experiences with cooperators, research and work experience in the CRSF has led to employment in the forest industry and academia (e.g., Seven Islands, Huber Resources, US Forest Service, University of Maine Fort Kent). Since 2020, the EPSCoR Track 2 INSPIRES project greatly expanded cross-institutional and interdisciplinary research opportunities for PhD and MS students from SFR, Spatial Information Science & Engineering, Computer Science, and the RiSE Center including several underrepresented minorities. Several undergraduate students supported by INSPIRES during years 1 and 2 of the project were accepted into forest science graduate programs for fall 2021, with one representing an inter-jurisdictional collaboration between UVM and UMaine.

Distribution of Students Gaining Work and Research Experiences Via CRSF Programs and Initiatives, FY19-FY22

|   | FY19 | FY20 | FY21 | FY22 |
|---|------|------|------|------|
| <b>Undergraduate</b>                      | 37   | 27   | 15   | 29   |
| <b>Undergraduate (UM)</b>                 | 27   | 25   | 13   | 27   |
| <b>Undergraduate (Other Institutions)</b> | 10   | 2    | 2    | 2    |
| <b>Graduate</b>                           | 28   | 18   | 16   | 17   |
| <b>MS</b>                                 | 20   | 6    | 9    | 10   |
| <b>MF</b>                                 | 4    | 3    | 2    | 1    |
| <b>PhD</b>                                | 2    | 9    | 5    | 6    |

**Research Reports (6)**

Daigneault, A., et al. (2021). Maine Forestry and Agriculture Climate Change Mitigation Potential. CRSF Final Report, July 2021.

Daigneault, A., Sohngen, B. (2022). Estimating Regional Carbon Leakage Rates with the Global Timber Model. Interim Report submitted to funder, June 2022.

De Urioste-Stone, S.M., Soucy, A.\*, Rahimzadeh-Bajgiran, P., Daigneault, A., Weiskittel, A. (2022). Forest climate change resilience: A socio-ecological forest systems approach. Final technical report submitted to USDA-AFRI Climate Change Program. Orono, Maine.

De Urioste-Stone, S.M., Soucy, A.\*, Rahimzadeh-Bajgiran, P., Daigneault, A., Weiskittel, A. (2021). Forest climate change resilience: A socio-ecological forest systems approach. Technical report submitted to USDA-AFRI Climate Change Program. Orono, Maine

Kenefic, L.S., Allogio, J.A., Ziegler, C.G., Rhodeland, A.J., Anand, V.A. 2021. Penobscot Experimental Forest historical photo archive: Research and operations from the 1950s through the 1980s. Fort Collins, CO: Forest Service Research Data Archive. <https://doi.org/10.2737/RDS-2021-0090>

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**Refereed Journal Publications (21)**

Allogio, J.A., Fraver, S., Kenefic, L.S., Wason, J.W., Berril, J.-P., 2021. Microsite requirements for successful regeneration in lowland northern white-cedar (*Thuja occidentalis* L.) forests. *Forest Ecology and Management*, 499 (119639). <https://doi.org/10.1016/j.foreco.2021.119639>

Ayrey, E., Hayes, D.J., Kilbride, J.B., Fraver, S., Kershaw, J.A., Cook, B.D., Weiskittel, A.R. 2021. Synthesizing Disparate LiDAR and Satellite Datasets through Deep Learning to Generate Wall-to-Wall Regional Inventories for the Complex, Mixed-Species Forests of the Eastern United States. *Remote Sensing*, 13(24), 5113. <https://doi.org/10.3390/rs13245113>.

