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Center for Research on Sustainable Forests 2019 Annual Report

Center for Research on Sustainable Forests

CENTER FOR RESEARCH ON SUSTAINABLE FORESTS
2021 ANNUAL REPORT

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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.

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.

Center for Research on Sustainable Forests
University of Maine
5755 Nutting Hall
Orono, Maine 04469-5755
crsf.umaine.edu

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MESSAGE FROM **THE DIRECTOR**

The Center for Research on Sustainable Forests (CRSF) continued its evolution as University of Maine research center in FY21 with several new and ongoing initiatives. Despite the continual challenges created by the global pandemic, dedicated CRSF faculty, staff and students have furthered our collaborations and generated numerous outcomes for our stakeholders.

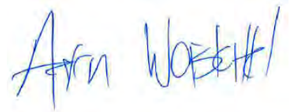
Of particular note this past FY, the Northeastern States Research Cooperative (NSRC) awarded 13 new projects across the region, including three involving the University of Maine; the Forest Climate Change Initiative's Science and Practice monthly webinar series organized with the Forest Stewardship Guild attracted strong participation both internal/external to Maine; and release of th Natural Climate Solutions for Forestry & Agriculture Final Report outlining the potential of alternative management strategies for increasing carbon sequestration. In addition, several external grants were received in FY21 from NASA Carbon Monitoring Systems, a NASA GEDI, several from the USDA, and one from the Maine Department of Inland Fisheries & Wildlife, which help to continue grow the CRSF research program and build capacity within the center.

CRSF has been an important home to statewide forest research since 2006 in support of private and public partnerships to address questions of forest health, climate and adaptation to benefit Maine's natural resources.

Ongoing efforts within CRSF also saw important forward progress in FY21. The NSF INSPIRES effort successfully submitted its Year 2 annual report in May outlining the numerous accomplishments being made on that project. This includes the deployment of custom wireless soil moisture sensors, development of novel code for processing hyperspectral imagery, the regional calibration of forest projection models, and engaging regional high school science teachers. It is exciting to think that we are only halfway through the INSPIRES project and already tremendous outcomes are being generated. Likewise, the Center for Advanced Forestry Systems (CAFS) in the second year of its NSF Phase 3 award supported significant progress on regional and national research and had strong participation in two virtual Industrial Advisory Board meetings. Finally, despite the challenges from the pandemic, invaluable long-term field data was collected at CRSF-supported field sites like the Holt Research Forest, Howland Research Forest, and Penobscot Experimental Forest.

More than ever, CRSF remains committed to effective and multi-dimensional outreach efforts to better communicate the need and importance of working forests. We continue to keep an active social media presence, while increasing content on our YouTube channel. We believe there has been good uptake of this information including the recent broadcast of Maine Public Broadcast's video on the Holt Research Forest, which aired in April 2021. As outlined in this annual report, CRSF has plenty of relevant and interesting science to showcase.

Again, I thank our dedicated faculty, staff, and students for another great year of success.



AARON WEISKITTEL

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

CRSF HIGHLIGHTS

- Project on Fostering Coastal Community Resilience in Maine (PIs: de Urioste-Stone & Bajgiran), concluding in August, has worked to improve understanding of how climate change will impact the coastal/marine tourism assets in the region, how these changes will impact the consumer base, and how to effectively develop adaptation strategies, becomes crucial to the resilience of these natural-resource dependent coastal communities.
- A Vulnerability Assessment Model of climate change developed by impacts integrates biophysical and socio-economic data. Model was tested and validated for the State of Maine.
- In collaboration with NSRC teams from Vermont, New Hampshire, and New York, 13 projects were selected for funding this year, including three projects with specific ties to University of Maine.
- CRSF greatly expanded its social media reach with new Instagram and Twitter accounts for the Inspires projects, and added 25 videos to its YouTube channel.
- Maine Public aired "Holt Research Forest: Four Decades of Long-Term Ecosystem Research" and Maine public access channels across the state aired many of the FCCI webinar recordings.
- Output for CRSF researchers include 16 journal articles, 39 presentations/meetings, 8 research reports, 5 theses, 7 media-related publications, 45 videos.
- FCCI Natural Carbon Solutions team released interim report Forestry and Ag GHG Mitigation (crsf.umaine.edu/forest-climate-change-initiative/ncs)
- An external review panel led by The Implementation Group (TIG) completed a 3-day assessment of CRSF's NSF INSPIRES Track 2 project.
- PI Weiskittel's Year 2 annual report for the National Science Foundation's INSPIRES Track 2 project led by CRSF in conjunction with University of New Hampshire and University of Vermont approved.
- NSF approved Year 1 progress made by the Center for Advanced Forestry Systems (CAFS) lead by CRSF Director Weiskittel and authorized this industry-university cooperative research center (IUCRC) for Year 2. Phase 3 Year 1 report available: https://crsf.umaine.edu/resource/cafs-year-1-ph-3-progress-report/
- CAFS Director Weiskittel organized and led two virtual IAB meetings for all CAFS sites; 80 participants attended from across the US representing forest industry, universities, and nonprofits.
- Research & Outreach Coordinator hired for the CFRU.
- CFRU Program Leader Weiskittel led the April CFRU Advisory Board meeting that involved over 20 forest stakeholders in Maine with over $500k in funding directed to various research projects with many involving University of Maine faculty.

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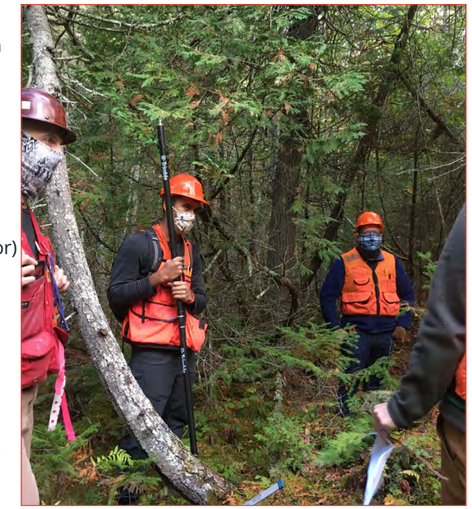
CRSF **PERSONNNEL**

Aaron Weiskittel, CRSF Director
Meg Fergusson, CRSF Communications & Outreach Specialist
Leslee Canty-Noyes, CRSF/CFRU Administrative Specialist
Regina Smith, CFRU Communications & Outreach Specialist

UMaine Faculty & Research Staff

Adam Daigneault (Assistant Professor)
Alessio Mortelliti (Associate Professor)
Ali Abedi (Professor)
Amanda Klemmer (Assistant Research Professor)
Amber Roth (Assistant Professor)
Anil Raj Kizha (Assistant Professor)
Anthony Guay (Remote Sensing Technical Specialist)
Bruce Segee (Professor)
Cen Chen (Postdoc Researcher)
Cheryl Spencer (Scientific Research Specialist)
Chris Wilson (IT Specialist)
Dan Harrison (Professor)
Daniel Hayes (Associate Professor)
Darren Ranco (Professor)
Erin Simons-Legaard (Assistant Research Professor)
Franzi Peterson (Assistant Professor)
Holly Hughes (Research Associate)
Ivan Fernandez (Professor)
Jack Witham (Research Scientist)
Jay Wason (Assistant Professor)
Jing Yuan (Post-Doc)
John Lee (Research Associate)
Josh Puhlick (Research Associate)
Kasey Legaard (Associate Scientist)
Kate Beard-Tisdale (Professor)
Keith Kanoti (University Forests)
Larry Whitsel (Research Scientist)
Laura Kenefic (Research Forester/ Faculty Associate)
Laura Millay (Research and Evaluation Coordinator)
Leo Edmiston-Cyr (Coding & Website Specialist)
Marina Van der Eb (Maine STEM Partnership Coordinator)
Neil Thompson (Professor, UMFK)
Nicole Rogers (Assistant Professor, UMFK)
Parinaz Rahimzadeh-Bajgiran (Assistant Professor)
Peter Nelson (Assistant Professor)
Salimeh Yasaei Sekeh (Assistant Professor)
Sam Roy (Research Assistant Professor)
Sandra DeUrioste-Stone (Associate Professor)
Sara Lindsay (Assistant Professor)
Shawn Fraver (Associate Professor)
Silvia Nittel (Associate Professor)
Sonia Naderi (Post-Doc)
Susan McKay (Professor)
Torsten Hahmann (Assistant Professor)



Researchers on the Penobscot Experimental Forest.

Researchers from Partner Institutions

Adrienne Leppold (Maine Dept. of Inland Fisheries & Wildlife)
Chris Hennigar (University of New Brunswick)
Chris Woodall (US Forest Service)
Dave Hollinger (US Forest Service)
Andrew Richardson (Northern Arizona University, Flagstaff, AZ)
Kathleen Savage (Woodwell Climate Research Center, MA)
Jennifer Watts (Woodwell Climate Research Center, MA)
Aaron Teets (Northern Arizona University, Flagstaff, AZ)
Daniel Obrist (University of Massachusetts, Lowell, MA)
Mary Whelan (Rutgers University, NJ)

Student Researchers

Graduate Students

Alyssa Campbell (Tourism, MS)
Alyssa Soucy (Tourism, PhD [EES])
Asha DiMatteo-LePape (Tourism, MS)
Elizabeth Pellecer (Tourism, PhD [EES])
Gabriela Wolf-Gonzalez (Tourism, MS)
Jennifer Carroll (NCS, [PhD])
Joey Reed (MS)
Kaitlyn Schulz (PEF, MS)
Lydia Horne (Tourism, PhD [EES])
MacKenzie Conant (Tourism, MS)
Noah Berkowitz (AFRI; withdrew)
Sarah Rappaport (Tourism, MS)
Sean Seeley (PEF, MF)
Valeria Briones (Tourism, MS)
Zoë Lidstrom (PEF, NCS, MF)
Zoe Read (Howland, MS)

Undergraduate

Bennett Wilson (PEF, BS)
Carolyn Ziegra (PEF, BS)
Elyse Daub (Howland, BS)
Joshua Goldsmith (Soil Productivity, BS)
Kasey Grass (Howland, BS)
MacKenzie Conant (Tourism, BS)
Madison Syer (Tourism, BS)
Nathaniel Burke (Tourism, BS)
Nicholas Ferrauolo (Tourism, BS)
Shane Miller (PEF, BS)
Carly Fredericks (PEF, BS)

Summer Students

Chelsea Patterson (Tourism, REU student)
McKenna Mollner (Tourism, REU student)
Morelys Rodriguez (Tourism, REU student from Puerto Rico)
Jack Prior (IGS, BS [McGill University])

CRSF **FINANCIAL REPORT**

During FY21 (July 1, 2020-June 30, 2021), CRSF researchers were awarded $2,205,545 to support their research, with an additional $645,945 in funding provided by gifts and internal support (see Table 1 for budget detail). Ten additional proposals were submitted during FY21 which, if awarded, could bring in more than $15M in extramural funding. Awards 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 FY21 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 $427,952 to support applied forestry research lead primarily by University of Maine System faculty. Total extramural funding of the CRSF topped $1.2 million in FY21. CRSF scientists were able to leverage their grant awards for an additional $936,073 in funding. The majority (86%) of the CRSF budget is allocated directly to the research described in this report, supporting CRSF projects and initiatives under the CFRU, Howland and Holt Research Forests, INSPIRES NSF research, Northeastern States Research Cooperative, Penobscot Experimental Forests, 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 (Figure 2).

A key source of financial support for the CRSF is provided by the Maine Economic Improvement Fund (MEIF). The $207,406 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 $2.64M from extramural and CRSF sources—a $12.70 return on investment for every dollar of MEIF funding.

Figure 1

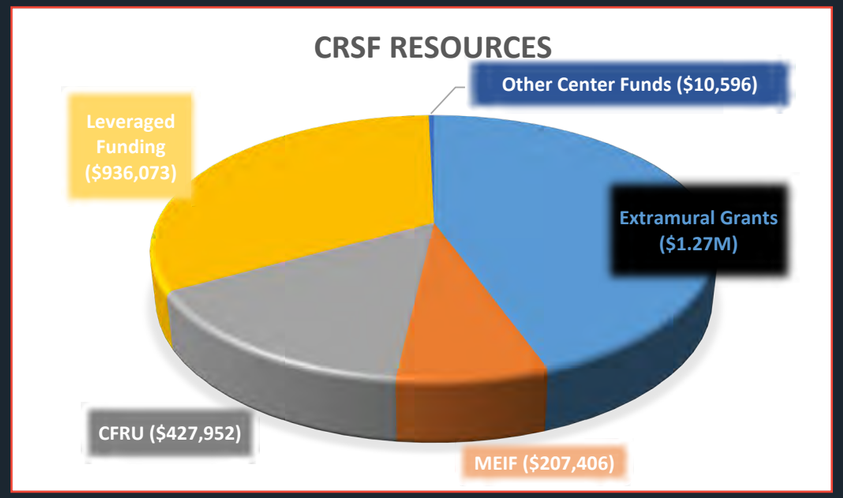


Figure 2

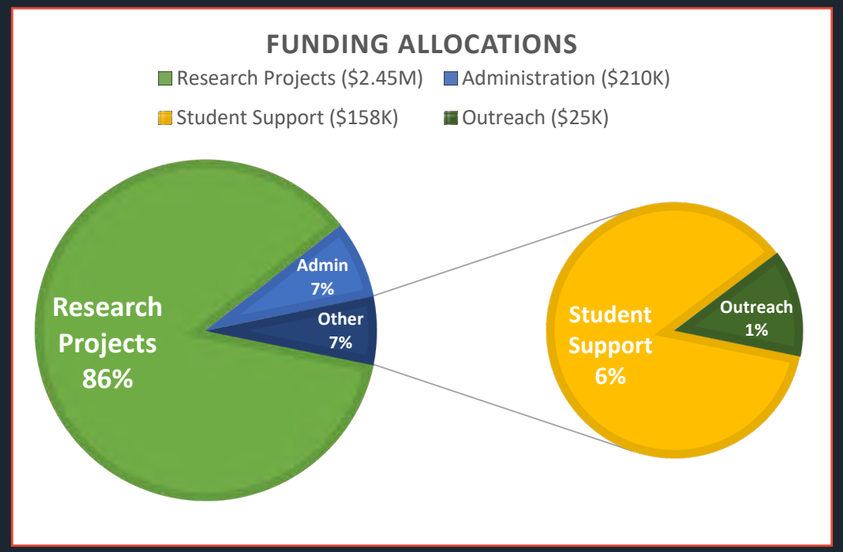


Table 1. CRSF Funding Resources

Amount	*Source*	*Lead PI*	*How Related*
	UMaine Funding Sources		
$207,406	Maine Economic Investment Fund	Weiskittel	Support Director's salary, CRSF staff, CRSF operations
$4,596	UMaine Munsungan Fund	Weiskittel	Support outreach and education projects
$6,000	CRSF Gift Fund	Weiskittel	Support research projects, graduate education, & CRSF operations
$427,952	Cooperative Forestry Research Unit	Weiskittel	Support research projects led by UMaine faculty
$645,954	***Total Center Funding***		
	External Grants		
$158,146	University of Vermont / US Dept of Agriculture	Kanoti/Kenefic	Development of a new silvicultural guide for northern conifers in the Northeast
$18,000	UMass Lowell / National Science Foundation	Fraver	Collaborative research on magnitude and pathway of gaseous Atmospheric mercury deposition in forests
$294,958	US Dept of Agriculture	Fraver	Support AmeriFlux work at the Howland Research Forest
$112,489	Maine TREE Foundation	Witham	Support research scientist and student field crews at Holt Research Forest
$169,199	National Aeronautics & Space Administration	Hayes/Weiskittel	Support forest carbon estimation (FORCE) project
$66,500	UNH / US Dept of Agriculture	Livingston	Support research on eastern white pine resilience and value
$14,515	ME Dept of Inland Fisheries & Wildlife	Witham	Support research on Holt Research Forest
$317,134	US Dept of Agriculture	Weiskittel	Meeting stakeholder needs for long-term research data and science discovery
$118,531	National Science Foundation	Weiskittel	I/UCRC Phase III - UMaine Membership in IUCRC Center for Advanced Forestry Systems
$1,269,472	***Total Extramural Funding***		
	Leveraged Grants		
$29,971	UMaine Research Reinvestment Fund Rural Health and Wellbeing Grand Challenge Grant Program	De Urioste-Stone et al.	Community resilience in a time of crisis: Lessons from the COVID-19 pandemic
$18,500	Senator George J. Mitchell Center for Sustainability Solutions FY 21 Grant Program	Horne et al.	Developing a transdisciplinary participatory framework as a tool for community-based climate change planning
$76,730	NOAA	De Urioste-Stone	Research with tourism industry partners on negative effects of climate change and identifying opportunities due to changing climate conditions.
$12,000	McIntire Stennis	De Urioste-Stone	Facilitate planning and coordination of forestry research
$10,060	UMaine Scholarly Materials and Equipment Award	Fraver	Toward a better understanding of the forest carbon cycle: Request for funds to purchase a portable CO2 gas analyzer.
$20,000	NCASI	Daigneault	Quantifying the GHG mitigation potential of natural climate solutions from Maine's working lands
$91,500	Forest Carbon Commercial Landowner	Daigneault	Quantifying the GHG mitigation potential of natural climate solutions from Maine's working lands

