
1865 THE UNIVERSITY OF MAINE
Center for Research on Sustainable Forests
2018 Annual Report
Meg Fergusson, *Editor*
Aaron Weiskittel, *Acting Director*

About the Center

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 geospatial 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 by Meg Fergusson. Used with Permission

2017–18 HIGHLIGHTS

Personnel

- **Dr. Aaron Weiskittel** continued as Acting Director of the CRSF. In addition, **Dr. Brian Roth** continued as Acting Director for the Cooperative Forestry Research Unit (CFRU).
- **Jenna Zukswert** has joined the CFRU as the new Research and Communications Coordinator. Jenna's focus will be on coordinating CFRU research and delivering research findings and tools to the membership.
- The CFRU will miss Cindy Smith, who has moved on to full-time work in the healthcare industry. In January, the CRSF welcomed **Leslee Canty-Noyes** to fill the position of Administrative Specialist. Leslee handles accounts and other administrative responsibilities for both the CFRU and CRSF.
- In her new role as CRSF's Communication and Outreach Specialist, **Meg Fergusson** is focused on development and dissemination of information on CRSF's forest-related research, data, and technologies to constituents and the interested public.

Forest Research

- The CFRU established the **Maine Adaptive Silviculture Network** (MASN). The initial three sites were selected on land owned by BBC Land, LLC, Irving Woodlands, LLC, and Seven Islands Land Company. This new network is a statewide series of operational-scale silvicultural treatments where future research on forest productivity and sustainability will be studied. The MASN installation owned by BBC Land, LLC, was harvested in July 2017.
- The **Nature-based Tourism Research Program** led by Dr. Sandra De Urioste-Stone conducted an undergraduate and graduate student service-learning project to facilitate tourism destination planning in western Maine in collaboration with local stakeholders through a grant provided by the Davis Educational Foundation.

HIGHLIGHTS

- **FOR/Maine Forest Industry Sub-Sector Analysis Committee,** led by Dr. Sandra de Urioste-Stone has conducted 5 focus groups and 13 semi-structured interviews with industry stakeholders representing land owners and managers, loggers, transportation, sawmills, pulp & paper mills, bioenergy, and professional services and groups. The key ideas that have emerged fall under three main themes: strengths of the Maine forest resources industry; challenges experienced by industry stake-holders; and future opportunities.

- **FOR/Maine Wood Supply Committee,** co-led by Dr. Aaron Weiskittel and Peter Triandafillou, commissioned and oversaw an analysis of Maine's current and future wood supply conducted by Sewall Company, which was completed in June 2018.

- CRSF began managing and coordinating the **Climate and Forest Network,** an outreach effort to improve networking and communications as well as collaborative research on climate change and challenges.

- **Howland Research Forest** scientists continue to conduct research on carbon and soil flux in collaboration with researchers from the US Forest Service, Northern Arizona University, Woods Hole Research Center, and NASA Goddard Space Flight Center.

- Long-term research efforts continue to flourish at the **Holt Research Forest** (HRF) and **Penobscot Experimental Forest** (PEF). An external review was conducted at the HRF and a strategic plan is being developed, while large-scale silviculture experiments on the PEF continue to gain data on biomass harvesting, pre-commercialization, and silvicultural rehabilitation.

- Drs. Erin Simons-Legaard, Kasey Legaard, and Aaron Weiskittel completed the 15-week **Maine Innovation, Research and Technology Accelerator** (MIRTA) program to help commercialize research on a high-value, low-cost geoinformatics system.

HIGHLIGHTS

- The **Northeastern States Research Cooperative** (NSRC) and Hubbard Brook Research Foundation convened a full-day stakeholder workshop on January 18, 2018, to generate a strategic vision for its future. Thirty-seven participants spoke on behalf of academia, private & public landownership, NGOs, and state & federal government. The **NSRC Business Report**, a collaboration of the USDA Forest Service and the four state NSRC directors, was published and widely distributed in March 2018. The publication is a comprehensive report on the program's contributions to research and applied knowledge about the Northern Forest over the past 16 years.

Outreach

- As the new lead site for the NSF I/URC **Center for Advanced Forest Systems** (CAFS), the CRSF hosted 30 academic and industry members from 9 states at the annual meeting and field trip held in Burlington, VT.
- The CFRU conducted a workshop and field tour on **Sustainable Forest Management and Soil Productivity** in June attended by a mix of nearly seventy CFRU members, academics from several institutions, and the community.
- Jenna Zukswert organized **two CFRU webinars** highlighting: (1) current spruce budworm conditions in Maine and an update on New Brunswick's early intervention program, and (2) deploying auto-acoustic devices to record and monitor Maine's forest songbirds.
- CRSF communications continues to maintain the **Maine Spruce Budworm Task Force** website (**sprucebudwormmaine.org**), the primary information source on budworm for the forest industry, state government, researchers, and the public.
- One day workshop was held at the **Holt Research Forest** to highlight the HRF and its 35-year history as well as current and future research efforts.

HIGHLIGHTS

- Drs. Aaron Weiskittel and Ivan Fernandez are leading a **forest climate change initiative** with cross-campus faculty participation.
- CRSF **co-hosted** seminars on understanding forest vulnerability to climate change and environmental resilience in a changing world.

