



2019 Annual Report

Meg Fergusson, Editor
Aaron Weiskittel, Director

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 initiatives including the Cooperative Forestry Research Unit (CFRU), Northeastern States Research Cooperative (NSRC), and National Science Foundation Center for Advanced Forestry Systems (CAFS). Under the leadership of Dr. Robert Wagner (2010-2016), CRSF focused on four major research programs: Commercial Forests, Family Forests, Conservation Lands, and Nature-Based Tourism. However, forestry is rapidly evolving, due in great part to changing market conditions and the unprecedented availability of data provided by technologies such as LiDAR, high-resolution imagery, and GPS. The CRSF is currently developing, integrating, and applying 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.

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Cover photo of Mt. Katahdin by Janette Landis. Used with Permission

CRSF Highlights

Led collaboration of transdisciplinary researchers to form the **Forest Climate Change Initiative (FCCI)**. The CRSF director and staff worked with FCCI-affiliated scientists to define the Initiative's purpose, and to develop a public-oriented website and outreach materials. FCCI is an effort to better link cross-campus expertise on issues related to climate change in the Northern Forest region. The website (<https://crsf.umaine.edu/forest-climate-change-initiative/>) and electronic mailing list are updated with resources and events related to the changing forest climate. The group consists of core and participating faculty across a broad range of disciplines. A special session by FCCI was conducted at this year's Maine Water & Sustainability Conference in Augusta, which included scientific technical presentations on climate change effects in the region and a stakeholder panel. FCCI faculty have begun to prepare data for a detailed statewide carbon budget.

Intelligent GeoSolutions (IGS) is an effort to leverage developed artificial intelligence algorithms to produce innovative large-scale geoproducts to support both novel research and effective land management. IGS has worked closely with the Advanced Computing Group to develop a robust software platform that automates the process of producing and refining these geoproducts on a cloud-based computational environment. The Forest Ecosystem Status and Trend (ForEST) application is expected to be launched in early 2020 and will guide the future of land management in this region.

CRSF Director Weiskittel led an **EPSCoR Track II proposal** with cross-system and cross-jurisdiction (UNH, UVM) faculty.

Continue to provide administrative and technical support the **FOR/Maine** effort that is working to strategically enhance the forest industry in Maine. A \$1M Phase II proposal for FOR/Maine was successfully submitted to the Economic Development Administration with CRSF Director Aaron Weiskittel as Co-PI.

Continued to lead efforts to revitalize and find funding and new partnerships for the **Northeastern States Research Cooperative (NSRC)**, which is a consortium between the US Forest Service and universities in four Northern Forest states.

CRSF Director Weiskittel along with FCCI faculty (Sandra De Urioste-Stone and Adam Daigneault) visited Washington, DC, to brief USDA NIFA Program Managers, US Forest Service R&D Leadership, and Maine's Federal delegation on

their research project, "Benchmarking Maine's Forest Product Sector and Assessing Future Markets for Rural Community Sustainability," that was completed in the fall of 2018.

Cooperative Forestry Research Unit (CFRU) hosted webinars on spruce budworm, mixedwood productivity following biomass harvesting & prescribed burning, and the value of long-term forest research in Maine. Webinars available on CRSF YouTube channel (Center for Research on Sustainable Forests, UMaine).

CFRU Program Leader Brian Roth and CRSF Director Weiskittel traveled region-wide to meet with current CFRU industry stakeholders and potential new CFRU members.

I/UCRC **Center for Advanced Forestry Systems (CAFS)** lead site Director Weiskittel led two industry advisory board meetings during the year. 40 members from industry and CAFS university sites attended the June IAB meeting and field trip in Athens, GA, to discuss current and future regional and national research projects and potential for Phase III funding from NSF.

Expanded efforts to **communicate and brand the CRSF** led to the development and expansion of the Center's logos and websites, creation of YouTube channel, and increased outreach efforts by serving as host to a number of meetings and conferences, including a regional Forest Guild Climate Change Meeting and information gathering session, Spruce Budworm Communications Task Force meetings, and CFRU quarterly cooperator meetings.



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View from Schoodic Peninsula. Photo courtesy Meg Fergusson.

Director's Report

The Center for Research on Sustainable Forests (CRSF) and Cooperative Forestry Research Unit (CFRU) continued to move forward on multiple fronts with a particularly productive and rewarding FY18-19. This included leadership on several key new initiatives such as the Forest Climate Change Initiative (FCCI), Intelligent GeoSolutions (IGS), and a funded National Science Foundation (NSF) Track 2 EPSCoR grant (INSPIRES). This is in addition to ongoing leadership and support for important CRSF programs such as NSF's Center for Advanced Forestry Systems (CAFS), the Northeastern Research Cooperative (NSRC), and FOR/Maine. In short, CRSF is on a bold upward trajectory that highlights its relevance and solid leadership with a rather bright future.

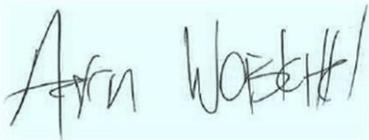
These new initiatives and continued activity on existing ones is important as the organization evolves with changes in resources and personnel. The new initiatives build new capacity and potential for CRSF, particularly INSPIRES, which is a 4-year, \$6M joint endeavor with the Universities of New Hampshire and Vermont focused on applying Big Data to a variety of ecological and economic issues facing the Northern Forest Region. IGS has the potential to revolutionize how forests in this region are mapped, monitored, and projected with the delivery of high-resolution, high-accuracy spatial products for forest managers. FCCI aligns very well with the State's recently formed Maine Climate Council (MCC), especially the Science and Technical Committee that includes myself and many other affiliated scientists. Supporting these initiatives while maintaining focus on the existing ones will be vital for the years to come.

In terms of ongoing programs, each remains highly unique yet interconnected within the Center. Support for the CFRU remains strong and the number of ongoing research projects is at an all-time high, covering a diversity of topics varying from habitat monitoring and remote sensing to forest operations. The CFRU is in the midst of strategically assessing its research priorities for the coming years and recently participated in a benchmarking exercise to evaluate its organization and function in comparison to other forest industry-university research cooperatives across the US. This exercise highlighted the unique strengths of the CFRU and some important challenges that will need to be resolved as it moves forward. With joint support from New Hampshire, New York, and Vermont, a dedicated focus was placed on obtaining supportive Federal legislation for refunding NSRC and both the House and Senate

Appropriations committees have included language for \$2M of annual funding for FY20. NSRC is a vital regional funding program for research and outreach in the Northeast, and with new funding should help to support University of Maine faculty and staff. Under the leadership of the CRSF, CAFS successfully submitted a Phase III proposal in December with 6 other universities, which would potentially provide close to \$4M of support for another 5 years for this national consortium of forest industry-university research cooperatives. Finally, FOR/Maine, which brings together all sectors of Maine's diverse forest industry to address current challenges, successfully submitted a Phase II proposal that would bring another \$1M to implement the broad strategic plan developed in Phase I.

Along with the abovementioned initiatives, outstanding staff, students, and faculty, and growing funding, I am excited and proud about where CRSF currently stands and is headed. We will continue our dedicated efforts for another productive and rewarding fiscal year ahead. Several new partnerships and initiatives are currently planned, which we look forward to reporting on in the future.

With gratitude and respect,

A handwritten signature in black ink that reads "Aaron Weiskittel". The signature is written in a cursive, slightly slanted style.

Aaron Weiskittel

Director, Center for Research on Sustainable Forests and
Center for Advanced Forestry Systems
Professor, Irving Chair of Forest Ecosystem Management

People

STAFF

Aaron Weiskittel, CRSF Director
Meg Fergusson, CRSF Communications & Research Specialist
Leslee Canty-Noyes, CRSF/CFRU Administrative Specialist
John Lee, Research Associate, Howland Research Forest
Holly Hughes, Research Associate, Howland Research Forest
Jack Witham, Associate Scientist, Holt Forest
Brian Roth, CFRU Program Leader
Jenna Zukswert, CFRU Communications and Research Coordinator
Stephan Dunham, CFRU Summer Research Field Crew Leader

CRSF AFFILIATED FACULTY

Adam Daigneault, Assistant Professor of Forest, Conservation and Recreation Policy, School of Forest Resources (CRSF/FCCI)
Dan Harrison, Department of Wildlife, Fisheries, and Conservation Biology (CFRU)
Daniel Hayes, Assistant Professor of Geospatial Analysis & Remote Sensing, School of Forest Resources (CRSF/FCCI)
Erin Simons-Legaard, Assistant Research Professor, School of Forest Resources (CRSF/IGS)
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Jay Wason, Assistant Professor, School of Natural Resources (CRSF/FCCI)
Joshua Puhlick, Research Associate, School of Forest Resources (CRSF/CFRU)
Kasey Legaard, Associate Scientist, School of Forest Resources (CRSF/IGS)

CRSF AFFILIATED FACULTY

Laura Kenefic, Research Forester, Penobscot Experimental Forest, US Forest Service (CRSF/CFRU)
Neil Thompson, Irving Woodlands Forestry Professor, Univ. of Maine Fort Kent (CFRU)
Nick Fisichelli, Forest Ecology Director, Schoodic Institute (CRSF/FCCI)
Sandra de Urioste-Stone, Program Leader, Nature-based Tourism; Assistant Professor, (CRSF/FCCI)
Shawn Fraver, Assistant Professor, School of Forest Resources, Howland Research Forest (CRSF/Howland, FCCI)

PROJECT SCIENTISTS

Adrienne Leppold, Maine Dept of Inland Fisheries & Wildlife (CFRU)
Amber Roth, Univ. of Maine (CFRU)
Anil Raj Kizha, Univ. of Maine (CFRU)
Anthony Guay, University of Maine (CFRU, CRSF)
Brian Sturtevant, USFS-NRS (NSRC)
C. T. Smith, University of Toronto (CFRU)
Chris Woodall, USFS-NRS (NSRC)
Christian Kuehne, Univ. of Maine (CFRU, NSRC)
Dan Hayes, Univ. of Maine (CFRU, CRSF)
Dan Walters, US Geological Survey (CFRU)
David Hollinger, USDA Forest Service (Howland)
Eric J. Gustafson, US Forest Service (NSRC)
Erin Simons-Legaard, Univ. of Maine (CFRU, NSRC)
Hamish Grieg, Univ. of Maine (CFRU)
Inge Stupak, Univ. of Copenhagen (CFRU)
Ivan Fernandez, Univ. of Maine (CFRU)
Jereme Frank, Univ. of Maine (NSRC)
John Campbell, US Forest Service Center (CFRU)
John Gunn, University of New Hampshire and Spatial Informatics Group (NSRC)
John Lloyd, Vermont Center for Ecostudies (CFRU)
Joseph Young, Maine Office of GIS (CFRU)

PROJECT SCIENTISTS

Joshua Puhlick, Univ. of Maine (CFRU)
Karin Bothwell, Univ. of Maine (CFRU)
Kasey Legaard, Univ. of Maine (CFRU, NSRC)
Laura Caldwell, Univ. of Maine (NSRC)
Laura Kenefic, USFS-NRS (PEF, NSRC, CFRU)
Mark Ducey, Univ. of New Hampshire (NSRC)
Mindy Crandall, Univ. of Maine (CFRU)
Parinaz Rahimzadeh, Univ. of Maine (NSRC)
Russell Briggs, SUNY-ESF (CFRU)
Shawn Fraver, Univ. of Maine (CFRU)
Thomas Buchholz, SIG (NSRC)

GRADUATE STUDENTS

Adriana Rezai-Stevens (CFRU)
Agné Grigaitė (CFRU)
Alyssa Soucy (Tourism)
Anna Buckardt-Thomas (CFRU)
Bina Thapa (NSRC)
Brooke Hafford MacDonald (Tourism)
Bruna Barusco (CFRU)
Bryn Evans (CFRU)
Cen Chen (CAFS, CFRU)
Erin Fien (Howland)
Harikrishnan Soman (CFRU, PEF)
Hatya Levesque (BS student, UMFK, CFRU)
Henry Amponsah (Holt)
Jack Chappen (CFRU)
James Alt (CFRU)
James Elliott (Tourism)
Jeanette Allogio (Howland, CFRU)
Joel Tebbenkamp (CFRU)
John Furniss (CFRU)
Kaitlyn Wilson (CFRU)
Kirstin Fagan (CFRU)
Lydia Horne (Tourism)
Margaret Mansfield (NSRC)
Samantha Anderson (CRSF, PEF, CFRU)
Sandesh Shrestha (Tourism)
Sean Ashe (CRSF)
Tyler Woollard (CFRU)
Xue Bai (NSRC)

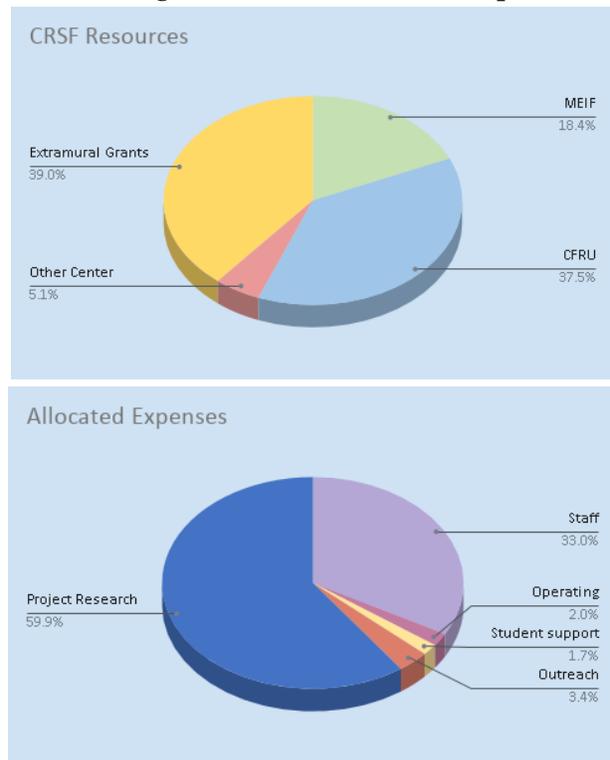
UNDERGRADUATE STUDENTS

Aaron Malone (BS student, UMaine, CFRU, PEF)
Andrew Bouten (BS student, UMFK, CFRU)
Asha DiMatteo-LePape (BS student, UMaine, Tourism)
Ashley Cooper (BS student, UMaine, Tourism)
Brian Greulich (BS student, UMaine, CRSF)
Corey Kotfila (BS student, UMaine, PEF)
Danielle Wyman (BS student, UMaine, Holt)
David Hogle (BS student, Sweden, CFRU)
David Holmberg (BS student, UMaine, PEF)
David Rubin (BS student, Yale, CFRU)
Davis Keating (BS student, UMaine, CRSF)
Elyse Daub (BS student, UMaine, CFRU)
Ethan Jacobs (BS student, UMaine, CFRU)
Evan Nahor (BS student, UMaine, CFRU, PEF)
Hope Kotala (BS student, UMaine, Tourism)
Jack Ferrara (BS student, UMaine, CRSF)
Jack Prior (Rising freshman, McGill, CRSF)
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Jacob Burgess (BS student, UMaine, CRSF)
Jacob Pliskner (BS student, UMFK, CFRU)
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Lydia Carlson (BS student, UMaine, CRSF)
MacKenzie Conant (BS student, UMaine, Tourism)
Meredith Melendy (BA student, Bates, Holt)
Michaela Kuhn (BS student, PEF)
Mike Redante (BS student, UMaine, PEF)
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Nathaniel Burke (BS student, UMaine, Tourism)
Nicholas Ferrauolo (BS student, UMaine, Tourism)
Paige Howell (BS student, Northeastern, Holt)
Shane Miller (BS student, UMaine, CFRU)
Soren Donisvitch (BS student, UMaine, CFRU)
Tyler DiBartolo (BS student, Humboldt, CFRU)

Financial Report

During FY19 (July 1, 2018-June 30, 2019), CRSF researchers submitted proposals totaling \$7,719,941. As of the end of the financial year, 10 of these proposals had successful outcomes; grants awarded in FY19 totaled \$482,318. These awards came from the National Science Foundation Industry/University Research, US Department of Agriculture, Nature Conservancy, and Maine TREE Foundation.

Income supporting the center in FY19 came from programs administered by or that support CRSF/CFRU staff and general operations, student employees, and outreach efforts (\$290,104); extramural grants supporting specific research projects (\$482,318) that were received by CRSF scientists from outside agencies; and CFRU cooperators contributed \$463,714. Total funding of the CRSF for FY19 was more than \$1.2 million (see Table 1 for budget detail). The majority (60%) of the CRSF budget is allocated directly to the research projects described in this report, supporting eighteen projects and initiatives under the auspices of the CRSF and CFRU, Howland and Holt Research Forests, Northeastern States Research Cooperative, Penobscot Experimental Forests, and the CAFS NSF/University cooperative. The remaining funds support personnel salaries and operating costs (35%), outreach (including webinars and meeting support; 3.5%), and student employees and awards (1.7%).



A key source of financial support for the CRSF is provided by the Maine Economic Improvement Fund (MEIF). The \$227,642 investment from MEIF is used to cover Director Weiskittel’s salary and fringe and to cover the Center’s personnel and operating costs. The MEIF funds have helped leverage \$526,176 from other CRSF sources and \$482,318 in extramural grants for a total leverage of \$1,008,494 (almost \$5 for every dollar of MEIF funding) of additional research funding.

TABLE 1. FY2018-19 BUDGET FOR THE CENTER FOR RESEARCH ON SUSTAINABLE FORESTS

RESOURCES			
<i>Center Sources</i>	Source	Principal Investigator	Amount
Cooperative Forestry Research Unit (CFRU)	CFRU	Roth	\$ 463,714
Maine Economic Improvement Fund	MEIF	Weiskittel	\$ 227,642
Northern States Research Cooperative	CRSF	Weiskittel	\$ 35,425
CRSF Gift Fund	Gift	Weiskittel	\$ 22,567
UMaine Munsungan Fund	Foundation	Weiskittel	\$ 4,470
Center Total			\$ 753,818
<i>Extramural Project Grants</i>			
Maine Ecological Reserves	Nature Cons.	Weiskittel et al.	\$ 9,350
Ctr for Advanced Forestry Systems Ph2 (Year 5+lead site)	NSF	Weiskittel	\$ 68,000
Support for Ameriflux Work at Howland Research Forest	USDA-FS	Fraver et al.	\$ 76,985
National Tree Biomass Project Maine	USDA-FS	Weiskittel	\$ 120,000
Holt Research Forest	Maine TREE	Witham	\$ 92,898
Penobscot Experimental Forest Res & Tech Transfer	USDA	Weiskittel	\$ 115,085
Grants Total			\$ 482,318
Total Income			\$ 1,236,136
ALLOCATION			
CRSF Director, CRSF staff salary & benefits	CRSF		\$ 227,505
CFRU Program Leader, CFRU staff & benefits	CFRU		\$ 180,541
Operating expenses	CRSF/CFRU		\$ 24,561
Salaries, Benefits, & Operating Total			\$ 432,606
Field crew & labs, student employees & student support	CRSF/CFRU		\$ 21,154
Outreach (web support, meeting & conferences)	CRSF/CFRU		\$ 41,642
Student Support & Outreach Total			\$ 62,796
Research Projects	Source	Principal Investigator	
<i>Cooperative Forestry Research Unit</i>			
Lowland Northern White Cedar	CFRU	Kenefic	\$ 8,215
Landscape-level Evaluation Deer Wintering Habitat	CFRU	Crandall	\$ 40,023
Spruce Budworm L2 Sampling	CFRU	B.Roth	\$ 9,550
Maine's Adaptive Silviculture Experiment Network MASN	CFRU	B.Roth	\$ 41,640
Long-Term Impact Whole Tree Harvest Weymouth Point	CFRU	Smith & B.Roth	\$ 38,408
Eval Effects of Timber Harvesting Operations on Soil	CFRU	Kizha	\$ 2,584
LiDAR Data Acquisition Project	CFRU	B.Roth	\$ 13,400
Dynamic Site Productivity Mapping	CFRU	Rahimzadeh	\$ 26,752
Development of Approaches for HW Responses	CFRU	Puhlick	\$ 16,522
Bicknell's Thrush Distribution & Habitat Use on Commercial Forests in Maine	CFRU	A.Roth	\$ 32,482
Large Scale Monitoring of Carnivores	CFRU	Mortelliti	\$ 6,692
Response of Marten Population 30 years Later	CFRU	Harrison	\$ 20,618
Ecological and economic outcomes of alternative riparian management strategies	CFRU	Greig	\$ 5,720
<i>Forest-Based Research & Metadata</i>			
Howland Research Forest	USFS	Fraver	\$ 76,985
Holt Research Forest	Maine TREE	Witham	\$ 92,898
Center for Advanced Forestry Systems Ph 2 (Year 5)	NSF	Weiskittel	\$ 63,811
Maine Ecological Reserves	Nature Cons.	Weiskittel et al.	\$ 9,350
Penobscot Experimental Forest Res & Tech Transfer	USDA	Weiskittel	\$ 115,085
National Tree Biomass Project Maine	USDA-FS	Weiskittel	\$ 120,000
Forest-Based Project Total			\$ 740,735
Total Allocation			\$ 1,236,136

Stakeholders

CRSF researchers strive to conduct not just cutting-edge forest science, but also real-world, applied science about Maine's forests, forest-based businesses, and the public that supports them. We build and foster relationships with a wide variety of organizations and their people to achieve common goals.