Chen, C., Rahimzadeh-Bajgiran, P., Weiskittel, A. 2021. Assessing spatial and temporal dynamics of a spruce budworm outbreak across the complex forested landscape of Maine, USA. *Annals of Forest Science* 78(2):33. [doi.org/10.1007/s13595-021-01059-y](https://doi.org/10.1007/s13595-021-01059-y)

D'Amato, A.W., Woodall, C.W., Weiskittel, A.R., Littlefield, C.E., Murray, L.T. 2022. Carbon conundrums: Do United States' current carbon market baselines represent an undesirable ecological threshold? *Global Change Biology*, 28:13, 3991-3994. <https://doi.org/10.1111/gcb.16215>

D'Amato, A., Foster, J., Simons-Legaard, E., Weiskittel, A. 2022. Integrating historical observations alters projections of eastern North American spruce-fir habitat under climate change. *Ecosphere* 13(4): e4016. [doi.org/10.1002/ecs2.4016](https://doi.org/10.1002/ecs2.4016)

George, A.K., Kizha, A.R., Kenefic, L. 2022. Timber harvesting on fragile ground and the impacts of uncertainties in the operational costs. *International Journal of Forest Engineering*, 33(1). <https://doi.org/10.1080/14942119.2022.1988432>

Granstrom, M., Crandall, M.S., Kenefic, L., Weiskittel, A.R. 2022. Tree quality and value: results in northern conifer stands after 65 years of silviculture and harvest. *Canadian Journal of Forest Research*. 52(5): 794-807. <https://doi.org/10.1139/cjfr-2021-0279>

Hollinger, D.Y., Davidson, E.A., Fraver, S., Hughes, H., Lee, J.T., et al. 2021. Multi-decadal carbon cycle measurements indicate resistance to external drivers of change at the Howland Forest AmeriFlux site. *Journal of Geophysical Research – Biogeosciences*. 126, e2021JG006276.

Kern, C.C., Kenefic, L.S., Kuehne, C., Weiskittel, A.R., et al. 2021. Relative influence of stand and site factors on aboveground live-tree carbon sequestration and mortality in managed and unmanaged stands. *Forest Ecology and Management* 493. <https://doi.org/10.1016/j.foreco.2021.119266>



Kizha, A.R., Nahor, E.R., Coogen, N., Louis, L.T., George, A.K. 2021. Residual Stand Damage across Varying Silvicultural Prescriptions. *Sustainability* 13(14), 7641.

Li, L., Wei, X., Zhao, J., Hayes, D., Daigneault, A., Weiskittel, A., Kizha, A.R., O'Neill, S.R. 2022. Technological advancement expands carbon storage in harvested wood products in Maine, USA. *Biomass and Bioenergy*, 161, p.106457.

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Poulter, B., Canadell, J., Hayes, D.J., & Thompson, R. (2022). Balancing Greenhouse Gas Budgets: Accounting for natural and anthropogenic flows of CO<sub>2</sub> and other trace gases. Elsevier. ISBN: 9780128149522, 450pp.

Puhlick, J.J., Weiskittel, A.R., Fernandez, I.J., Solarik, K.A., Sleep, D.J.H. 2022. Evaluation of projected carbon accumulation after implementing different forest management treatments in mixed-species stands in northern Maine, *Carbon Management*, 13:1, 190-204, DOI: 10.1080/17583004.2022.2063761

Simons-Legaard, E., Legaard, K., Weiskittel, A. 2021. Projecting complex interactions between forest harvest and succession in the northern Acadian Forest Region. *Ecological Modeling* 456: 109657. doi. [org/10.1016/j.ecolmodel.2021.109657](https://doi.org/10.1016/j.ecolmodel.2021.109657)

Soucy, A., De Urioste-Stone, S., Fernandez, I.J., Weiskittel, A., Rahimzadeh-Bajgiran, P., Doak, T. 2021. Forest Policies and Adaptation to Climate Change in Maine: Stakeholder Perceptions and Recommendations. *Maine Policy Review* 30(1): 66-77. doi.org/10.53558/XNWP9949

Soucy, A., De Urioste-Stone, S., Rahimzadeh-Bajgiran, P., Weiskittel, A. 2021. Drivers of Climate Change Risk Perceptions among Diverse Forest Stakeholders in Maine, USA. *Society & Natural Resources*, DOI: 10.1080/08941920.2021.1991066