Data Tools

- The CRSF continued its efforts to be the region's research data portal and geospatial observatory for forests of the Northeastern US. In addition to updating the CRSF home website, we continue to support three online tools for forest resources professionals and the public:

  Northeast Forest Information Source (NEFIS) – an online, open source, web portal for applied forestry information (**nefismembers.org**). Nearly 2,000 documents are available on a wide range of topics ranging from economic issues, to emerging technology, to forest management. User numbers continue to grow steadily as we work to grow the regional audience.

  Maine Forest Spatial Tool – displays a wide variety of geospatial data on forest resources across the State of Maine for both forest resource professionals and the public (**mfst.acg.maine.edu**).

  Maine Forest Dashboard – provides customizable forest statistics and changes using long-term data from the Maine Forest Service in a way that helps residents, visitors, businesses, scientists and policy makers better understand current conditions and historic trends (**maineforestdashboard.com**).

CRSF scientists continue to provide a strong return for every dollar provided by the Maine Economic Improvement Fund (MEIF) to support CRSF research. In the past year, there has been over $9 in return for every $1 invested.

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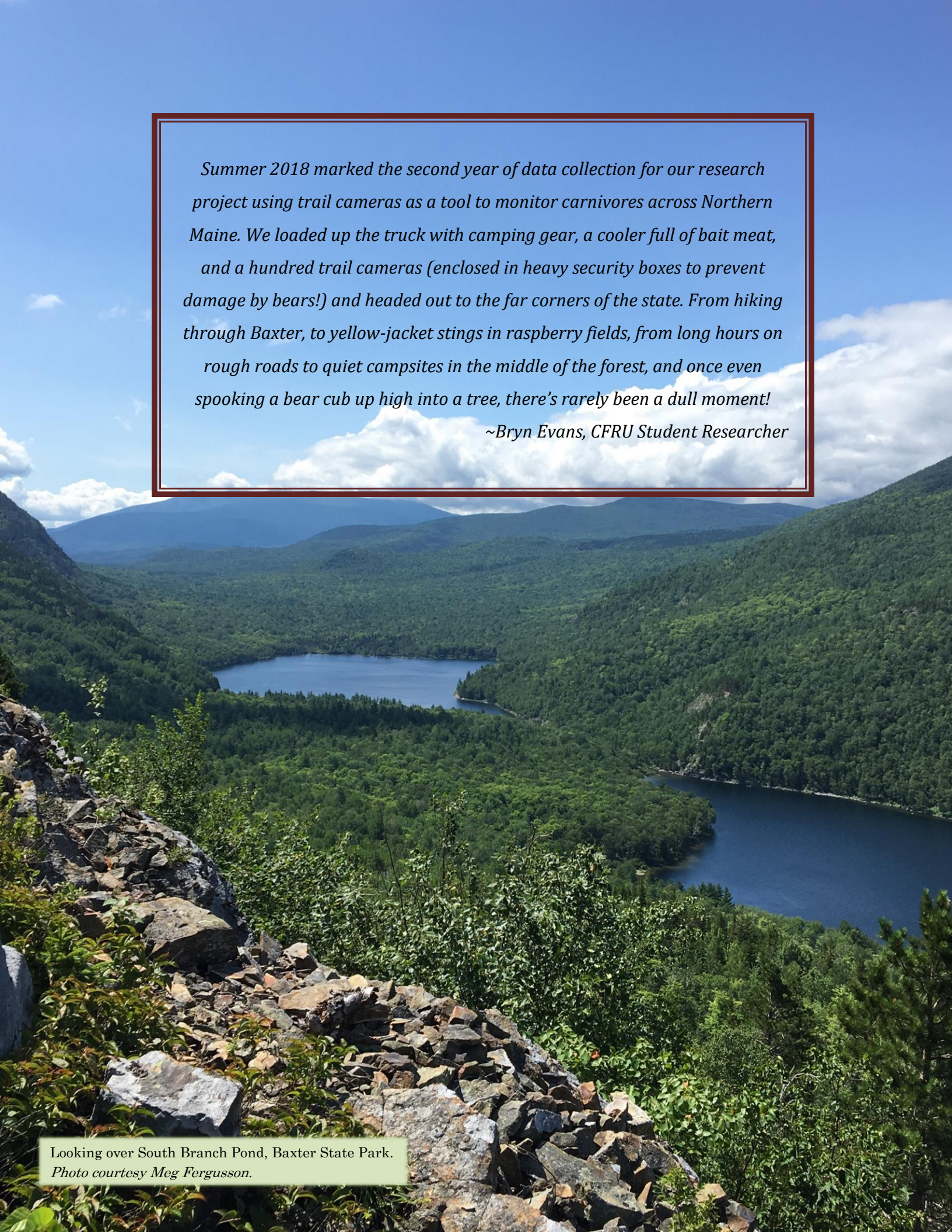
Stream research. Photo courtesy Pam Wells, Oakleafs Studios.



Summer 2018 marked the second year of data collection for our research project using trail cameras as a tool to monitor carnivores across Northern Maine. We loaded up the truck with camping gear, a cooler full of bait meat, and a hundred trail cameras (enclosed in heavy security boxes to prevent damage by bears!) and headed out to the far corners of the state. From hiking through Baxter, to yellow-jacket stings in raspberry fields, from long hours on rough roads to quiet campsites in the middle of the forest, and once even spooking a bear cub up high into a tree, there's rarely been a dull moment!

~Bryn Evans, CFRU Student Researcher

Looking over South Branch Pond, Baxter State Park.
Photo courtesy Meg Fergusson.