Over the past year we have worked with the following partners:

Acadia Forestry, LLC	Maine Department of Inland Fisheries and Wildlife
Acadia National Park	Maine Division of Parks and Public Lands
American Consulting Foresters	Maine Forest Service
American Tree Farm System	Maine Forest Products Council
Ameriflux	Maine Office of GIS
Appalachian Mountain Club	Maine Office of Tourism
Baskahegan Corporation	Maine Tree Foundation
Baxter State Park, Scientific Forest Management Area	Mosquito, LLC
BBC Land, LLC	National Science Foundation
Canopy Timberlands Maine, LLC	Natural Resources Conservation Service
Clayton Lake Woodlands Holding, LLC	New Brunswick Department of Natural Resources
Cornell University	New England Forestry Foundation
Downeast Lakes Land Trust	North Woods Maine, LLC
EMC Holdings, LLC	Nova Scotia Department of Natural Resources
Field Timberlands	PenBay Regional Land Trust
Forest Society of Maine	Pennsylvania State University
Frontier Forest, LLC	Penobscot Experimental Forest
Highstead's Regional Conservation Partnership	Plum Creek Timber Company, Inc.
Hilton Timberlands, LLC	Prentiss & Carlisle Company, Inc.
Huber Engineered Woods, LLC	Professional Logging Contractors of Maine
Irving Woodlands, LLC	ProFOR Consulting
James W. Sewall Company	Quebec Ministry of Natural Resources
Katahdin Forest Management, LLC	ReEnergy Holdings, LLC
LandVest	Robbins Lumber Company
Maine Bureau of Parks and Lands	
Maine Department of Agriculture, Conservation, and Forestry	
Maine Department of Environmental Protection	

Forest Climate Change Initiative (FCCI)



FCCI-affiliated scientists began meeting in the Fall of 2018 with the objective of better coordinating regional research and scientists working on the potential effects of climate change on forests. UMaine has significant expertise on climate and forest resources across academic units and research centers, and the FCCI will lead a coordinated focus on issues that link climate and forests, including tree growth and mortality, forest health, operability, ecosystem services (carbon storage, water quality, wildlife

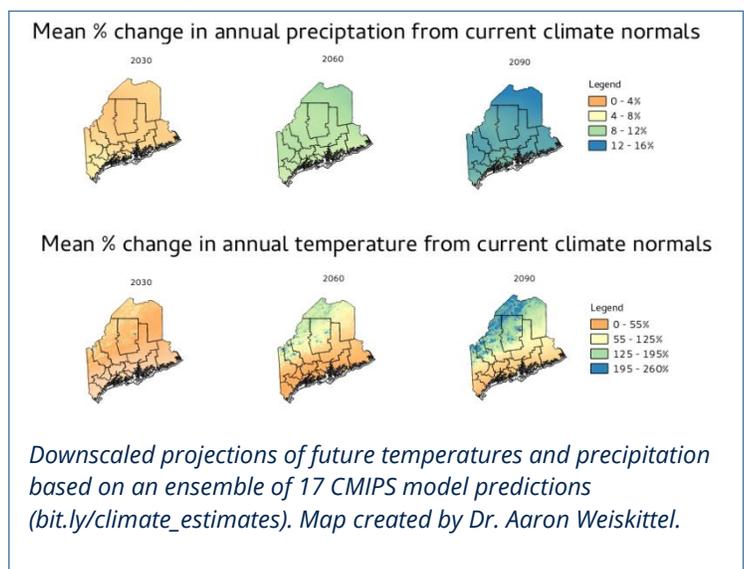
habitat), and recreation opportunities. In addition, FCCI will nurture collaborative partnerships with groups outside the University, such as the Schoodic Institute at Acadia National Park and the US Forest Service.

In April 2019, FCCI hosted a conference session to highlight the goals of this initiative and to begin a larger discussion on research priorities. The session featured an overview of current FCCI activities, presentations on the current state of knowledge across multiple disciplines, and a panel discussion of stakeholders on their experiences and information needs regarding emerging weather patterns and climate change.

Potential Concerns to Be Addressed

- Climate effects and unpredictability on forest products industry and tourism (ski industry, hiking, state and national parks, etc.) infrastructure
- Big data needs on precipitation, erosion, and variability
- Effects on tree growth and species migration
- Increase/decrease of native and non-native pests
- Spatial mapping and forecasting of effects
- Implications for sustainable eco-tourism and forestry

The FCCI has developed a web portal intended to serve as a point of access to these resources and encourage networking among university expertise as well as external stakeholders.



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

Intelligent GeoSolutions (IGS)

High Value, Low Cost Geoinformatics for Land Managers



IGS, formed in 2019 by Drs. Aaron Weiskittel, Erin Simons-Legaard, and Kasey Leggaard, is working to develop sophisticated machine learning algorithms that will provide near real-time, highly accurate geospatial information about forest attributes of high relevance to forest management, scalable to large areas using satellite imagery and USFS FIA plot data.

Forest managers need timely, relevant information on the condition and spatial distribution of forest resources to help set management objectives, plan land use actions, and ensure the long-term sustained yield of wood fiber without compromising forest health or nontimber resources.

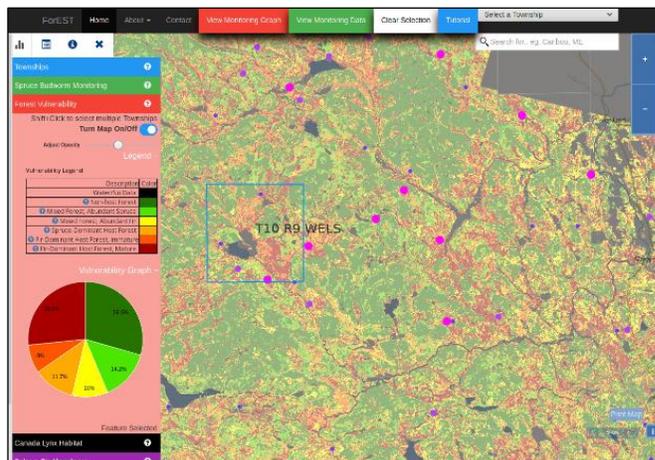
The IGS approach combines support vector machines (SVMs) to model complex, nonlinear relationships based on limited training data with the adaptability of a genetic algorithm (GA). The GA guides the evolution of models to simultaneously increase accuracy and reduce bias, an important source of error that causes systematic over- or under-prediction. By simultaneously generating many hundreds of candidate models, IGS can select specific models or blend multiple models to tailor predictive performance to specific user needs, avoiding the pitfall of assuming that one map fits all users. IGS methods are highly adaptive and highly efficient, reducing production time and cost.



Forest Ecosystem Status and Trends (ForEST) App

The IGS team is developing a brand new interactive web mapping application for release in early 2020. ForEST will provide decision support to private and public forest managers, natural resource agencies, conservation organizations, and other stakeholders through the development of new knowledge and modes of knowledge

management and transfer. Forest vulnerability layer using our predictive model based on multiple forest, topographic, and climatological factors. ForEST will enable the visualization and interpretation of high-resolution maps of forest and habitat conditions that will be updated annually from freely available satellite imagery using an innovative and nearly automated process.



crsf.umaine.edu/forest-research/igs

Nature-Based Tourism

Program Leader: Sandra de Urioste-Stone

Tourism plays 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. Tourism in Maine provides economic and non-economic values to its citizens, including nature conservation, cultural heritage maintenance and pride, and infrastructure and facility improvement. 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. 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.



Related to her nature-based tourism work, Dr. Sandra de Urioste-Stone was awarded a grant from the National Science Foundation Research Traineeship program to support the preparation of future leaders in the STEM (Science, Technology, Engineering, and Math) workforce. The **Enhancing Conservation Science and Practice** program at the University of

Maine is designed to help train the next generation of interdisciplinary environmental conservation leaders.

Highlights of the Nature-Based Tourism program from 2018–19 include ongoing progress to learn from experts on how to improve Maine's forest-based economy and address associated uncertainties and risks. In its second year, the Fostering Coastal Community Resilience in Maine project focused on 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. Insight from responses to these questions are crucial to the resilience of these natural-resource dependent coastal communities.

crsf.umaine.edu/nature-based-tourism

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

*Sandra De Urioste-Stone (PI), Parinaz Rahimzadeh-Bajgiran (Co-PI)
Affiliated Scientists: Bridie McGreavy, Laura Rickard, Erin Seekamp*

YEAR 2 PROGRESS REPORT

Summary

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.

Project 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

- We use a comparative case study design with a mixed methods approach.
- The study sites are Camden, Mount Desert Island, and Machias, all of which are important coastal tourism destinations in Maine.
- We have conducted 20 in-depth semi-structured interviews with an embedded pile sort activity of tourism stakeholders in coastal Maine to understand climate change risk

perceptions and identified mitigation and adaptation strategies being used. Data is being analyzed in NVivo Plus 12.

- We conducted a mixed mode visitor survey at the three study locations. We surveyed a total of 1,353 visitors on-site, and 480 of those completed the follow-up survey instrument, with a response rate of 35.48%. Data are currently being analyzed in SPSS.

Key Findings / Accomplishments

- Preliminary findings from the pile sort activity suggest that when participants think about climate change, they are concerned about the drivers of climate change and resulting impacts specific to their locale. Identifying solutions to climate change are important for participants, most often identified as mitigation, adaptation, building resilience, and infrastructure investments.
- Participants in the interviews 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 and non-profit land managers. 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
- Among the terms most frequently used by participants during interviews include people, know, climate and change. 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.
- Preliminary findings from the visitor survey indicate that the majority (almost 90%) of visitors believed that climate change is currently happening, is caused by carbon dioxide emissions, and that humans are the primary contributor to climate change.
- When asked about likely climate change impacts to MDI and Acadia National Park, visitors indicated that the increased presence of ticks and mosquitoes, an increase in heat waves and extreme weather events, a longer summer season, and increased visitation to Acadia National Park were the most likely outcomes related to climate change. Not all of these impacts would necessarily result in reduced visitor numbers or negative consequences to the destination as a longer summer season was expected to increase visitation overall and extend seasonal tourism.
- When asked which factors posed a *threat* to tourism on MDI and in Acadia National Park, visitors responded that the increased presence of ticks was the highest threat, followed closely by an increased presence in mosquitoes. Higher temperatures and an increased number of heat waves were also seen as high threat events.

Maine Forest Industry Sub-Sector Analysis

*Sandra De Urioste-Stone (Principal Investigator), Jane Haskell (Co-PI),
Linda Silka (Co-PI), Aaron Weiskittel (Co-PI),
Brooke Hafford MacDonald (MSc student), Lydia Horne (PhD student)*

YEAR 2 PROGRESS REPORT

Summary

Maine's forest and forest products industry are vital to Maine's economy. Recent estimates by the University of Maine indicate that the total economic impact of Maine's forest industry in 2014 was \$9.8 billion, representing 6% of state GDP and 5% of state employment. However, closure of



Penobscot River Trails, Grindstone, ME. Photo courtesy Meg Fergusson.

six pulp & paper mills between 2010 and 2016 has impacted over 7,500 jobs in the state. While ongoing efforts are focused on mitigating the short-term economic impact of these changes in rural communities, it is crucial that Maine also develop a broad and long-term strategic plan to promote and build its future forest products sector.

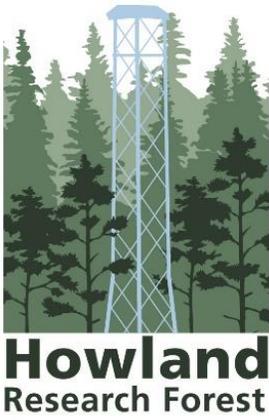
Accomplishments

- ❖ Facilitated additional focus groups and interviews with stakeholders (e.g., small woodlot owners, government agencies, non-governmental organizations).
- ❖ Conducted thematic data analysis.
- ❖ Integration of information from newspaper articles, and prior studies on transportation challenges in Maine to the data we are currently generating via focus groups and interviews.



RESEARCH FORESTS

The CRSF works cooperatively with scientists, foresters, and students to support research on three long-term research sites in Maine. Holt Forest, situated on 300 acres in Arrowsic and funded by Maine TREE Foundation and research grants, has been the site of a long-term pine-oak forest ecosystem study since 1983, collecting data on trees and regeneration, small mammals, and a variety of avian species. Research has been conducted at the site by a number of multi-disciplinary teams of scientists from the University of Maine's College of Natural Sciences, Forestry, and Agriculture since its inception. The Howland Forest is a continuously operating forest ecosystem research site established in 1986 by University of Maine researchers with the cooperation of International Paper. Studies at Howland Forest focus on nutrient cycling, forest ecology, ecosystem modeling, acid deposition, remote sensing, climate change, and carbon sequestration. The site welcomes research scientists from the University of Maine as well as institutions throughout the country and is home to various model and sensor development efforts. The Penobscot Experimental Forest is managed via a Joint Venture Agreement between the University of Maine and US Forest Service Northern Research Station. The PEF hosts long-term research conducted by USFS scientists, university researchers, and professional forest managers in Maine and provides the setting for forestry education and public outreach.



Howland Research Forest

Established in 1986 through a partnership between the University of Maine and International Paper Company, the Howland Research Forest is a forest ecosystem research site in central Maine, representing a low-elevation conifer/northern hardwood transitional forest dominated by spruce and hemlock.

Collaborations between the USDA Forest Service, NASA, NOAA, EPA, the US Department of Energy, Woods Hole Research Center, and the University of Maine have maintained an active research program in carbon and nutrient cycling, remote sensing, climate change, and more.

Home to the second-longest flux record in the United States (20+ years, since 1996), 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 20 years of data provide a time series long enough for robust analyses of relationships between CO₂ flux and various environmental variables.

The Howland Research Forest is located in the transition zone between the eastern deciduous forest and the boreal forest in eastern North America. A mature multi-aged spruce–hemlock forest comprises approximately 170 of the 220 hectares owned by Northeast Wilderness Trust. The forest is dominated by red spruce (*Picea rubens*) and eastern hemlock (*Tsuga canadensis*), consisting of approximately 90% conifer, and 10% deciduous tree species. In 2007, the Howland Research Forest was purchased by the [Northeast Wilderness Trust](#).



Instruments collect flux data at the top of the main Howland Research tower. Photo courtesy Meg Fergusson.

umaine.edu/howlandforest

2018-19 Research Update: US Forest Service Joint Venture Agreement to Support AmeriFlux Research at the Howland Forest

*Dr. Shawn Fraver (PI), Associate Professor, UMaine School of Forestry (SFR);
John Lee, Research Associate, SFR/CRSF; Holly Hughes, Research Associate, SFR/CRSF;
Erin Fien, Graduate Student, SFR/EES*

Summary

The AmeriFlux network is a nation-wide set of research sites measuring fluxes of CO₂, water, energy, as well as other terrestrial processes, to quantify and understand carbon sources and sinks and the response of terrestrial ecosystems to climate and disturbance. The Howland Research Forest, Maine, is one of the Core Sites of the AmeriFlux program. The general expectations for Core Sites include providing high quality 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



M.S. student Jeanette Allogio recording forest inventory data at the Howland Research forest, Maine. Photo courtesy Shawn Fraver.

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. Recent graduate students associated with this project include Erin Fien (M.S., graduated August, 2018).

Accomplishments

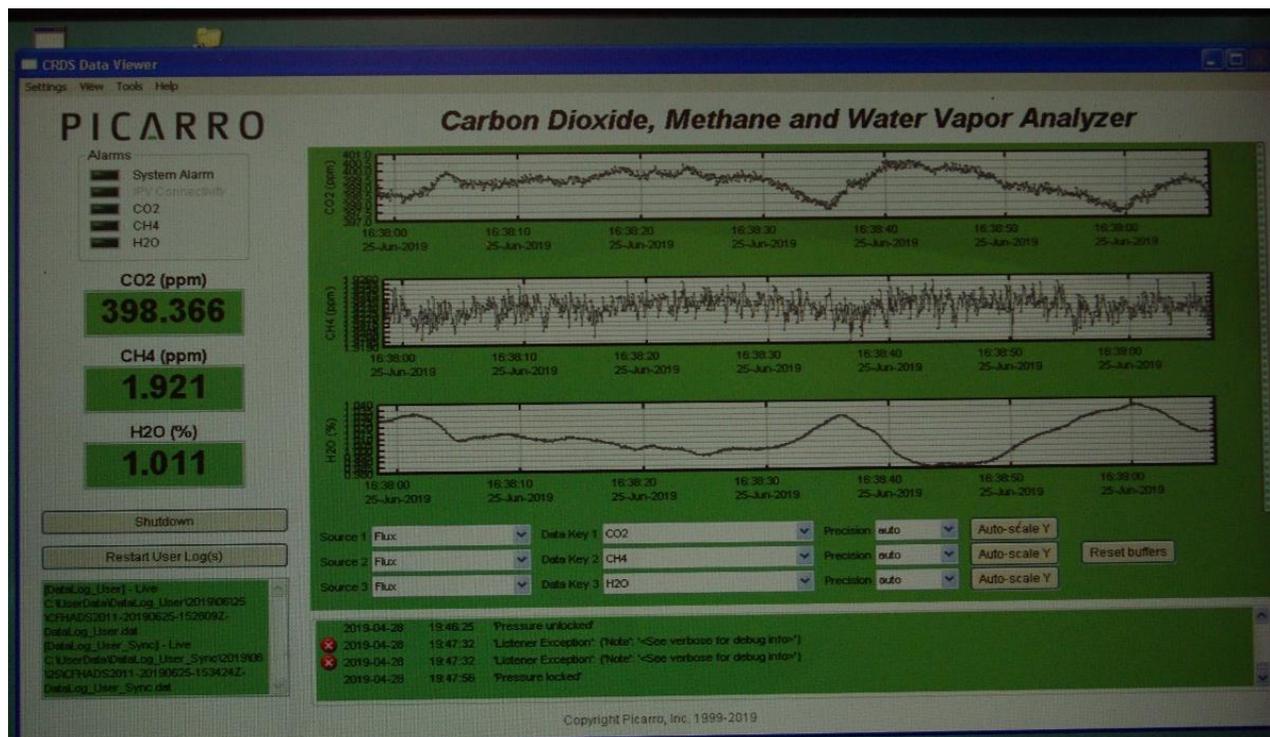
The Howland Forest site has had continuous atmosphere-forest canopy CO₂ flux data since 1996, making it the second longest running canopy flux site in North America.

Future Plans

Ensure continuous data streams from the Howland Forest site. Foster continued graduate student involvement in Howland Forest research.

Partners / Stakeholders / Collaborators

- Dave Hollinger, US Forest Service, Northern Research Station, Durham, NH
- Andrew Richardson, Northern Arizona University, Flagstaff, AZ
- Kathleen Savage, Woods Hole Research Center, MA
- Aaron Teets, Northern Arizona University, Flagstaff, AZ
- Amanda Armstrong, NASA Goddard Space Flight Center, MD
- Northeast Wilderness Trust, Montpelier, VT



Continues measurement of carbon flux onsite at Howland Research Forest.

Penobscot Experimental Forest

The Penobscot Experimental Forest (PEF) is one of **80 experimental forests and ranges** nationwide designated by the Chief of the **U.S. Forest Service** for long-term ecology and management research. Land for the PEF was purchased in 1950 by nine pulp, paper, and land-holding companies and leased to the Northeastern Forest Experiment Station (now the **Northern Research Station**) of the U.S. Forest Service as a site for long-term forest management research in the northeastern spruce-fir forest. In 1994, the industrial owners of the PEF donated the land to the University of Maine Foundation. When the PEF was donated, the industrial owners stated that the mission of the forest is: to afford a setting for long-term research conducted cooperatively among Forest Service scientists, university researchers, and professional forest managers in Maine; to enhance forestry education of students and the public; and to demonstrate how the timber needs of society are met from a working forest. Today, the University of Maine



Mixed-age stand at Penobscot Experimental Forest. Photo courtesy Meg Fergusson.

and Northern Research Station manage the PEF under a Joint Venture Agreement.

Forest Characteristics

About 10 miles north of Bangor, Maine, the PEF is in the Acadian Forest, a region covering much of Maine and Atlantic Canada. This is an ecotone between boreal and broadleaf biomes dominated by northern conifers. Red spruce is the signature species. Balsam fir, a boreal species, is at its southern limit, while eastern hemlock and eastern white pine are at their northern limits. Stand-replacing fires are less frequent than in the boreal or other temperate forests. Insect epidemics (e.g., spruce budworm) and windstorms cause sporadic mortality. Most of the forest in the region has been periodically cut since the 18th

century; a water-powered sawmill was located on the land that became PEF in the late 1700s.

The Acadian Forest is more compositionally diverse than commercial spruce-fir forests farther north. The canopy is dominated by conifers, including hemlock, spruce (mostly red but some white and black), balsam fir, northern white-cedar, white pine, and an occasional tamarack or red pine. These species often occur as mixedwoods (i.e., in softwood-hardwood mixtures in which neither component contributes more than 75% of basal area). Common hardwoods include red maple, paper and gray birch, and trembling and bigtooth aspen.