Soucy, A., Rahimzadeh-Bajgiran, P., De Urioste-Stone, S.M., Weiskittel, A., Duveneck, M., McGreavy, B. (2021). A comprehensive and spatially explicit regional vulnerability assessment of the forest industry to climate change. *Journal of Forestry*. doi: <https://doi.org/10.1093/jofore/fvab057>

Teets, A., Moore, D.J.P., Alexander, M.R., Blanken, P.D., Bohrer, G., Burns, S.P., Carbone, M.S., Ducey, M.J., Fraver, S., et al. 2022. Coupling of tree growth and photosynthetic carbon uptake in six North American forests. *Journal of Geophysical Research: Biogeosciences* 127, e2021JG006690. <https://doi.org/10.1029/2021JG006690>.

Woodall, C.W., Weiskittel, A.R. 2021. Relative density of United States forests has shifted to higher levels over last two decades with important implications for future dynamics. *Scientific Reports* 11(1):18848. doi. [org/10.1038/s41598-021-98244-w](https://doi.org/10.1038/s41598-021-98244-w)

Zhao, J., Daigneault, A., Weiskittel, A. 2022. Estimating regional timber supply and forest carbon sequestration under shared socioeconomic pathways: A case study of Maine, USA. *PLOS Climate*, 1(5), p.e0000018.

### **Presentations / Workshops / Meetings / Field Tours (62)**

Briones, V., Hayes, D., Weiskittel, A. 2021. Analyzing Past and Future Impacts of Seasonal Climate Change on Forest Phenology in Maine. AGU Fall Meeting. Dec.

Bugbee, S., Puhlick, J.J. 2021. Silvicultural strategies to promote forest resiliency to future change. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18.

Cooperative Forestry Research Unit. 2021. Fall Field Tour: MASN site, Nashville Station; CTRN site, T7 R6. October 18.

Daigneault, A. 2021. "Climate Impacts and Carbon Sequestration Potential for Maine's Forests" Presented at Maine Forest Service Annual Employees Retreat. September 16.

Daigneault, A. 2021. "Carbon and Natural Climate Solutions Potential for Maine's Forests" Presented at Knox-Lincoln Soil & Water Conservation District Annual Meeting. October 20.

Daigneault, A., A. Weiskittel, E. Simons-Legaard. 2022. "Landscape-level assessment of alternative management strategies for optimizing carbon sequestration in complex managed forests." Presented at NCASI Spring 2022 Meeting, April 20.

Daigneault, A., A. Weiskittel. 2021. "Carbon and Natural Climate Solutions Potential for Maine's Forests." Presented at SAPP Fall 2021 Meeting, November 19.

Daigneault, A., T. Gordon. 2021. "An Integrated Approach to Quantifying the GHG Mitigation Potential of Natural Climate Solutions from Maine's Working Lands" Presented at US Climate Alliance Natural and Working Lands Group Fall 2021 Meeting. October 26.

Douglas, L. 2021. "Rusty Blackbird use of commercial spruce-fir forests of northern New England." Oral presentation for The Maine Chapter of the Wildlife Society Fall Meeting & Wildlife Research Symposium, December 2.

Fergusson, M.W. 2022. Coastal Spruce-Fir FCCI field tour. Schoodic Peninsula, February 24.

George, A.K., Louis, L.T., Alex, A., Kizha, A.R. 2021 Cost of Logging and Residual Stand Damage: Insights from the MASN Study. Cooperative Forestry Research Unit. October 21, 2021. Ashland, ME.

Hagan, J., Gunn, J., McKinley, P., Reed, M. 2021. Thirty years of change in commercial forest management and implications for bird conservation in Maine (1992-2022). Presentation to NCASI Northern Research Committee, August 4.

Hagan, J., Gunn, J., McKinley, P., Reed, M. 2021. Thirty years of change in commercial forest management and implications for bird conservation in Maine (1992-2022). Presentation to SFI SIC, Dec 1.

Hayes, D. 2021. Findings update at the annual GEDI competed science team meeting. Nov.