Director's Report

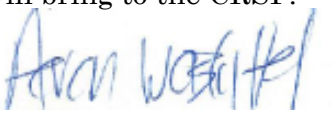
The Center for Research on Sustainable Forests (CRSF) continued its transition as a research center in 2017–18 under the second year of leadership by Acting Director Dr. Aaron Weiskittel. CRSF continues to remain vibrant and engaged on a variety of fronts throughout Maine, the larger Northern Forest region, and the US. The focus on helping to promote and sustain the region's forest-based economy was a key priority in the past year, while trying to build national relevance as an applied research center on forests.

In 2017–18, the emphasis was on building capacity and executing a future vision for the CRSF that was initially outlined in 2016–17. The university continued its external review of the CRSF, which was initiated in 2016 after Dr. Wagner's retirement. Key priorities for the past year were documenting as well as communicating important outcomes of the Northeastern States Research Cooperative, leading the National Science Foundation Center for Advanced Forestry Systems into a potential Phase III, and co-leading the Maine Spruce Budworm Task Force and Maine Forest Economic Growth Initiative. All of these efforts are covered in detail within this annual report and showcase the importance of the CRSF for coordinating a range of research efforts.

The CRSF has continued to evolve and refine its mission to remain relevant. In particular, emphasis is now being placed on high-value, low-cost geoinformatics given the need for better informed forest management, particularly at the landscape level. Based on the self-study conducted in 2016–17, the CRSF identified this area as a particular strength and future opportunity. In the coming year, a strategic plan and advisory board will be formed to help guide additional future efforts within the CRSF. Being able to coordinate and communicate research relevant to the region and nation's forest-based economies will remain a critical element irrespective of current as well as future directions.

Overall, I remain excited by the CRSF's ongoing success and bright future, which is only possible by the contributions of a dedicated staff, productive affiliated scientists, and motivated graduate/undergraduate students. In particular, I commend the CFRU's Executive Committee for their help with the leadership transitions within both the CRSF and CFRU as well as communicating the value that both organizations provide to the state's forest industry.

Given the new initiatives, I look forward to what the coming years will bring to the CRSF.



Aaron Weiskittel
Acting Director

PEOPLE

Leadership & Staff

Aaron Weiskittel, Acting Director

Brian Roth, Acting CFRU Director

John Lee, Research Associate, Howland Research Forest

Holly Hughes, Research Associate, Howland Research Forest

Jack Witham, Associate Scientist, Holt Forest

Jenna Zukswert, CFRU Communications and Research Coordinator

Meg Fergusson, CRSF Communications and Outreach Specialist

Leslee Canty-Noyes, CRSF Administrative Specialist

Cynthia Smith, CFRU Administrative Specialist

CRSF Affiliated Faculty

Sandra de Urioste-Stone, School of Forest Resources, Nature-based Tourism

Shawn Fraver, School of Forest Resources, Howland Research Forest

Dan Harrison, Department of Wildlife, Fisheries, and Conservation Biology, CRSF

Jane Haskell, Geroge J. Mitchell Center for Sustainability Solutions, Univ. of Maine (Tourism)

Laura Kenefic, Research Forester, Penobscot Experimental Forest, US Forest Service

Neil Thompson, Irving Woodlands Forestry Professor, Univ. of Maine Fort Kent

Project Scientists

Eric Blomberg, Univ. of Maine (CFRU)

Russell Briggs, SUNY-ESF (CFRU)

Thomas Buchholz, Spatial Informatics Group (NSRC)

Laura Caldwell, Univ. of Maine (NSRC)

John Campbell, US Forest Service Center (CFRU)

Mindy Crandall, Univ. of Maine (CFRU)

Mark Ducey, Univ. of New Hampshire (NSRC)

Ivan Fernandez, Univ. of Maine (CFRU)

Jereme Frank, Univ. of Maine (NSRC)

Shawn Fraver, Univ. of Maine (CFRU)

Anthony Guay, University of Maine (CFRU, CRSF)

John Gunn, University of New Hampshire and Spatial Informatics Group (NSRC)

Eric J. Gustafson, US Forest Service (NSRC)

Dan Hayes, Univ. of Maine (CFRU, CRSF)

Patrick Hiesl, Clemson University (CFRU)

David Hollinger, USDA Forest Service (Howland)

Laura Kenefic, USFS-NRS (NSRC, CFRU)

Daniel Kneeshaw, University of Quebec at Montreal (CFRU)

Christian Kuehne, Univ. of Maine (CFRU, NSRC)

Kasey Legaard, Univ. of Maine (CFRU, NSRC)

David MacLean, University of New Brunswick (CFRU)

Caroline Noblet, Univ. of Maine (Family Forests, Tourism)

Gaetan Pelletier, Northern Hardwoods Research Institute (CFRU, NSRC)

Parinaz Rahimzadeh, Univ. of Maine (CFRU, NSRC)

Robert Seymour, University of Maine (NSRC)

Erin Simons-Legaard, Univ. of Maine (CFRU, NSRC)

C. T. Smith, University of Toronto (CFRU)

Cheryl Spencer, Univ. of Maine (NSRC)

Brian Sturtevant, USFS-NRS (NSRC)

Robert Wagner, Purdue University (CFRU)

Dan Walters, US Geological Survey (CFRU)

Chris Woodall, USFS-NRS (NSRC)

Joseph Young, Maine Office of GIS (CFRU)

Graduate Students

Jeanette Allogio (Howland)

Leah Beck (Tourism)

Karin Bothwell (CFRU)

Xue Bai (NSRC)

Mark Castle (NSRC)