Research

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



Graduate students conducting research on browse and natural regeneration at the PEF. Photo courtesy Meg Fergusson.

the Management Intensity Demonstration (1950-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). Treatments are applied at the stand level and include single-tree selection cutting on 5-, 10-, 15-, and 20-year cutting cycles, modified (guiding) and fixed diameter limit cutting, uniform and irregular shelterwood, precommercial and commercial thinning, and commercial and silvicultural clearcutting. Harvesting operations have evolved over time from hand crews with horse or cable skidding to mechanized harvesting with processors, forwarders, or grapple skidding. As such, treatment application and outcomes are

relevant to contemporary forest management, and **measured response variables** include a suite of commodity production and ecological variables.

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. As a result, the PEF is a national leader in experimental forest data publication and a valuable resource for researchers worldwide interested in using longitudinal forest data in their studies. The PEF is also the location of a **Smart Forest** network installation, linking wireless sensor data collection across sites.



USFS Research Scientist Laura Kenefic is a fan of the trees at the PEF. Photo courtesy Meg Fergusson.

Education and Demonstration

In addition to a number of demonstration areas, the PEF provides opportunities for training and education of University students and others through field tours, workshops, and summer and school-year employment. Numerous graduate student and faculty research projects have been overlain on the Forest Service experiments, making the PEF a key part of both research and academics at the University.

[crsf.umaine.edu/forest-research/
penobscot-experimental-forest](https://crsf.umaine.edu/forest-research/penobscot-experimental-forest)

Holt Research Forest



2018 marked the 36th year of existence for Holt Research Forest (HRF). HRF 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. The 2017 [Board of Visitors Report](#) reinforced these conclusions with more urgency given to the continuation of the research and expansion of outreach and education at HRF.

The connection to CRSF over the past several years has raised the visibility of HRF within the University and steps are firmly underway to raise the awareness of HRF in the public's eye as well as within the forestry research and practices community. Over the past year, these steps have included the production of videos, discussions with potential collaborators related to a new research and management plan, and improved programming.

The [HRF Strategic Plan](#) (2019-2029) was developed by Brian Kloeppe, past president of the Organization of Biological Field Stations and a participant in the NSF-sponsored board of visitors meeting. The plan includes 6 strategic directions: Research Excellence, Education Excellence, Outreach Excellence, Administrative Excellence, Facility Development, and Accountability and Success Measures, and points the way for the University of Maine and Maine TREE Foundation to move forward and enable HRF to reach its full potential.

On the ground, the reduced field research schedule continued for another year, yet all scheduled field work was successfully completed. Data collected included seed samples, bird maps, small mammal trapping, and seedling counts. Significant progress was made on the data management project. HRF hosted over 90 visitors this year, including formal workshops, visiting scientists, and school children.

holtforest.org

Progress Report on Holt Research Forest (HRF) – June 2019

NSF Planning Grant

This grant has been completed except for filing of final report to NSF. We view the grant as a success and hope that the strategic plan for HRF will lead to additional opportunities for funding from outside sources. The grant provided funding for several versions of a video that will enable HRF to take some steps toward greater visibility statewide. A longer, 26-minute video is in the final editing stage for airing on the MPBN Community Film Series. Additional funds are being sought to carry on this effort.

Data Management

The vast majority of the **data has been homogenized and posted** to the Forest Ecology Monitoring Cooperative (FEMC) website. “The mission of the Forest Ecosystem Monitoring Cooperative is to serve the northeast temperate forest region through improved understanding of long-term trends, annual conditions, and interdisciplinary relationships of the physical, chemical, and biological components of forested ecosystems.” We decided to use this site because our data sets and research goals matched so closely.

Clarke Cooper has concluded his portion of the data management project to date. His work on instructions and programs for the metadata associated with each file is ongoing and will continue. Other items Clarke completed is an automated backup of HRF files to a UMaine server as well as standardization of research files between computers. He will continue to update data sets and work on improving the HRF pages on the FEMC website.

Undergraduate and graduate students have undertaken the scanning of current and archival data sheets to create a digital backup of all data.

Research Plan and Timber Harvesting

Discussions between Barrie, Henry, and loggers to conduct a harvest this year in the southwest portion of the property are ongoing. Future harvests may include the northwest portion of the property as well. In conjunction with a UMaine research plan and consultation with MTF and Barrie, a harvest will be scheduled for 2020 following the summer field work. The final study design has not been completed but in addition to a modified shelterwood and group selection harvest we hope to include deer exclosures and possibly controlled burns. We hope to focus on the parts of the east side of the property where mixed mesic types are dominant. Regeneration of red oak will be one of the primary goals of the management conducted.

Summer Students

This year we have hired 4 students to assist with field work at HRF. The primary objective is to update as much of the timber inventory data as possible. One student (Paige Howell from Northeastern University) who began May 20 will only be here for 6 weeks. The additional 3

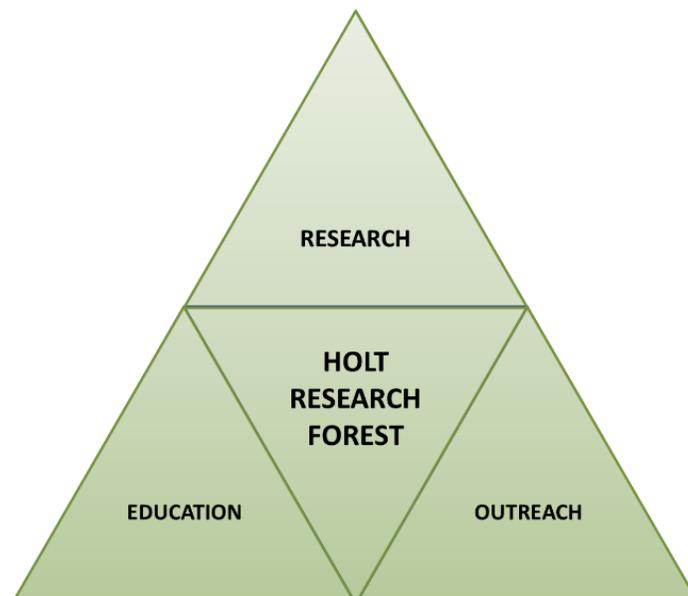
students (Henry Aponsah from UMaine, Danielle Wyman from UMaine, and Meredith Melendy from Bates College) began on June 3 and will be here for 10 weeks. To date, Paige has collected all seed samples, replaced failing seed bags and trap stands, worked on grid system maintenance, and organization and maintenance of field equipment. For all the students considerable time has been used for learning the HRF grid system, learning to identify trees, saplings, seedlings, and seeds, and learning the sampling methods.

Students are being housed in the log house and they all seem to be quite content with the accommodations. UMaine students will continue work on seed counting and sorting on their return to campus.

Educational Programs – Outdoor Classroom

No workshops are currently scheduled. Kevin Doran’s retirement from MFS this spring has slowed the process as we find new collaborators. A brief meeting with District Forester Shane Duigan sparked some ideas and he indicated his willingness and interest in assisting with programs at HRF. No additional information on a replacement for Kevin has been heard.

Kennebec Estuary Land Trust will be using HRF again this summer for two weeks of day camp. You can see a link to the web site advertising the camp is provided [here](https://www.kennebecestuary.org/summer-camp) or <https://www.kennebecestuary.org/summer-camp>. A notice of the camp went out on the Arrowsic town email list recently with the Education Committee highlighting how great it was to have such an activity in town. KELT has applied for a summer camp license to make it officially recognized by the State of Maine. The application requires approval of the septic system by the plumbing inspector. This has resulted in some scrutiny of HRF by the Arrowsic Planning Board and Code Enforcement Officer. Jack attended a planning board meeting in May to assure the planning board that HRF was operated within the constraints of the conditional use permit granted for the outdoor classroom.





Forest-based Research

The CRSF is home to a number of forest-based research programs. The Cooperative Forestry Research Unit (CFRU) serves the large, commercial forest landowners of Maine and has more than 30 members representing over 8 million acres of forestland. CFRU scientists conduct applied research that provides Maine's forest landowners, forestry community, and policymakers with the information needed to ensure both sustainable forestry practices and science-based forest policy. The Center for Advanced Forestry Systems (CAFS) is an NSF industry-university cooperative whose goal is to facilitate the connections between forestry research programs and industry members to solve complex, regional and national industry-wide problems. The CRSF took over as the lead program site for CAFS in 2018. The Northeastern States Research Cooperative (NSRC) is a competitive grant program that was funded by the USDA Forest Service through 2016 to support cross-disciplinary, collaborative research in the Northern Forest; the CRSF oversees Theme 3, encompassing research that will quantify, improve, and sustain productivity of the Northern Forest as a working forest landscape. We are hoping to re-establish funding for the NSRC in FY20.

Cooperative Forestry Research Unit (CFRU)



New challenges face our forest industry these days as CFRU members employ new technologies and applications to address long-standing problems. For example, CFRU research projects now use LiDAR to map streams and wet areas, update decades-old soil surveys, quantify timber inventories, and predict the quality and distribution of wildlife habitat. CFRU researchers also use high-resolution imagery from satellites, airplanes, and UAVs to identify tree species biomass, forest types, disturbance history, and foliage losses to damaging agents such as the spruce budworm. By employing machine learning algorithms that are combined with the power of super computers, we are producing statewide high-resolution georeferenced maps of the aforementioned attributes. These detailed maps provide landowners and managers near real-time data to visualize and quantify changes, problems, and opportunities for the resources they manage, thereby reducing the uncertainty of “surprise forestry” that we are all so familiar with.



Other new initiatives are the implementation of a regional Adaptive Silviculture Network (MASN) (see page 35) and consideration for CFRU expansion to a regional cooperative that would include members from New York, Vermont, and New Hampshire. These major initiatives will better position the CFRU to respond to problems that will be facing forestland owners and managers in the future in the areas of forest sustainability, adaptation, and resilience, among others. Regional expansion will bring opportunities to broaden our research findings, leveraging a larger pool of funding sources led by a wider group of collaborating scientists.

umaine.edu/cfru

Silviculture & Productivity

SILVICULTURE AND OPERATIONS IN NORTHERN WHITE-CEDAR LOWLANDS: A PILOT STUDY

Laura Kenefic (USFS); UMaine: Anil Raj Kizha , Shawn Fraver, Hamish Greig, Amber Roth, Jay Wason, Keith Kanoti

Progress Report (Year 1)

Northern white-cedar is found in mixed stands and white-cedar-dominated lowlands. Though research over the last decade has addressed management of white-cedar in mixtures, there are still questions about management of lowlands. Such stands are important for commodity production and ecological values. This collaborative and interdisciplinary project is generating new findings related to silviculture, production, and ecology in a regionally important forest type, facilitating effective and active management by CFRU member organizations and others.

Key Findings

In FY18, pre-harvest measurements were completed on one site (Penobscot Experimental Forest), and harvesting is scheduled for winter 2018–19 using a cut-to-length system. Additional study sites have been identified on cooperator lands (Baskahegan Company and Wagner Forest Management) and were visited to determine suitability for the study in fall 2018. These sites will be inventoried in summer 2019 for harvesting in winter 2019–20 using cut-to-length and whole-tree systems, respectively.

Findings from the first site indicate that:

- Volumes of dead wood are high in unharvested white-cedar-dominated lowlands, likely due to slow rates of decay.
- High water table in white-cedar-dominated lowlands limits tree establishment and growth to elevated microsites such as those from stumps and buried wood.
- Both seedlings (sexual reproduction from seed) and layers (asexual reproduction from branches that root to the ground) are common on white-cedar-dominated lowlands.
- Layers can originate from tree branches resting on the ground as well as established seedlings and saplings apparently pressed down by snow and ice loads.
- Saplings of other species (e.g., balsam fir, alder) often compete with white-cedar in the understory.

In light of our finding that both layers and seedlings are common in lowland white-cedar stands, we have undertaken an additional study of mode of regeneration. Specifically, co-PI Wason is supervising an undergraduate intern in the Experiential Learning for Multicultural Students program in the development of a key to distinguish layers and seedlings by microscopic cell structure. Seedlings were excavated across belt transects at the first study site for this work.

EVALUATING THE COSTS AND IMPACTS OF TIMBER HARVESTING OPERATIONS ON SOIL COMPACTION

UMaine: Anil Raj Kizha., Harikrishnan Soman; CFRU: Brian Roth

Progress Report (Year 1)

Rising costs of forest operations and decreasing revenue generated from harvesting are becoming critical challenges in forest management throughout the northeastern United States. Along with this, the low markets for comminuted forest residues and stricter policies on environmental protection have prompted utilization of these materials as slash mats on skid trails for minimizing soil disturbances. The aim of this study was to evaluate the cost of different silvicultural treatments and utilization of forest residues generated from a mechanized timber harvesting operation for implementing Best Management Practices (BMPs). The field-based experiment was done in central Maine at one of the CFRU Maine's Adaptive Silviculture Network (MASN) sites, where four forest stands were managed at varying intensities following silvicultural prescriptions common to the region (partial harvest (PH) and clearcut (CC) treatments). Variables measured included delay-free cycle times of various timber harvesting machines, predictor variables, and stand features. The total cost of PH was higher than that of CC (\$22.94 m⁻³ versus \$14.88 m⁻³). Of the various operational phases, the costs associated with skidding was the highest and ranged from 52 to 70% of the total cost for PH and CC, respectively. The cost of BMP implementation was estimated to be between \$10 and 52 PMH⁻³, or \$1.0 and \$3.7 m⁻³, and was influenced by several factors, including machine maneuverability and the extent of area which demanded BMP implementation. This information on the cost and productivity for timber harvesting operations, along with BMP implementation, will support the development of economic and environmentally sustainable harvesting strategies.

Key Findings

- Clearcut operations were found to be economically more feasible than partial harvest operations.
- For both clearcut and partial harvests, primary transportation was the costliest component.
- Cost of BMP implementation was found to range between \$1.0 and \$3.7 m⁻³.
- Efficiently laid skid trails can reduce BMP implementation costs to a great extent even if the site is poorly drained.

MAINE'S ADAPTIVE SILVICULTURE NETWORK (MASN)

CFRU: Brian Roth; UMaine: Aaron Weiskittel, Anil Raj Kizha., Amber Roth

Progress Report (Year 2)

This is the second year of a five-year project to establish a new region-wide study series: Maine's Adaptive Silviculture Network (MASN). The MASN study will be the backbone for new research in the areas of growth and yield, wildlife habitat, harvest productivity, regeneration dynamics, remote sensing of inventory, forest health, and others. There has been much interest from researchers

wishing to take advantage of these study sites on research problems of interest to CFRU membership. In addition to the American Forest Management (AFM) installation established at Grand Falls township (TWP) in the summer of 2017, there have been two additional installations established in 2018: T16 R8 on Irving Woodlands, LLC and T13 R15 on Seven Islands Land Company. Three more installations are laid out and harvests planned for 2019: Stetsontown TWP on Wagner Forest Management, Thorndike TWP on Weyerhaeuser Company, and the Massabesic Experimental Forest of the U.S. Forest Service (USFS) Northern Research Station.

Key Findings

- Baseline protocols have been documented and preliminary data collected on forest birds, inventory, understory vegetation, harvest damage, and 360-degree photo documentation.
- In addition to the first installation on AFM at Grand Falls TWP, two installations were established and harvested in 2018: T16 R8 on Irving Woodlands, LLC and T13 R15 on Seven Islands Land Company.
- Three installations are laid out and harvests planned for the Fall/Winter of 2018: Stetsontown on Wagner Forest Management, Thorndike TWP on Weyerhaeuser Company, and the Massabesic Experimental Forest of the USFS Northern Research Station.
- A study on the cost of BMP implementation was completed on the first installation (see study “Evaluating the Costs and Impacts of Timber Harvesting Operations on Soil Compaction” in this report).
- The CFRU 2018 Fall Field Tour included a stop at the T16 R8 installation where the study was introduced and the problems associated with managing diseased beach discussed.

LONG-TERM IMPACTS OF WHOLE-TREE HARVESTING: THE WEYMOUTH POINT STUDY

Univ. of Toronto: C.T. (Tat) Smith; SUNY-ESF: Russell D. Briggs; USFS: John L. Campbell; UMaine: Ivan Fernandez, Shawn Fraver; CFRU: Brian E. Roth; Univ. of Copenhagen: Inge Stupak

Progress Report (Year 3)

The Weymouth Point study was initiated in 1979 to determine the effects of whole-tree clearcutting a spruce-fir forest on watershed nutrient cycling and budgets. Fixed-area plots established on two adjacent watersheds (unharvested and clearcut) enable evaluation of long-term effects of harvest residue treatments on tree growth and long-term dynamics in soil and whole ecosystem carbon (C) and nutrient pools. Between 1979 and 2015, 52 permanent study plots were established across three soil drainage classes in the unharvested and clearcut watersheds. Residue treatments applied in 1981 include: whole-tree harvesting (WTH), return of lopped and scattered delimiting residues to the site (LOP), and return of chipped delimiting residues to the site (CHP). Stand density and basal area for plots located in the mature, unharvested reference and harvested watersheds were strongly affected by age and silvicultural treatments, but not by delimiting residue treatments or fertilizer. Ecosystem C and nutrient budget modeling is ongoing.

Key Findings

- Forest floor measurements in 2016 indicate significant decomposition (ranging from 67-76% of original mass) during the 35-year period from 1981–2016: 112 to 35 Mg/ha or loss of 77 Mg/ha (69%) for WTH; 169 to 55 Mg/ha or loss of 114 Mg/ha (67%) for LOP; 176 to 43 Mg/ha or loss of 133 Mg/ha (76%) for CHP.
- Soil samples collected in the 2017 field season were processed at the University of Maine and analyzed for pH, Walkley-Black C, total C and N, Bray-P and exchangeable Ca, Mg and K at SUNY-ESF. • Concentrations of total C and N appear to be somewhat higher in harvested watershed soils (WTH, LOP and CHP treatments) than reference watershed soils (REF) at 0–10 and 25–50 cm depths, but less Bray-P and exchangeable Ca.
- Carbon was estimated in standing dead wood (snags and stumps) and downed dead wood (coarse woody debris and fine woody debris) of the unharvested forest (REF) and for different harvesting residue treatments: whole-tree harvesting (WTH), return of lopped and scattered delimiting residues to the site (LOP) and return of chipped delimiting residues to the site (CHP) using methods of Ducey and Fraver (2018), Harmon et al. (2011) and Woodall and Monleon (2010). Preliminary results shows that dead woody debris in the unharvested forest is about three times that observed in harvested watershed treatments.
- Two MSc students from the University of Copenhagen, Bruna Barusco and Agnė Grigaitė, are working under the supervision of Drs. Inge Stupak and Tat Smith to complete the second objective of the Weymouth Point project: to compare measurement-based estimates of 35- year forest ecosystem C pools with C dynamics predicted by the CBM-CFS3 model.
- A workshop was arranged at the University of Maine at Orono on June 7 th and 8th , 2018 titled “Long-Term Site Productivity Research: Lessons from Other Regions and Opportunities for Maine.”



Unharvested white-cedar-dominated lowlands. Photo courtesy L. Kenefic.

Growth & Yield Modeling

DEVELOPMENT OF INDIVIDUAL TREE AND STAND-LEVEL APPROACHES FOR PREDICTING HARDWOOD MORTALITY AND GROWTH RESPONSE TO FOREST MANAGEMENT TREATMENTS IN MIXED-SPECIES FORESTS OF NORTHEASTERN NORTH AMERICA

UMaine: Joshua J. Puhlick, Christian Kuehne

Progress Report (Year 1)

In Year 1 of this two-year project, we acquired data from existing forest inventories with repeat measurements of tree attributes in Maine, New Brunswick, and Nova Scotia. We also conducted repeat measurements of crop trees on the Penobscot Experimental Forest Rehabilitation Study and the Silvicultural Intensity and Species Composition experiment. These data sources will be used to develop growth and mortality response functions for common hardwood species of northeastern North America to account for treatment effects after various forest management activities.



Assessing paper birch crop tree quality on the Penobscot Experimental Forest Rehabilitation Study. Photo by J. Puhlick.

Key Findings

- In Year 1 of the project, we acquired data from existing forest inventories with repeat measurements of tree attributes in Maine, New Brunswick, and Nova Scotia. This involved meeting and signing data agreements with colleagues at the Northern Hardwoods Research Institute in Edmundston, New Brunswick (Gaetan Pelletier) and the University of New Brunswick in Fredericton (Chris Hennigar). Forest inventory data from the Penobscot Experimental Forest in central Maine were acquired from the U.S. Forest Service. We also requested forest inventory data from colleagues in Québec (Steve Bédard, Ministère des Forêts, de la Faune et des Parcs).
- In addition to data acquisition, we also conducted repeat measurements of crop trees on the Penobscot Experimental Forest Rehabilitation

Study (during the summer and fall of 2017) and the Silvicultural Intensity and Species Composition experiment (late fall 2017 and early spring 2018). The Rehabilitation Study measurements were used to evaluate crop tree growth and quality in cutover mixed-wood stands after rehabilitation treatments. A manuscript with the results of this analysis were published in a peer-reviewed journal. The measurements from both studies will be used to develop tree growth and yield models for early successional hardwood and mixed-wood stands.