Table 1 continued			
$25,000	Maine Farmland Trust	Daigneault	Quantifying the GHG mitigation potential of natural climate solutions from Maine's working lands
$22,981	Mitchell Center Sustainability Grant	Daigneault	Quantifying the GHG mitigation potential of natural climate solutions from Maine's working lands
$487,717	USDA NIFA Foundational & Applied Science Program	Legaard	Intelligent GeoSolutions
$106,406	NSF I/URC CAFS	Legaard	Multi-regional evaluation of new machine learning algorithms for mapping tree species distribution and abundance
$4,000	PEF Research Operations Team	Kenefic	Professional staff support
$21,208	CFRU	Kenefic	Update the spruce-fir silviculture guide
$10,000	NCASI	Puhlick	MASN carbon analysis
$936,073	***TOTAL LEVERAGED FUNDS***		

CRSF **STAKEHOLDERS**

CRSF researchers strive to conduct not just cutting-edge forest science, but also real-world, applied science about Maine's forests, forest-based economy, and the public that supports them. We build and foster relationships with a wide variety of organizations and their people to achieve common goals and to engage Maine communities interested in science-based forest and ecosystem research. Over the past year we have worked with the following partners:

Cooperative Forestry Research Unit Cooperators

Acadia Forestry, LLC
American Forest Management
Appalachian Mountain Club
Baskahegan Company
Baxter State Park, SFMA
BBC Land, LLC
Clayton Lake Woodlands Holding, LLC
David B. Field
Downeast Lakes Land Trust
EMC Holdings, LLC
Fallen Timber, LLC
Forest Society of Maine
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 and Lands
Mosquito, LLC
New England Forestry Foundation
Prentiss & Carlisle Company, Inc.
Robbins Lumber Company
Sandy Gray Forest, LLC
Sappi North America
Seven Islands Land Company
Solifor Timberland, Inc.
Sylvan Timberlands, LLC
The Conservation Fund
The Forestland Group, LLC
The Nature Conservancy
Tree-Star Timberlands, LLC
Wagner Forest Management
Weyerhaeuser Company

INSPIRES

Appalachian Mountain Club
US Forest Service, Northern Research Station
The Nature Conservancy
Dartmouth University
Maine Municipal Association
Wabanaki Youth Science Programs
University of New Hampshire
University of Vermont

Intelligent GeoSolutions

Maine GeoLibrary
NOAA Coastal Change Analysis Program
Penobscot Experimental Forest
University of Maine Advanced Computing Group
University of Maine Barbara Wheatland Geospatial Analysis Laboratory
USDA Forest Service, Forest Inventory and Analysis Program, Northern Research Station

Nature-based Tourism

Acadia National Park
Appalachian Mountain Club
Cooperative Forestry Research Unit membership
DownEast Acadia Regional Tourism
Forest Stewards Guild
Maine Bureau of Parks & Lands
Maine Climate Council
Maine Medical Research Institute
Maine Woods Consortium
Manomet
Schoodic Institute
Small Woodlot Owners
Sunrise County Economic Council
University of Maine at Machias
Forest Climate Change Initiative
Maine Forest Service
Schoodic Institute
Appalachian Mountain Club
Forest Stewards Guild

Howland Research Forest / Holt Research Forest / Penobscot Experimental Forest

Forest Ecosystem Monitoring Cooperative
Maine TREE
Northern Arizona University, Flagstaff, AZ
Northern States Research Cooperative
Rutgers University, NJ
University of Massachusetts, Lowell, MA
USDA Forest Service, Northern Research Station, NH
Woodwell Climate Research Center, MA

Natural Climate Solutions

American Farmland Trust
Clark University
Colorado State University
Hubbard Brook Research Foundation
Maine Climate Table
Maine Farmland Trust
Northern Institute of Applied Climate Science, USDA Northern Forests Climate Hub
The Nature Conservancy, Maine
The Nature Conservancy, Massachusetts
University of Vermont
USDA Climate Hub
Wolfe's Neck Center for Agriculture and the Environment

Eastern White Pine

Nicholas Brazee, Plant Disease Clinique Specialist, UMass
Steve Roberge, Forest Extension Specialist, UNH

GEDI Forest Carbon Estimation

Michigan State University
University of Minnesota

Ecological Reserves Carbon Analysis

Nancy Sferra, The Nature Conservancy
Justin Schlawin, Maine Natural Areas Program

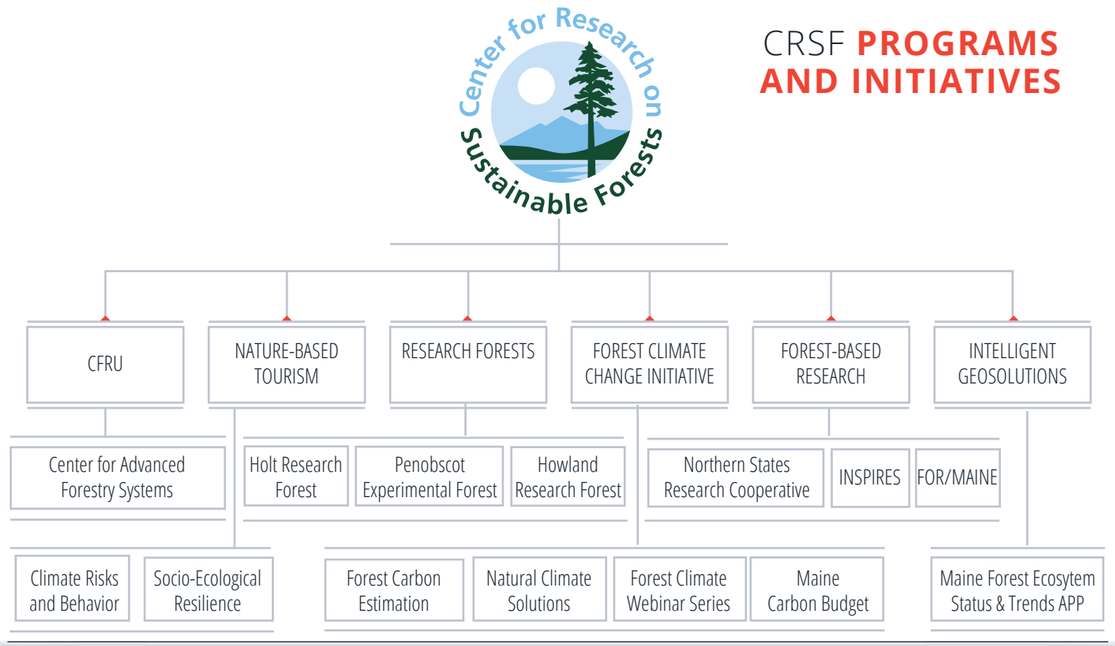
Assess and Monitor Acadian Forests

Charles (Tat) Smith, University of Toronto
Eugene Mahar, LandVest Timberland Division
Gordon Gamble, Wagner Forest Management
Greg Adams, Irving Woodlands, LLC
Greg Lawrence, Northeastern Soil Monitoring Cooperative
Ian Prior, Seven Islands Land Company
Jamin Johanson, USDA Natural Resources Conservation Service
Keith Kanoti, University Forests Office
Kenny Fergusson, Huber Resources Corporation
Nicholas Butler, USDA Natural Resources Conservation Service
Pat Sirois, Maine SFI Implementation Committee (Maine SIC)
Scott Bailey, Northeastern Soil Monitoring Cooperative

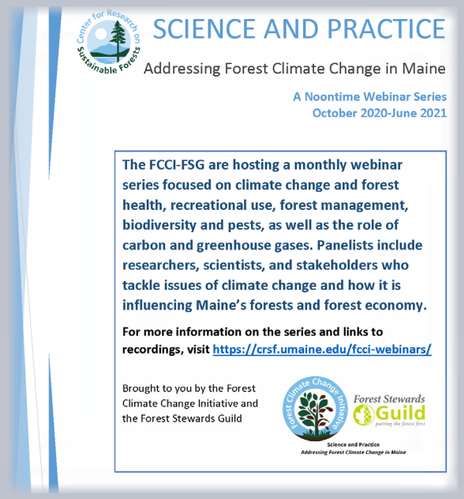
MASN Carbon Analysis

Kevin A. Solarik (National Council for Air and Stream Improvement)
Darren J.H. Sleep (Sustainable Forestry Initiative Inc.)

CRSF **PROGRAMS AND INITIATIVES**



The CRSF is lucky to have 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. Throughout the 2020-21 academic year, the Munsungan Endowment made it possible for CRSF to host the FCCI Science and Practice webinar series on forest climate change and adaptation in Maine. Gifts to the CRSF fund benefit student researchers and special projects on forest-related issues.



Forest Climate Change Initiative

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

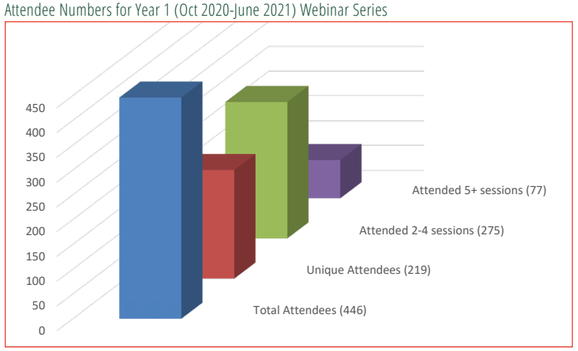
The FCCI team is a collaboration of interdisciplinary scientists from the University's School of Forest Resources, School of Food & Agriculture, and the Climate Change Institute, Schoodic Institute at Acadia National Park, and the Appalachian Mountain Club.

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. Each month, a slate of panelists comprised of researchers, scientists, and stakeholders tackled issues of climate change and how it is influencing Maine's forests and forest economy. The nine webinars engaged nearly 450 attendees from the university, public, conservation, and private forest sectors in discussion and Q&A sessions. Videos of each session are available via the **CRSF YouTube channel**.

FCCI-FSG plan to expand the webinar series in late 2021 by adding half-day field tours for planned webinars focused on the four primary forest types in Maine: spruce-fir, oak-pine, coastal spruce-fir, and mixed hardwood.

Detailed information on past and future webinars and field tours
can be accessed on the
FCCI Forest Climate Change Webinar Series Webpage

Attendee Numbers for Year 1 (Oct 2020-June 2021) Webinar Series



Webinar Topics October 2020-June 2021

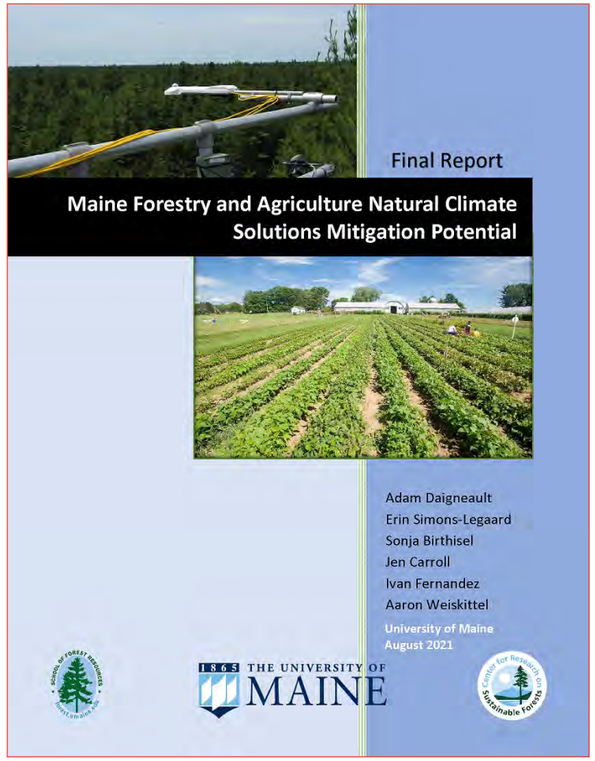
October	*Forest Operations with Virtual Field Tour (30 min video) and Best Management Practices*
November	*Carbon Budget, Management, and Credits*
December	*Warming/Changing Winters*
January	*Forest Biodiversity and Species Shifts*
February	*Forest Vulnerability Assessment*
March	*Forest Health: Northern Forests and Pests*
April	*Visualize Forest Composition and Health using the Electromagnetic Spectrum*
May	*Converging Policy and Practice: Carbon/Climate/New Directions*
June	*Managing Brown Ash for Resiliency Against EAB and Climate Change*

Natural Climate Solutions (NCS) Initiative

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

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.

The Maine Forestry & Agriculture NCS Mitigation Potential final report presents findings from a part of the larger Maine Natural Climate Solutions Initiative project that seeks to: (1) assess current practices to determine the degree to which foresters and farmers are using NCS; (2) determine the most cost-effective NCS for Maine; (3) understand key barriers to adopting NCS; and (4) generate information about which practices can be implemented on a broader scale. This report represents a critical step during implementation of Maine's climate action plan, providing a basis for science-informed decision-making by exploring the potential benefits of alternative NCS practices.



In tandem with the release of the final report, the NCS Initiative released a series of natural climate solutions fact sheets for forestry and agriculture in Maine. These fact sheets highlight key findings from the report and are available on the NCS website.

Nature-Based Tourism

crsf.umaine.edu/nature-based-tourism

Dr. Sandra De Urioste-Stone continues to lead our Nature-Based Tourism program, focused on research into the impacts of climate change on land cover management. The Nature-Based tourism program engages students and researchers in geo-spatial, economic, and social science analyses to develop solution-driven approaches to climate change.

Climate change will have a significant impact on the forest industry and will require strategies that promote sustainable forest management. Understanding perceptions of climate change impacts is critical to supporting the use of adaptation strategies, informing future research, and supporting decision-making. One project spearheaded by this program used a multi-method approach to identify and understand experts' concerns in regards to future climate change impacts on the forest industry in Maine.

Maine's outstanding tourism assets, along with the diversity of outdoor recreation opportunities, attract millions of visitors annually to and within Maine. Challenges to capturing growth opportunities relate to changes in visitor travel behavior, economic crises, limited tourism planning, and changing environmental conditions.

Another project sought to understand the determinants of climate change risk perceptions among forest resource stakeholders, which is critical to eliciting broad support for adaptation. Notably, political orientation, belief in climate change, social norms, affect, and experience with weather-related impacts were all significant predictors of perceived risk.

Natural resource-based economies, such as forestry and tourism, are important to Maine's citizens as they support rural livelihoods and stewardship of the environment. These industries 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. By regularly gathering, analyzing, and communicating information about the trends and factors that influence tourism development in Maine we expect to increase the efficiency of and opportunities for Maine's tourism industry.