Cen Chen (CAFS, CFRU)

Garth Dixon (NSRC)

Erin Fien (NSRC; Howland)

Lydia Horne (Tourism)

Anil Koirala (CFRU)

Cathie-Jo Langley (NSRC)

Brooke Hafford MacDonald (Tourism)

Margaret Mansfield (NSRC)

Andrew Morgan (Tourism)

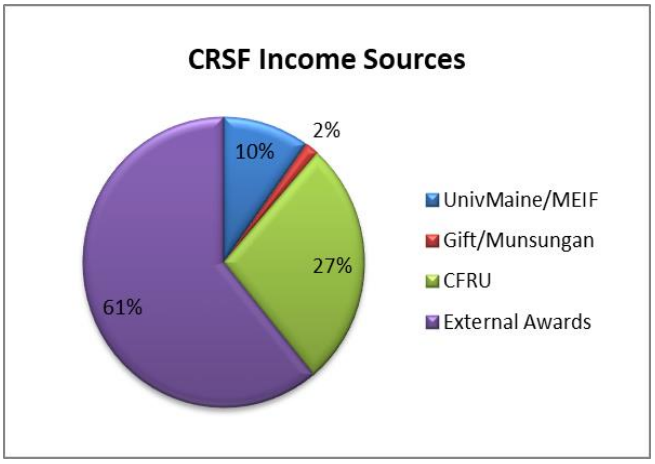
Bethany Muñoz (NSRC)

Joel Tebbenkamp (CFRU)

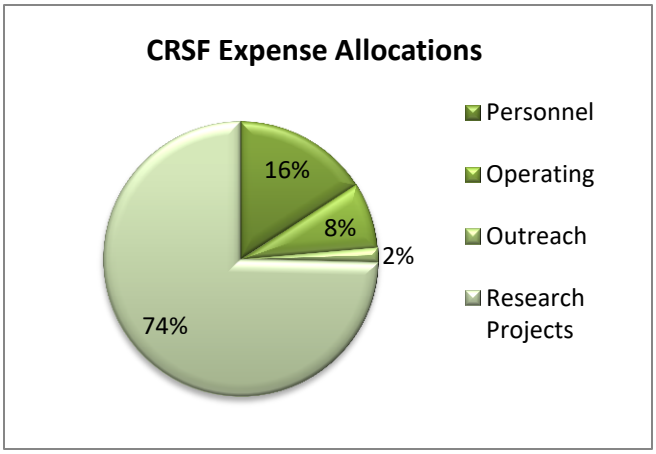
Bina Thapa (NSRC)

FINANCIAL REPORT

Income supporting the center in FY 2017-18 came from programs administered by or that support the general operations and outreach efforts of the CRSF ($206,915), extramural grants supporting specific research projects ($1,094,728) that were received by CRSF scientists from outside agencies, and CFRU cooperators contributed $493,694. Total funding of the CRSF for FY 2017–18 was nearly $1.8 million (see Table 1 for budget detail).



The majority (74%) of the CRSF budget is allocated directly to the research projects described in this report, supporting eighteen projects under the auspices of the CFRU, Howland and Holt Research Forests, Northeastern States Research Cooperative, Penobscot Experimental Forests, and CAFS NSF/University cooperative. The remaining funds support personnel salaries (16%), outreach (including webinars and meeting support; 2%), and operating expenses (including student researchers; 8%).



A key source of financial support for the CRSF is provided by the Maine Economic Improvement Fund (MEIF). The $177,338 investment from MEIF is used to cover Director Weiskittel's salary and fringe ($135,979) and to cover the Center's personnel and operating costs ($41,359). The MEIF funds have helped leverage $523,271 from other CRSF sources and $1,094,728 in extramural grants for a total leverage of $1,617,999 (or more than $9 for every dollar of MEIF funding) of additional research funding.