DEVELOPING A DYNAMIC AND REFINED FOREST SITE PRODUCTIVITY MAP BY LINKING BIOMASS GROWTH INDEX TO REMOTELY SENSED VARIABLES

UMaine: Parinaz Rahimzadeh, Aaron Weiskittel; Univ. of New Brunswick: Chris Hennigar

Progress Report (Year 1)

Forest potential productivity is an important measure for sustainable forest planning and management. However, its quantification has always been a challenging task, particularly on a regional scale. Due to the essential need for a fine-resolution region-wide map of forest productivity for effective large-scale forestry planning and management, a novel productivity model, biomass growth index (BGI), was suggested by Hennigar et al. for the Acadian region. The model explains only 53% of the variation in plot aboveground biomass growth partly because of poor soils data resolution and incomplete stand development history in the model. Based on the strong potential for the improvement of this model by incorporation of techniques using remote sensing (RS) data, several newly-launched Sentinel-2 satellite derived variables were selected for the analysis. Twenty-one Sentinel-2 derived variables including nine single spectral bands and 12 spectral vegetation indices (SVIs) with a combination of other variables were used to predict tree volume/ha (GTV), height, and the Site Index (SI20). Initial model runs showed a 10 to 12 % increase in out of bag (OOB) r^2 when Sentinel-2 variables were included in the prediction of total volume in combination with BGI. Site Index was not predicted with the same accuracy as GTV, but it is still promising.

Key Findings

Prediction of GTV using species composition, age, Mgmt., BGI, and Sentinel-2 spectral bands and indices:

- Model runs showed a 10–12 % increase in out of bag (OOB) r^2 when Sentinel-2 data was included in the prediction of total volume (Table 5). Prediction of stand-level volume based on age, species composition, management type, and BGI yielded an OOB r^2 of 68%, whereas the addition of the Sentinel-2 data increased the OOB r^2 To 80%. Additionally, dropping species composition as a predictor variable did not significantly affect the OOB r^2 (80% vs. 78%). In all cases, band 2 (green) was the strongest predictor variable, even outperforming age as a predictor of GTV.
- After reviewing the correlation matrix of the bands and indices, all bands and indices with the exception of green and near infrared (NIR) bands and Sentinel-2 rededge position index (S2REP) and Normalized Difference Vegetation Index 45 (NDVI45) were dropped from the

model as they did not contribute significantly to model performance. Results for height prediction incorporating Sentinel-2 data were similar to those obtained for GTV.

- Removing age and management variables and running the model on only BGI, three Sentinel-2 derived variables (green and near infrared (NIR) bands and Sentinel-2 rededge position index (S2REP)) yielded an OOB r2 of 62%.

Prediction of GTV using only Sentinel-2 best bands and indices:

- Prediction of total volume (GTV), with spectral bands and indices performed the best when two single bands (green and NIR) and two SVIs (S2REP and NDVI45) were used.
- Prediction of GTV using only the best bands and indices and BGI resulted in an out of bag r 2 of 62.5%. Removing BGI reduced the out of bag r2 to 59.3%. BGI does not seem to have considerable effects on predicting GTV).

Prediction of Site Index (SI20) with species composition, age, Mgmt., BGI, and Sentinel-2 spectral variables:

- SI20 was not predicted with the same accuracy as GTV but still promising (e.g., SI20~Age, Mgmt, BGI, July Sentinel-2 (green, NIR, S2REP and NDVI45) and species: OOB r2 = 69.7).
- This part is still in progress, and the final results will be presented in the final report.

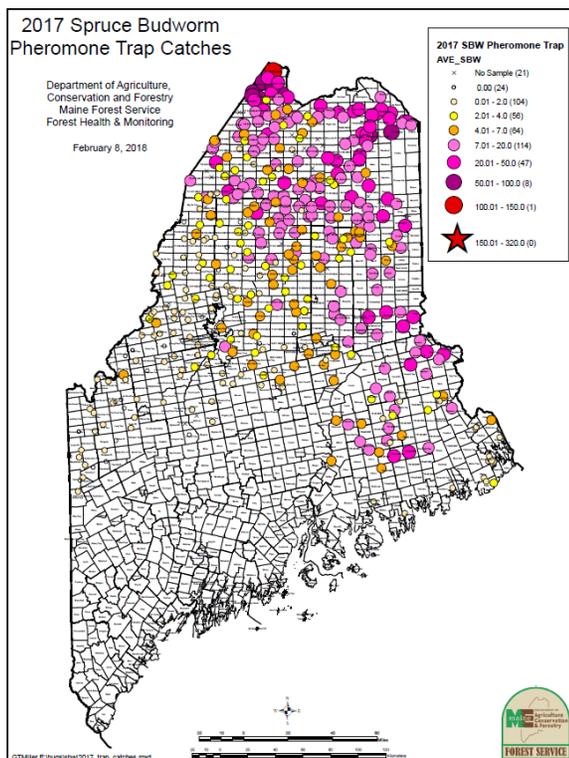
SPRUCE BUDWORM POPULATION MONITORING: L2 SURVEYS

CFRU: Brian Roth; UMaine: Erin Simons-Legaard, Kasey Legaard

Progress Report (Year 2)

Sampling the second instar (L2) larval population of spruce budworm can identify areas of local population growth (versus immigration) and help managers anticipate the degree of defoliation to be expected during the next growing season.

Although there is generally thought to be a positive relationship between pheromone trap catch and larval abundance, the strength of that relationship is likely to vary in space and time. In Maine and New Brunswick, L2 counts have so far been highly variable in areas with high moth trap catch and overall rates of L2 occurrence across plots have been relatively low. This project aims to collect data on pheromone trap catch and larval abundance in northern Maine ahead of the next outbreak



Key Findings

- Data from the winter of 2017–18 indicate that there continue to be very low levels of SBW overwintering larvae in northern Maine.
- 2017–18 L2 samples from Maine yielded a total of 32 larvae across 13 sample locations. No larvae were recovered at 242 of the 255 sites sampled.

- A limited aerial survey in late 2017 in northern Maine did not identify any areas where defoliation was evident.

STATEWIDE LIGHT DETECTION AND RANGING (LIDAR) DATA ACQUISITION

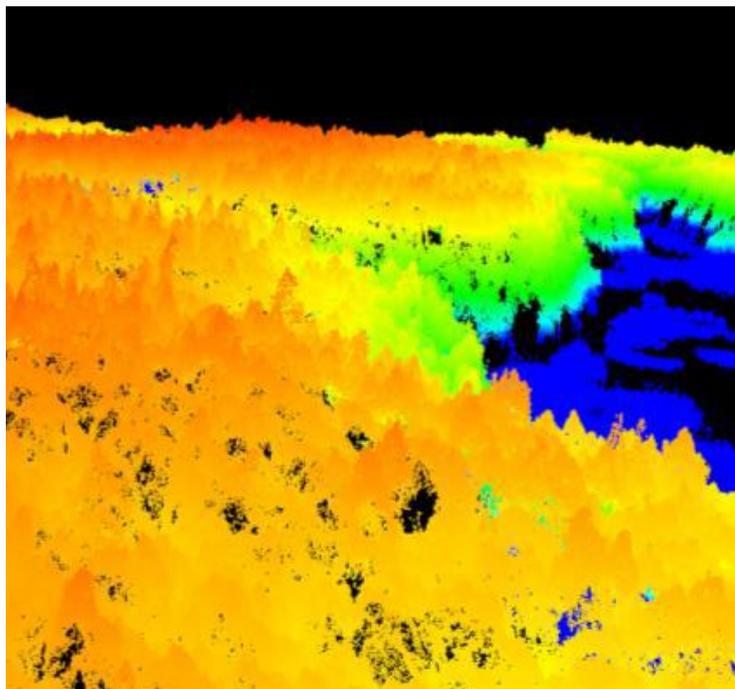
CFRU: Brian Roth; Maine office of GIS: Joseph Young; US Geological Survey: Dan Walters

Final Report (Year 5)

Light detection and ranging (LiDAR) is a remote sensing technology that uses pulses of light to generate a three-dimensional map of objects that reflect the light. These 3-D point clouds can be combined with ground truth data from field plots to generate algorithms that predict forest metrics such as merchantable volume, basal area, canopy height, stem density, etc., on a raster basis across the landscape. Combined with Geographic Information Systems (GIS), forest managers have the ability to make accurate, large-scale assessments of forest resources across the landscape. The goal of this project is to assemble a complete statewide base LiDAR dataset. This dataset will lay the groundwork for future high-resolution statewide mapping projects such as wet areas, soils, and wildlife habitat.

Key Findings

- There were approximately 6,000 square miles of new acquisition to USGS QL2 specifications and an additional 1,000 square miles covering areas with previously acquired LiDAR.
- Sensor problems, a short window of optimum data acquisition in the spring, and early snows in the fall of 2018 unfortunately prevented full data acquisition.



LiDAR points colored by elevation. Image courtesy The Wheatland Lab.

Wildlife Habitat

RESPONSES OF MARTEN POPULATIONS TO 30 YEARS OF HABITAT CHANGE IN COMMERCIALY MANAGED LANDSCAPES OF NORTHERN MAINE

UMaine: Daniel Harrison, Erin Simons-Legaard, Kirstin Fagan, Tyler Woollard

Progress Report (Year 1)

Since the enactment of the Maine Forest Practices Act, it is unclear to what degree forest-dependent wildlife have responded to the resulting patterns of landscape composition and connectivity. Previous CFRU-funded research on American marten, an area- and fragmentation-sensitive forest carnivore, demonstrated the utility of martens as an effective umbrella species for 71% of vertebrate species in Maine. Based on species occurrence models that were based on previous radio telemetry projects with martens funded by the CFRU, we predicted a widespread loss of marten habitat coincident with decreasing extent and increased fragmentation of suitable habitat patches during 1970–2007. Marten are a highly sought furbearer, and understanding more recent changes in habitat supply for martens is needed to ensure that marten harvests are sustainable and to ensure that managed landscapes continue to support viable marten populations. Thus, the goal of our project is to assess the cumulative effects of changes in habitat composition and landscape configuration on martens from 1989–2019 by documenting and comparing multi-scalar habitat associations and densities of resident marten over time. We are replicating systematic live-trapping and radio-tracking protocols conducted during previous studies during 1989–97. Preliminary results indicate that, despite consistent spatial and temporal



trapping effort, our 2018 spring catch rate was lower than experienced during seven prior field seasons conducted in the same area. We monitored 5 resident martens in 2018 and obtained > 40 locations on each. Further analyses will integrate data from our 2018–19 field seasons with prior studies, will compare the patterns of habitat selection and spatial use of resident martens, and will test and develop new models for predicting marten occurrence in contemporary landscapes.

Key Findings

- We established 292 trap sites throughout T4 R11 and T5 R11 WELS. Based on sex-specific home range estimates from prior studies, our trapping scheme resulted in effective surveyed areas of 179.4 km² and 153.7 km² for male and female marten, respectively. The spring 2018 trapping session (17 May–4 July) consisted of 2,954 trap nights and yielded 12 captures and recaptures, including 9 individual marten (7 males, 2 females). Despite consistent spatial and temporal trapping effort, our catch rate (0.4 captures per 100 trap nights) was substantially lower than observed during seven prior field seasons conducted in the same area.
- We affixed radiocollars to seven captured marten, two of which dispersed from the study area in late May. We attempted to locate each of the five remaining marten daily during the leaf-on season via ground-based telemetry (date of initial capture through 29 September), with locations of individual marten separated by a minimum of 12 hours to ensure spatial and temporal independence. We obtained an average of 45 relocations per animal, with location times distributed around the clock. Field testing with hidden radiotransmitters resulted in a mean angular error of 3.2° (standard deviation (SD) = 2.4) and a mean location error of 58.9 m (SD = 24.3). These error metrics were used to estimate confidence ellipses associated with individual locations.
- Consistent with prior marten research in the area, locations with confidence ellipses < 4.4 ha (99.6% of locations collected in 2018) were used to calculate 95% minimum convex polygon (MCP) home ranges.
- Despite comparatively lower trapping effort during fall (e.g., 102 total trap nights during fall versus 364 during spring), our fall capture success rate (14.7 captures per 100 trap nights) was an order of magnitude larger than our spring capture success rate among comparable trap sites (0.5 captures per 100 trap nights). This difference likely reflects the influx of juvenile animals known to disperse from Baxter State Park during this period (Phillips 1994), emphasizing the importance of surveying the density and spatial distribution of resident marten during May and June and avoiding surveys during other times of the year when nonresident animals represent the preponderance of captures.

BICKNELL'S THRUSH DISTRIBUTION AND HABITAT USE ON COMMERCIAL FORESTS IN MAINE

UMaine: Amber Roth, Kaitlyn Wilson; Maine Department of Inland Fisheries and Wildlife: Adrienne Leppold; Vermont Center for Ecostudies: John Lloyd

Progress Report (Year 1)

Bicknell's thrush (BITH) is a range-restricted habitat specialist occurring in balsam fir-dominated montane forests that have been recently disturbed and are undergoing successional growth. The

species traditionally occurs at elevations above 800 m in the U.S., but if suitable habitat is available, BITH can occur at lower elevations. The potential for suitable habitat at lower elevations exists in Maine because of the state's unique distribution of tree communities and due to changes in forest structure and composition brought about by forestry practices. By means of telemetry, resource selection functions, and LiDAR, we aim to understand the use of breeding habitat for BITH in commercial forestlands in Maine. The research will produce a description of BITH use of commercially managed fir-spruce forests in Maine. Furthermore, the research will contribute to the development of Maine-specific forest BMPs to provide high-quality breeding habitat for BITH while meeting commercial forest landowner objectives.

Key Findings

- We radio-marked 20 Bicknell's thrush (male = 18, female = 2) during 2018.
- We successfully tracked 11 individuals (6 in the harvested landscape, 5 in the non-harvested landscape) and collected 35–45 locations per bird.
- Preliminary data suggest that the species is using lower elevation habitat in commercial forests in Maine.
- Following analysis of habitat use, we will be able to recommend management practices to land managers to conserve breeding habitat for Bicknell's thrush on commercial forests in Maine.

DEVELOPMENT OF LARGE-SCALE OPTIMAL MONITORING PROTOCOLS FOR CARNIVORES

UMaine: Alessio Mortelliti, Bryn Evans

Progress Report (Year 1)

This is a multi-year, collaborative research project between the University of Maine, the Maine Department of Inland Fisheries and Wildlife, and the Cooperative Forestry Research Unit. We began with a pilot season during winter 2017 to test configurations of trail cameras to detect multiple carnivore species, followed by a summer of large-scale surveys. Year 1 of the CFRU project from October 2017 to September 2018 encompassed the first full-scale winter surveys, as well as the second summer season expanding into new regions and revisiting a subset of prior sites. We also cataloged the camera trap data by species observed in each image for the first year of surveys, and conducted preliminary occupancy models indicating interesting trends for top priority species and that the robust study design will provide valuable information to managers and researchers interested in how forestry practices and wild carnivore population dynamics interact.

Key Findings

- From our pilot season, we selected the optimal arrangement and spacing of trail cameras using multi-method analyses in program
- We selected an array of three cameras, with bait and lure, spaced 100 m apart to most effectively collect information on elusive carnivores in Maine, prioritizing marten, fisher, and coyote.
- During our first full year of large-scale surveys, we surveyed 120 sites in both summer and in winter, in 15 distinct study areas, for a minimum of two weeks each.
- Prior to our second summer field season, we selected sites representative of the first year study design components to be "permanent" survey locations, to allow analyses of trends

over the four year project, as well as sites in new study areas to expand our geographic coverage and include areas of intermediate timber harvest.

- From June to October 2018, we surveyed 40 permanent sites and 48 new sites for a minimum of three weeks each. Sampling fewer points in a season allowed for the longer survey period, which will enable a comparison of the overall benefit of additional weeks per survey. Table 6 summarizes our survey effort over either completed or planned for the first two years of the project.

LANDSCAPE-LEVEL EVALUATION OF DEER WINTERING HABITAT IN NORTHERN MAINE

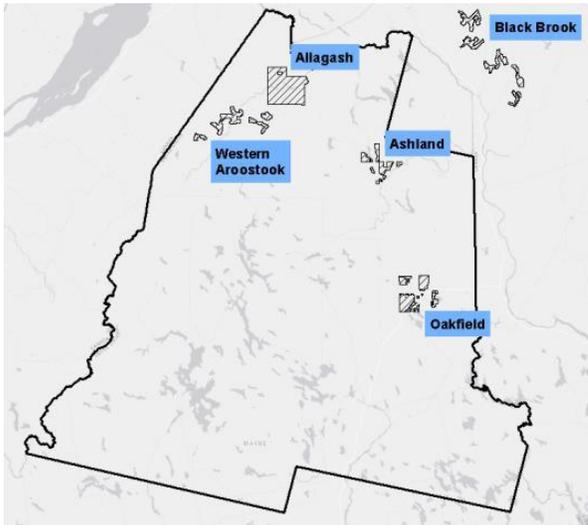
UMaine: Mindy S. Crandall, Amber Roth, Erin Simons-Legaard, Anthony Guay, Karin Bothwell, Daniel Hayes; CFRU: Brian Roth

Final Report

The goal of this project was to expand current wildlife habitat, forest management, and landscape dynamics knowledge in a novel way, bridging previous work and newly available spatial data to contribute information that will help reduce landowner uncertainty and achieve better habitat results in deer wintering areas. To date, we have completed a region-wide analysis to identify areas that currently exhibit the characteristics of white-tailed deer wintering habitat and a quantitative evaluation of that habitat's distribution. Results confirmed that the original zones effectively protected patches of softwood-dominated forest from intensive timber harvests; many patches of potential wintering habitat persist across northern Maine and tend to be aggregated on the landscape. Specific deer wintering area boundaries were digitized from aerial surveys conducted during winter in 1957–2015 across northern Maine. We developed two deer habitat quality models, one using the Maine Department of Inland Fisheries and Wildlife's deer wintering areas management guidelines for primary and secondary winter shelter and the second also includes basking habitat within 250 m of the winter shelter. Historically occupied deer wintering areas continue to have a high proportion of high-quality wintering habitat. The deer wintering areas for which we have the most recent occupancy information (1990s in Maine, 2000s–2010s in New Brunswick) had the lowest proportion of high-quality wintering habitat, suggesting that deer may be selecting these deer wintering areas, at least in part, for other reasons.

Key Findings

- While deer wintering area management restrictions can result in a financial loss relative to a business-as-usual scenario, this finding is not universal and is highly dependent on landowner objectives and starting stand conditions. Further work is needed to expand calculations to a landscape level.
- Deer wintering area boundaries were digitized from aerial surveys conducted during winter in 1957–2015 across northern Maine and western New Brunswick. Deer wintering area occupancy information from Maine was collected in 1957–99 (17 years with data) and 2003–15 (4 years with data) in New Brunswick. No deer surveys were conducted in years when snow conditions were inappropriate for an area. As a result, not all study site clusters were surveyed within a year, and there were many years when no surveys were conducted anywhere in the study area.



Project study area, including 10 million- acre area (bold black outline) used for expanded map of potential deer wintering habitat and five study site clusters in northern Maine and western New Brunswick (black hatched areas) that were the area of interest for the deer wintering habitat quality models.

- We developed two deer habitat quality models, one using the Maine Inland Fisheries and Wildlife’s “Guidelines for Wildlife: Managing Deer Wintering Areas in Northern, Western and Eastern Maine (version 2.4.10)” to map primary and secondary winter shelter and the second also included basking habitat within 250 m of the winter shelter. Contrary to our prediction, the proportion of non-winter deer habitat (i.e., anything other than winter shelter and basking habitat) did not decline since time of deer wintering area occupancy. Historically occupied deer wintering areas continue to have a high proportion of high-quality wintering habitat, both winter shelter and basking habitat. Deer wintering areas occupied in the 1990s (Maine) and 2000–2010s (New Brunswick) suggest that these most recently occupied deer wintering areas have the lowest proportion of high-quality wintering habitat.
- We identified four key issues with the deer habitat quality model development that should be addressed in future models. First, our study site clusters were not clipped to deer wintering areas because these areas were being digitized into a GIS concurrently with habitat model development. Second, we modeled canopy cover based on leaf-on LiDAR data but this metric would be more accurately modeled for winter shelter using leaf-off LiDAR data. Third, we assumed that canopy cover was highly correlated with canopy closure which we know is inaccurate. Canopy closure is difficult to measure from LiDAR data, and a procedure has yet to be developed by anyone in the field. Finally, the lack of recent/current deer wintering area occupancy information precluded comparing them to historically occupied deer wintering areas.
- We defined the composition component of deer wintering habitat based on the four most abundant tree species (which were northern white-cedar, balsam fir, red spruce, and black spruce), within the 373 Fish and Wildlife Protection subdistricts (P-FWs) that occurred within our 10 million-acre study area. Average relative abundance within the P-FWs for these species were 22%, 20%, 17%, and 10%, respectively. In combination, the four species represented 69% of the relative abundance of live tree biomass on average; one of the four species was the dominant species in 94% (350 out of the 373) of the P-FWs in our study area.
- In total, 744,875 ha of mature forest (i.e., > 40 years old) had the compositional characteristics associated with P-FWs (Figure 21a). Seventy-nine percent (591,399 ha) of this deer wintering habitat occurred in patches greater than or equal to 10 ha. P-FWs commonly encompassed portions of larger habitat patches.
- Simulations suggested landscape-scale risk of budworm mortality varied widely by P-FW, and was strongly influenced by the local dominance of host species.