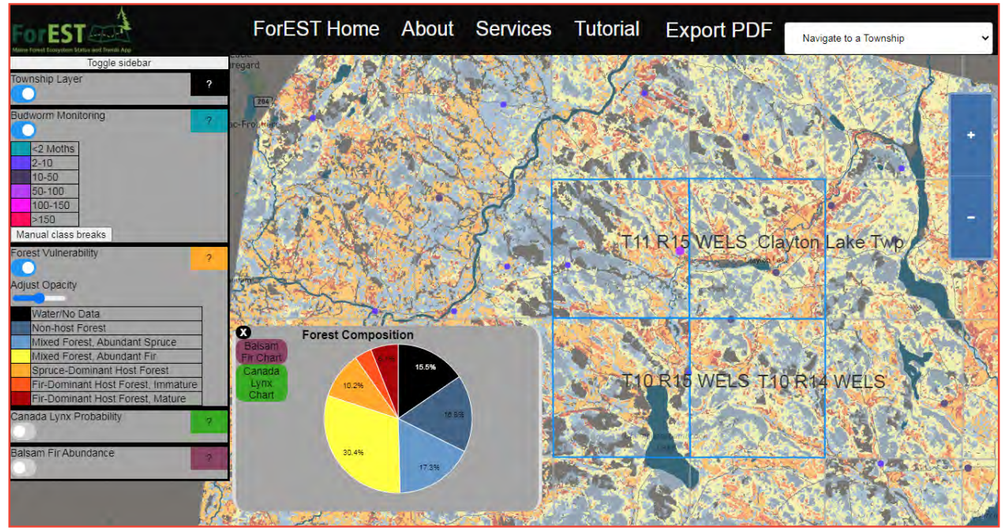
Intelligent GeoSolutions

crsf.umaine.edu/forest-research/igs

Forest Management Concerns

Accurate and up-to-date geospatial data are a modern requirement for resource management and conservation, land use planning, economic development, and policy making. Intelligent GeoSolutions (IGS) was launched in 2019 with the goal of developing and distributing high-quality, low-cost geospatial information relevant to forest resource management and applied forest research. Satellite remote sensing imagery from programs such as Landsat and Sentinel have the potential to enable near-real time mapping of spatial forest attributes as well as changes in landscape conditions. The partnership of IGS team technical expertise with the UMaine Advanced Computing Group offers a unique, local resource for advanced geospatial services. Details on IGS project objectives and outcomes are provided in the CRSF Project Reports section.

One key objective for IGS has been to improve access to spatial data. The Maine ForEST (Forest Ecosystem Status and Trends) App is the culmination of three years of research and software development for a geospatial tool that can provide state of the art maps of forest conditions derived from satellite imagery, allows exploration of regional budworm population monitoring data and provides users with the ability to evaluate forest risk and identify natural resource tradeoffs.



CENTER FOR ADVANCED FORESTRY SYSTEMS

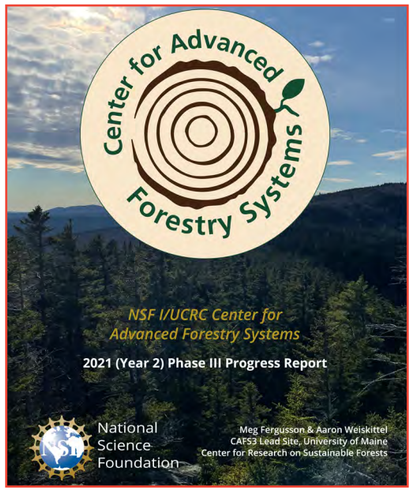
crsf.umaine.edu/forest-research/cafs

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 FY21, CAFS was supported by $3.7M in contributions from 138 industry members across 7 sites.

Despite the shutdowns associated with the global pandemic, throughout 2020-21 CAFS researchers were able to continue their research and share it with the broader scientific community through refereed publications and virtual presentations at scientific meetings. Graduate student training is featured in CAFS research and technology transfer, allowing them to gain valuable knowledge of applied problem-solving using interdisciplinary techniques across multiple scales. CAFS sites aggressively recruit graduate students from among under-represented groups in a concerted effort to increase the diversity of the workforce for both academia and industry in this traditionally diversity-deficient discipline. CAFS research activities allow undergraduate students to experience the excitement of forest science and mentorship to pursue graduate education.

Current research topics include: improving white pine seedling survival, stand and tree responses to late rotation fertilization and thinning, assessing and mapping regional variation in potential site productivity and site carrying capacity, evaluation of machine learning algorithms for mapping tree species distribution, using hyperspectral imaging to evaluate forest health risk, long-term soil productivity experiments, and physiological response to commercial fertilization programs.

CAFS members sites are University of Maine, North Carolina State Univeristy, Oregon State University, Purdue University, University of Georgia, University of Idaho, and University of Washington. In FY22, CAFS will expand sites to University of Maine at Fort Kent and Montgomery Community College.



Detailed project reports can be accessed via the Year 1 and Year 2 CAFS annual reports.

INSPIRES

crsf.umaine.edu/inspires

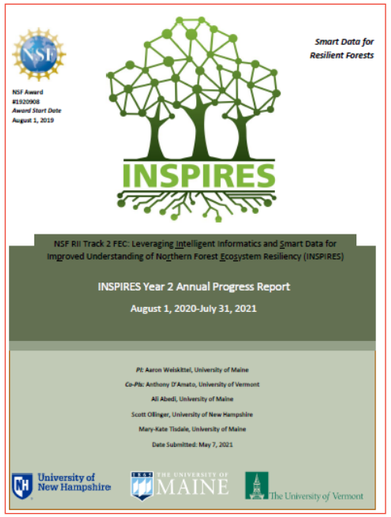
The **Leveraging Intelligent Informatics and Smart Data for Improved Understanding of Northern Forest Ecosystem Resiliency** (INSPIRES; *Smart Data for Resilient Forests*) project is an interjurisdictional partnership between research and higher educational institutions in Maine, New Hampshire, and Vermont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

The INSPIRES team currently involves 64 individuals with the majority being faculty from the three states (36; ME = 19, NH = 11, VT = 6), bolstered by undergraduate/graduate students (18), post-doctorate researchers (2) and professional staff (8). The structure of the project is centered around four core research themes: (1) Advanced Sensing and Computing Technologies; (2) Smart Environmental Informatics; (3) Integrated Ecological Modeling; and (4) Quantitative Reasoning Skills in Context. These themes are building an understanding of current and future changes in the Northern Forest with a focus on key ecological and socioeconomic drivers.

During Year 2, INSPIRES team members were successful in developing strategies to enhance team building, completing the planned external project review, and supporting enhanced interjurisdictional research collaboration, particularly among the project's student participants.

Notable Achievements

- Collaborative Research Committee (CRC) formed to discuss cross-theme and cross-institution collaboration opportunities and needs
- Deployment of Mayfly-based sensor suites at 5 locations
- Data Sharing Subcommittee developed guide on best practices for data sharing inside INSPIRES and to identify team outputs
- Recruitment and hiring of 1 post-doc, 6 graduate students, and 2 undergraduate students across the three institutions
- Output: 21 published/in review peer-reviewed articles, 14 presentations, 3 data/model/technology products, and 14 presentations



The Year 1 and 2 INSPIRES annual reports fully describe INSPIRES program and research project efforts.

COOPERATIVE FORESTRY RESEARCH UNIT

umaine.edu/cfru

Founded in 1975, the CFRU is one of the oldest industry/university forest research cooperatives in the United States. The CFRU is composed of 32 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. In early 2021, the CFRU welcomed Regina Smith as the new Research & Outreach Coordinator. Regina has greatly increased dissemination of key research outputs through traditional channels while developing and sharing videos through the new CFRU YouTube channel.

CFRU Ongoing Projects (detailed project reporting available via the CFRU website)

Habitat & Biodiversity

- Responses of Marten Populations to 30 Years of Habitat Change
- Development of Large-Scale Optimal Monitoring Protocols for Carnivores in Maine
- Quantifying Ecological & Economic Outcomes of Alternative Riparian Management Strategies
- Watershed-Scale Drivers of Temperature and Flow of Headwater
- Rusty Blackbird Use of Commercial Spruce-Fir Forests in Northern New England

Inventory & Growth Modeling

- Long-Term Outcomes of Beech Bark Disease: 40-Year Results
- Maine's Adaptive Silviculture Network (MASN)
- Quantifying Regeneration Outcomes and Logging Residues in MASN
- Identifying Opportunities for Improving Small-Diameter Tree Harvesting
- Strategies, Logistics & Market Diversification

Silviculture & Management

- Assessing and Monitoring Soil Productivity, Carbon Storage, and Conservation on MASN
- Measurements, Models and Maps: Large-Area Forest Inventory from Airborne LiDAR Data
- Spruce Budworm L2 Survey
- Interdisciplinary Spatial Modeling of Terrain, Wetness, Soils and Productivity

Professor Dan Harrison oversees students working on responses of marten populations to habitat change

NORTHEASTERN STATES RESEARCH COOPERATIVE

nsrcforest.org

In late 2020, a revitalized and re-funded Northeastern States Research Cooperative (NSRC) reinvigorated efforts to put regional forest research to work across the Northern Forest. Strong partnerships are the foundation of the NSRC's success, and partners include leaders from the USFS-NRS and the four universities overseeing the program, citizens of the Northern Forest, principal investigators and their co-researchers, and personnel from cooperating organizations. UMaine's CRSF jointly directs the program with its regional partners and USFS.

Prior to the 2020 Request for Proposals, a 17-person External Advisory Committee (EAC) served to identify priority issues facing forest stakeholders in the Northern Forest region and set the research agenda for the request. The EAC recommended that the NSRC prioritize research by: (1) how relevant it is across the four-state region, as opposed to a narrower focus on localized areas or individual states; and (2) how actionable it is to practitioners, decision makers, and other stakeholders.

In spring 2021, 13 projects were funded with nearly $1.6 million to explore a broad range of concerns related to land use and sustainable forestry, rural communities and economic development, climate change, biodiversity, recreation and tourism, invasive pests and diseases, and Traditional Ecological Knowledge. These projects were carefully vetted by an external stakeholder panel, which prioritized research based on the potential to engage stakeholders and to have meaningful impact to the region.

To acknowledge and address structural inequities in opportunities for Indigenous youth to participate in forest research, and to invest in the cultural and intellectual sovereignty of Tribal forest traditions alongside other forms of applied forest research, NSRC leaders awarded two projects under a separate Indigenous Forest Knowledge Fund proposal request; the awardees were chosen by a committee composed of program organizers representing forest science, public outreach and education, and Tribal climate/forest science and cultural values.

Results from these projects, as well as annual progress reports, are shared on the NSRC website.

RESEARCH FORESTS

crsf.umaine.edu/forest-research

Northern Research Station
Penobscot Experimental Forest

The PEF is home to long-term silviculture and ecology research by the Forest Service (1950s to present) and the University of Maine (1990s to the present), contributing to sustainable management of working forests in Maine and elsewhere.

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 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.

HOLT
Research Forest

The Holt Research Forest has been the site of a long-term pine-oak forest ecosystem study continuously since 1983, collecting data on trees and regeneration, small mammals, and a variety of avian species. Since its inception, HRF has been a site for cooperating researchers, training opportunities for graduate and undergraduate students, and public service and outreach to the community. The HRF research plan has two goals: (1) to monitor long-term changes in animal and plant populations and (2) to document the effects of forest management on these species.

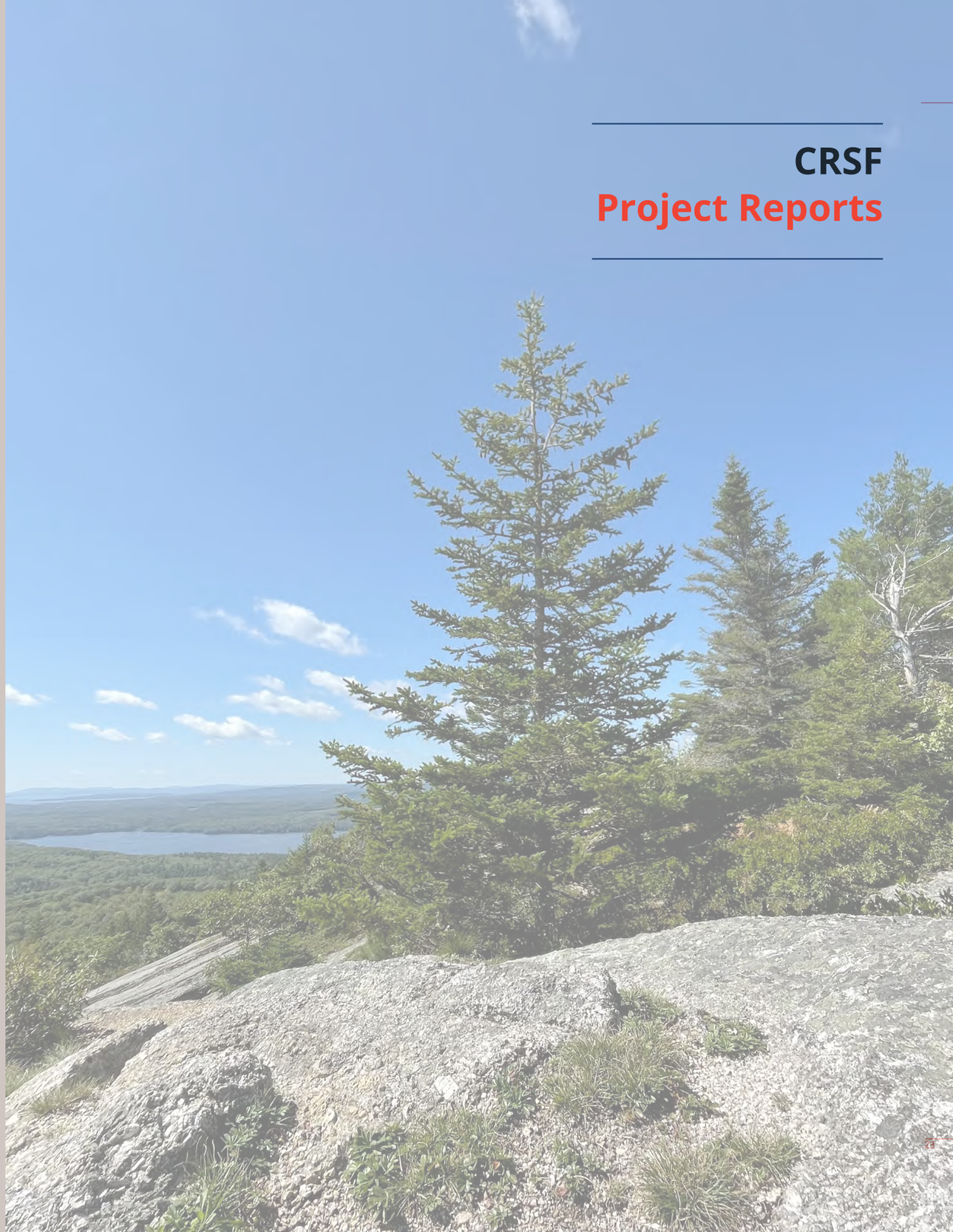
Continuous, long-term data sets in ecology such as the one at HRF are rare and unusually valuable. Most ecological research operates in time scales of 2-5 years, driven by cycles of funding and graduate projects, while ecological processes often occur over decades. The HRF is the only operating oak-pine research forest in Maine and it is one of only two forests (with the Harvard Forest) dedicated to oak-pine research in the Northeast. Though the oak and pine forest types represent only 10% of Maine's forestland, over 80% of the forest cover in Maine's southern counties is oak pine types and it is responsible for a significant portion of Maine's total forest economy. To learn more about the Holt Forest, visit holtforest.org.

HOWLAND FOREST

Home to the second-longest flux record (since 1996) in the United States, the Howland Research Forest is a founding member site of the Ameriflux network. The site maintains three eddy flux towers; two towers (the "main" and "west" towers) are located in a mature spruce–hemlock forest approximately 800 meters apart. Howland has the second longest running flux record 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 CO2 flux and various environmental variables.

Established in 1986 through a partnership between the University of Maine and International Paper Company, Howland Research Forest's forest ecosystem research site located in central Maine has hosted numerous collaborations between the USDA Forest Service, NASA, NOAA, EPA, the US Department of Energy, Woods Hole Research Center, and the University of Maine. The CRSF continues to support an active research program in Howland focused on carbon and nutrient cycling, remote sensing, climate change, and more.

CRSF
Project Reports



Fostering Forest Landscape Planning and Adaptive Capacity in Anticipation of a Regional Insect Outbreak

Erin Simons-Legaard (PI), Kasey Legaard, and Aaron Weiskittel

Center for Research on Sustainable Forests

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. Our proposed research is directly responsive to USDA goals in our intent to provide actionable knowledge and decision support to forestland owners and managers about the long-term consequences to forest health, resilience, and productivity associated with different mitigation strategies to limit insect damage in a forest ecosystem that has also been identified as vulnerable to climate change effects.

Objectives

- 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.
- Identify forest conditions that promote the early establishment of local budworm populations, using contemporary population monitoring data and satellite imagery.
- 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.
- Increase local and regional adaptive capacity using a Participatory GIS approach and online mapping system.