Hayes, D. 2021. Forest carbon estimation project. Poster at the AGU Fall Meeting. Dec.

Hayes, D., et al. 2021. LiDAR-derived wall-to-wall forest inventory of several attributes including AGB. Updated Landtrendr run that covers historical forest disturbance metrics over the New England / Maritime Canada region up to 2021.

Jackson, De Urioste-Stone, Daigle, Beeftink, Silka, Gardner, Lieberthal, Martin. 2022. On COVID-19 and Tourism: Drivers of Travel Behavior and Place-based Appeal of Maine Rural Destinations. Maine Sustainability and Water Conference (MSWC), Augusta, ME, March 30.

Kenefic, L.S. 2021. Applying Irregular Shelterwood: Long-Term Results from Maine. Presentation for the Nova Scotia Department of Natural Resources and Renewables, December.

Kenefic, L.S. 2021. Balsam Fir and White Spruce Silvics and Ecology. Presentation in the Lake States Module of the U.S. Forest Service, National Advanced Silviculture Program, September.

Kenefic, L.S. 2021. Long-Term U.S. Forest Service Research on the Penobscot Experimental Forest. Field Tour for Silviculture/Wildlife Class, University of Maine, October.

Kenefic, L.S. 2021. Science and Practice: Addressing Forest Climate Change in Maine: Spruce - Fir. Presentation and Field Tour in the Forest Climate Change Initiative, University of Maine, Center for Research on Sustainable Forests and Forest Stewards Guild, October.

Kenefic, L.S. 2021. Silviculture Matters: Long-Term U.S. Forest Service Research on the Penobscot Experimental Forest. Field Tour for Silviculture/Forest Ecology Class, University of Maine, November.

Kenefic, L.S. 2021. Silviculture of White Spruce, Balsam Fir, and Northern White-Cedar. Presentation in the Lake States Module of the U.S. Forest Service, National Advanced Silviculture Program, September.

Kenefic, L.S. 2022. Climate Smart Forestry - Silviculture and Operations. Presentation at the Wagner Forest Management Annual Training, May.

Kenefic, L.S. 2022. Managing Northern Conifers for Climate Change and Market Resiliency. Presentation at the New England Society of American Foresters Annual Winter Meeting, March.