Partnerships

An important dimension of the CRSF's mission is collaboration with other programs that can help advance research on various aspects of forest resources. These partnerships strengthen our overall mission by leveraging funds, facilities, and talent, as well as fostering interdisciplinary cooperation on key issues facing forest resources. For example, CRSF continues to provide leadership as part of the **Spruce Budworm Task Force**, maintaining its website and related social media focus on all aspects of budworm-related research efforts related to the coming spruce budworm outbreak in northern Maine. The CRSF also leads Theme 3 of the **Northeastern States Research Cooperative (NSRC)**, which has provided competitive research funding since 2006 for projects that advance understanding about forest productivity. CRSF researchers are active participants in the **National Science Foundation's Center for Advanced Forestry Systems (CAFS)**, which provides funding with nine other industry/university forest research cooperatives across the country. CRSF is also home to long-term research forests, including Howland Research Forest, which is part of the national **Ameriflux** network measuring the atmospheric flux of carbon dioxide; Holt Research Forest, site of ecosystem research; and the Penobscot Experimental Forest, a USFS-UMaine research partnership. The CRSF is a proud partner in **Forests for Maine's Future**, which provides a social media and website connection on important forest resource issues to the general public, and collaborates on a number of relevant issues with the **Maine Forest Product's Council**, **Maine TREE Foundation**, and the **Maine Forest Service**. Finally, we extend our appreciation to the **Munsungan Endowment** for supporting many of the CRSF's outreach efforts.



Center for Advanced Forestry Systems



This year saw the completion of the final year of Phase II for the UMaine site under the [Center for Advanced Forestry Systems](#) (CAFS). CAFS is funded by the National Science Foundation (NSF) Industry/University Cooperative Research Centers Program (I/UCRC) in partnership with CFRU members. CAFS is a partnership between CFRU members and I/UCRC to support a University of Maine research site for CAFS. CAFS unites ten university forest research programs with forest industry members across the United States to collaborate on solving complex, industry-wide problems at multiple scales. CAFS is a multi-university center that works to solve forestry problems using multi-faceted approaches and questions at multiple scales, including molecular, cellular, individual tree, stand, and ecosystem levels. Collaboration among scientists with expertise in biological sciences (biotechnology, genomics, ecology, physiology, and soils) and management (silviculture, bioinformatics, modeling, remote sensing, and spatial analysis) is at the core of CAFS research.

During the 5-year span of Phase II the NSF contributes \$60,000 per year to the center as long as CFRU members contribute a minimum of \$350,000 per year to support the work of the site. This past year of CAFS funding supported two projects led by University of Maine researchers (Understanding and Modeling Competition Effects on Tree Growth and Stand Development Across Varying Forest Types and Management Intensities and Modeling the Influence of Spruce Budworm on Forest Productivity). In 2017, the University of Maine became the lead institution for CAFS and CRSF Director Weiskittel was approved as Director. In June 2018, the CRSF organized the annual Industry Advisory Board meeting held in Athens, Georgia. Thirty-five participants used the day to review and discuss ongoing research, assess new proposals, and consider the future of CAFS after Phase II ends. The meeting was followed by a full-day field trip around Georgia's Loblolly Pine plantations looking at fertilization trials and rain exclusion sites.



FOR/Maine



Strong forest. Strong economy. Strong communities.

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. The coalition was created with support from the U.S. Economic Development Agency and U.S. Dept. of Agriculture to assess Maine's current industry, assets, and readiness, and to determine a strategy to capitalize on new opportunities. The CRSF is an integral part of this effort, leading committees focused on the forest industry sector and wood supply. Maine forests are a critical anchor for the state's overall economy, and forest outputs can be made into a staggering array of products, from packaging and advanced building materials, to eco-friendly chemicals and biodegradable plastics (replacing harmful petrochemicals), textiles, and cutting edge medical and technical products made from nanocellulose. Technology, globalization, and evolving social trends are bringing change and new opportunities to Maine's traditional forest economy. The industry is adapting and diversifying in response, developing new economic revenue streams to produce sustainable, bio-based products for both domestic and global markets—all while conserving natural lands for recreation, tourism, and wildlife. Maine's forest communities are creating the conditions to attract investment and high-quality jobs to rural areas, including efforts to redevelop mill sites and improve broadband access in rural areas. FOR/Maine has established three primary goals to ensure that Maine adapts to market changes quickly and strategically in order to maintain our leading role in the global forest economy.

Goal 1: Sustain and strengthen Maine's existing forest products businesses.

Goal 2: Attract capital investments and develop greater economic prosperity in the forest products sector, for both existing and new businesses across the state.

Goal 3: Support the revitalization of Maine's rural communities as places where people want to live, work and visit.

For more information on FOR/Maine, visit their website at www.formaine.org.

Northern States Research Cooperative



The **Northeastern States Research Cooperative** (NSRC), a critically important source of funding for applied forest research and outreach efforts throughout the Northern Forest since its inception in 2001, is jointly directed through the USDA Forest Service, Northern Research Station, and a designated institution in each of the four Northern Forest states: The Rubenstein School of Environment and Natural Resources at the University of Vermont, the University of New Hampshire in

cooperation with the Hubbard Brook Research Foundation in New Hampshire, the Center for Research on Sustainable Forests at the University of Maine, and the State University of New York College of Environmental Science and Forestry.

Over the years, NSRC has provided funding for more than 335 individual projects from 50 different organizations. Projects span 14 core research interest areas, particularly Atmospheric Pollution, Forest Management & Productivity and Land Use Planning & Development. This has resulted in an extensive and relevant body of knowledge that applies to a range of stakeholders throughout the region. NSRC research has been the subject of 174 graduate student theses, more than 300 peer-reviewed publications, and approximately 900 professional presentations. In 2017, after 16 years and nearly \$25 million in research funding, the US Forest Service funding for the NSRC was suspended. In January 2018, the NSRC directors and Hubbard Brook Research Foundation convened a full-day workshop to generate a strategic vision for its future. Participants represented a wide spectrum of perspectives, ranging from university researchers, private landowners, conservation groups, and private, state, and federal foresters to legislative representatives and the NSRC administrators. Workshop attendees focused on Northern Forest research priorities, funding obstacles, and new and ongoing concerns and the role a revamped NSRC might play.

Throughout 2018-19, the NSRC directors have continued to seek Forest Service funding from Congress, as well as federal agencies like the Department of Commerce. They are actively exploring partnership opportunities with regional groups with similar charges such as the Northern Border Regional Commission and Forest Ecosystem Monitoring Cooperative, but it is crucial to note that the FEMC and NBRC do not fund new research.

Northern Forest Narratives

Dr. Jay Wason



Assistant Professor of Forest Ecosystem Physiology, University of Maine School of Forest Resources

Current Research: Addressing climate change and drought impacts on forest tree physiology.

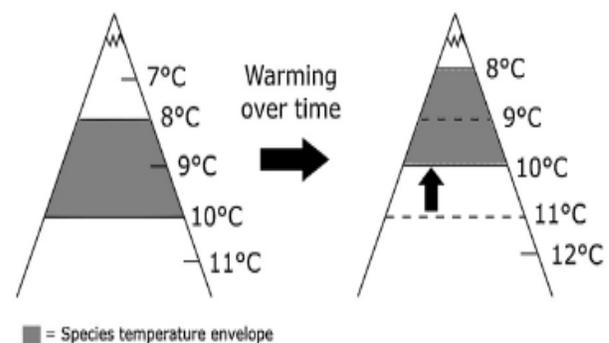
NSRC Project Participation: Global Change Fingerprints in Montane Boreal Forests; NSRC funding provided support for Jay's Research Assistantship and field work to complete his PhD research

When Jay began his doctoral studies at SUNY-ESF, he was not too familiar with the role of NSRC—but that changed drastically when his advisor Martin Dovciak was awarded a grant in 2011 to study the implications of global change on montane boreal forests and related implications for biodiversity and management of the Northern Forest. The NSRC funding meant a small research project that was originally focused on one mountain (Whiteface in NY) could be expanded beyond the Adirondacks to 12 mountains across the Northern Forest region (including 3 in Maine: Old Speck, Sugarloaf, and Mt. Bigelow).

The NSRC grant provided several years of funding for an assistantship that enabled Jay to conduct the field research that served as the basis for his 2016 PhD dissertation. Jay gained invaluable practical knowledge as he was charged with setting up the research sites and sensors for data collection, measuring and analyzing microclimates at the network of vegetation plots, permitting, and hiring additional field technicians.

As a young student from New York State, Jay pictured himself staying focused on the Adirondacks and environs. Yet this project broadened his horizons as the work led him to collaborate with researchers and stakeholders across the Northeast, and to interact with federal and state agencies

Conceptual depiction of how a hypothetical temperature envelope on one mountain can shift upslope with climate warming. Detection of rapid temperature change in montane ecosystems throws into doubt the theory that mountains will have more stable climates that could protect some boreal species from climate change.



According to Jay, in addition to financial support for his research, NSRC “helped me to establish connections [TNC, UVM, Dartmouth, UM] and expand academic breadth and opportunity for new collaborations. The scope of the work accomplished has led not only to my dissertation and a number of journal articles, but was directly relevant to gaining post-doc work at Yale.”

When asked if there were resources other than NSRC to support the research, he said: “Not at the same size and scope. We would not have been able to expand to that scale without the funding. It allowed us to have greater applicability and to publish in much better journals than would have been the case if we were restricted to a single site.”

Now, as he forges ahead with his career at the University of Maine, he is frustrated that the NSRC is not currently funding new projects. It was a program that was instrumental to a generation of grad students such as Jay, and the lack of such a regional program has directly hindered research capability and his ability to support the next generation of forest researchers.

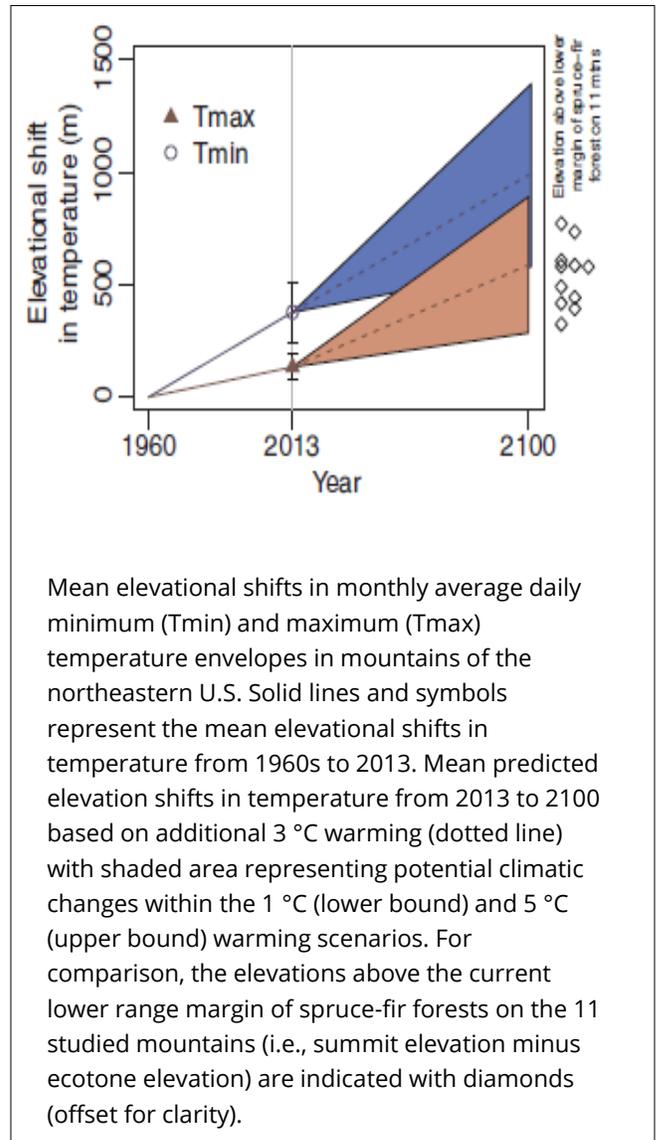


Dr. Jay

Wason joined the SFR faculty in 2018 as an Assistant Professor of Forest Ecosystem Physiology. Before joining SFR, Dr. Wason was a postdoctoral associate at the Yale School of Forestry & Environmental Studies. His research uses lab and field studies to determine the physiological responses of northeastern forest trees to novel future climate conditions.

To learn more about the project goals and outcomes:

<https://nsrcforest.org/project/montane-tree-species-distributions-not-yet-shifting-upslope-response-changes-climate>



Silvicultural Strategies for Mitigating Northern Forest Carbon Reversal Due to Spruce Budworm

Mark Ducey, University of New Hampshire; John Gunn, University of New Hampshire; Thomas Buchholz, Spatial Informatics Group

Affiliated Scientist: Ethan Belair, University of New Hampshire

YEAR 3 PROGRESS REPORT

Summary

An outbreak of eastern spruce budworm (SBW; *Choristoneura fumiferana*) is projected to impact the Northern Forest Region in the coming decade, and many forest stands in the region are at risk of substantial disturbance. The SBW outbreak will affect product flows and yields, as well as stand structures and carbon storage. The direct impacts of SBW and associated salvage or pre-salvage activities carry risks of carbon reversal, which must be factored into eligibility and pricing for forest-based greenhouse gas offsets in the region. At the same time, sound SBW risk management may confer some benefits by reducing or mitigating stand- and landscape-level risk, and by capturing carbon in wood-in-use pools from at-risk and dying trees that would otherwise be lost.

We have been using a modeling approach, based on current data from the U.S. Forest Inventory and Analysis (FIA) program, to understand the value and carbon consequences of salvage, pre-salvage, and business as usual scenarios across a range of stand risk profiles, both in the presence and absence of SBW attack. In the final year of this project, we have focused our attention on greenhouse gas consequences, and on development of operational guidance for

pre- and post-attack silviculture that can help mitigate carbon impacts and put high-risk stands on a more sustainable trajectory.

Project Objectives

- Develop projections of future forest and wood-in-use C pools for FIA plots and re-measured old-growth plots in the Northern Forest region, under alternative management strategies and budworm attack outcomes.
- Evaluate the influence of initial stand conditions and probability of budworm attack on optimal C strategies and the tradeoffs associated with alternative choices.

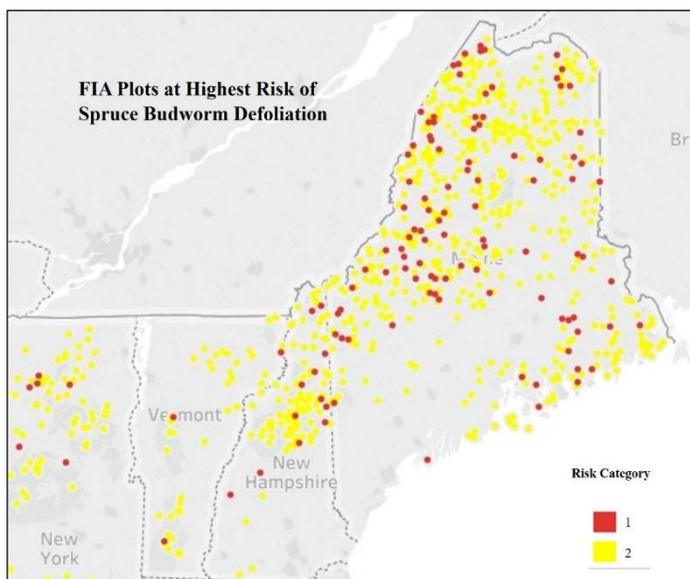


Figure 1. Map of highest-risk FIA plots for SBW attack in the study region.

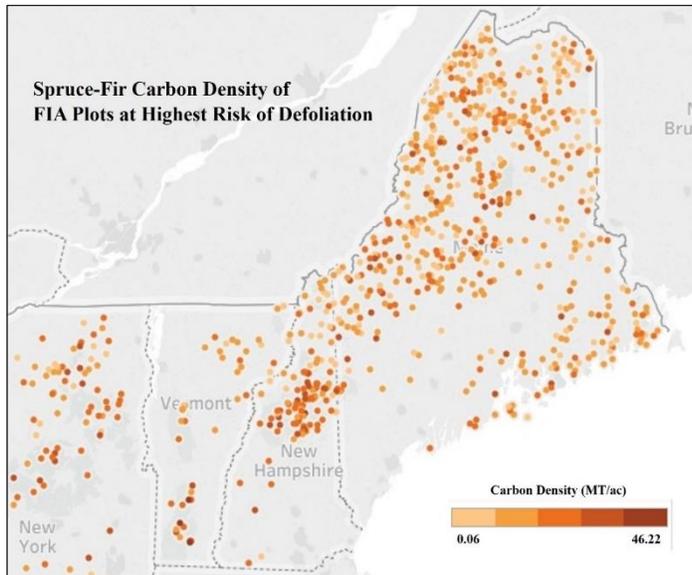


Figure 2. Carbon at risk from SBW attack on FIA plots with the highest risk rating

- Assess the carbon offset market transaction feasibility of implementing strategies for avoiding or mitigating budworm-associated C reversal.

Approach

We formalized the alternatives put forward by Hennigar et al. (2011) and Wagner et al. (2014), into a structured decision network enumerating the meaningfully different alternatives for simulation. This work was completed in prior project years.

We used the Forest Vegetation Simulator (FVS-FFE) to simulate future C and product yields for FIA plots in the Northern Forest.

Simulations included business-as-usual (BAU), enhanced risk management, and no-management alternatives for each plot. Plots were grouped based on the risk categories developed by Wagner et al. (2014). This work was completed for all scenarios, for all plots in the study area, in the last project year. Example results are shown in Figures 1 and 2.

The results of the simulation have been ported to a web-enabled, interactive mapping and graphing tool to allow users to query the data by plot attributes and geographically. We have continued to update the website as new results have been obtained. A screen capture of the web site is shown in Figure 3.

We tracked forest C stocks (e.g., live and dead trees, belowground roots, leaf litter) and life cycle GHG emissions of harvested wood products for 40 years using model outputs derived from FVS scenarios. Forest sector life-cycle emissions used assumptions developed for the Northern Forest region by Hennigar et al. (2013) and further modified by Gunn and Buchholz (Gunn and Buchholz, 2018). Life-cycle forest-sector C pools include: 1) storage in above- and below-ground live biomass and dead organic matter components (Total Stand Carbon); 2) storage in forest products in use and in landfills; 3) forest-sector emissions by harvest, transport, and manufacturing or avoided emissions (substitution; bioenergy). This work was finalized during this project year; example results are shown in Figure 4.

Key Findings / Accomplishments

As part of the initial stratification of stands in the study region into risk categories, we identified a widespread pattern of under-stocking across the study region. We also found that the only significant contribution to an increase in merchantable stocking comes from balsam fir, the preferred host of SBW. These findings informed a manuscript which was published during this project year (Gunn et al. 2019).

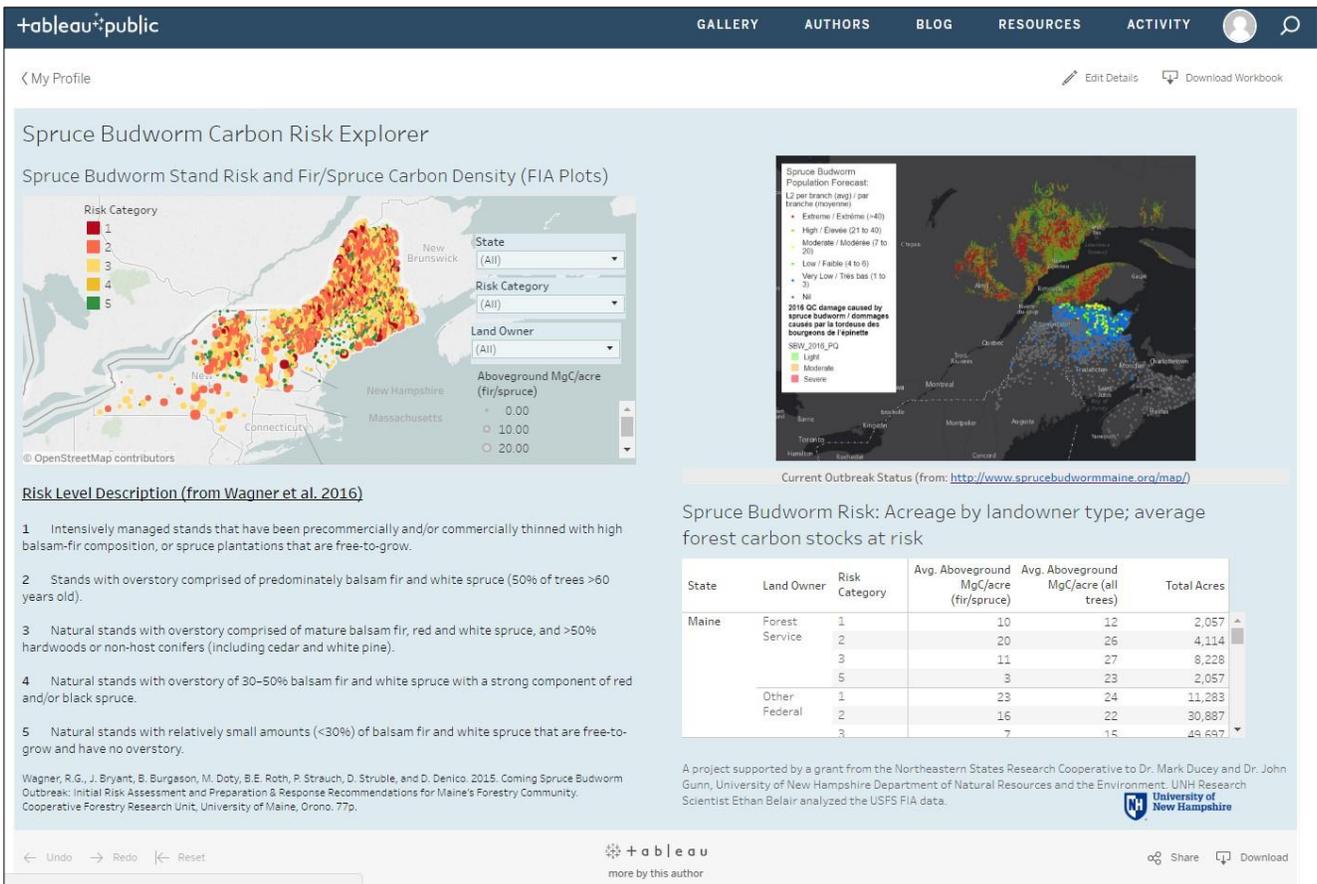


Figure 3. Web portal for interactive query and display of FIA data and simulation results.