Accomplishments

Objective 1

- In Year 1 we conducted a preliminary analysis of environmental factors that influenced historic defoliation patterns. In total the historic plot dataset includes measurements from 424 ~0.5 acre circular plots distributed across northern Maine. Plot locations were recorded in the field on paper topographic maps. In Year 1 we completed the process of scanning the topo maps and georeferencing locations for a subset of the plots (n= 150) within a ~4 mil acre area of northern Maine. This area also served as the test region for mapping relative tree species abundance ca. 1975 using historic Landsat Thematic Mapper imagery.
- We modeled the effects of plot-level variables derived from inventory data and landscape-level variables from the historic forest map on cumulative defoliation (1975-1985) using the Random Forest machine learning algorithm. Our set of predictor included 16 plot variables (e.g., forest type, slope, aspect, drainage class, tree height, tree diameter). Landscape variables quantified the amount of the neighboring landscape (@ 500, 1000, and 2500 m) composed of 7 forest types: host-dominant softwood (immature/mature), host-dominant mixedwood (immature/mature), other softwood, other mixedwood, and hardwood. Host forest was mapped based on high abundance of balsam fir or spruce sp.
- Relative importance of predictors suggested that plot variables were more influential on susceptibility to defoliation, but neighboring forest conditions were also important. The most influential variables were balsam fir basal area (ft2/acre) and number of balsam fir trees at the plot. Secondary but also important variables included the amount of 1) mature, host-dominated forest or 2) hardwood forest within 500 m of the plot. Cumulative defoliation had a positive relationship with amount of host forest in the neighboring landscape, and a negative relationship with amount of hardwood forest.
- Year 1 results suggest landowner strategies to reduce risk of budworm defoliation should consider the composition of the neighboring landscape in addition to balsam fir abundance when identifying areas for mitigation actions, with preference given to high risk forest in higher risk landscapes.

Objective 2

- Budworm population monitoring is at the core of Maine's strategic response plan, and the Maine Forest Service (MFS) has substantially increased monitoring over baseline efforts in collaboration with project scientists and members of the UM Cooperative Forestry Research Unit (CFRU). With the help of Maine's large landowners, a monitoring network of more than 400 locations has been established across northern, western, and Downeast Maine to deploy pheromone traps to catch and count moths and to collect tree branches to count budworm larvae.
- In Year 1 we obtained counts of moths and second in-star larvae (L2), collected 2014-2019 across the network, from MFS (moths) and CFRU (L2). We used available moth data to perform a preliminary investigation assessing the influence of forest conditions (ca. 2010), using previously developed forest maps, on early outbreak patterns.
- Statewide the average number of moths caught increased ~400% from 16 in 2014 to 67 moths/trap in 2018, driven by a notable increase in Maine's most northern county (Aroostook) where the average increased ~500% from 26 to 139 moths/trap. As of 2019, counts of second generation larvae (L2s) remained low statewide, suggesting that moth increases are due to immigration from neighboring outbreak areas in New Brunswick rather than an increase in local population growth.
- A Random Forest analysis of annual average moth catch explained roughly 60% of the variability in the data, half of which was attributable location (i.e., latitude and longitude). The additional 30% was explained by mapped forest conditions. The percent of high risk forest (i.e., mature forest with ≥75% host abundance) within 500 m of a trap location was an influential factor. Amount of softwood and non-host in the surrounding landscape (within 2500 m of the trap location) were also identified as important, further highlighting the inherent multi-scale nature of budworm population dynamics.
- Year 1 results suggest regional population dynamics (e.g., distance from source populations in Canada) continue to play a dominant role in Maine, and as a consequence prioritization of actions to reduce risk of defoliation should take geographic location, as well as host abundance, into consideration.

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 1 we conducted a rigorous recalibration of LANDIS-II parameters to improve representations of climate change effects on competitive interactions between tree species. We first clustered gridded projections of future monthly climate (maximum temperature, minimum temperature, total precipitation) under RCP 4.5 (intermediate CO2 emission scenario) to identify spatial climate patterns. We then used PnET-II to project changes in species productivity (2020-2100) for each cluster under a range of RCPs. Projected changes in species productivity will be used to parameterize the LANDIS-II FLM to model the spatial impacts of climate change on future forest conditions.
- Projections of species productivity indicate annual net primary productivity varies statewide, but general patterns of declining productivity amongst northern conifers (e.g., balsam fir and spruce sp.) driven by climate changes are apparent. Defoliation by spruce budworm will cause a loss of productivity for the same species, and the interactive effects have important implications for rates of carbon sequestration system wide.

Significant Challenges

- Loss of project personnel (graduate student)
- Lost productivity due to COVID19 impacts on project personnel (specifically, closure of public schools and childcare facilities) and outreach opportunities

Future Plans and Opportunities

- Expand analysis of cumulative defoliation to include the historic dataset in its entirety and include additional site variables (e.g., terrain and distance to defoliation hotspot). Future results will improve our understanding of factors, other than host presence, that influence stand-level defoliation risk.
- Complete statewide mapping of contemporary (ca. 2021) distributions of budworm host tree species and explore developing patterns of population establishment and growth using an unsupervised machine learning algorithm referred to as a self-organizing map (SOM).
- Calibrate the LANDIS-II Biomass Insect Module using the results from Objectives 1 and 2. Once complete we can develop scenarios that explore interactions between outbreak intensity and intensity of landowner response to outbreak conditions.
- Offer outreach workshops to introduce potential users to our interactive web-based mapping system, ForEST App, and to solicit feedback on prototype geospatial tools developed by student programmers.

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

William H. Livingston (PI)
School of Forest Resources

Eastern white pine (EWP) is a major component of eastern forest with over 186 million mbf (15 billion ft^3) 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

- 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.

Approach

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.

Key Findings

- Due to COVID restrictions, most of the project's activities have been delayed until 2022.
- The online Eastern White Pine Management Institute is currently being designed and created at UNH.

Significant Challenges

- COVID 19 travel restrictions have prevented work on the project. We are planning on resuming activities in Fall 2021.
- Future Plans (next year & beyond) and Opportunities (please include planned proposals)
- The Eastern White Pine Management Institute will become available by fall 2021.
- Initial workshops are being planned by UNH and UMass for fall 2021. UMaine will contract a film-maker to begin work on creating videos for online use.
- UMaine will plan a Eastern White Pine Symposium to be held jointly with the New England Society of American Foresters Winter Meeting in Portland, ME, March 23-25, 2022.

GEDI Forest Carbon Estimation (FORCE)

Daniel Hayes (PI), Aaron Weiskittel, David Sandilands

School of Forest Resources, Center for Research on Sustainable Forests

NASA's Global Ecosystem Dynamics Investigation (GEDI) uses a LiDAR instrument on the International Space Station (ISS) to make precise measurements of the structure of forests and the Earth surface. GEDI measurements can be used in conjunction with other data within a spatial modeling framework designed to fill the gaps in the observations to produce full coverage maps of forest metrics. The goal of our Forest Carbon Estimation (FORCE) project is to use GEDI 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 42°N to the northern extent of GEDI acquisitions (51.6°N), 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

- Demonstrate the spatial modeling approach at multiple scales with high-resolution data at a sample of intensive study areas as well as using moderate-resolution data across the full study domain.
- Extrapolate GEDI forest structure metrics using a joint modeling strategy with satellite imagery and other, wall-to-wall spatial data sets (Stage 1 model component).
- Develop wall-to-wall maps of forest biomass and pixel-level uncertainty for the study domain (Stage 2 model component).
- Evaluate the biomass map product outputs against regional-scale benchmarks at contrasting spatial scales.
- Leverage the joint modeling strategy with future GEDI data and disturbance maps for improved monitoring of biomass and its change.

Approach

The core of the approach is the development of a spatial regression modeling framework capable of ingesting existing field-based data from inventory plot networks to calibrate and assess the uncertainty of GEDI-derived predictions of biomass and other forest structure variables. We will build Bayesian hierarchical linear models to predict multiple variables simultaneously using a flexible framework capable of jointly modeling spatially misaligned forest inventory plot measures with spaceborne LiDAR observations. The framework is based on a two-stage modeling approach: First, wall-to-wall explanatory covariates (e.g., Landsat imagery) are used in a joint regression model to spatially predict gridded surfaces of GEDI LiDAR metrics (e.g., canopy cover and vertical profiles). Second, the wall-to-wall GEDI LiDAR metrics serve as the covariates in another joint regression model to predict forest metrics (e.g., aboveground biomass) based on response variables estimated by plot-based inventory data. The output of the Bayesian modeling is a joint posterior predictive distribution of the response variables, thereby allowing the propagation of variable prediction uncertainties through each modeling stage. The resulting wall-to-wall biomass

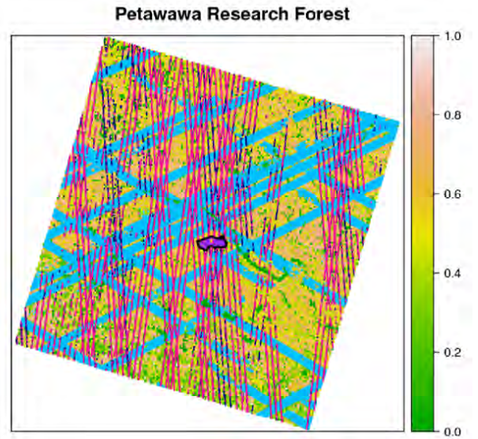


Figure 1. Map of the Landsat-based enhanced vegetation index scene over the Petawawa Research Forest in Ontario, Canada. The blue and pink lines show 2019 orbital collections of GEDI and ICESat-2 data, respectively.

and forest structure prediction maps can then be spatially aggregated to produce statistically robust summary estimates with associated confidence intervals.

Key Findings

- 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.

Accomplishments

- Developing new partnerships with colleagues at Michigan State University and University of Minnesota
- Holding regular, biweekly project meetings
- Constructing customized tools (in R, Python, and Google Earth Engine) to download, process, and visualize GEDI data
- Recruitment of one MS student and one PhD student to work on the project

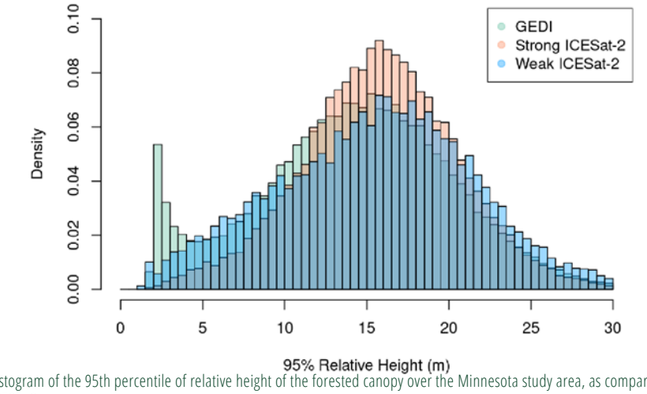


Figure 2. Histogram of the 95th percentile of relative height of the forested canopy over the Minnesota study area, as compared between GEDI and ICESat-2.

Significant Challenges

- Data availability and accessibility are difficult
- Critical data quality issues to be addressed
- Limited existing tools to work with GEDI data
- Remote / virtual meetings
- Recruiting / hiring a graduate student

Future Plans and Opportunities

- Continue to assemble and process GEDI data for our study domain
- Continue to build tools for processing and analyzing GEDI data
- Run pilot studies connecting field, remote sensing, and lidar at intensive study sites Complement GEDI data with other spaceborne lidar collections (i.e., ICESat-2)
- Organize and process regional-scale spatial covariate data using cloud-based platforms

Fostering Coastal Community Resilience in Maine: Understanding Climate Change Risks and Behavior

Sandra De Urioste-Stone (PI), Parinaz Rahimzadeh-Bajgiran
School of Forest Resources, Center for Research on Sustainable Forests

Final Report

Maine's dependence on natural assets to attract tourists to coastal areas makes the nature-based tourism industry, and the economies of surrounding rural communities, sensitive to changes in climate and weather conditions. Hence, an improved understanding of how climate change will impact the coastal/marine tourism assets in the region, how these changes will impact the consumer base, and how to effectively develop adaptation strategies, becomes crucial to the resilience of these natural-resource dependent coastal communities. Our research aims to enhance the ability of coastal tourism destination communities to cope with the negative effects of and capitalize on emerging opportunities that ecological and travel modifications resulting from climate change might bring using effective collaboration models.

Objectives

- Investigate coastal tourism stakeholder climate change risk perceptions; identify current and planned mitigation strategies; assess current and likely adaptive behavior in response to climate change risk; and identify socio-economic and institutional barriers to adaptation.
- Measure visitor climate change risk perceptions, and estimate resulting potential behavioral changes (e.g., destination, activity participation, seasonal visitation patterns) to the risk of climate change in coastal destinations.
- Study the current effects of climate on coastal tourism destinations, coastal-scapes, and other natural assets using social, meteorological and satellite remote sensing data in the region.
- Integrate and share results with community stakeholders to jointly develop best practice strategies to increase the adaptive capacity of the coastal tourism industry in Maine.

Approach

Research activities were conducted in collaboration with stakeholders in three selected Maine coastal tourism destinations: Camden, Machias, and Mount Desert Island. In Phase 3, we integrated data and facilitated a series of participatory planning workshops to share our findings with stakeholders and jointly develop climate change adaptation strategies in collaboration with stakeholders.

- A total of 42 semi-structured phenomenological interviews were conducted with tourism stakeholder in the study regions in Maine. A pile sort activity was embedded within the interviews to identify group cognition.
- A mixed-mode survey was administered to visitors of MDI to identify factors contributing to tourist climate change risk perceptions, and adoption of coping behaviors to respond to climate change. We surveyed a total of 1,353 visitors on-site, and 480 of those completed the follow-up survey responses, with a response rate of 35.48%.
- A group of graduate students and partners collaborated in developing a collaborative platform to share study results. A series of virtual climate change planning workshops with tourism stakeholders on MDI were conducted in 2021.

Key Findings

Interviews

- Many participants have discussed building community resilience in terms of leveraging resources and developing partnerships with other local businesses and organizations. Strong social networks resulting in frequent collaborations, especially between non-profits, appear to be key for bolstering destination resilience and addressing community concerns, such as poverty, natural resource conservation, and economic development. These partnerships have also been effective in sharing knowledge, resources, and skill sets across stakeholder groups and between tourism destinations. Natural resource dependent livelihoods and personal outdoor recreation habits were important for connecting participants with first-hand observations of environmental changes and a valuation of environmental protection.
- Participants have overall demonstrated high awareness and concern for climate change impacting coastal Maine. The increasing tick population and resulting spread of Lyme disease is of especially high concern among the National Park Service, non-profit land managers, and business owners. These participants have repeatedly discussed the need for more research to understand visitor perceptions of ticks and resulting behavioral changes in relation to visitor education and land management decisions. Other climate change impacts of high concern are increased storms.
- Further, among the terms most frequently used by participants during interviews include people, know, climate and change (see Word Cloud). Participants usually referred to climate change in terms of the implications to humans. It was also mentioned climate change in connection to having or lacking knowledge on the topic.

Visitor Survey

- Findings from the visitor survey indicate that the majority (almost 90%) of visitors surveyed believed that climate change is currently happening, is caused by carbon dioxide emissions, and that humans are the primary contributor to climate change. It is important to note that the majority of visitors (93.6%) acknowledge that climate change is at least partially caused by human behaviors, though fewer recognize the link between tourism and climate change (58%). Over 75% of visitors to Acadia National Park expressed some level of climate change concern with almost half indicating they were very concerned about climate change. Only 9.6% of visitors were unconcerned or not concerned at all.
- The hierarchical regression analysis of visitor survey responses explained 45.5% of the variance in visitors' climate change risk perceptions at a nature-based tourism destination. Analysis of psycho-social factors influencing visitor risk perceptions indicates that exposure to weather or health messages, being female, having higher belief in climate change, having more experience with climate change impacts, and having a more altruistic values orientation (as opposed to a biospheric or egoistic orientation) are all significant predictors of visitor climate change risk perceptions. These are consistent with results from similar studies. Unfortunately, we found no significant link between risk perceptions and intention to engage in substitution behaviors. It appears that, in our model, perceptions have weak predictive power when it comes to intention to substitute (e.g., destination selection, seasonal shifts in visitation, activity participation).
- According to several participants, disease outbreaks, increased mosquitoes, increased ticks, increased rain, and extreme weather events were most likely to decrease outdoor recreation activity. Actions participants were most likely to adopt in case of climate change impacts to outdoor recreation resources include pursuing other outdoor recreation/tourism activities (activity substitution), visiting MDI and Acadia National Park during another time of year (temporal substitution), or substituting another location in the U.S. (spatial substitution).