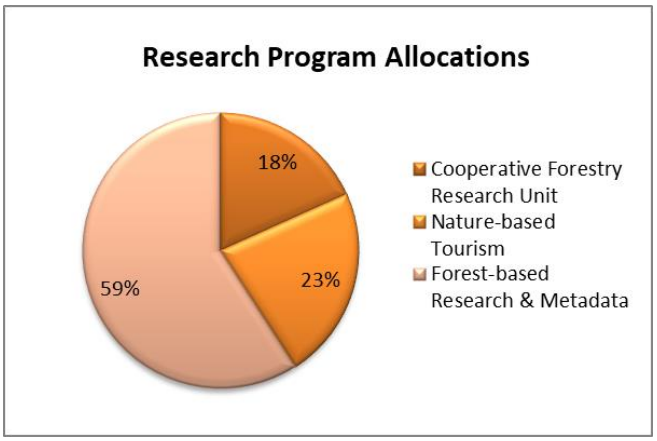


Table 1. FY 2017-18 Budget for Center for Research on Sustainable Forests

Center Sources	Source	Principal Investigator	Amount
Cooperative Forestry Research Unit (CFRU)	CFRU	Roth	$ 493,694
Northeastern States Research Cooperative Theme 3 (NSRC)	USDA-FS	Weiskittel	$ 45,000
Maine Economic Improvement Fund	MEIF	Weiskittel	$ 177,338
Center for Advanced Forestry Systems Phase 2 (Year 4)	NSF	Weiskittel	$ 60,000
CRSF Gift Fund	Gift	Weiskittel	$ 26,421
UMaine Munsungan Fund	Foundation	Weiskittel	$ 3,156
		Center Total	**$ 805,609**
Extramural Project Grants			
Fostering Forest Resources Climate Change Resilience	USDA-FS	De Urioste-Stone	$ 150,000
Assessing and Monitoring the Influences of Forest Management Practices	SFI	Puhlick	$ 90,000
Support for Ameriflux Work at Howland Research Forest	USDA-FS	Fraver et al.	$ 260,666
National tree biomass project Maine	USDA-FS	Weiskittel	$ 75,000
Holt Research Forest+supplemental	Holt	Weiskittel	$ 111,500
Benchmarking Maine's Forest Product Sector	USDA-NIFA	Weiskittel	$ 150,000
Fostering Coastal Communities	NOAA	De Urioste-Stone	$ 152,562
		Grants Total	**$ 989,728**
		Total Income	**$ 1,795,337**
ALLOCATION			
CRSF Director, CFRU Program Leader, CRSF support staff salary & benefits			$ 286,453
Field crew & lab student support & operating expenses			$ 139,518
Outreach (webinars, web support, meeting & conferences)			$ 29,577
		Salaries, Benefits, & Operating Total	**$ 455,548**
Research Projects	**Source**	**Principal Investigator**	
Cooperative Forestry Research Unit			
Strategies for Rehabilitating Beech-Dominated Stands	CFRU	Roth	$ 22,000
Long-term Impacts of Whole Tree Harvesting: Weymouth Point Study	CFRU	Smith/Roth	$ 18,150
A Decision Support System for Selecting Efficient Harvesting Systems	CFRU	Kizha	$ 15,815
Maine's Adaptive Silviculture Experimental Network (MASEN)	CFRU	Roth	$ 32,094
Eval Timber Harvest Op on Soil	CFRU	Kizha	$ 18,370
Identifying Relationships between Spruce Budworm Larval Density, Moth Abundance, and Forest Conditions at the Onset of an Outbreak	CFRU	Simons-Legaard & Legaard	$ 35,220
Development an Application of Early Detection and Monitoring of SBW Defoliation Using Remote Sensing	CFRU	Rahimzadeh	$ 22,748
Populations Dynamics Spruce Grouse	CFRU	Harrison	$ 29,954
Landscape-level Evaluation of Deer Wintering Habitat in Northern Maine	CFRU	Crandall	$ 50,710
		CFRU Project Total	**$ 245,061**
Nature-Based Tourism			
Fostering Forest Resources Climate Change Resilience	USDA-FS	De Urioste-Stone	$ 150,000
Fostering Coastal Communities	USDA-AFRI	De Urioste-Stone	$ 152,562
		Nature-Based Tourism Project Total	**$ 302,562**
Forest-Based Research & Metadata			
Northeastern States Research Cooperative Theme 3 (NSRC)	USDA-FS	Weiskittel	$ 45,000
Howland Forest: Support for Ameriflux Work at Howland Research Forest	USFS	Fraver	$ 260,666
National Tree Biomass Project Maine	USDA-FS	Weiskittel	$ 75,000
Holt Research Forest	MaineTREE	Weiskittel	$ 111,500
Benchmarking Maine's Forest Product Sector	USDA-FS	Weis/Daig/de Urioste	$ 150,000
Center for Advanced Forestry Systems Phase 2 (Year 4)	NSF	Weiskittel	$ 60,000
Assessing and Monitoring the Influences of Forest Management Practices on Soil Productivity, Carbon Storage, and Conservation in the Acadian Forest Region	SFI	Puhlick	$ 90,000
		Forest-Based Project Total	**$ 792,166**
		Total Allocation	**$ 1,795,337**

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

Sandy Gray Forest, LLC
SAPPI Fine Paper
Seven Islands Land Company
Simorg North Forest, LLC
Small Woodland Owners Association of Maine
Snowshoe Timberlands, LLC
St. John Timber, LLC
Sylvan Timberlands, LLC
Social and Economic Sciences Research Center, Washington State University
The Forestland Group, LLC
The Nature Conservancy
Timbervest, LLC
UMaine Cooperative Extension
University of Massachusetts-Amherst
University of New Brunswick
University of New Hampshire
University of Vermont, Rubenstein School of Environment and Natural Resources
UPM Madison Paper
USDA Forest Service, Northern Research Station
USDA Forest Service, Family Forest Research Center
USGS Maine Cooperative Fish & Wildlife Research Unit
USGS West Virginia Cooperative Fish & Wildlife Research Unit
Wagner Forest Management
West Virginia University
Weyerhaeuser Company
Woods Hole Research Center

Forest-Based Research

Commercial Forests (CFRU)

Maine's commercial forests cover the northern half of the state and provide the backbone of the state's annual $8 billion forest products economy. These private landowners manage large tracts of land that involve complex decisions about a wide variety of forest resource issues over long periods of time. To help meet this challenge, these landowners recognized the need long ago for a strong applied research program to provide new information about how to best manage their lands. As a result, they partnered with the University of Maine in 1975 to form the Cooperative Forestry Research Unit (CFRU).

Program Manager Dr. Brian Roth anticipates strong progress after a year of some uncertainty and challenges for the CFRU with the departure of prior CFRU Director Dr. Bob Wagner for Purdue University and a year-long review of the CRSF by the Vice President of Research Office at the University of Maine. It is time to look to the future and build a strong foundation that will support the next generation of applied research and technology transfer for a changing forest ownership and forest products marketplace. One of the most common themes heard during visits with CFRU membership was the need to get the valuable information that the Cooperative generates out into the hands of the foresters and managers who can make use of it. To this end, Jenna Zukswert was hired to the position of Research and Communications Coordinator in December 2017. In the first half of 2018 Jenna successfully launched a number of webinars and issued several research reports for public consumption.