- Kenefic, L.S. 2022. Northern Conifer Silviculture in the Northeastern United States. Presentation at the University of Missouri, School of Natural Resources, March.
- Kenefic, L.S. and Kabrick, J. 2022. The Science and Art of Managing for Complex, Multi-Species Temperate Mixedwood Forests. Presentation in the U.S. Forest Service Rooted in Research Webinar Series, February.
- Kenefic, L.S. et al. 2021. Beech Bark and Leaf Diseases & The Many Values of Beech. Field Tour at the Penobscot Experimental Forest, October.
- Kenefic, L.S. et al. 2021. Human and Ecological Barriers to Northern White-Cedar Sustainability. Presentation at the Ecological Society of America Meeting, November.
- Kenefic, L.S. et al. 2021. Managing Mixedwoods with a Shade-Tolerant Softwood Component in the Northeastern U.S. Presentation at the Society of American Foresters National Convention, September.
- Kenefic, L.S. et al. 2022. Northern Conifer Silviculture Guide. Presentation at the New England Society of American Foresters Annual Winter Meeting and to the NCSG Advisory Panel, March.
- Kenefic, L.S. et al. 2022. Northern White-Cedar: The Tree of Life. Poster presentation at the New England Society of American Foresters Annual Winter Meeting, March.
- Kizha, A.R., Alex, A., George, A.K., Louis, L.T. 2020. Cost of Harvesting Small-diameter Trees: Comparing Semi-Mechanized and Mechanized Harvesting Operation. Society of American Foresters National Conference. Providence, RI. Oct 18-Nov 1.
- Lieberthal, Gardner, De Urioste-Stone. 2022. Economic and Political Drivers of COVID-19 Policy in 2020." Maine Sustainability and Water Conference (MSWC), Augusta, ME, March 30.
- Livingston, W. 2022. Bear Brook State Park, NH, field tour on low density white pine management, June 24.
- Livingston, W. 2022. Durgin & Crowell Lumber Co. field tour, Springfield NH, June 23.
- Livingston, W. 2022. Mast Yard State Forest, NH, workshop on measuring white pine needle damage and Caliciopsis canker symptoms, June 24.
- Livingston, W. 2022. Updates on Insect Pests of Eastern White Pine, including Southern Pine Beetle Outbreak in NC in 2000. New England Society of American Foresters Annual Winter Meeting, Eastern White Pine Symposium, March.
- Livingston, W. Host. 2022. Eastern White Pine: Past, Present, and Future. New England Society of American Foresters Annual Winter Meeting, Eastern White Pine Symposium, March.
- Livingston, W. Host. 2022. Trends in white pine management across the range. Eastern White Pine Symposium, Part 2, June 23-24.
- Livingston, W. Host. 2022. Eastern White Pine Symposium, Part 1. New England Society of American Foresters Annual Winter Meeting, March.
- Livingston, W. Host. 2022. Eastern White Pine Symposium, Part 2. Manchester/Concord, NH, June 23-24.
- Louis, L.T., Daigneault, A., Kizha, A.R. 2021. Biomass harvesting amidst market and policy constraints: perspectives of foresters and loggers in the Northeastern United States. Council on Forest Engineering and International Symposium on Forestry Mechanization (COFE-FORMEC). Sep 27-30. Oregon State University, Corvallis, OR (Accepted).
- Louis, L.T., Kizha, A.R., Daigneault, A. 2020. Uncertainty in Timber Harvesting Cost and Productivity: A Review. Society of American Foresters National Conference. Providence, RI. Oct 18-Nov 1.
- Louis, T.L., Kizha, A.R. 2020. Woody Biomass Harvest: Comparing Conventional with Exclusive Cost Apportioning Methods. University of Maine 2020 Student Symposium. Bangor, ME. Oct 2nd.
- Ouimette, A., Ollinger, S.V., Hastings, J., Johnson, C.E., Foster, J.R., Weiskittel, A.R., D'Amato, A.W. 2021. Including Microbial Processes is Important for Modelling Carbon and Nitrogen Dynamics During Wood Decay. AGU Fall Meeting. Dec.
- Puhlick, J.J. 2021. Assessing and monitoring the influence of forest management practices on soil productivity, carbon storage, and conservation on the Maine Adaptive Silviculture Network. Cooperative Forestry Research Unit Advisory Committee Meeting (final reporting, virtual presentation). Orono, ME, October 20.
- Puhlick, J.J., Goldsmith, J. 2021. Non-native earthworm discoveries and implications for forest health. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18.
- Puhlick, J.J., Goldsmith, J., Brann, A. 2021. Strategies for altering species composition in stands with American beech and beech bark disease on the Maine Adaptive Silviculture Network. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18.
- Read, Z., S. Fraver, J.A. Forrester, I. Fernandez, J. Wason, C.W. Woodall. 2022. Carbon dioxide emissions from deadwood in forests of the Northeastern U.S.A. ESA 2022 Abstract, Oral Presentation. Montréal, August 14-19.
- Roth, A., Foss, C., Douglas, L. 2021. Rusty Blackbird Nesting Habitat: To PCT or Not To PCT? Oral Presentation for NCASI Virtual Conference, September 14-16, 2021.
- Schulz, K. et al. 2021. The Effect of Harvesting on Lowland Northern White-Cedar Stand Structure and Composition. Presentation at Forest Ecosystem Monitoring Cooperative Conference, December.
- Schulz, K. et al. 2022. Management and Climate Change Impacts on the Sustainability of Lowland Northern White-Cedar. Presentation at the New England Society of American Foresters Annual Winter Meeting, March.
- Scott, L., Smith, S., Petrik, M., Gunn, J., Belair, E., Buchholz, T., Ducey, M. 2021. Rule-based classification to optimize forest carbon sequestration following an eastern spruce budworm outbreak. Presented at the 2021 International Boreal Forest Research Association Conference: Fairbanks, Alaska, USA, August.
- Weiskittel, A.R., Fergusson, M.W. 2021. Oak-Pine Ecosystems/Holt Research Forest FCCI field tour. Arrowsic, ME, December 3.
- Weiskittel, A.R., Fergusson, M.W. 2021. Spruce-Fir forests/Penobscot Experimental Forest FCCI field tour. Bradley, ME, October 29.
- Weiskittel, A.R., Fergusson, M.W. 2022. Mixed Hardwood FCCI field tour. Rangeley, ME, April 29.
- Weiskittel, A.R., Puhlick, J.J. 2021. Carbon accumulation after implementation of forest management treatments on the Maine Adaptive Silviculture Network. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18.
- Woodall, C.W., Weiskittel, A.R. 2021. Relative density of United States forests has shifted to higher levels over last two decades with important implications for future dynamics. Scientific Reports. 11 (1). <https://doi.org/10.1038/s41598-021-98244-w>.
- Zhou, J. E. Roy, J. Lee, D. Hollinger, S. Fraver, S. Bollen, D. Obrist. 2021. Net ecosystem exchange of atmospheric gaseous elemental mercury (GEM) over an evergreen needle forest. Abstract at AGU meeting, New Orleans, December 13-17.
- Zhou, J., E. Roy, J. Lee, D. Hollinger, S. Fraver, S. Bollen, D. Obrist. 2022. Comparing net ecosystem exchange patterns of atmospheric gaseous elemental mercury (GEM) between a deciduous and coniferous temperate forest. The 15th International Conference on Mercury as a Global Pollutant - ILM Exhibitions, Virtual, July 24-29.
- Ziegra, C. et al. 2021. The Effect of Microtopography, Soil Moisture, and Canopy Openness on Survival of Northern White-Cedar Regeneration. Poster presentation at the New England Society of American Foresters Annual Winter Meeting, March.