Forest management actions such as salvage harvesting designed to mitigate pest impacts over time can have positive impacts on overall C balances, by reducing the risk of catastrophic loss in susceptible stands and landscapes and by capturing C in at-risk or dying trees by using the harvested wood in building materials or displacing fossil-fuel intensive energy sources. However, this carbon resilience comes at a short-term cost to the atmosphere that can last up to 20 years.

Decisions to salvage dead or dying trees should weigh the climate change implications of near-term net emissions and economic benefits vs. potential long-term recovery of forest carbon.

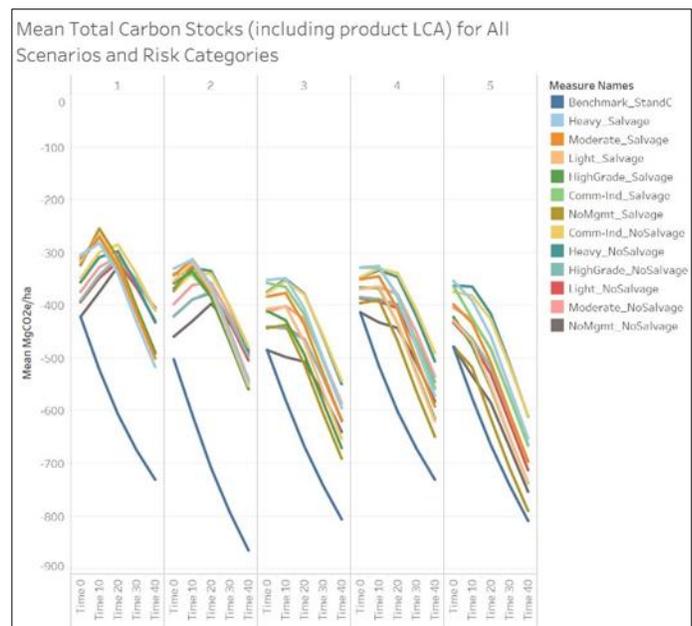


Figure 4. Total forest and product carbon stocks for all silvicultural scenarios and risk categories.

Nitrogen Controls on Detrital Organic Matter Dynamics in the Northern Forest: Evidence from a 26-year Nitrogen Addition Experiment at the Bear Brook Watershed in Maine

Dr. Ivan J. Fernandez, School of Forest Resources and Climate Change Institute, University of Maine; Dr. Marie-Cécile Gruselle, Dr. Shawn Fraver, and Dr. Christian Kuehne, School of Forest Resources, University of Maine; Cheryl J. Spencer, Michaela Kuhn, Audrey Garcia, and Devon Rossignol, School of Forest Resources, University of Maine; Matt Bonner and Cowin Sikora, Ecology and Environmental Sciences, University of Maine; Ridge Osgood, Wildlife, Fisheries, and Conservation Biology, University of Maine; Elyse Daub, Bangor High School

YEAR 3 PROGRESS REPORT

Summary

The main goal of this project is to better understand the influence of elevated N input on downed wood debris dynamics. The focus of the work over the past year has been the analysis of downed coarse and fine woody debris (CWD and FWD, respectively) already collected in the project. No additional installation or collection activities were carried out this past year for the standard wood 'decay stake' experiment at the Bear Brook Watershed in Maine (BBWM) as planned. Between 1989 and 2016, the BBWM was a manipulative whole-ecosystem and paired-watershed experiment with one watershed receiving N fertilizer and another one remaining untreated. In 2016 West Bear treatments ceased and the research focuses on recovery from acidification and response to a changing climate. Prior ¹⁵N tracer additions at the site allow us to determine the fate of N in decomposing wood stakes and woody debris. To our knowledge, this study is one of the first to investigate N and ¹⁵N dynamics in coarse and fine woody debris concomitantly for two major tree species (*Acer saccharum* and *Picea rubens*) in the Northern Forest in relation to ecosystem N status.

Project Objectives

- Determine the biomass, C and N concentrations, and ¹⁵N composition, of downed woody detritus in the treated and the reference watersheds at the BBWM by species and decay class.
- Compare C and N dynamics and ¹⁵N recoveries in standard 'decay stakes' of sugar maple and red spruce between watersheds in a field decomposition experiment.
- Test the influence of ecosystem N status, decay stake characteristics (tree species, initial wood density and chemistry), and local drivers of decomposition on C and N dynamics and ¹⁵N recoveries of sugar maple and red spruce wood 'decay stakes' in a field decomposition experiment.

Approach

During the past year analyses continued from samples collected as part of the descriptive approach of CWD and FWD sampled at the BBWM in prior years. The 'decay stakes' from the experimental approach were left in place this past year as planned in the study of in situ wood decomposition.

Key Findings / Accomplishments

- A total of 402 CWD and FWD samples were processed at the University of Maine, and then shipped and analyzed at the University of California – Davis Stable Isotope Facility.
- Samples were analyzed for total C, total N, ^{13}C , and ^{15}N .
- 66 samples needed to be reanalyzed in order to meet the C and N mass criteria for isotopic analysis and were rerun separately for ^{13}C and ^{15}N .
- Sample distribution included isotopically treated: 278 total (142 CWD, 136 FWD), external to the treatment area 124 total (38 CWD, 86 FWD).

Future Plans

- Assembling all of the data, reviewing final QA/QC prior to statistical analyses and writing.
- Writing a publication on C and N budgets at the BBWM including downed CWD and FWD C, N content and isotopic data.
- Collecting the first half of the red spruce and sugar maple 'decay stakes' (160 in total) from the field and determine the mass loss and chemistry (C, N, ^{15}N) of the 'decay stakes'.
- Submitting the processed decomposed decay stakes to UC Davis Stable Isotope Facility for C, N, and ^{15}N analyses.
- Writing a publication on the influence of ecosystem N status and local drivers of decomposition on mass loss, chemistry, and ^{15}N recoveries of sugar maple and red spruce wood 'decay stakes'.



Classifying and Evaluating Partial Harvests and Their Effect on Stand Dynamics in Northern Maine

Dr. Christian Kuehne, Dr. Kasey Legaard, and Dr. Aaron Weiskittel, School of Forest Resources, University of Maine

Affiliated Scientist: Dr. Erin Simons-Legaard, School of Forest Resources, University of Maine

FINAL REPORT

Summary

This project used both field measurements and remote sensing data sources to quantitatively characterize harvesting trends across Maine. Owing to substantial methodological improvements and a collaboration with the University of Maine System Advanced Computing Group, a statewide expansion of remote sensing and spatial analyses based on new, more efficient software implementations of existing algorithms was conducted. As a result, we refined methods for mapping harvest events, harvest intensity, and pre-harvest composition which resulted in tangible improvements to maps. The improved maps revealed that regional differences in factors that influence harvest regimes such as ownership, forest management legacy, and bioclimatic conditions caused apparent regional differences in post-harvest conditions. Based on these findings, we further developed new harvest probability and intensity as well as harvest response submodels for incorporation into the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD). The harvest occurrence submodels verified the results from our mapping efforts on influential factors while the response functions were driven by thinning intensity and to a lesser extent by thinning method. The derived equations substantially improve prediction accuracy of stand-level post-harvest conditions and dynamics and will be used to update wood supply projections for the state of Maine as part of potential future research efforts.

Project Objectives

- Refine and evaluate the distribution of partial harvest conditions in Maine.
- Map incremental changes in partial harvest conditions across a ~10 million acre study area and a ~30 year time period.
- Predict and quantify the shift in species composition and structure of residual stands created following partial harvest.

Approach

Apply a forest harvest classification system based on basal area removed, residual basal area, and pre-harvest species composition to USFS Forest Inventory and Analysis (FIA) plot

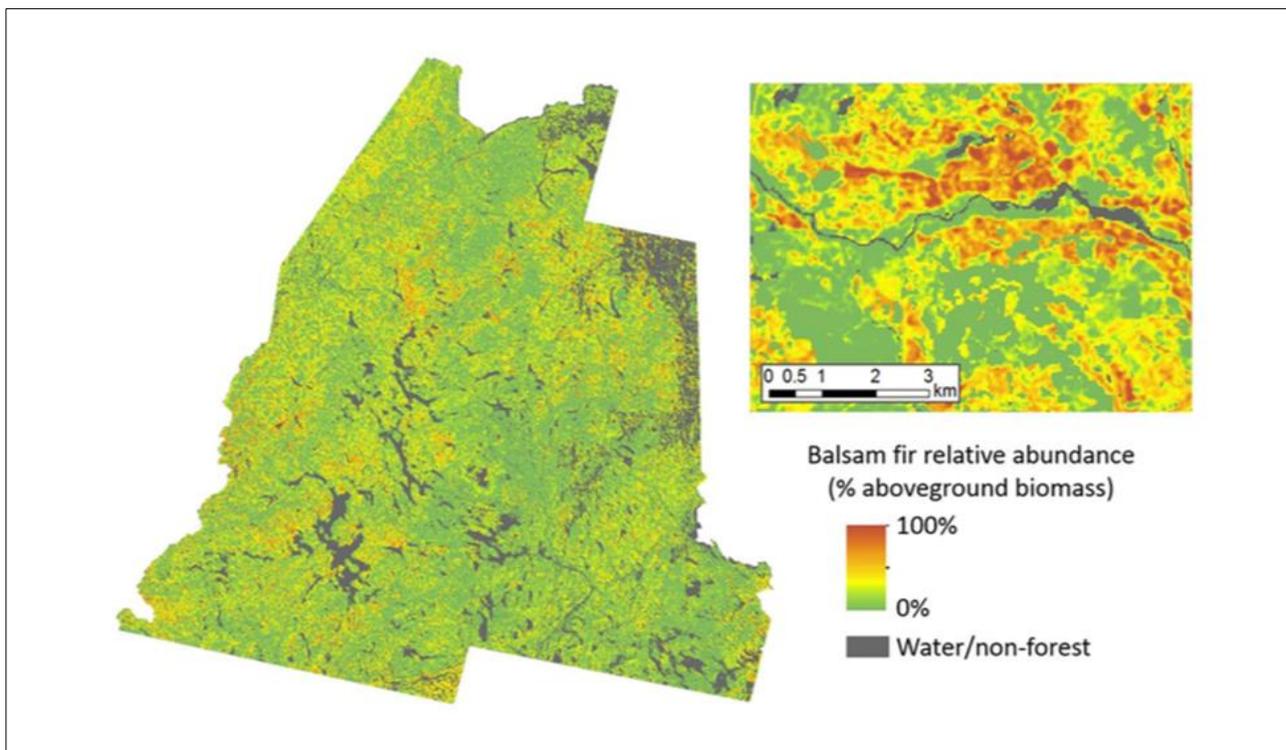


Figure 1. Example of satellite-derived map of forest conditions using machine learning techniques that effectively reduce undesirable systematic error as part of the ongoing collaboration with the UMS Advanced Computing Group.

measurements to evaluate the distribution of partial harvest conditions across a ~15 year time period.

Map partial harvest conditions across a ~30 year time period using spatial models of basal area removed, residual basal area, and pre-harvest species composition based on a time series of Landsat satellite imagery linked to FIA field measurements (Figure 1).

Predict/project the development of residual stands created from partial harvest using a newly developed harvest submodel to be incorporated into the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD).

Further extend and update FSV-ACD by incorporating additional submodels (so-called thinning modifiers) projecting individual tree growth and mortality after various types of partial harvest.

Key Findings / Accomplishments

We have compiled FIA data statewide (2000-2015) and classified apparent harvest events across three separate measurement cycles at each plot. After compiling results into rolling 5-year measurement periods, we have analyzed outcomes for trends in harvest conditions and found little evidence of contemporary shifts in partial harvest practices as characterized by the proposed harvest classification system.

Regional differences in factors that influence harvest regimes (e.g., ownership, forest management legacy, bioclimatic conditions) caused apparent regional differences in harvest

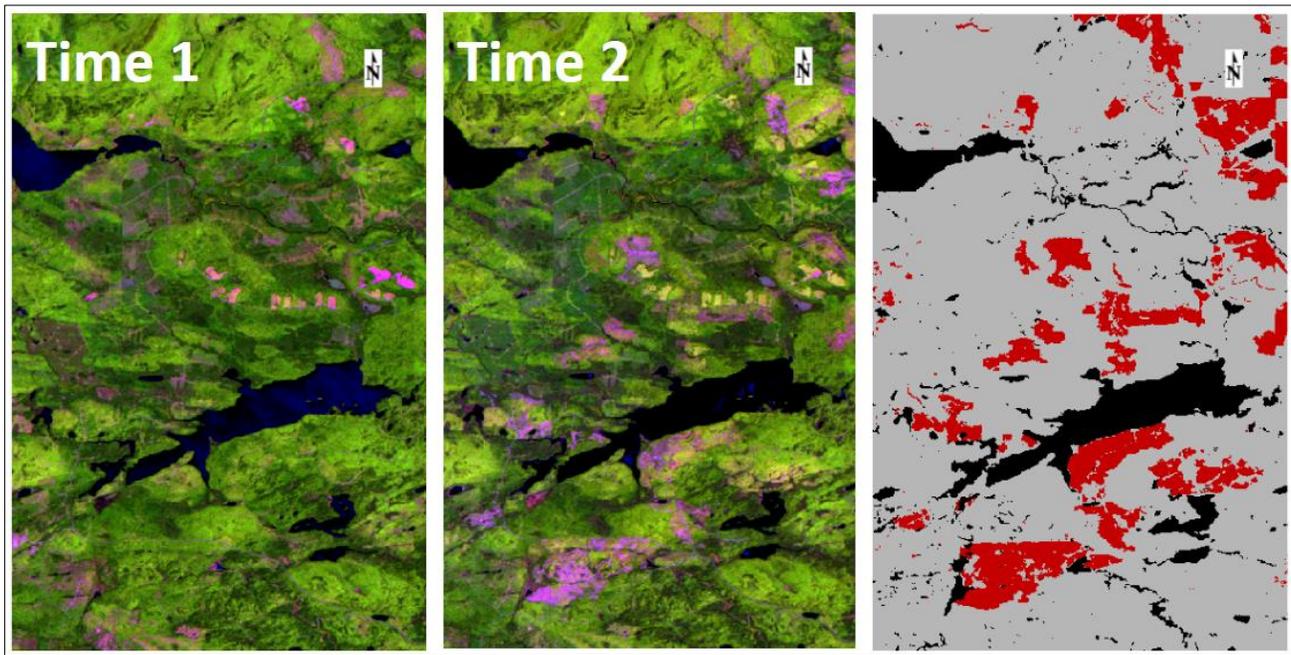


Figure 2. Sample of preliminary forest change detection outcomes generated from a new machine learning and remote sensing workflow developed in collaboration with the UMS Advanced Computing Group. This machine learning approach effectively eliminates bias in maps of forest disturbance, enabling more consistent estimation of disturbance characteristics and more reliable detection of temporal trends.

conditions. These differences are of potential importance to spatial wood supply analyses, reinforcing the need to extend analyses by linking FIA to Landsat.

We have refined methods for mapping harvest events, harvest intensity, and pre-harvest composition, through significant improvements in data handling and prediction algorithms. These resulted in tangible improvements to maps.

Under other funding, we have partnered with software and cyberinfrastructure engineers in the University of Maine System (UMS) Advanced Computing Group to develop a much more parallelized implementation of our prediction algorithms coupled with more efficient and more flexible workflows. This new software implementation helped us to overcome computation and data management barriers that have thus far limited work to a northern Maine study area. A statewide expansion of mapping objectives now provides a comprehensive accounting of harvest trends needed for a statewide spatial wood supply analysis (Figure 2).

In order to account for and implement the aforementioned new findings we also developed and incorporated new submodels into FVS-ACD, namely (i) stand- and individual tree-level harvest equations predicting probability and intensity of harvest activities and (ii) individual tree-level harvest response functions for the two most important conifer species of the study area (red spruce and balsam fir).

Among the most influential stand- and tree-level attributes affecting harvest occurrence were quadratic mean diameter, stand density, elevation, and ownership, as well as diameter at breast height, basal area in larger trees, and species, respectively. Duration and magnitude of the individual tree-level annual diameter increment, height to crown base increment, and mortality

response functions were significantly influenced by thinning intensity and to a lesser extent by thinning method (Figure 3).

We have partially leveraged this project and obtained additional funding to support refinement of predictions of stand dynamics after forest management interventions (funding agency: Cooperative Forest Research Unit, funding amount: \$34,102, project title: Development of individual-tree and stand-level approaches for predicting hardwood mortality and growth response to forest management treatments in mixed-species forests of northeastern North America).

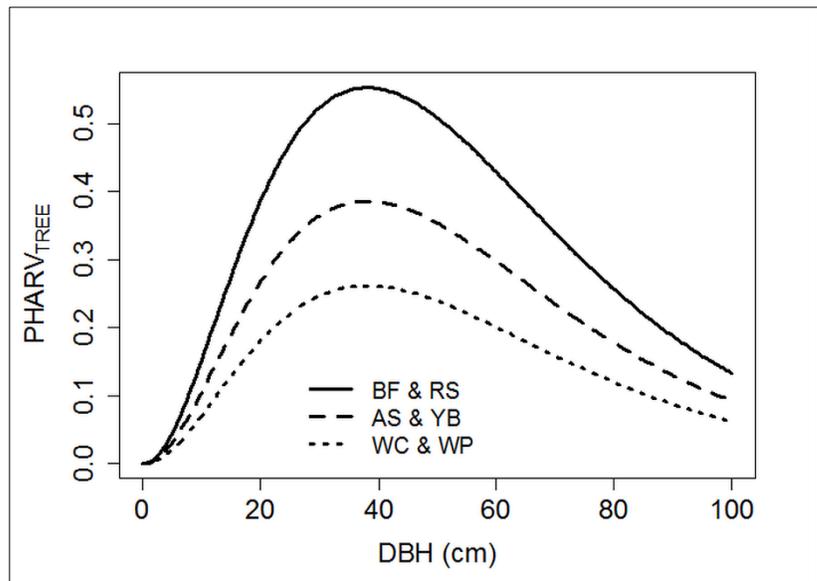


Figure 3. Predicted 5-year harvest probability ($PHARV_{TREE}$) for individual balsam fir/red spruce (BF & RS), ash/yellow birch (AS & YB), and northern white cedar/white pine trees (WC & WP) of harvested plots as a function of diameter at breast height (DBH).

In addition, as part of the initiated collaboration with the UMS Advanced Computing Group further funding for undergraduate student involvement could be secured (funding source: University of Maine System Research Reinvestment Fund Student Awards Competition, award type: undergraduate assistantship, project title: Leveraging machine learning and high-performance computing to deliver the spatial data needed by Maine's forest industry).

Future Plans

- Information derived from plot-level analyses and mapped partial harvest conditions will be used to define common classes of partial harvest and the resulting residual stand conditions.
- Development of harvest response functions for common hardwood species such as yellow birch, red and sugar maple, and red oak.
- Using the updated Acadian Variant of the Forest Vegetation Simulator we will project the development of residual stands created from common classes of partial harvest to quantify short- and long-term shifts in species composition and structure.
- Finally, an all-new wood supply analysis for the state of Maine can be conducted based on results from above research efforts.

A Long-Term Perspective on Biomass Harvesting: Northern Conifer Forest Productivity 50 Years after Whole-Tree and Stem-Only Harvesting

Laura Kenefic, USDA Forest Service, Northern Research Station; Bethany Muñoz, USDA Forest Service, Northern Research Station and University of Maine, School of Forest Resources; Aaron Weiskittel, Ivan Fernandez, Jeffrey Benjamin, and Shawn Fraver, University of Maine, School of Forest Resources

FINAL REPORT

Project Summary

Though whole-tree harvesting has become increasingly common in the northeast, there are concerns about the incremental removal of biomass on long-term site productivity relative to conventional bole only harvests. Furthermore, application of prescribed burning on slash following harvest, also has the potential to significantly reduce aboveground biomass affecting long-term site productivity. However, limited knowledge exists pertaining to the influence of either treatment on northern mixedwood productivity in the long-term.