Participatory Workshops

- During participatory workshops, participants identified climate change impacts that fell into six broad categories: (1) increasing heat and temperatures; (2) changes to precipitation and water resources; (3) changes to flora and fauna; (4) unpredictability of impacts; (5) changes in visitation; and (6) human impacts from climate change and increased visitation.

- Potential adaptation actions identified by the group fell under four major categories that would address both modeling sustainability and addressing increases in visitation: (1) Target communication and education efforts across the island to a variety of groups, including visitors, residents, and those working in the hospitality industry; (2) Focus efforts on transportation across the island to increase the walkability of the downtown, reduce traffic through strategies such as carpooling, and increasing bike lanes; (3) Continue to collect, analyze, and share data regarding visitation to MDI to ensure collaboration and inform management actions; and (4) Maximize the ability of the hospitality industry to handle increasing visitation during the shoulder seasons.
- Barriers to implementing the adaptation prioritized include a lack of a dedicated and long-term leadership position to ensure a consistent messaging and collaboration, and the funding and the time necessary to complete these actions.

Accomplishments

- Established a community of learning whereby faculty, graduate students, and undergraduate students support and learn from one another.
- Created a team of researchers and partners seeking to integrate social and biophysical data relevant for decision making.
- Trained nine graduate and six undergraduate students in qualitative research methods, survey research methodology and procedures, and management and logistics techniques.
- Increased capacity of students and faculty to develop effective science communication tools.
- We are collaborating with partners to develop a communication and facilitation plan to share study results, and conduct participatory activities to identify strategies and develop planning tools to help enhance the ability of community destinations to cope and respond to changing conditions.
- This project will support tourism industry stakeholders and community partners enhance their ability to respond to negative effects of climate change, while taking opportunities that are brought by changing climate conditions.
- Enhanced transdisciplinary research and collaboration capacity at UMaine.
- Four grant proposals funded; one proposal unfunded; one proposal in preparation.

Significant Challenges

- Have had numerous potential participants live in Maine only during summer and early fall, hence making scheduling interviews difficult or impossible since the start of the grant. Many tourism business providers are only present in the area during peak tourism season, with limited time for other activities besides running their businesses.
- Experienced some difficulty recruiting interview participants due to COVID-19. We have switched to phone interviews to ensure the safety of all research participants and researchers. Unfortunately, this has eliminated the ability to do pile sorts with participants. Furthermore, we acknowledge that potential participants are under increased stress due to the uncertainty surrounding COVID-19 and may be less willing to participate in interviews.
- We had to delay the participatory workshops given travel and gathering restrictions. We plan to modify some of the tools for online delivery, and potentially facilitate several workshops in person if conditions permit.

Future Plans and Opportunities

- Submit at least two scholarly journal articles.
- Enhance collaborative efforts with partners.
- Submit future grant proposals to continue the work

Fostering Forest Landscape Planning and Adaptive Capacity in Anticipation of a Regional Insect Outbreak

Sandra De Urioste-Stone (PI), Brandon Lieberthal, Karen Beeftink, Allison Gardner, John Daigle, Linda Silka

Center for Research on Sustainable Forests

Tourism is one of Maine's largest industries, generating over $6.5 billion in tourism spending and 116,000 jobs (about 1 in every 6 jobs) in 2019. Despite the economic growth of tourism in recent years, COVID-19 has significantly affected already depressed rural communities in the state, and thus, the current tourism landscape in Maine is uncertain. New regulations for businesses and destinations; changing travel guidelines; evolving urban-rural mobility due to health risk perceptions; new pressures posed on outdoor recreation assets; and tightening of immigration regulations will influence economic development, resource management, and travel behavior in years to come. The proposed effort brings together researchers and practitioners from tourism and outdoor recreation, rural planning, social and community psychology, disease ecology, and mathematics. Lessons from this research could have important implications for rural communities responding to other health, environmental or economic shocks. This project began in June 2021.

Objectives

The goal of this project is to understand the effects of the pandemic on Maine's tourism industry and enhance the capacity of rural tourism destinations to respond to the impacts of the pandemic. We will pursue this goal through four research objectives (O) and associated research questions (R.Q.) and hypotheses (R.H.):

(O.1) Measure visitor motivations and travel behaviors to travel to/within the State
Q.1.What factors influence visitor decisions to travel to/within Maine during the pandemic? Q.2. Which place attributes have attracted visitors and which have served as barriers to considering Maine as a tourism destination during the pandemic?

(O.2) Understand perceptions and adaptation strategies of tourism stakeholders (i.e., tourism providers, town planners, and resource managers) as related to the pandemic
Q.3. What economic development risks and opportunities do tourism stakeholders identify?

(O.3) Identify correlations between environmental, sociodemographic, economic, and political variables and high transmission of COVID-19 in Maine towns
H.1. Initially, transmission was highest in urban areas of Maine, and human population density and network connectivity were the best predictors of transmission risk
H.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

(O.4) Facilitate planning efforts with tourism stakeholders in rural destinations affected by the pandemic to share results and identify strategies that will enhance their resilience
Q.4. What adaptation strategies can tourism stakeholders use to effectively respond to the short-term, medium-term, and long-term impacts of the pandemic?
Q.5. What product development, marketing, and resource management strategies can tourism stakeholders use to respond to changing visitor demographics and travel behaviors?

Approach

The project includes (1) social science surveys to explore how the pandemic influences visitor travel decisions, and tourism stakeholder opinions and actions associated with the impacts of COVID-19; (2) epidemiological modeling to retrospectively assess the vulnerability of rural, tourism-dependent communities to COVID-19

transmission; (3) a content analysis of Maine news media to identify frequency and message content related to COVID-19 and tourism; and (4) participatory workshops to create economic recovery and preparedness plans to overcome development obstacles posed by the pandemic.

Key Findings

- A total of 61 respondents from the Maine Bureau of Parks and Lands completed an online questionnaire that included several questions on the impacts of the COVID-19 pandemic to State Parks and Public Reserve Lands. The pandemic was identified as the third most influential factor impacting the work of the Maine Bureau of Parks and Lands.
- Participants mentioned that the COVID-19 caused a significant increase in visitor numbers to Maine State Parks in 2020.
- A total of 4,329 newspaper articles from have been published from September 2019 through June 2021 on COVID-19 and travel. Only Maine newspapers found in the Maine Newsstand database were included (Figure 1).

Accomplishments

- Created a transdisciplinary team of researchers to integrate social and biophysical data relevant to stakeholders.
- Training one undergraduate students and two graduate students in how to conduct social science research (strategies to conduct rigorous, reliable, and ethical studies).

Significant Challenges

- The pandemic has presented significant challenges in our ability to conduct field work.

Future Plans and Opportunities

- Conduct and analyze visitor survey (fall 2021-spring 2022).
- Conduct and analyze tourism provider survey (fall 2021-spring 2022).
- Conduct epidemiological modeling (fall 2021-spring 2022).
- Attend and present at one scientific conference (summer 2022).
- Facilitate participatory meetings with stakeholders (summer 2022).
- Submit grant proposal to expand research on this area (fall 2022).

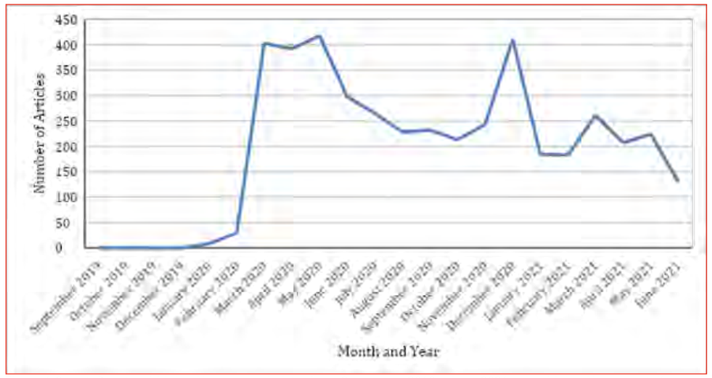


Figure 1 Search Results of Maine Newspaper Articles from September 2019 – June 2021 using Maine Newsstand. Keywords combinations used: (COVID-19 OR pandemic OR coronavirus) AND (tourism OR travel OR visitation OR recreation) AND Maine. Figure generated by McKenna Mollner, REU student.

AmeriFlux Research at the Howland Forest

Shawn Fraver (PI), John Lee, Holly Hughes
School of Forest Resources, Center for Research on Sustainable Forests
Dave Hollinger
USDA Forest Service

The AmeriFlux network is a nationwide set of research sites measuring fluxes of CO2, 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 in Howland 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.

Project Objectives

The primary objective of this project is to support ongoing research activities at the Howland Research Forest, Maine. These activities include (1) providing overall technical support for the CO2 flux, meteorological, soil flux, and ecological activities associated with the Howland Forest AmeriFlux site, (2) assisting with sensor calibration, telecommunications, flux calculations, data processing, and ecological measurements, (3) Ensure adequate communication between the University of Maine and Forest Service personnel regarding project status, (4) sharing data freely with the AmeriFlux Management Project, and various AmeriFlux data repositories, and (5) providing general upkeep and safety of the Howland Forest site, including liaising with the Howland Forest landowner.

Approach

The project objectives are met through the work of two full-time 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. Such research allows us to address additional questions complementary to the core AmeriFlux mission, thereby expanding the project's reach and scope.

Key Findings / Accomplishments

- The Howland Forest site has had continuous atmosphere-forest canopy CO2 flux data since 1996, making it the second longest running canopy flux site in North America.

Future Plans

- We have begun a new research endeavor, led by M.S. student Zoe Read, to determine the factors that influence carbon dioxide (CO^2) and methane (CH4) fluxes from coarse woody debris (fallen logs) and fine woody debris (slash) at the Howland Research Forest.
- Flux from these forest components is understudied; however, recent research suggests flux rates may be higher than previously assumed.
- Results from this work will partially fill a knowledge gap in our understanding of the forest carbon cycle.

An Integrated Approach to Quantifying the GHG Mitigation Potential of Natural Climate Solutions from Maine's Working Lands

Adam Daigneault (PI), Ivan Fernandez, Aaron Weiskittel, Erin Simons-Legaard
School of Forest Resources, Center for Research on Sustainable Forests

Maine's working landscape can play an important part in Maine's GHG mitigation strategy, but the most cost-effective and impactful practices are currently unknown. This research has three distinct components. First, we combine economic and biophysical methods to identify the mitigation potential for 16 different 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 will be developed. Second, we engage stakeholders using focus groups and surveys to gauge the degree that these NCS practices could be implemented, identifying the most valued options and critical impediments to implementation. Potential stakeholders range from large forest landowners to small and diversified family farms. Third, we develop 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). Collectively, this research will accelerate the implementation of NCS in Maine and other states with similar goals and land management systems.

Objectives

- 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.
- Develop an outreach plan for project partners to engage with policymakers and farmers.

Approach

1. 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.
2. Stakeholder Input. We will solicit feedback via focus group discussions and surveys about the initial findings developed in #1. This will help us better understand whether practices we estimate as cost-effective might work in the real world. Potential stakeholders include 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.
3. Alternative Pathways. We will couple the findings from components 1 and 2 with the development of alternative scenario pathways based on the IPCC's shared socio-economic (SSP) and relative concentration pathway (RCP) frameworks. This approach will allow us to estimate potential uncertainty in NCS mitigation potential under a range of climatic, policy, and socio-economic futures. These pathways are likely to 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).

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 could sequester an additional 0.1 to 5.3 million tons of carbon dioxide equivalent per year ($MtCO_2e/yr$). 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 $\$20/tCO_2e$ (Figure 1).
- We estimate that doing NCS practices on Maine's agricultural lands could reduce the state's GHG emissions by 0.01 to 0.57 $MtCO_2/yr$. The most cost-effective practices included constructing anaerobic digesters on dairy farms and amending crop and pastureland soils with biochar. Jointly implementing practices for the agricultural sector is estimated to cost $18.9 million/yr or $\$33/tCO_2e$. 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).
- For context, Maine's forests have sequestered an average of 12 $MtCO_2e/yr$ 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 MtCO2e/yr.
- Most climate mitigation studies estimate that carbon prices should be $40 or more. This suggests that Maine NCS practices should be cost-competitive.

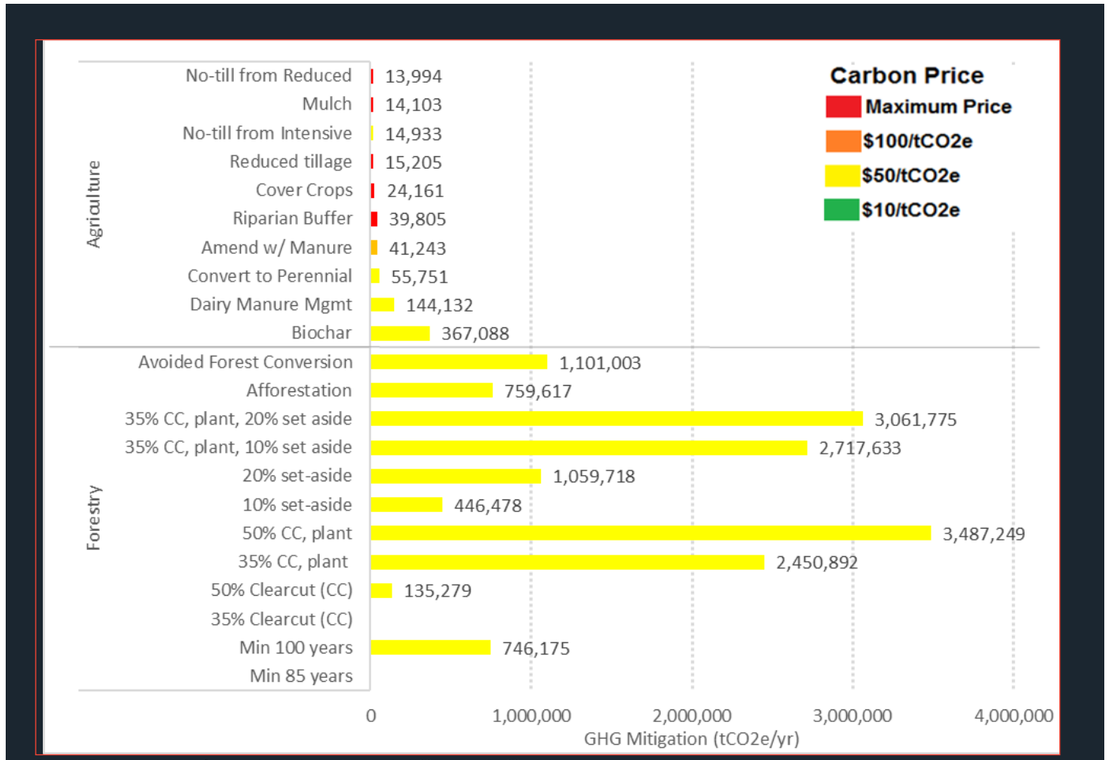


Figure 1. Total annual Maine forest and agriculture mitigation by NCS practice ($MtCO_2e/yr$)

OUTCOMES

Accomplishments

- Interim analysis and findings have been summarized and distributed via an August 2020 report.
- Findings have been presented during more than a dozen stakeholder meetings held across the state, including several webinars.
- Results have been used to support the Maine Climate Council's "Maine Won't Wait" Climate Action Plan, released in December 2020.
- Forest manager and farmer focus groups (n=9) to identify barriers and opportunities to implement NCS concluded in February 2021.
- 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).
- Furthermore, 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.

Significant Challenges

- Covid 19 has limited our ability to conduct in-person farmer and forester focus groups and engage in stakeholder outreach. We will turn to virtual focus groups in the fall, if required.

Future Plans and Opportunities

- Release final report and related factsheets in July 2021.
- Draft manuscripts on NCS analysis and landowner/farmer focus group findings

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

Adam Daigneault (PI), Aaron Weiskittel, Samuel Roy

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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

- Use publicly available data to construct a time series of quantitative socio-economic resilience indicators for all communities located within the Northern Border Region;
- 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;
- 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; and
- 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, fact sheets, and an interactive map that could be linked with the NBRC's map of the Region on the website.

Approach

Work jointly with the University of Vermont and Hubbard Brook Research Foundation to:

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; and
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, fact sheets, and an interactive map that could be linked with the NBRC's map of the Region on the website.