This year, 34 members representing 8.14 million acres of Maine's forestland raised $467,353 in member contributions and leveraged an additional $138,047 in extramural grants and in-kind support. An additional $1,153,165 in leveraged funding for LiDAR acquisition from federal and local sources and $60,000 from the National Science Foundation as part of CFRU's membership in the national Center for Advanced Forestry Systems (CAFS) has helped to support the Commercial Thinning Research Network and Growth & Yield modeling projects.

Project highlights include (1) embarking on an ambitious new study series: Maine's Adaptive Silviculture Network (MASN). The first installation of 18 that are planned for the state has been established with five treatments in Grand Falls Township on BBC Land, LLC with two more installations selected on Irving Woodlands and Seven Islands Land Company. (2) A new study examining the long-term impacts of whole-tree harvesting was initiated on the Weymouth Point Study Area. Preliminary analysis indicates that aboveground biomass, 35 years after harvesting, did not vary by harvest type or soil rock volume after adjusting for differences in stand density. (3) Landsat imagery and derived vegetation indices (VIs) were used to model current-year spruce budworm defoliation in Quebec and Maine. The most effective model used a combination of VIs to predict defoliation, with accuracy greater than 50% across all defoliation severity classes. This method was found to be comparable to aerial sketch maps in terms of accuracy. (4) A region-wide, geospatial analysis of deer-wintering areas (DWA) has been completed. Economic analyses suggest that financial loss is not universal and is highly dependent on landowner objectives and stand conditions at the start of the simulation.

2018 CFRU Field Tour. Photo courtesy Jenna Zukswert.

CFRU PROJECT SUMMARIES

Silviculture & Productivity

Harvest Costs and Long-Term Economic Benefits of Pre-Commercial Thinning in Spruce-Fir Stands: The Austin Pond Case Study

Patrick Hiesl, Paul Smith's College; Mindy S. Crandall, University of Maine

Final Report Summary

PCT plot after thinning with a harvester. Photo courtesy P. Hiesl.

Available information on the long-term economic impact of pre-commercial thinning (PCT) in spruce-fir stands is limited. At the Austin Pond study site, a spruce-fir stand that was partially treated with PCT allowed for long-term projections of stand growth and net present value (NPV). These projections indicated that PCT reduced the time to economic maturity by 11 years but also increased maximum NPV by approximately $1,500/ha. In addition, PCT more than doubled the average stem size. Compared to the control, commercial thinning (CT) reduced maximum NPV by approximately $200/ha for every 10% of basal area removal. However, CT also increased the average stem size. A separate analysis of Commercial Thinning Research Network (CTRN) data from unthinned locations further indicated that thinning from below returned the highest NPV compared to dominant and crown thinning, and doubled the average stem size compared to the control.

Maine's Adaptive Silviculture Network (MASN)

Brian Roth, CFRU; Aaron Weiskittel, Anil Raj Kizha., and Amber Roth, University of Maine

Year 1 Progress Report Summary

CFRU members embarked on an ambitious new study series in 2017: Maine's Adaptive Silviculture Network. Considerable value has been realized from earlier CFRU long-term study areas such as the Weymouth Point Study (1981-), the Austin Pond Study (1978-), and the Commercial Thinning Research Network (2001), and these studies continue to provide useful data. However, these studies have limitations for various reasons: (1) little to no replication across the landscape, (2) small treatment areas, (3) lack of operational treatments, (4) limited range of treatments, and (5) focus on softwood

stand types. 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 many more.

Developing Management Guidelines for the Forest Products Trucking Industry in Maine

Anil Raj Kizha., University of Maine; Brian Roth, CFRU; Anil Koirala, University of Maine

Photo courtesy A. Kizha.

Final Report Summary

Secondary forest products transportation is one of the major components in timber harvesting operations in terms of economics, public visibility, and safety. This study was designed to document the challenges and opportunities within the trucking industry for the state of Maine and develop management guidelines. An extensive scientific literature was carried out, in which a total of 131 scientific articles published from 2000 to 2015 were collected and categorized into six different research themes. This helped in better understanding the current trends and advances in the field. A cross sectional survey was conducted in a conference setting to document and rank the major challenges. The survey yielded a 31% response rate, and the major challenge for the state was determined to be the availability of market and lack of skilled labor (see Figure 1). For developing a management guideline with validated resolutions for the trucking-related problems, a qualitative case study method with semi-structured interviews was implemented. The primary intention was to understand the perspectives of stakeholders on field level solutions.