To address these knowledge gaps, this project quantified productivity in the oldest known study of biomass harvesting in temperate forests worldwide, at the Penobscot Experimental Forest in Maine. This study, named C33, was established in 1964-65 within a 70-80-year-old spruce-fir dominated stands of low-moderate production potential, before the widespread conceptualization of whole-tree harvesting. Treatments were a strip-cut (all trees > 1.3 m in height were felled) with 1) whole-tree harvesting (WTH); 2) stem-only harvesting (SOH); and 3) stem-only harvesting with prescribed burning (SOHB) (Figure 1). Within four years following treatment, it was observed that the hardwood component of the regenerating stand increased compared to pre-harvest estimates.



Todd Douglass (left) and Hari Soman (right) of the University of Maine conducting time trials on equipment used during the 2018 winter harvest in C33. Photo courtesy Bethany Muñoz

Sites that received SOHB were observed to have the greatest hardwood composition relative to the either WTH or SOH. Additional observations following treatment note greater exposure of mineral soil in WTH than in SOHB.

Beginning in 2014, new permanent sample plots (PSPs) were installed to quantify stand structure, carbon stock, composition, and soil and foliar nutrients in three treatments. Fifty years after treatment, we found that neither WTH nor SOHB reduced productivity relative to SOH as expressed by stand structure and carbon stock. Prior to the first application of treatments stands were observed to have 50 percent spruce-fir and 25 percent hardwood composition. At the time of our sampling, these stands now only were 36 percent spruce-fir and 60 percent hardwood composition.

Treatments that received SOHB were still found to have the greatest hardwood composition relative to the other treatments. This may have been due to mortality of advance softwood regeneration, or reduction of softwood seed source. At the species-level, eastern white pine was found to be greatest on WTH sites, which may have been due to greater exposure of mineral soil initially observed following treatment. These findings suggest that long-term site productivity is not degraded on northern mixedwood sites of low-moderate production potential following a single application of WTH and SOHB. Future work will be informed further by soil and foliar nutrient data collected in 2014-15.

Sites were re-harvested and re-burned in 2018.

Project Objectives

- Quantify site productivity (stand structure, composition, and carbon stock) 50 years after treatment in a designed experiment of clearcutting with WTH, SOH, and SOHB
- Determine the effect, if any, of incremental (SOH, SOHB, WTH) biomass removal on productivity
- Determine soil and foliar nutrient status 50 years after treatment with WTH and SOH

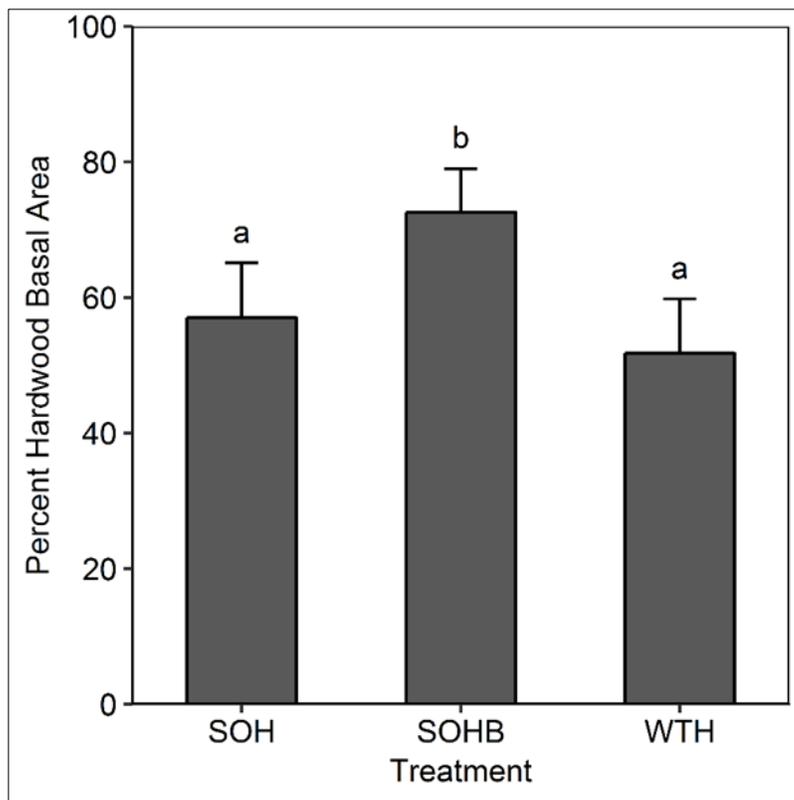


Figure 1. Least-squares means and standard errors of hardwood basal area by treatment, for trees with a dbh ≥ 1.3 cm. Different lower-case letters indicate a significant difference in least-squares means.



In-woods stroke delimber used during the 2018 winter harvest in C33. Photo courtesy Bethany Muñoz

- Synthesize our findings with those from other studies of WTH in the Northern Forest to provide insight for future sustainable biomass harvesting guidelines
- Address concerns over repeated WTH on sites with low to moderate production potential

Approach

At each PSP, height, diameter at breast height (dbh, 1.37 m), and species of living and standing dead trees were measured for stand structure, carbon stock, and composition analysis. For plant-available nutrient measurements, we installed ion exchange resin membranes (IERMs) at the bases of two red maple (*Acer rubrum*) and two balsam fir (*Abies balsamea*) trees demonstrating dominant characteristics within each unit; that is, each tree had one cation and one anion IERM strip placed side by side, at a distance $\sim 10\times$ the dbh of the tree, azimuth of 180° .

Foliage samples were then obtained on the upper 1/3 canopy from each of those trees, targeting the current year's growth. Down woody debris ≥ 10 cm in diameter was measured using modified Brown's transects on all PSPs (van Wagner 1968, Brown 1971, Brown 1974). Regeneration up to < 1.37 m in height was inventoried on all PSPs.

Depth of the 'O' horizon within the soil was measured, as well as both parent material and soil drainage type confirmed in field, for use as potential explanatory variables on all PSPs.

Key Findings / Accomplishments

- Evidence of a shift in species composition from spruce-fir (*Picea* – *Abies*) to predominantly hardwood composition
 - Treatments that received prescribed burning (SOHB) had greater hardwood composition than either WTH or SOH, likely due to mortality of advance softwood regeneration
 - Eastern white pine (*Pinus strobus*) was most abundant in WTH, relative to SOH and SOHB (though in smaller numbers), likely due to greater ground disturbance (scarification) associated with whole-tree skidding
- No significant differences among treatments were found for either stand structure or productivity (i.e. stem density, total basal area, dominant height, total aboveground carbon stock, and quadratic mean diameter).
- Publication of findings in *Forest Ecology and Management*.

Table 1. Summary of products removed in the 2018 winter harvest on C33, by species-specific product.

Product	Tons
SP/Fir pulp	109.68
Pine Pulp	64
Hemlock pulp	11.54
Aspen Groundwood pulp	11.39
Hardwood Pulp	1293.87
SP/Fir logs	57.5
White pine Logs	51.947
Hemlock Logs	1.44
Hardwood Logs	3.915
Hardwood boltwood	0.702
Total Tons	1605.984



From left, Lauren Keefe, Jamie Behan, Jim Alt, Tony Guay, and David Sandilands from University of Maine setting up three Trimble Geo7x's for ground control point (GCP) installation on C33. GCPs were used to “ground truth” near infrared imagery collected by an unmanned aerial vehicle (UAV). Photo courtesy: Bethany Muñoz.

Learning from the Past to Predict the Future: Validation of the Spruce Budworm Disturbance Model in Northwestern Maine

*Brian R Sturtevant, USFS, Northern Research Station;
Eric J. Gustafson, USFS, Northern Research Station;
Kasey Legaard, University of Maine School of Forest Resources*

YEAR 4 PROGRESS REPORT

Summary

The goal of our research is to validate a new LANDIS-II disturbance extension (Budworm Population Disturbance) against observed budworm damage for a historic outbreak in northwestern Maine as documented by aerial surveys and state impact reports. To date we have mapped forest conditions *circa* 1985 using machine-learning techniques applied to Landsat TM imagery and historic plot data, with relatively high accuracy. Budworm model parameters implemented within LANDIS-II have produced the range of anticipated budworm behaviors and consequent impacts under increasingly realistic scenarios (i.e., homogeneous host, neutral landscapes with different proportion of host species, and actual landscapes under alternative harvest regimes for the Border Lakes Landscape (Minnesota & Ontario). Future work will finalize the backcasting of 1985 Maine forests to pre-outbreak conditions *circa* 1975, integrate edge effects and wind-driven dispersal necessary to scale-up simulations to large landscapes (104-105 km²), and the model validation by comparison with a historic outbreak in Maine.

Project Objectives

1. *Map forest conditions ca. 1975* using previously developed maps, historic plot data, and new remote sensing analyses
2. *Retrospective modeling of the last outbreak in Maine* to validate modeled budworm outbreaks against documented outbreak behavior.

Approach

Objective 1

- Utilize Landsat Thematic Mapper imagery, terrain attributes, and climate data to map spruce-fir distributions in 1985, and then backdate to the pre-outbreak conditions of 1975 using a previously developed time series of forest disturbance maps.

- Compile data and locations for field plots measured by the USDA Forest Service, Forest Inventory and Analysis project during the 1980-1982 forest survey of Maine, and by private landowners during the last spruce budworm outbreak.
- Develop and apply a predictive modeling algorithm capable of providing alternative mapped distributions differing in spruce-fir acreage.

Objective 2

- Develop parameters for the Spruce Budworm Population disturbance extension for LANDIS-II that reproduce observed outbreak behaviors for the Border Lakes Landscape (BLL) of NE Minnesota and adjacent Ontario.
- Apply the above parameters to simulations of budworm outbreak dynamics in space and time using the forest conditions of northwestern Maine in 1975 as the initial conditions for the outbreak.
- Replicated simulations will produce statistical distributions of landscape-scale outbreak features in terms of dynamics (extent, duration) and impacts (growth reduction, mortality) that will be compared (via confidence intervals) to documented features of budworm outbreak of the 70s and 80s.

Key Findings / Accomplishments

Objective 1

Year One

- 178 historic spruce-fir plot locations were digitized from hand-written records provided by the U. Maine Cooperative Forestry Research Unit.
- Topo-climatic attributes and Landsat images were compiled and pre-processed for predictive modeling and mapping.
- We developed a new machine learning approach to the problem of predicting class distributions from incomplete reference data by combining a 1-class support vector machine prediction algorithm (SVM; Liu et al. 2002) with a multi-objective genetic algorithm (Deb et al. 2002). This is a new approach to prediction from presence-only reference data that simultaneously generates multiple maps with varying levels of class prevalence.
- An initial comparison of our 1-class multi-objective SVM algorithm with an analogous 2-class SVM algorithm demonstrated that both could predict contemporary spruce-fir distributions at approximately 85% accuracy with mapped acreage matching that obtained from USFS FIA field plots.

Year Two

- We performed a more thorough verification of the 1-class multi-objective SVM algorithm developed in Year One, including execution on a larger set of test problems.

- With the assistance of the Maine Forest Service and USFS FIA Program, we obtained plot coordinates for a large set of historic plot measurements made during the 1982 and 1995 forest surveys of Maine.
- We used historic FIA measurements to predict spruce-fir distributions using a 2-class SVM algorithm, and compared outcomes to those generated by our 1-class approach based on CFRU plot data.
- Direct comparisons were made complicated by multiple factors, including differences in sample size, plot placement relative to stand conditions, and plot location accuracy, and more work is needed to refine outcomes before selecting a single best approach.
- We made significant progress in developing spatial algorithms and code needed to back-date predicted spruce-fir distributions to 1975.

Year Three

- After comparing multiple approaches to the problem of mapping historic spruce-fir distributions, we elected to use plot data measured for the 1982 and 1995 USFS forest surveys of Maine. We were able to obtain GPS coordinates of all plots measured for the 1995 inventory, and associated those coordinates with a subset of plots that had also been measured the early 1980s. USFS plot data offered multiple advantages over the historic CFRU plot data, including much more accurate locations and a larger, more representative sample that allowed for estimation of true spruce-fir prevalence within our study area.
- We included measurements from the 1995 inventory to provide a more representative reference sample than was available from 1982 data alone. All sample locations were screened for prior disturbance using previously developed forest disturbance maps. To obtain reference data labels for our classification algorithm, we used forest type assignments made by the contemporary FIA national forest type algorithm (McWilliams et al. 2005). SVM classification models were trained using 1985 Landsat imagery, resulting in maps depicting 1985 conditions.
- Our approach includes the production of multiple maps depicting different amounts of spruce-fir forest for the purposes of evaluating sensitivity to uncertainty in host species distributions. Cross-validated estimates of producer's and user's accuracy for the spruce-fir class ranged from about 75-85%.
- We combined 1985 spruce-fir occurrence with a more general 1975 forest type map to obtain a 1975 map differentiating host-dominant softwood and mixedwood from other forest types. In areas disturbed between 1975 and 1985, spruce-fir occurrence was backdated using models trained on terrain and climate data only. In the absence of independent reference data, we cannot estimate the accuracy of these backdated forest type maps. But by simultaneously constructing multiple maps with different spruce-fir distributions, we can evaluate how a primary source of uncertainty in initial conditions affects simulation outcomes.

Year Four

- Given reasonable maps of forest composition circa 1975 (Years 1-3 above), the remaining challenges were a. to stratify forest composition by age classes – specifically for host-dominant forest types, b. develop methods to stratify FIA plot data circa 1982 the combination of forest types and age classes in the 1975 maps, and c. define the species age cohort lists corresponding with these plots to produce the initial conditions inputs for LANDIS.
- Item ‘a’ was addressed using the same remote sensing methodology applied in year 3 to produce the forest type maps. FIA plots indicated above were further stratified into immature (≤ 40 years), and mature (> 40 years) age classes for all budworm host – dominant classes, yielding a total of 8 forest type/age combinations: Immature Host-dominant Softwood; Immature Host-dominant Mixedwood; Mature Host-dominant Softwood; Mature Host-dominant Mixedwood; Other Softwood; Other Mixedwood; Hardwood; Previously Disturbed (Figure 1).

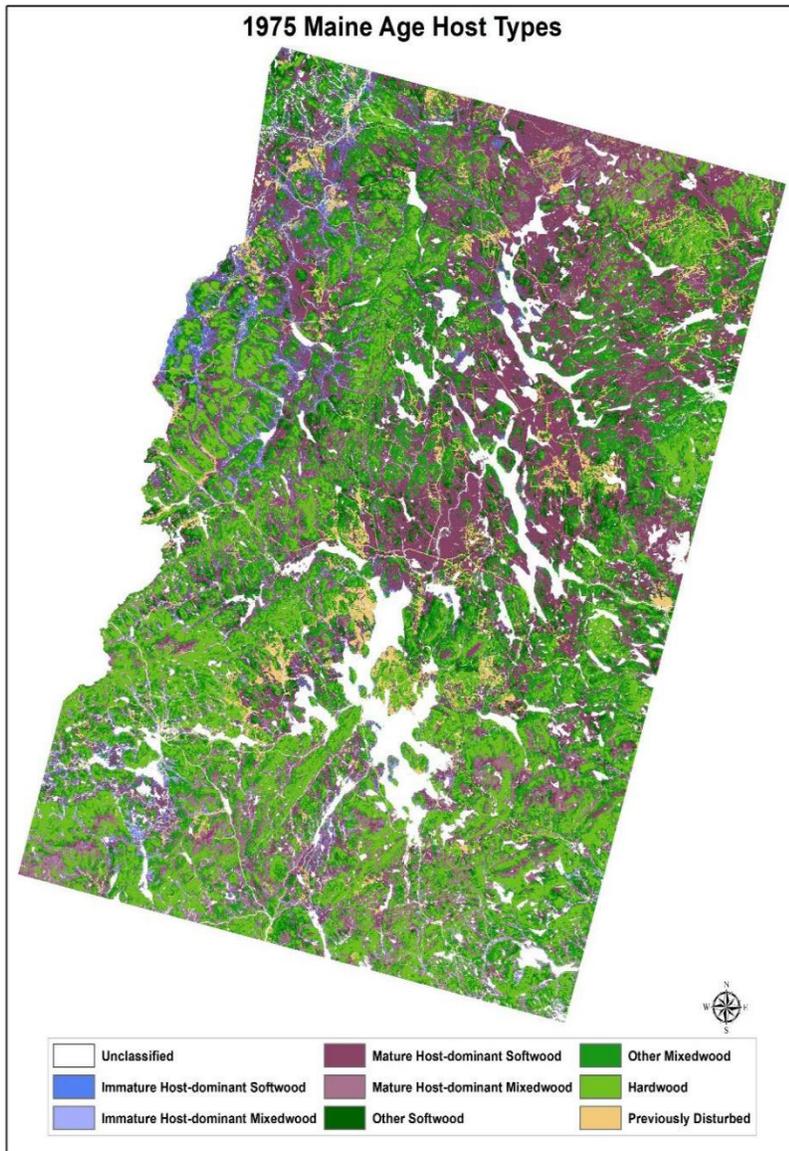


Figure 1. Map of 1975 forest conditions differentiating host-dominant softwood and mixedwood from other forest types. We have produced multiple maps depicting different spruce-fir distributions in order to evaluate the sensitivity of simulation outcomes to uncertainty in host species distributions. This particular map is based on a model for which predicted spruce-fir prevalence matches a reference estimate of spruce-fir prevalence. Other maps either over- or under-estimate spruce-fir prevalence by specific amounts.

- Items 'b' and 'c' were impacted by the lack of reliable age information in the 1982 FIA data. We therefore developed age-diameter relationships by tree species for Maine's annual FIA data (circa 2000 (1999-2017)) using available site index tree data. These relationships were used to aggregate individual tree observations for the two counties overlapping the NW Maine study area into tree species age classes (e.g., 20-year classes). Tree species with < 5% basal area within a plot were first screened out to reduce plot-level complexity. The resulting tree species age classes correspond to the tree species cohorts present within a plot (used as the input that plot observation represents for LANDIS initial conditions: item 'c'). FIA seedling data were used to identify presence or absence of a 1-year old species age cohort for the plots. Associated species cohort biomass were used to classify each of the plots into one of the 8 forest type/age classes above. These plots were then randomly assigned to the forest age type map produced above to approximate forest conditions in the northern Maine circa 1975.

Objective 2.

Year One

We developed population parameters to produce the range of temporal outbreak behaviors observed within the Border Lakes region (Robert et al. 2012, 2018):

- Critical outbreak behaviors have been reproduced according to hypothesized relationships with hardwood content of the forest.
- Demonstrated realistic responses in terms of damage experienced by forests, and the consequent response of the forest via succession in LANDIS-II.
- While some critical outbreak behaviors were reproduced under spatialized modeling environments (i.e., explicit dispersal), the spatial feedbacks generally overwhelmed the temporal effects, such that the system was dominated by fine-scaled spatial waves spirals that did not allow the outbreak to synchronize over long time periods.

Year Two

- We constructed a system for systematic evaluation of parameter assumptions and parameter space – enabling more rapid calibration of the model
- We had a breakthrough in dispersal parameters that enabled system synchronization across small test landscapes
- The latest parameterization remains sensitive to landscape conditions in a way that is consistent with observed spatiotemporal outbreak behavior in the Border Lakes Landscape. In essence, outbreak frequency increases as synchrony breaks down, as observed in natural systems. Further, the simultaneous increase in frequency and decrease in synchrony is a nonlinear function of the amount and configuration of budworm host. Hence, outbreak dynamics are an emergent property of the feedback between the insects and the forest.

Year Three

- We systematically evaluated the outbreak dynamics across a series of “neutral landscapes”, where we could control different features of the landscape such as host proportion, host configuration (i.e., fragmentation), and temporal dynamics. In the latter, we contrasted combinations of host versus nonhost initial conditions, where forest succession could proceed unimpeded, and also forest vs nonforest (water) where forest pattern and extent was fully constrained. We found that outbreak periodicity is sensitive to both the enemy dispersal radius (a calibrated parameter) and the proportion of host (an emergent property of the simulations).
- We evaluated the three contrasting harvest scenarios present within the Border Lakes Landscape: No Harvest (wilderness), Minnesota Logging Practices (small cuts), and Ontario Logging Practices (large cuts). While there was very good agreement between observed and modelled budworm outbreak behavior for the No Harvest and Minnesota Logging Practice scenarios, behavior for the Ontario Logging Practices scenario was not. We suspect that realistic behavior for this scenario will only be possible for simulations at much broader extents.

Year Four

- Modeling activities for year 4 were focused on integration of more realistic long-distance dispersal kernels into the model, and addressing edge effects to which earlier simulations indicated the model to be sensitive.
- The budworm model now has the capability to accommodate directional dispersal distributions associated with wind patterns observed within a given study area. Such distributions may be informed by either archived weather records or by summarization of more detailed budworm flight models.
- The model also has the capacity to address principle edge effect types representing the host abundance of regions beyond the simulated study area. For example, it can accommodate non host areas (such as the Great Lakes or Atlantic Ocean), or gradients in host abundance (i.e., increasing host abundance vs decreasing host abundance).
- We have standardized the methods for developing the remaining input parameters for LANDIS-II Biomass Succession that are readily adaptable to NW Maine.