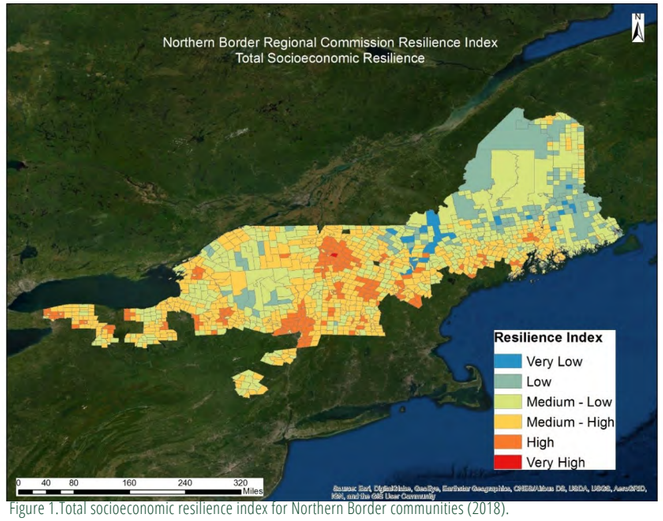


Figure 1.Total socioeconomic resilience index for Northern Border communities (2018).

Key Findings

- First, there has been noticeable progress in FY20. First, we have produced revised estimates for more than 30 resilience metrics for more than 1,000 communities across the Northern Border region, including total socioeconomic resilience (Figure 1). Total resilience is estimated to be highest in areas surrounding Burlington, VT, Hanover, NH, and Saratoga Springs, NY and lowest in Downeast Maine, Northern New Hampshire, and parts of the Adirondacks. The individual community, social, economic, and housing focused resilience indices all have varying influence on total resilience, although many of these indices are highly correlated in parts of the Northern Border region. Further analysis will identify which of the individual metrics are likely to have the strongest influence on socioeconomic resilience, thereby providing insight on what communities can focus on to maintain or improve their overall well-being.
- Second, we conducted a statewide survey to evaluate Maine resident perceptions on community resilience, natural resource industries, and socio-economic impacts of Covid-19 in Summer 2020 (Figure 2). 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.

OUTCOMES

Accomplishments

- Draft quantitative indicators findings have been presented to Northern Border Regional Commission Executive Director.
- Focus on identifying socioeconomic resilience indicators to support, grow, and diversify Maine's rural economy.
- Developed partnerships with researchers and other stakeholders that are committed to improving the cultural, economic, and civic future of Maine.
- Directly involve graduate and undergraduate student researchers to build their personal and professional development.
- Design and enumerated statewide survey in Summer '20 to assess individual perceptions and impacts of Covid-19 on Mainers (*N* = 503).

Significant Challenges

- Covid-19 has limited our ability to conduct focus groups and engage in stakeholder outreach. We have shifted in person outreach efforts to FY '22.

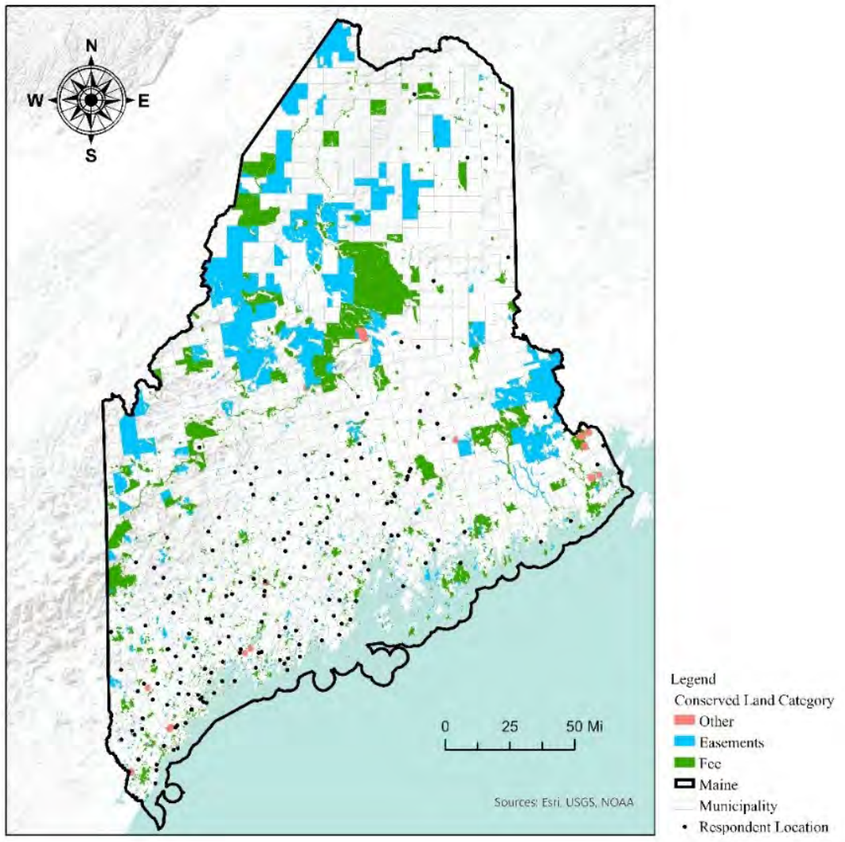


Figure 2. Distribution of Maine resilience survey respondents (*N*=503)

Future Plans and Opportunities

- Continue with activities, as laid out in the work plan/approach discussed above.
- Present interim findings to NBRC executive board in Fall 2021.
- Conduct focus groups and engage in stakeholder outreach
- Continue collaboration with UVM and HBRF 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.

FOR/Maine: Forest Economy Roadmap

Aaron Weiskittel

Center for Research on Sustainable Forests

The Forest Opportunity Roadmap/Maine (FOR/Maine) is a unique cross-sector collaboration between industry, communities, government, education, and nonprofits, which have come together to realize the next generation of Maine's forest economy. Phase II of the project is sustaining collaborative efforts for implementation of the Forest Economy Roadmap. In April 2021, FOR/Maine hosted a half-day virtual summit, Forwarding the Future of Maine's Forest Bioeconomy, to share committee deliverables with a wide audience. The video presentations focused on workforce development, woodland owner outreach and engagement, strategic investment attraction and communicating the opportunity in Maine's forests.

Activities & Accomplishments

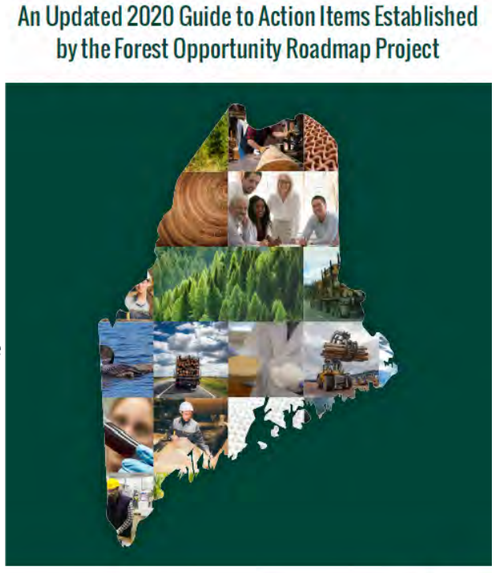
- Marketing Program for the Forest Products Industry
- Redevelopment of Idle Mill Sites
- Develop & Implement a Workforce Strategy for Maine's Forest Products Industry
- Conduct a Logistics Best Practices Modeling Pilot Project
- Extend the Forest Modeling to New England and Canada
- Forest Management Principles Outreach & Support to Southern Maine Landowners
- Support Marketing of New Forest Products Technologies Developed at UMaine
- Communications Plan for FOR/Maine Implementation Projects

Project Timeline

The FOR/Maine effort continues to gain momentum and focus. The work of committees is beginning to coalesce around strategic investment attraction, workforce development and communicating an ambitious vision for Maine's forest bioeconomy.

Challenges

The effort continues to advance along a backdrop of difficulties for many in the forest economy supply chain, particularly loggers and truckers. FOR/Maine is working to strike a chord of optimism and an orientation towards the future of Maine's forest bioeconomy without alienating those who are presently facing real challenges.



IGS Project Objectives & Outcomes

Kasey Legaard (PI), Erin Simons-Legaard, Aaron Weiskittel, Larry Whitsel

Center for Research on Sustainable Forests, UMaine Advanced Computing Group

Satellite remote sensing has the potential to satisfy many of the information needs of forest management, but its use has been slowed by persistent difficulties in predicting relevant forest attributes from readily available, low-cost satellite imagery. The Intelligent GeoSolutions (IGS) team has specifically targeted this problem with the development of multi-objective machine learning algorithms. The IGS approach combines the strength of support vector machines (SVMs) to model complex, nonlinear relationships based on limited training data with the adaptability of a multi-objective genetic algorithm (GA). The GA guides the evolution of models to simultaneously increase accuracy and decrease specific patterns of systematic error, reducing or eliminating the tendency toward over- or under-estimation in forest maps. Multi-objective machine learning methods have been integrated with customizable remote sensing workflows, executed on University of Maine cloud computing and high performance computing systems.

Objectives

- Support multi-objective landscape management through the provision of high-quality maps of timber and non-timber resources relevant to commercial forests, scalable across large areas at low cost.
- Improve access to forest maps and spatial information relevant to large-area land use planning and policy challenges.
- Advance machine learning, remote sensing, and geospatial R&D relevant to forest mapping, ecological modeling, and natural resource management.

Accomplishments

Objective 1. High-quality, low-cost data for commercial forestlands

- Completed development of key software components implementing IGS workflows for high throughput processing of satellite imagery and production of tree species distribution maps, forest type maps, and forest change detection maps.
- Transitioned IGS data processing and machine learning to UMaine cloud computing and high performance computing systems.
- Initiated trial projects in partnership with forest industry for alpha product development.

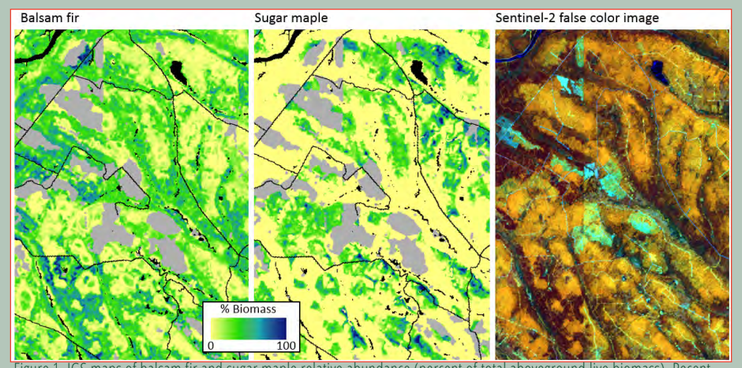


Figure 1. IGS maps of balsam fir and sugar maple relative abundance (percent of total aboveground live biomass). Recent canopy change is shown in grey, and non-forest, derived from public land cover data, is shown in black. A Sentinel-2 visible/ infrared false color image is shown for comparison.

Objective 2. Improving access to spatial data

- Released the first version of the Forest Ecosystem Status and Trends App (https://forestapp.acg.maine.edu), an interactive web mapping application designed to provide decision support to private and public forest managers, natural resource agencies, conservation organizations, and other stakeholders throughout an impending spruce budworm outbreak, using IGS layers and data collected by budworm monitoring programs.
- Established a collaboration with the Maine GeoLibrary, NOAA Coastal Change Analysis Program, and University of Maine Wheatland Geospatial Lab to fund and develop a next-generation, high-resolution land cover map of Maine, including detailed forest type information at 10 m spatial resolution.

Objective 3. Machine learning, remote sensing, and geospatial R&D

- Published the first of a sequence of IGS methods papers, describing the use of multi-objective machine learning for tree species mapping.
- Developed and implemented an automated two-stage prediction workflow for tree species occurrence and abundance using multi-objective support vector classification and regression.
- Developed new methods to quantify and visualize spatial uncertainty using the output of multi-objective machine learning algorithms.
- Developed and implemented machine learning methods to accommodate missing data in support vector regression problems.
- Implemented and evaluated alternative methods to fuse many multi-objective machine learning classification models into a single best outcome.
- Established a northeast regional data sharing agreement with the USDA Forest Service, Forest Inventory and Analysis Program, permitting use of plot location data for forest attribute mapping across seven northeastern states.

Significant Challenges

- Loss of project personnel (software developer)
- Difficulty recruiting student participants, partly due to COVID19 and campus closure
- Lost productivity due to COVID19 impacts on project personnel (specifically, closure of public schools and childcare facilities)

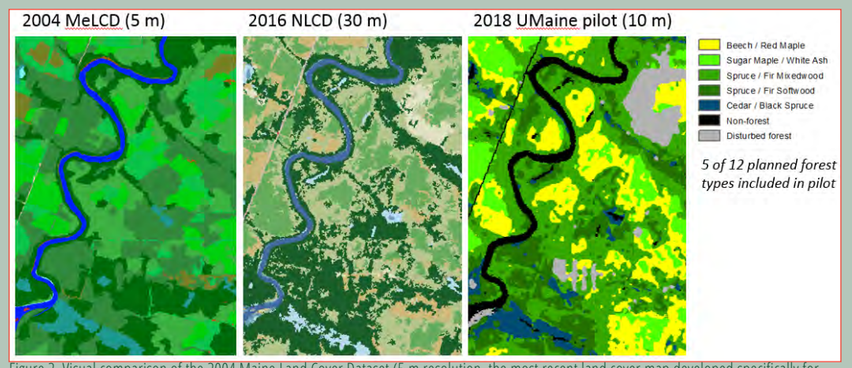


Figure 2. Visual comparison of the 2004 Maine Land Cover Dataset (5 m resolution, the most recent land cover map developed specifically for Maine), the 2016 National Land Cover Database land cover product (30 m resolution), and an IGS pilot forest cover product (10 m resolution), developed as part of a collaborative project to produce a new statewide high-resolution land cover map.

Future Plans and Opportunities

Objective 1

- Implementation of workflows to augment satellite remote sensing data with airborne laser scanning data and high resolution digital photography.
- Integration of IGS workflows with additional open-source statistical and machine learning libraries.
- Completion of trial projects with industry partners; execution of service agreements supporting large-scale data production.
- Execution and evaluation of IGS methods in multiple forest regions, including test areas in the northeast, northcentral, northwest, and southeast.

Objective 2

- Continued development of the Forest Ecosystem Status and Trends App (https://forestapp.acg.maine.edu), including the statewide expansion of data layers, incorporation of new layers and new summary analysis tools, and the implementation of a user account system including custom reporting functions.
- Initiation of statewide high-resolution land cover mapping in collaboration with the Maine GeoLibrary, NOAA Coastal Change Analysis Program, and University of Maine Wheatland Geospatial Lab.

Objective 3

- Publication of additional IGS methods papers, focused on 1) further advances in tree species mapping, 2) unbiased time series of forest disturbance maps, and 3) model/map fusion methods.
- Continued development of methods to quantify and visualize spatial uncertainty using multi-objective machine learning outcomes.
- Development of alternative approaches to the integration of airborne laser scanning and satellite remote sensing data to improve forest type mapping outcomes.
- Continued development of methods to efficiently scale machine learning and remote sensing workflows across larger areas.
- Establish a multi-regional data sharing agreement with the USDA Forest Service, Forest Inventory and Analysis Program, permitting use of plot location data for forest attribute mapping across the conterminous U.S.

IGS forest change detection sample, 30 m resolution, superimposed over high resolution digital photography.

Penobscot Experimental Forest: Sustaining Productive Forests

Laura Kenefic (PI), Aaron Weiskittel

US Forest Service Northern Research Station, Center for Research on Sustainable Forests

The U.S. Forest Service and Center for Research on Sustainable Forests continued their long-standing collaboration with another year of forestry research and demonstration at the Penobscot Experimental Forest (PEF) in Bradley and Eddington. There were a number of important staff transitions, including departure of the Forest Service research ecologist and forester and University of Maine data manager. Student, term, and temporary employees were hired to cover essential duties. Despite restrictions on work and travel during the covid-19 pandemic, essential fieldwork in the foundational studies continued. The 70th anniversary of the PEF was celebrated; remeasurements were completed in studies of even- and uneven-aged silviculture, exploitive harvesting, and forest health; a socially distanced forest tour and a number of virtual presentations and guest lectures were made; manuscripts were published or submitted for publication; and additional funds were leveraged for research and science delivery.

Key Findings / Accomplishments

- Remeasurements and timber marking were completed in a number of long-term silviculture studies on the PEF by University of Maine student and recent-graduate employees. This included the 70th year of continuous inventory and treatment application.
- The 40-year-old study of beech bark disease was remeasured and preliminary findings on the emerging concept of beech bark disease tolerance were presented in the field and virtually.