### Theses (3)

- Briones, V. (2021). Forest phenology in Maine: Trends and drivers over the past two decades and implications to resource managers. School of Forest Resources, University of Maine (MS thesis).
- DiMatteo-LePape, A. (2021). A Socio-Ecological Examination of Moose and Changing Seasonality in Maine. University of Maine (MS thesis).
- Louis, L.T. 2021. Economics and operational decision constraints of small-diameter tree harvesting. University of Maine, Orono (PhD thesis).

### Awards (2)

- George F. Dow Graduate Scholarship (University of Maine, NSF) awarded to M.S. student Zoe Read (2022). Presentation: Greenhouse Gas Emissions from Deadwood in Northeastern Forests.
- Maine Association of Wetland Scientists Stipend awarded to M.S. student Zoe Read (2021). Proposal: Methane and Carbon Dioxide Fluxes from Deadwood in a Forested Wetland.

### Videos (9)

- Original content and recorded webinars produced for the CRSF YouTube Channel
- INSPIRES Teacher Tour: Workshop Intro: INSPIRES Theme 4 hosted teachers from around the northeast for a field visit at the Schoodic Institute in Maine to support integration of Quantitative Reasoning in Context using forestry science and research.
- INSPIRES Teach Workshop: Research Goals: INSPIRES Theme 3 researchers worked with teachers Maine, Vermont & New Hampshire to install climate data instrumentation with the goal of setting up data collection stations at regional schools.
- Forest Ecosystem Sensor Site Install
- FCCI Webinar: Mixed Hardwood Forests in Western Maine
- FCCI Field tour: Schoodic Peninsula
- FCCI Webinar: Coastal Spruce-Fir/Schoodic Peninsula
- FCCI Field tour: Holt Research Forest
- FCCI Webinar: Oak-Pine Ecosystems/Holt Research Forest
- FCCI Webinar: Spruce-Fir forests/Penobscot Experimental Forest



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