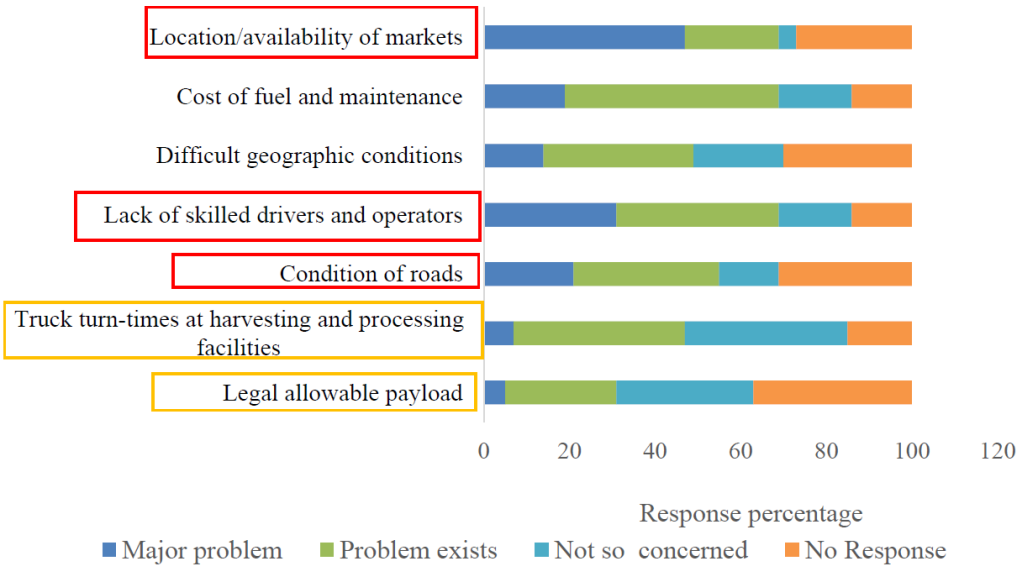


Figure 1. Ranking of the major problems faced by the forest trucking industry. Problems marked in red represent the most severe challenges. Problems marked in yellow were considered of less concern.

Long-Term Impacts of Whole-Tree Harvesting: The Weymouth Point Study

C.T. (Tat) Smith, University of Toronto; Russell D. Briggs, SUNY-ESF; John L. Campbell, US Forest Service; Ivan Fernandez and Shawn Fraver, University of Maine; Brian E. Roth, CFRU

Year 2 Progress Report Summary

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. The experimental design, which includes fixed-area plots established on two adjacent watersheds (uncut and clearcut), enables evaluation of long-term effects of harvest residue treatments on tree growth and long-term dynamics in soil and whole ecosystem carbon and nutrient pools. Between 1979 and 2015, 58 permanent study plots were established across three soil drainage classes in the uncut and clearcut watersheds. Residue treatments applied to 12 plots of the watershed that was harvested in 1981 include: whole-tree removal (WTH), return of lopped and scattered delimbing residues to the site (LOP), and return of chipped delimbing residues to the site (CHP). The residue treatment CHP significantly ($\alpha = 0.1$) affected DBH, height, and biomass of the naturally regenerated trees. However, tree growth was significantly affected by differences in stand density but not by residue treatment nutrients returns or soil stone-volume. The variation in stand density across treatments suggests that chipped residue application reduced stand density by 600 stems per hectare on CHP sites, which significantly enhanced growth of remaining trees. Analysis of tree growth and nutrient loading associated with residue removal (WTH) or addition (CHP, LOP) 35 years after harvest suggests that whole-tree harvesting has not reduced stand growth.

Strategies for Rehabilitating Beech-Dominated Stands

Robert Wagner, Purdue University, Aaron Weiskittel, University of Maine; Arun Bose, Swiss Federal Research Institute; Brian Roth, CFRU; Gaetan Pelletier, University of Moncton

Final Report Summary

High densities of naturally regenerated American beech following single- or multiple-entry selection or shelterwood harvesting in hardwood stands is a problem, and beech regeneration is most often infected with beech bark disease, rendering it of little or no value for forest products. Infected beech regeneration generally grows faster than other hardwood species under most overstory conditions and is able to competitively suppress the natural regeneration of high-value hardwood species such as sugar maple, yellow birch, and red maple. Using data from FIA plots in the northeastern USA, beech stands were grouped into five distinct stand structural and compositional stand types. Strategies were identified for managing beech in these various stand types (Figure 2).