Drone view of regeneration at the PEF. Photo courtesy R. Kenefic.

- Carbon storage and sequestration outcomes from the Compartment Management Study were published and presented to a number of stakeholder groups and via virtual presentations.
- A manuscript on the 65-year outcomes of the Compartment Management Study for landowners was submitted to the U.S. Forest Service, Northern Research Station and is in press.
- Data summaries were prepared for a number of virtual presentations and a socially distanced tour.
- Proposals collaboratively written by the Forest Service PI and University faculty and staff were funded by the PEF Research Operations Team, Cooperative Forestry Research Unit, and Northeastern States Research Cooperative.
- High-resolution maps of PEF roads and permanent sample plot locations were prepared in support of a review of a right-of-way request by an adjoining landowner, and for the University Forest and U.S. Forest Service websites.
- Data management and archiving continued, with QAQC, organization, and naming of 545 historical PEF photos (1950s to 1980s).

Future Plans

- Re-purpose inactive management units on the PEF for new collaborative University of Maine – U.S. Forest Service studies of forestry and carbon storage.
- Further develop and disseminate findings from the beech bark disease tolerance study.
- Generate 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.

Lowland Northern White-Cedar Ecology and Management

Laura Kenefic (PI), Jay Wason, Shawn Fraver, Anil Raj Kizha

US Forest Service Northern Research Station, School of Forest Resources

Northern white-cedar is a common tree throughout northeastern and north-central U.S. and adjacent regions of Canada; it is the fifth most abundant species in Maine in terms of growing stock volume. Yet there is much we still don't know about this ecologically and economically important tree. 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. This work contributes to the research portfolio of the Cedar Club: an informal group of researchers in the U.S. and Canada working with practitioners to answer questions relevant to forest management. Work in FY21 included pre- and post-harvest inventories in stands harvested on commercial forestlands in Danforth and Dyer Township, Maine, planting and competition studies, and the use of sensor technology to monitor environmental conditions such as temperature, moisture, and depth to water table in managed and unmanaged stands.

Key Findings / Accomplishments

- Pre-harvest measurements and timber marking were completed in lowland cedar stands in Dyer Township; one of two stands was cut. Many trees had signs of logging damage from previous harvests and were decayed.
- Water level sensors and i-buttons were deployed in control and harvested stands at Penobscot Experimental Forest, Danforth, and Dyer Township.
- A manipulative study of cedar seedlings and branches was initiated at Penobscot Experimental Forest to determine the potential of pinned and cut branches to layer in different substrates.
- Cedar and balsam fir seedlings were planted in pits, mounds, and flats in gaps and under the canopy to assess survival and growth in different microclimatic conditions.
- Two virtual Cedar Club meetings were hosted; one for researchers and one for practitioners.
- Research outcomes were presented at regional, national, and international conferences and two Cedar Club meetings were held for information exchange among scientists and with practitioners

Future Plans

- Continue remeasurements of harvested and control stands to determine effects of management on ecological characteristics of cedar stands and potential of silviculture for sustainable use.
- Complete revision of the Silviculture Guide for Northern White-Cedar in collaboration with the U.S. Forest Service and Canadian Forest Service.

Cedar and balsam plantings at the PEF. Photo courtesy Carolyn Ziegra.

Projecting Carbon Storage and Accumulation of the Maine Ecological Reserves

Joshua Puhlick (PI), Aaron Weiskittel

Center for Research on Sustainable Forests

FINAL REPORT

Estimates of carbon (C) storage and accumulation in ecological reserves are needed to inform planning and policy decisions related to mitigating global climate change and C management. Therefore, we used 682 plots with repeated measurements of forest attributes from 37 reserves across Maine to determine aboveground C stocks and accumulation, and to project future C accumulation. We also used 10,503 USDA Forest Service Forest Inventory and Analysis (FIA) subplots across managed forests in Maine to compare observed C stocks and accumulation between managed forests (FIA) and reserves (Maine Ecological Reserve system). Our findings indicate that forest C objectives can be achieved with forests managed using silvicultural treatments to maintain or enhance C accumulation and with reserves where timber is not harvested. The benefits of C storage in Maine's Ecological Reserve system lends support for the expansion of reserves in Maine and the establishment and monitoring of reserves in other states.

Objectives

- Determine past and current aboveground forest C stocks (live trees and dead wood; Mg ha^{-1}) and average annual net change in C (AAC; Mg ha^{-1} yr^{-1}) using measurements of forest attributes on permanent plots of the Maine Ecological Reserve system.
- Model aboveground forest C stocks 20 years into the future using inventory data from the Maine Ecological Reserve system and a regional growth and yield model.
- Compare current C stocks and observed AAC between managed forests (using FIA data) and reserves by forest type groupings.

Approach

Measurements of standing trees (live and dead) and downed woody debris on permanent plots of the Maine Ecological Reserve system and subplots of the FIA program were used to determine past and current C stocks. For the reserve plots, model projections of tree growth and mortality were used to calculate live tree C stocks over time.

Key Findings

- For the reserves, current aboveground C in live trees, standing dead trees, and downed coarse woody debris was 89.4 ± 37.7 (mean ± SD) Mg ha^{-1}. Observed AAC in live trees, standing dead trees, and downed coarse woody debris was 0.894 ± 1.949 Mg ha^{-1} yr^{-1}.
- For reserve plots with repeated measurements of forest attributes and location information, soil C represented 67 ± 13% of the total forest C stock.
- Our models of C stocks indicated that the difference in C stocks between managed forests and reserves depended on forest type group.
- In 2040, aboveground C in live trees across reserves was projected to be 108.9 ± 34.6 Mg ha-1. For these same plots, projected AAC in the aboveground portions of live trees was 1.096 ± 0.539 Mg ha^{-1} yr^{-1}.

Assessing and Monitoring the Influence of Forest Management Practices on Soil Productivity, Carbon Storage, and Conservation in the Acadian Forest Region

Joshua Puhlick (PI), Marie-Cécile Gruselle, Ivan Fernandez

Center for Research on Sustainable Forests

This project involves using empirical soils data from across the Acadian Forest Region to inform best management practices related to soil productivity, carbon storage, and conservation. As part of the project, researchers are evaluating soil nutrient status, soil carbon storage, and soil compaction on Maine Adaptive Silviculture Network (MASN) installations. During this reporting period, Puhlick, Fernandez, and Wason published an article about the discovery of European earthworms at two MASN installations in northern Maine. This discovery has implications for northern Maine forests because non-native earthworms can cause abrupt changes in forest ecosystems by altering soil properties and depleting or redistributing soil carbon stocks. Monitoring changes in soil carbon will be important for evaluating loss or accumulation of soil carbon in areas with and without non-native earthworms. Other accomplishments include developing a collaborative effort with the USDA Natural Resources Conservation Service for sampling soils at a MASN installation in Mayfield, Maine.

Objectives

A major goal of this project is to evaluate the influence of different forest management practices on soil productivity, carbon storage, and conservation across operational-scale research installations in Maine. Specific objectives included identifying forest management practices and soil properties that: (1) promote adequate nutrient availability that supports forest sustainability, (2) maintain or enhance soil carbon stocks, and (3) minimize compaction and erosion.

Approach

- In 2020 (before timber harvesting), soil sampling was completed at the Nashville Plantation installation on timberlands managed by Seven Islands Land Company.
- At Nashville Plantation, soil samples were collected from 18 quantitative soil pits and soil organic (O) horizon attributes were measured at 54 locations.

- Data from Nashville Plantation and two other installations (Seven Islands and Sauls Brook) were used to examine soil attributes in areas with and without earthworms.

Key Findings

- At Seven Islands, earthworms were only found across a portion of the installation, and the median O horizon carbon stock in the area with earthworms was 34% less than that of areas without earthworms.
- At Nashville Plantation, earthworms were found across the entire installation and the median O horizon carbon stock was 39% less than that of a similar forest without earthworms.
- No earthworms were detected at Sauls Brook.
- Areas with earthworms had no or minimal eluvial (E) horizons, while earthworm-free locations always had E horizons.
- Earthworm presence was always associated with a topsoil (A) horizon, reflecting mechanical mixing and organic matter processing by earthworms.
- Accomplishments (re: UMaine SVV and beyond, broader impacts, intellectual merit)
- Puhlick and Fernandez developed a collaborative effort with Nicholas Butler (USDA NRCS) to continue soil sampling efforts on the MASN. In 2021, Butler's team sampled soils and Puhlick's team inventoried live trees at the Mayfield installation.
- Final publication of an article on soil compaction (Puhlick and Fernandez, 2020).

Future Plans and Opportunities

- Next year, researchers plan to publish an article on changes in soil nutrients and carbon one year after timber harvesting on a subset of the MASN installations.

Below: Earthworms have consumed most of the organic horizon in this area of the forest at Nashville Plantation. *Left:* Earthworms were discovered at Nashville Plantation in 2020. *Photos couresy Joshua Puhlick.*

Projecting Carbon Sequestration on the Maine Adaptive Silviculture Network

Aaron Weiskittel (PI), Joshua Puhlick
Center for Research on Sustainable Forests

FINAL REPORT

Comparing forest and harvested wood product carbon (C) stocks and accumulation among forest management treatments commonly applied in managed forests is needed to inform planning and policy decisions for C objectives. Therefore, we quantified pre- and post-harvest C stocks and projected C accumulation over a 31-year period (to ~2050) among forest management treatments that were applied on a subset (*n* = 3) of the Maine Adaptive Silviculture Network installations in northern Maine, USA. Models of C accumulation indicated that low harvest severities (based on biomass removals) and greater representation of tree species with low tolerance of shade were associated with greater C accumulation. To accomplish C objectives, our results emphasize the importance considering forest reserves and using targeted yet operationally feasible silvicultural treatments that promote forest resilience relative to climate change.

Objectives

- Determine pre- and post-harvest C stocks for the aboveground portions of live trees, dead wood, and harvested wood products using repeat measurements of forest attributes on permanent plots.
- Estimate aboveground forest and product C stocks over a 31-year period starting with post-harvest stand conditions in 2018 and 2020, and assess the cumulative sum of net changes in C.
- Evaluate the influence of pre- and post-harvest stand attributes and harvest severity indices on the predicted average annual net change in C for the aboveground portions of live trees, dead wood, and harvested wood products.

Approach

- Post-harvest measurements of forest attributes on permanent plots of the MASN were used to determine current C stocks and to model future forest C stocks.
- Projections of tree growth and mortality were used to calculate live tree C stocks and estimate dead wood recruitment over time.
- Post-harvest inventories of dead wood were also used to estimate the residence times of dead wood that was present at the start of the simulation period, and C stored in wood products was estimated from trees cut on permanent plots and residence time equations.

Key Findings

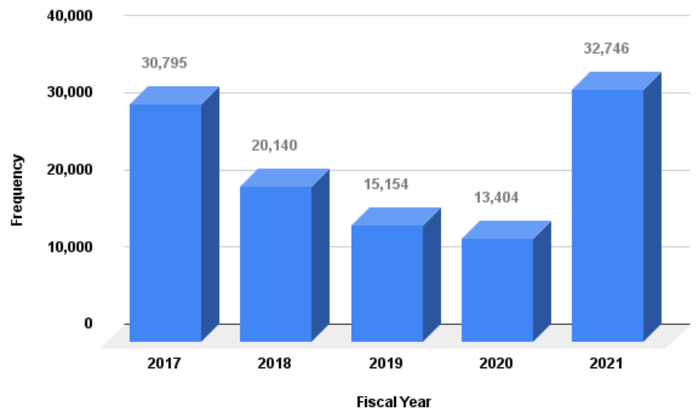
- Our projections of C accumulation in the aboveground portions of live trees, dead wood, and harvested wood products over a 31-year period (to ~2050) indicated that unharvested controls and a management unit with improvement cutting were net C sinks.
- Models of C accumulation indicated that low harvest severities and greater representation of tree species with low tolerance of shade were associated with greater C accumulation.
- The controls were relatively resilient to simulated increases in tree mortality due to the presence of disturbance agents and natural senescence. This resiliency was partially due to the high diversity of tree species at each of the study sites.

Improvement cut at Nashville Plantation, Maine. The seed sources of tree species such as yellow birch, sugar maple, and red spruce were retained. Additionally, large eastern hemlocks were retained to meet biodiversity and carbon storage objectives. Other objectives included maintaining a multi-aged structure and plan to regenerate yellow birch in gaps during future harvests. Photo coutesy Joshua Puhlick.

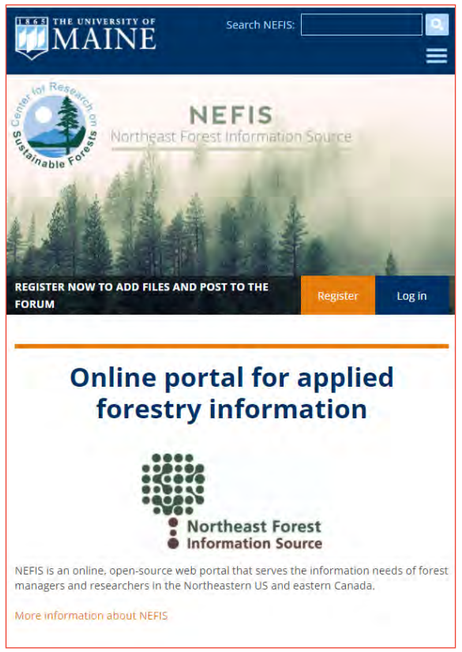
Low elevation spruce-fir forest at Deboullie Ecological Reserve. Photo courtesy Joshua Puhlick.

CRSF **WEBSITES & SOCIAL MEDIA**

The CRSF staff strive to make forest science research conducted at UMaine readily accessible to researchers, scientists, stakeholders, policy makers, and the public in clear and understandable ways. We embrace social media as part of that strategy, and are pleased that the reach of those platforms and access to our websites expanded significantly throughout FY21.



CRSF websites (CRSF, CFRU, SBW, NEFIS) usage over past 5 years. Increase in FY21 reflects success of disemmination efforts to stakeholders.



Website/Social Media Links
CRSF Website
CRSF Umaine Facebook
CRSF Twitter: @MaineForests
NEFIS research portal
Spruce Budworm website
Spruce Budworm Facebook
CFRU website

CRSF RESEARCH **PRODUCTS & OUTPUTS**

*denotes graduate student; +denotes undergraduate student

Refereed Journal Publications (16)

Buyaskas, Michael, *Bryn E. Evans and Alessio Mortelliti. 2020. Assessing the effectiveness of attractants to increase camera trap detection of North American Mammals. Mammalian Biology 100: 91-100. doi: 10.1007/s42991-020-00011-3

Hollinger, D.Y., E. A. Davidson, S. Fraver, H. Hughes, J. T. Lee, A. D. Richardson, K. Savage, D. Sihi, and A. Teets. In Press. Multi-decadal carbon cycle measurements indicate resistance to external drivers of change at the Howland Forest AmeriFlux site. Journal of Geophysical Research – Biogeosciences.

Horne, L.*, De Urioste-Stone, S.M., Daigle, J. & Noblet, C. In Press. Climate change resilience in the face of uncertainty: A phenomenological study. The Northeastern Naturalist.

Horne, L.*, De Urioste-Stone, S.M., Seekamp, E., Rickard., L., Rahimzadeh-Bajgiran, P. & McGreavy, B. 2021. Determinants of visitor climate change risk perceptions in Acadia National Park, Maine, USA. Journal of Outdoor Recreation and Tourism, 35. doi: https://doi.org/10.1016/j.jort.2021.100401

Ignatiadis, M., Daigneault, A., Sponarski, C., & Reed, J. 2020. Operationalizing sense of place to evaluate potential conflicts in natural resource-dependent rural economies. Journal of Environmental Policy & Planning, 23:4, 446-466. https://doi.org/10.1080/1523908X.2020.1858769

Kern, C.C.; Kenefic, L.S.; Kuehne, C.; Weiskittel, A.R.; Kaschmitter, S.J.; D'Amato, A.W.; Dey, D.C.; Kabrick, J.M.; Palik, B.J.; Schuler, T.M. 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.

Kuehne, C., Russell, M.B., Weiskittel, A.R., Kershaw, J.A. 2020. Comparing strategies for representing individual-tree secondary growth in mixed-species stands in the Acadian forest region. Forest Ecology and Management 459, 117823.