Future Plans

- Finalize the initial conditions for NW Maine circa 1975. This stage is virtually complete.
- Complete strategic calibration of model parameters under “real world” conditions
- Move simulations to Maine pending reasonable parameterization of population dynamics for the Border Lakes region.
- Prepare 2-3 manuscripts that a. document the model, and b. report on the model dynamics within the Border Lakes Landscape (Minnesota/Ontario) vs Maine.

Understanding Landscape-Level Factors Influencing Spruce Budworm Outbreak Patterns in Maine and Forecasting Future Risk at High Spatial Resolution

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YEAR 3 PROGRESS REPORT

Summary

Accurate annual spruce budworm (SBW) defoliation data are essential for effective forest management, planning and understanding factors influencing SBW outbreaks. Landscape mapping of SBW defoliation is based on aerial sketch mapping (ASM). We developed a model to detect and quantify SBW annual defoliation using Landsat imagery in another project and applied the method to historical Landsat-MSS imagery to detect SBW defoliation as the historical ASM SBW defoliation data are very coarse in resolution. We need to improve historical SBW defoliation maps of Maine to understand factors influencing SBW outbreak. Several data including annual egg mass, SBW ASMs, defoliation field data, forest cover type, Landsat-MSS imagery for three years (1975, 1978, 1982) were collected and their accuracy has been being evaluated. Landsat-MSS imagery has shown to have the potential to map SBW defoliation extent at finer resolution with more accuracy than ASMs. Detection of historical SBW defoliation was possible using Landsat-MSS NDVI data and the produced maps can be used to complement coarse-resolution aerial sketch maps of the past outbreak. The shortcomings are: the unavailability of the imagery in the SBW biological window where annual defoliation can be detected and detecting light defoliation.

Project Objectives

- To develop and suggest a practical method to add accuracy to aerial sketch maps using satellite remote sensing and ancillary data.
- Apply suggested method to refine historical ASM of Maine (the current version is too coarse and inaccurate) and to identify landscape factors affecting SBW outbreak patterns.

Approach

The study area: (~100*150 km²) was located in the northern part of Maine (Figure 1). Forest cover type is composed of coniferous species in particular balsam fir and red spruce, deciduous species of red maple, sugar maple, yellow birch, white birch, American beech and mixed stands of coniferous and deciduous trees. Over 90% of the forestlands are privately owned and are of commercial value. Intensive clear-cutting during the SBW outbreak between 1970s and 1980s

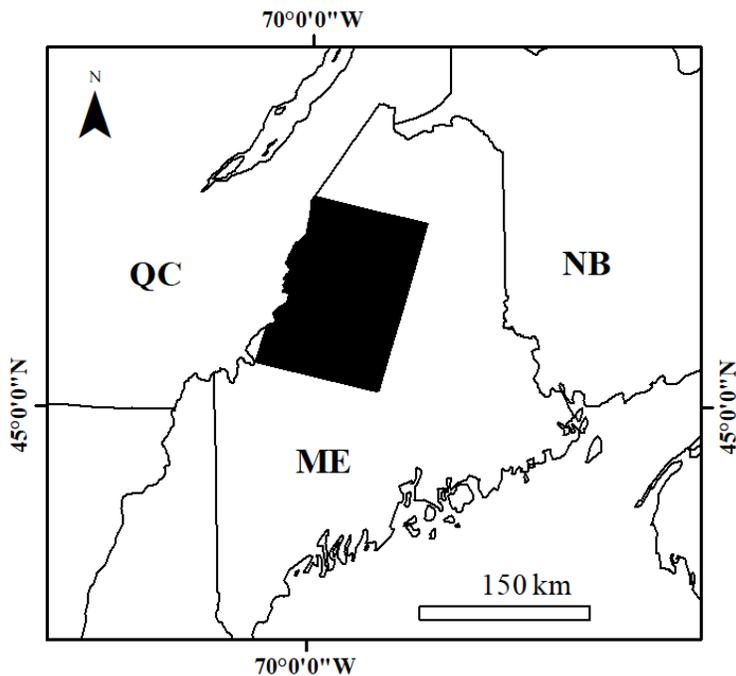


Figure 1 Location of the study areas in Maine, USA. The study area (~100*150 km²) was located in Landsat-MSS scene 13/28.

and SBW-induced defoliation were the major landscape-scale causes of change in the region. Forest conditions in Maine have changed considerably as a result of SBW-induced spruce-fir stand mortality, which killed between 72.5 and 90.6 million m³ of fir [Maine Forest Service, 1993], and intensive salvage logging.

Satellite data, pre-processing and field data: For the study area in Maine, relative radiometric normalized Landsat-MSS imagery for a pre-defoliation years (1972 and 1973), two defoliated years (1975 and, 1982) and a Landsat-derived forest cover type map for 1975 having 60m spatial resolution [Legaard et al., 2015] were acquired.

For 1975, 1978 and 1982, three images of DOY 211, 223 and 221 were available and were used for defoliation detection. Cloud and cloud shadow were removed using automated cloud cover identification. Because the northern part of the study area was found to be moderately defoliated in 1973 based on historical ASMs and SBW egg mass data [Hennigar et al., 2013], to produce pre-defoliated imagery, an image from early September 1972 for row 12/28 was acquired, radiometrically normalized and applied to replace spectral band values in the northern part of Landsat-MSS scene 13/28 of 1973.

SBW defoliation detection: The method for the Maine study area was also based on multi-date change detection using VIs [Hall et al., 2009; Townsend et al., 2012]. However, Landsat-MSS sensors only had four spectral bands (green, red, and two NIR) with a spatial resolution of 60 m so that many common vegetation indices could not be estimated, therefore change detection was based only on NDVI. Among different spectral bands and VIs that could be used for foliage damage detection using Landsat MSS, bands red and NIR2 (2 and 4) and NDVI are suggested as the best for vegetation change studies. Expected defoliation levels derived from SBW egg-mass data were used for comparison with Landsat-MSS derived defoliation maps. A total of 349, 247 and egg-mass data plots were used for years 1975 and 1982, respectively. Egg mass data were converted to defoliation levels and the equation presented in Hennigar et al., 2013. Ordinal regression was used to evaluate the relationship between expected defoliation levels and NDVI changes in both years. Any reduction in NDVI larger than 0.05 was considered as defoliation and SBW defoliation maps were produced from NDVI data. Percentage of correctly identified defoliated areas was determined by comparing defoliation information derived from egg-mass data and those derived from Landsat-MSS.

Key Findings / Accomplishments

- The relationship between defoliation levels estimated from egg mass data and change in mean NDVI values was weak but statistically significant. Not much variation in defoliation levels was explained by NDVI variation as indicated by low pseudo- R^2 values (e.g., pseudo- $R^2 = 0.038$, p value: 0.001 for 1975). On average, 52% of plots were correctly identified as either defoliated or non-defoliated. In all years the identification accuracy was considerably higher at greater defoliation levels. Due to the weak statistical relationship between expected defoliation data and NDVI in Maine but better accuracy for defoliation identification (% correctly identified data), only defoliated vs. non-defoliated classes were mapped (Figure 2).

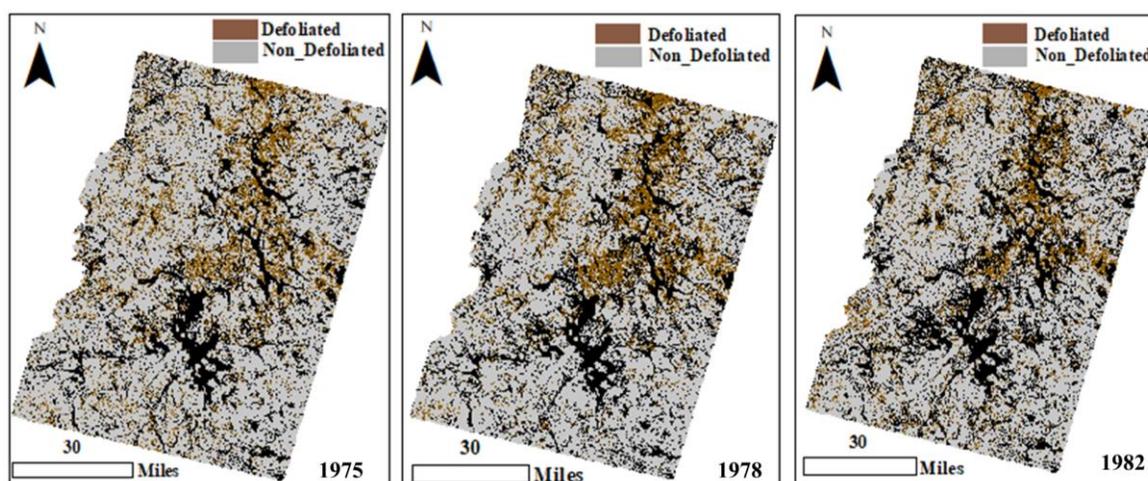


Figure 2 Landsat-MSS SBW defoliation occurrence maps at 60 m spatial resolution

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BOOK CHAPTERS (2)

1. Horne, L., De Urioste-Stone, S. M., Daigle, J., Noblet, C., Rickard, L. Kohtala, H., & Morgan, A. (In Press). Climate change risk in nature-based tourism systems: A case study from Western Maine, USA. In Pröbstl-Haider, U., Richins, H., & Türk, S. (Ed.), *Winter tourism: Trends and challenges*.
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PRESENTATIONS / WORKSHOPS / MEETINGS / FIELD TOURS (47)

1. PEF: Twenty-three field tours for visitors from the American Forest Foundation; Canadian Provinces of New Brunswick and Nova Scotia; Cooperative Forestry Research Unit; Maine Forest Service; Natural Resources Conservation Service; University of Arkansas; University of Maine; U.S. Forest Service, Northern Research Station, Northeastern Area State and Private Forestry, and Washington Office; and others, including the Northeast Silviculture Institute Spruce-Fir module.
2. PEF: Numerous presentations at local, regional, national, and international meetings including the Eastern Canada-USA Forest Science Conference (New Brunswick); New England Society of American Foresters Annual Meeting (Vermont); Northern White-Cedar Ecology and Management Meeting (Quebec); Society of American Foresters National Convention (place); North American Forest Ecology Workshop (Arizona); and others.
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24. Kizha., A. R. 2018. Harvest productivity, residual stand damage, and soil disturbance. Outcome Based Forestry and Long-Term Research: CFRU Fall Field Tour, September, Irving Woodlands, LLC in Ashland, Maine
25. Kohtala, H., Horne, L., and De Urioste-Stone, S. M. 2018. Understanding visitor risk perceptions of Lyme disease in Acadia National Park. Acadia Science Symposium. October 20, Bar Harbor, Maine.

26. Muñoz Delgado, B., and Kenefic, L. 2018. C33 post-burn site tour. Visit by USDA Forest Service scientist, Institute for Applied Ecosystem Studies: Theory and Application of Scaling Science in Forestry, to Penobscot Experimental Forest. October 12. Bradley, ME.
27. Muñoz Delgado, B., and Kenefic, L. 2018. Silviculture matters tour. Visit by American Forest Foundation and Wells Forest to the Penobscot Experimental Forest. November 16. Bradley, ME.
28. Muñoz Delgado, B., & Kenefic, L. 2018. Silviculture Matters tour. Visit by USDA Forest Service, Research and Development, Forest Inventory and Analysis, and Northeastern Area State and Private Forestry, Leadership to the Penobscot Experimental Forest. November 8. Bradley, ME.
29. Muñoz Delgado, B., & Kenefic, L. 2018. Silviculture Matters tour. Visit by USDA Forest Service, Research and Development Leadership to Penobscot Experimental Forest. October 25. Bradley, ME.
30. Muñoz Delgado, B., & Kenefic, L. 2018. Silviculture Matters tour. Visit by USDA Forest Service, Research and Development Leadership to Penobscot Experimental Forest. August 21. Bradley, ME.
31. Muñoz Delgado, B., Kenefic, L., and Patterson III, W. 2019. Fuel management approaches while harvesting northern mixedwood stands in Maine. New England Society of American Forests Annual Winter Meeting. March 27-29. Burlington, VT.
32. Muñoz Delgado, B., Kenefic, L., Patterson III, W., and Weiskittel, A. 2019. Fuels management in northern mixedwoods in light of an uncertain climate future. 12th North American Forest Ecology Workshop. June 23-27. Flagstaff, AZ.
33. Muñoz Delgado, B., Kenefic, L., Patterson III, W., and Weiskittel, A. 2018. Northern mixedwood fuels-deadwood structure and regeneration following repeated whole-tree and stem-only harvests with and without prescribed burning. Eastern Canada and United States biennial meeting. October 19-21. Fredericton, New Brunswick, Canada.
34. Muñoz Delgado. 2019. C33 fuels training with the Penobscot Experimental Forest field crew. Visit by the Holt Research Forest to the Penobscot Experimental Forest. June 5, 2019. Bradley, ME.
35. Rahimzadeh-Bajgiran, P. 2019. Remote sensing technology for forestry applications in North America: An update, Research Seminar at Takasaki University, Takasaki, Japan, June 3.
36. Rahimzadeh-Bajgiran, P. Weiskittel, A., Kneeshaw, D., and MacLean, D. A. 2018. SBW defoliation detection using satellite remote sensing techniques: lessons from the past and future outlook, Spruce Budworm Early Intervention Strategy Science Workshop, March 13-14. Fredericton, NB, Canada.
37. Richley, A. 2018. Silviculture class tour. Visit by University of Maine, School of Forest Resources, silviculture classes, to the Penobscot Experimental Forest. October 2018. Bradley, ME.
38. Richley, A. 2018. Silviculture matters tour. Visit by USDA Forest Service scientist (Sustainable Management of Central Hardwood Ecosystems and Landscapes) and University of Missouri, Associate Professor for Silviculture, to Penobscot Experimental Forest (Mixedwood Initiative). October 19. Bradley, ME.
39. Roth, B. E. 2018. Introduction to Maine's Adaptive Silviculture Network. CFRU Fall Field Tour: Outcome Based Forestry and Long-Term Research, September. T16 R8, Maine.
40. Shrestha, S., De Urioste-Stone, S. M., Rahimzadeh-Bajgiran, P., Beitzl, C., & Sherchan, S. 2019. Mountain livelihood strategies in a time of change: A case study of Upper Mustang in Nepal. 25th International Symposium on Society and Natural Resource Management. June 2-7, Oshkosh, Wisconsin.
41. Soman, H., and Kizha., A. 2018. Economics of hybrid clear-cutting system involving at-stump processing and soil reinforcement strategies. Eastern Canada and United States biennial meeting. October 19–21. Fredericton, New Brunswick, Canada.
42. Soman, H., Nahor, E., and Kizha., A. R. 2018. Evaluating operational cost and residual stand conditions in varying silvicultural prescriptions. 41st Annual Meeting of the Council on Forest Engineering, July. Williamsburg, Virginia
43. Soucy, A., De Urioste-Stone, S. M., Hafford MacDonald, B., Horne, L., DiMatteo-LePape, A., Kohtala, H., McBride, S., and Gardner, A. 2019. Mitigating tick-borne disease risk in Acadia National Park. 25th International Symposium on Society and Natural Resource Management. June 2-7, Oshkosh, Wisconsin.
44. Soucy, A., De Urioste-Stone, S. M., Weiskittel, A., Rahimzadeh-Bajgiran, P., and Daigneault, A. 2019. Prioritizing forest stakeholder perceptions of climate change risks in Maine. 25th International Symposium on Society and Natural Resource Management. June 2-7, Oshkosh, Wisconsin.
45. Teets, A., Moore, D.J.P, Blanken, P. D., Burns, S. P., Carbone, M. S., Fraver, S., Gough, C. M., Hollinger, D. Y., Novick, K. A., Ollinger, S. V., Ouimette, A. P., Pederson, N., Vogel, C. S., Richardson, A. D. 2019. Identifying lags between annual

CO₂ uptake and aboveground biomass increment: A synthesis across six AmeriFlux sites. North American Forest Ecology Workshop, Flagstaff, AZ, 25 June.

46. Teets, A., Fraver, S., Weiskittel, A., and Hollinger, D. 2018. Quantifying climate-growth relationships at the stand-level in a mature mixed-species conifer forest. *Global Change Biology* 24:3587-3602.
47. Thapa, B. 2019. Presentation at Heart of the Continent advances the state of the art. Heart of the Continent Partnership, Science Symposium, Duluth, MN.

POSTERS (4)

1. Burke, N., Kohtala, H., Cooper, A., DiMatteo-LePape, A., Horne, L., Soucy, A., and De Urioste-Stone, S. M. 2018. Visitor surveys: Climate change risk perceptions. Acadia National Park Science Symposium. October.
2. DiMatteo-LePape, A., De Urioste-Stone, S. M., Kamath, P., & Lichtenwalner, A. 2019. Moose-winter tick interactions in Maine. UMaine Student Symposium. April 10, Bangor, Maine.
3. Evans, B. E., C. Mosby, and A. Mortelliti. Large scale monitoring for carnivores in Maine, USA: Assessing linear arrays of multiple trail cameras to increase detection success. International Martes Working Group Symposium, July/August. Ashland, Wisconsin.
4. Evans, B. E., Mosby, C., and Mortelliti, A. 2018. Large scale monitoring for carnivores in Maine, USA: Assessing linear arrays of multiple trail cameras to increase detection success. International Martes Working Group Symposium, July/August, Ashland, Wisconsin.

THESES (9)

1. Aiken, K. 2019. Personality in small mammals: From home range to microhabitat selection. Honors Thesis, University of Maine.
2. Nahor, E. 2018. Residual stand damage: A comparison of silvicultural prescriptions. Capstone paper, University of Maine, Orono.
3. Preece, C. J. 2018. Long-term effects of harvest residues on spruce-fir forest growth following whole-tree and stem-only harvesting at Weymouth Point. MFC thesis, University of Toronto, Ontario.
4. DiMatteo-LePape, A. 2019. A qualitative study of the perceived risks of the impacts of moose-winter tick interactions on human health, Maine economy and Maine culture. Honors thesis to obtain a Bachelor's in Parks, Recreation and Tourism, and Ecology and Environmental Sciences, University of Maine.
5. Elliott, J. 2019. A socio-ecological approach to wildlife disease risk: Moose, winter ticks and disease. MS (Forest Resources) thesis, University of Maine.
6. Fien, E. 2018. Drivers of tree growth and mortality in an uneven-aged, mixed-species conifer forest of northeastern United States. M.S. thesis, University of Maine.
7. Hensley, V. 2019. Living on the edge: Thermophysiology of the southern flying squirrel at its northern range margin. University of Maine Electronic Thesis and Dissertations. Orono, ME. 69 pp.
8. Soman, H. 2019. Productivity, costs, and best management practices for major timber harvesting frameworks in Maine. PhD dissertation, University of Maine.
9. Uykun, C. 2018. Above-ground biomass and carbon estimations and recommendations for forests in Turkey. MS thesis, Michigan Technological University.

NEWS MEDIA (3)

1. North Atlantic Fire Science Exchange (NAFSE). (2 November 2018) Fall Newsletter: New North Atlantic Research – Prescribed burning in northern mixedwood forests, Penobscot Experimental Forest (Maine). <https://mailchi.mp/9b627987b8f1/nafse-newsletter>
2. Mitchell, K. (17 September 2018) FOXBangor 22: Controlled burn for training and research. <https://www.foxbangor.com/news/item/44883-controlled-burn-for-training-and-forest-research>
3. Catalina, E. 2018. Carnivores on Camera. UMaine Today Fall/Winter 2018 and online feature with video: umainetoday.umaine.edu/stories/2018/carnivores-on-camera

WEB PAGES (2)

1. Forest mapping: When the budworms come to dinner.
<https://www.mghpcc.org/forest-mapping-when-the-budworms-come-to-dinner/>
2. A web page has been developed to allow users to interactively query and explore the FIA data and simulation results from this project, using the Tableau interface for maps and graphics:
<https://public.tableau.com/profile/john.gunn#!/vizhome/SpruceBudwormRiskMapv2/Dashboard>

WEBINARS (3)

1. Muñoz Delgado, B., Kenefic, L., Weiskittel, A., Fernandez, I., Benjamin, J., Dibble, A., Patterson III, W. 2019. Fifty years later: Mixedwood productivity following biomass harvesting and prescribed burning in the Penobscot Experimental Forest. Cooperative Forestry Research Unit, Webinar Series Resources. Mixedwood Management: Concepts and New Findings. April 17, 2019. <https://youtu.be/J8oIJVgmamA>
2. Fernandez, I., Roth, B. 2019. Worth the Wait: The Value of Long-Term Forest Research in Maine. Cooperative Forestry Research Unit, Webinar Series. February 13, 2019. <https://www.youtube.com/watch?v=mzlfynuDASQ&t=47s>
3. Blomberg, E., Thompson, M. 2018. Considering Bats in Forest Management. Cooperative Forestry Research Unit, Webinar Series. November 14, 2018. <https://www.youtube.com/watch?v=0UXhJcx1ufY>



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