Legaard, K., E. Simons-Legaard, and A. Weiskittel. 2020. Multi-objective support vector regression reduces systematic error in moderate resolution maps of tree species abundance. Remote Sens 12: 1739. doi 10.3390/rs12111739

Louis, L.T.* and Kizha, A.R. 2021. Wood biomass recovery cost under different harvesting methods and market conditions. International Journal of Forest Engineering, 32(2): 164-173. doi.org/10.1080/14942119.2021.1874206

Puhlick J.J., Fernandez I.J., Wason J.W. 2021. Non-Native Earthworms Invade Forest Soils in Northern Maine, USA. Forests 12(1):80. https://doi.org/10.3390/f12010080

Puhlick, J. J. and I. J. Fernandez. 2020. Influence of mechanized timber harvesting on soil compaction in northern hardwood forests. Soil Sci. Soc. Am. J. 84(5): 1737-1750. doi: 10.1002/saj2.20127.

Puhlick, J.J.; A.R. Weiskittel, L.S. Kenefic, C.W. Woodall, I.J. Fernandez. 2020. Strategies for enhancing long-term carbon sequestration in mixed-species, naturally regenerated northern temperate forests. Carbon Management.

Simons-Legaard, E., K. Legaard & A. Weiskittel. 2021. Projecting complex interactions between forest harvest and succession in the northern Acadian Forest Region. Ecological Modeling (In press).

Soucy, A.* & De Urioste-Stone, S.M. (2020). Tourist behaviour and tick-borne disease risk. WIT Transactions of Ecology and the Environment, 248, 77-88. doi: 10.2495/ST200071

Soucy, A.*, De Urioste-Stone, S.M., Rahimzadeh-Bajgiran, P., Weiskittel, A., & McGreavy, B. 2020. Understanding characteristics of forest land managers and small woodlot owners for communicating climate change adaptation. Trees, Forests, and People. doi: https://doi.org/10.1016/j.tfp.2020.100036

Soucy, A.*, De Urioste-Stone, S.M., Rahimzadeh-Bajgiran, P., Weiskittel, A., & McGreavy, B. 2020. Forestry professionals' perceptions of climate change impacts on the forest industry in Maine, U.S. Journal of Sustainable Forestry. doi: https://doi.org/10.1080/10549811.2020.1803919

Refereed Journal Articles Under Review (6)

Horne, L.*, De Urioste-Stone, S.M., McGreavy, B., Seekamp, E., Rickard., L. & Rahimzadeh-Bajgiran, P. (2nd Review). Understanding community resilience to climate change in the Bay of Machias, a rural nature-based tourism destination in Maine. Target Journal: Journal of Sustainable Tourism.

Horne, L.*, Wolf-Gonzalez, G.*, DiMatteo-LePape, A.*, Briones, V.*, Soucy, A.*, & De Urioste-Stone, S. M. (1st Review). Climate change planning in a coastal tourism destination, a participatory approach. Target Journal: Journal of Environmental Planning and Management.

Puhlick et al. Evaluation of projected carbon accumulation after implementing different forest management treatments in mixed-species stands in northern Maine: The Maine Adaptive Silviculture Network. In review.

Sherman, G., & Daigneault, A. Evaluation of Maine Resident Perceptions on Community Resilience, Natural Resource Industries, and Covid-19 Socio-Economic Impacts. Under Review at Society and Natural Resources (submitted June 2021).
Soucy, A.*, De Urioste-Stone, S.M., Rahimzadeh-Bajgiran, P., & Weiskittel, A. (In Review 1st). Drivers of climate change risk perceptions among forest stakeholders in Maine, USA. Society and Natural Resources.
Soucy, A.*, De Urioste-Stone, S.M., Rahimzadeh-Bajgiran, P., Weiskittel, A., Duveneck, M., & McGreavy, B. (In Review 1st). A comprehensive and spatially explicit regional vulnerability assessment of the forest industry to climate change. Journal of Forestry.

Research Reports (8)

Burke, N.,+ Conant, M.,+ MacDonald, B.,* & De Urioste-Stone, S.M. 2020. NPS 2019 research summary report—Visitor perceptions of ticks and tick-borne illnesses in Acadia National Park. Final report submitted to National Park Service, Orono, Maine. 21pp.
Daigneault et al. 2020. Maine Forestry and Agriculture Climate Change Mitigation Potential. CRSF Interim Report, August 2020.
De Urioste-Stone, S.M., Horne, L.*, & Rahimzadeh-Bajgiran, P. 2020. Fostering coastal community resilience in Maine: Understanding climate change risk and behavior. Technical report submitted to NOAA. Orono, Maine. 19pp.
De Urioste-Stone, S.M., Soucy, A.*, Rahimzadeh-Bajgiran, P., Daigneault, A., & Weiskittel, A. 2020. Forest climate change resilience: A socio-ecological forest systems approach. Technical report submitted to USDA-AFRI Climate Change Program. Orono, Maine. 5pp.
Granstrom, M.; Kenefic, L.S; Crandall, M.; Stockwell, S.; Giffen, A. In press. Managing your woodland: Forestry research translated for landowners. General Technical Report. U.S. Forest Service, Northern Research Station.
Hollinger, D. Y., E.A. Davidson, S. Fraver, H. Hughes, J.T. Lee, A.D. Richardson, K. Savage, D. Sihi, A. Teets. 2021. Howland Forest 25-year data - Multi-decadal carbon cycle measurements indicate resistance to external drivers of change at the Howland Forest AmeriFlux site. Fort Collins, CO: Forest Service Research Data Archive.
Kenefic, L.; Houston, D.; Muñoz Delgado, B.; McNulty, S.; Livingston, W. 2021. Long-term outcomes of beech bark disease: 40-year results. In: Fergusson, M.; Weiskittel, A., eds. Cooperative Forestry Research Unit: 2020 Annual Report. Center for Research on Sustainable Forestry, University of Maine. Orono, ME: 31-35. https://umaine.edu/cfru/annual-reports/
Puhlick, J.J., and Weiskittel, A.R. 2021. Carbon stocks and sequestration on ecological reserves in Maine. General Technical Report. Available on the Maine Natural Areas Program website.

Theses (5)

Allogio, J.* 2020. Microsite requirements for successful regeneration in lowland northern white-cedar (Thuja occidentalis L.) forests. Orono, ME: University of Maine, School of Forest Resources. Electronic Theses and Dissertations. 3293.
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).
Horne, L.* 2020. Fostering coastal destination resilience in Maine: Understanding climate change risks and behaviors. Dissertation to obtain PhD in Ecology and Environmental Sciences, University of Maine.
Soucy, A.* 2020. Fostering climate change resilience: A socio-ecological forest systems approach. MSc thesis in Forest Resources, School of Forest Resources, University of Maine.

Conference Papers (2)

Fagan, K.E.,* D.J. Harrison, E.M. Simons-Legaard, and T.F. Woollard.* 2020. Challenging the assumed superiority of camera- versus capture-based surveys for assessing occupancy: A case study with a cryptic forest mustelid. Presentation. The Wildlife Society Annual Meeting, September 28-October 2, Virtual.
Woollard, T. F.,* D.J. Harrison, E. M. Simons-Legaard, and K.E. Fagan.* 2020. A longitudinal study of shifting habitat selection by American martens in response to 30 years of extensive forest harvesting. Presentation. The Wildlife Society Annual Meeting, September 28-October 2, Virtual.

Presentations / Workshops / Meetings / Field Tours (39)

Carroll, J.,* & Daigneault, A., "Natural climate solutions pathways to achieving net zero emissions in Maine" Presented at AGU Fall Meeting, December 7, 2020.
CRSF's Forest Climate Change Initiative hosted a series of 10 webinars from October 2020 to June 2021 on forest climate change.

Daigneault, A. & Simons-Legaard, E. "Benefits and Costs of Natural Climate Solutions for Maine's Working Forests" Presented at UNB Atlantic Forest Research Collaborative Professional Development e-lectures. June 10, 2021.
Daigneault, A. & Simons-Legaard, E. "Putting a price tag on Maine's Natural Climate Solutions Part 2: Forestry" Webinar hosted by USDA Northeast Climate Hub. March 4, 2021.
Daigneault, A. & Weiskittel., A. "Natural Climate Solutions for Maine's Managed Forests" Webinar hosted by Maine Forest Products Council, September 17, 2020.
Daigneault, A. "Maine Climate Council Update & Natural Climate Solutions for Maine's Managed Forests." Presented at MESAF 2020 Annual Fall Meeting, October 13, 2020.
Daigneault, A. "Natural Climate Solutions for Maine's Managed Forests" Webinar hosted by Maine Audubon Society, August 25, 2020.
Daigneault, A. "Natural Climate Solutions for Maine's Managed Lands" Presented at Land for Maine's Future Climate, Carbon & Resilience workshop, November 17, 2020.
Daigneault, A. "Natural Climate Solutions for Maine's Managed Lands" Webinar hosted by Forest Carbon Discussion Group, October 21, 2020.
Daigneault, A. "Natural Climate Solutions for Maine's Working Forests" Presented at FOR/Maine Summit 2021, April 9, 2021.
Daigneault, A., & Birthisel, S. "Putting a price on Maine's Natural Climate Solutions Part 1: Agriculture" Webinar hosted by Maine Climate Table. March 3, 2021.
Daigneault, A., Simons-Legaard, E., & Weiskittel, A. "Natural Climate Solutions for Maine's Managed Forests" Webinar hosted by Manomet and Climate Smart Lands Network, July 15, 2020.
De Urioste-Stone, S.M. & Horne, L.* (2020). Community resilience theory and measures, for EES 590 Resilience Theory and Practice. September.
Douglas, L. and A. Roth. 2020. "Rusty Blackbird use of commercial spruce-fir forests of northern New England." Oral presentation for 27Th Annual Conference of The Wildlife Society, 2020. This presentation was also posted on International Rusty Blackbird Working Group's (IRBWG) website. http://rustyblackbird.org/2020-symposium-presentations-at-the-wildlife-societys-annual-conference/
Fernandez, I., Nelson, S., Simons-Legaard, E., Soucy, A.*, De Urioste-Stone, S.M., Daigneault, A., Kanoti, K. (2021). Converging policy and practice. Forest Climate Change Initiative Science and Practice: Addressing Forest Climate Change in Maine Webinar Series. May 5, University of Maine, Orono, Maine. (Virtual)
Kenefic, L. S. and J. J. Puhlick. 2020. Carbon outcomes of silvicultural alternatives at the Penobscot Experimental Forest. Maine Climate Table, Forest Carbon Discussion Group (co-presentation, oral presentation), Online Webinar. September 23, 2020. Recording available online: https://crsf.umaine.edu/resources-2/
Louis, L..T.,* and Kizha, A.R. 2020. Exclusive Product Allocation: Costing Small-diameter Trees in Maine. October 2. Umaine Student Symposium (virtual).
Louis, L..T.,* Kizha, A.R, and Daigneault, A. 2020. Predicting Uncertainties in Timber Harvesting Cost and Productivity. October 30. SAF National Convention (virtual).
Reed, J., Daigneault, A., & Bell, K. 2021. The Economic Resilience of Natural Resource Dependent Communities in the United States. Poster presented at Maine Sustainability and Water Conference. Augusta, ME., March 31-April 1, 2021.
Soucy, A.*, De Urioste-Stone, S.M., Rahimzadeh-Bajgiran, Weiskittel, A., & McGreavy, B. (2020). Perceptions of climate change adaptation among forest land managers and small woodlot owners. SAF National Convention. October 25-29. Virtual. (Presentation; Student Presentation Award—3rd Place)
Soucy, A.*, Rahimzadeh-Bajgiran, R., & De Urioste-Stone, S.M. (2021). Forest vulnerability assessment. Forest Climate Change Initiative Science and Practice: Addressing Forest Climate Change in Maine Webinar Series. February 3, University of Maine, Orono, Maine. (Virtual)
Soucy, A.,* & De Urioste-Stone, S.M. (2020). Tourist behaviour and tick-borne disease risk at Acadia National Park, Maine. 9th Sustainable Tourism Conference. July 8-10, Virtual.
The Maine Bureau of Public Lands and Maine Forest Service, including Directors Andy Cutko and Patty Cormier, toured the cedar research on the PEF and visited studies of beech bark disease tolerance and irregular shelterwood in August of 2020.
Virtual presentations of findings from PEF research were given regionally (Forest Carbon Discussion Group and Forest Carbon for Large Landowners, Steering Committee), nationally (Society of American Foresters National Convention), and internationally (Nova Scotia Provincial Government, Forestry Roundtable; Northern Hardwood Conference). A virtual tour and presentation were prepared for the Forest Service's National Advanced Silviculture Program, and three guest lectures about outcomes from PEF research were delivered in the University of Maine SFR 408/509 Silviculture class.
Virtual presentations of findings from the cedar research were given nationally (Society of American Foresters National Convention) and internationally (Society for Ecological Restoration, Cedar Club Meeting and Workshop).

Awards (2)

De Urioste-Stone, S.M. 2020. "G. Peirce and Florence Pitts Webber Outstanding Forestry Research Award", University of Maine.

Soucy, A.*, De Urioste-Stone, S.M., Rahimzadeh-Bajgiran, Weiskittel, A., & McGreavy, B. 2020. Perceptions of climate change adaptation among forest land managers and small woodlot owners. SAF National Convention. October 25-29. Virtual. (Presentation; Student Presentation Award—3rd Place)

Newspapers / Periodicals / Television / Web Pages / Patents (7)

Daniel Harrison served as a guest speaker on two YourForest podcasts, which were distributed for audio listening in the U.S. and Canada.

Forests for Wildlife with Daniel Harrison, December 9, 2020, https://yourforestpodcast.com/episode-1/2020/12/8/96-forests-for-wildlife-with-daniel-harrison

Valuing Forests with Milo Mihajlovich, Robert Wagner, and Daniel Harrison, November 18, 2020, https://yourforestpodcast.com/episode-1/2020/11/17/95-valueing-forests-with-milo-mihajlovich-robert-wagner-and-daniel-harrison

"UMaine, NASA will map carbon in forests, helping monitor their health, climate progress" – Mainebiz, November 2020

Senator George J. Mitchell Center for Sustainability Solutions. We're all in this together: Students lead climate-planning project, by Elizabeth Solet, December, 2020.

The earthworm discovery was showcased in Bangor Daily News, and ABC 7 and Fox 22 of Bangor.

U.S. Forest Service, Research and Development, Penobscot Experimental Forest, 70th Anniversary: https://www.facebook.com/fsresearch/photos/the-penobscot-experimental-forest-pef-in-east-central-maine-is-quietly-celebrati/2695226004028411/

UMaine News. Guidance for discussing climate change risks in Acadia National Park provided in UMaine-led study, by Marcus Wolf, July 7, 2021.

UMaine News. Rural Health and Wellbeing Grand Challenge Grant awards announced, April 20, 2021.

Project Webpages/Websites Maintained by CRSF (10)

- Center for Research on Sustainable Forests: https://crsf.umaine.edu
- Center for Advanced Forestry Systems: https://crsf.umaine.edu/forest-research/cafs/
- Cooperative Forestry Research Unit: https://umaine.edu/cfru/
- ForEST App: https://forestapp.acg.maine.edu/
- Forest Climate Change Initiative: https://crsf.umaine.edu/forest-climate-change-initiative/
- INSPIRES: https://www.newenglandsustainabilityconsortium.org/inspires-smart-data-resilient-forests
- Intelligent GeoSolutions: https://crsf.umaine.edu/forest-research/igs/
- Natural Climate Solutions: https://crsf.umaine.edu/forest-climate-change-initiative/ncs/
- Northeastern Forest Information Source: https://nefismembers.org/
- Spruce Budworm Task Force: https://www.sprucebudwormmaine.org/

Videos (45)

- CRSF YouTube channel (29 videos, including the FCCI webinars)
- CFRU YouTube channel (5 videos)
- Carbon Outcomes of Silvicultural Alternatives at the Penobscot Experimental Forest, L.S. Kenefic and J. Puhlick
- Managing Northern White-Cedar in Mixedwood Stands
- Northern White-Cedar Research Update
- Northern White-Cedar Silviculture in Mixed Irregular Stands
- The Cedar Club: Its Origin, Achievements, and Future
- Understanding Layering in Northern White Cedar
- Penobscot Experimental Forest 70th Anniversary (6-part series on Vimeo)
  Video 1: The Beginning; Video 2: In Common; Video 3: First Research; Video 4: Lost & Found; Video 5: Lasting Impact; Video 6: A Different Way

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