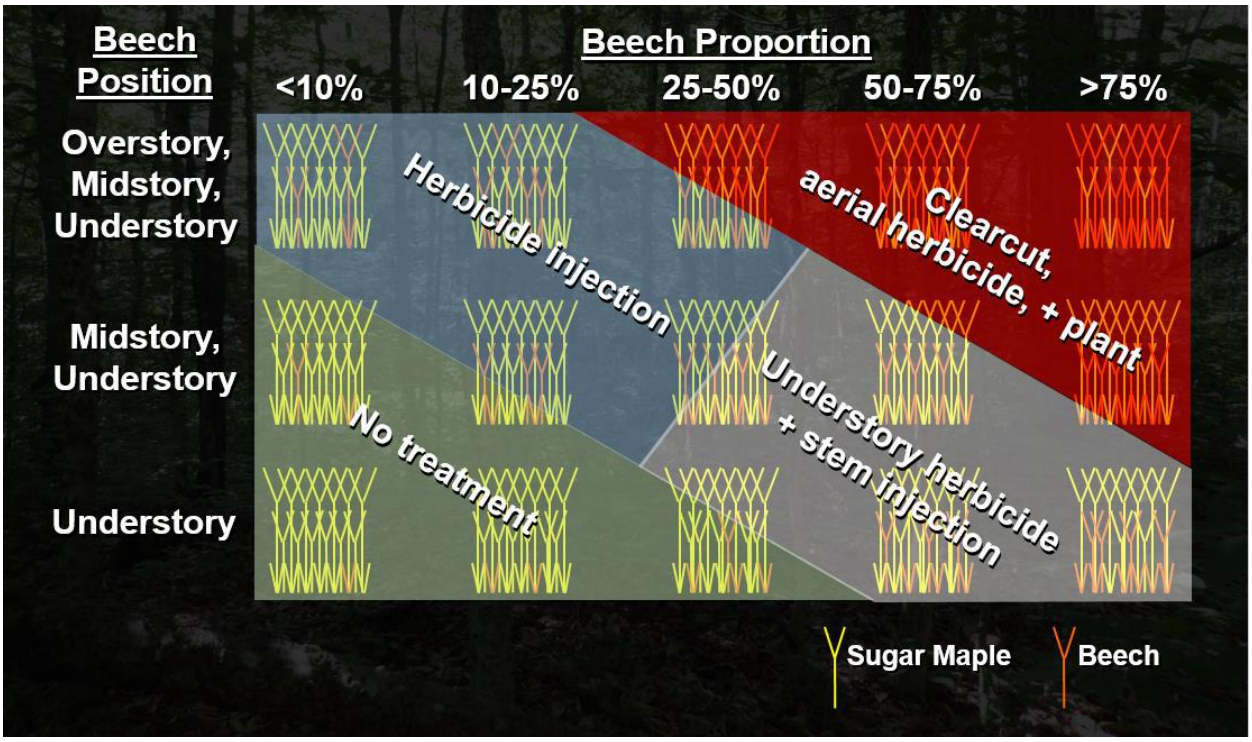


Figure 2. Management recommendations based on beech relative abundance at under- , mid-, and overstory layers of the stand structure.

Modeling and Monitoring

Maine Statewide Light Detection and Ranging (LiDAR) Data Acquisition

Brian Roth, CFRU; Joseph Young, Maine Office of Geographic Information Systems; Dan Walters, US Geology Survey

Year 5 Progress Report Summary

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 3D point clouds can be combined with ground-truthed data from field plots to generate algorithms that predict forest metrics such as merchantable volume, basal area, canopy height, and stem density on a raster basis across the landscape. Combined with Geographic Information Systems (GIS), forest managers have the capability of making accurate, large-scale assessments of forest resources across the landscape. The goal of this project is to assemble a complete statewide base LiDAR data set. This would provide a historic benchmark for comparing future acquisitions of LiDAR data.

Identifying Relationships between Spruce Budworm Moth Abundance, Larval Density, and Mapped Forest Conditions for Risk Assessment during Outbreak Development

Erin M. Simons-Legaard, University of Maine; Kasey R. Legaard, University of Maine; Brian E. Roth, CFRU

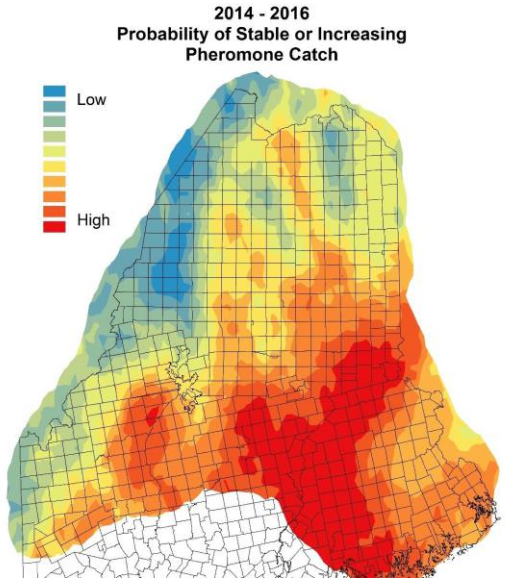


Figure 3. Probability of stable or increasing pheromone catch, modeled throughout the study area using the data collected from pheromone traps from 2014 through 2016.

Year 2 Progress Report Summary

Risk of defoliation and damage due to spruce budworm varies in space and time as an outbreak develops. Our approach to providing the information needed for understanding changing budworm population conditions is based on repeat sampling of pheromone traps and larval (L2 instar) density using a network of locations established across northern Maine in Year 1. Trap and L2 locations provide the basis for developing predictive models of moth or larval abundance (Figure 3). As of winter 2016, the number of sampled locations with L2 remained low, failing to provide a sufficient sample size for modeling larval abundance. Comparing mapped forest conditions with average trap catch (2015-16), we determined that ~60% of the variability in catch could be explained, and that trap location (i.e., latitude and longitude) and percent of high-risk forest (i.e., mature forest with ≥75% host) within 500m of a trap location were the most influential factors.

Development of a Novel Model for the Early Detection and Monitoring of Spruce Budworm (SBW) Forest Defoliation over Maine using Fine Resolution Remote Sensing Imagery

Parinaz Rahimzadeh, University of Maine; Aaron Weiskittel, University of Maine; Daniel Kneeshaw, University of Quebec at Montreal; David MacLean, University of New Brunswick

Final Report Summary

This project was conducted to develop a cost-effective, rapid, and accurate method for timely detection of annual spruce budworm (SBW) defoliation using satellite remote sensing technology. This tool will be an essential need for timely planning and management of the new SBW outbreak in Maine. Landsat satellite imagery were applied for detection and quantification of current/annual SBW defoliation on landscape scale in Quebec (North Shore region). Several Landsat-derived vegetation indices (VIs) were

estimated over a period of four years to detect and quantify SBW defoliation using a non-parametric statistical method. The results showed that the VIs can effectively detect (around 95%) and classify areas of defoliation. This model can be used to detect and estimate SBW severity for the future SBW outbreak in Maine similar to aerial sketch maps (ASM), but more accurately, near-timely, more cost effective, and not subjective. This research was largely completed in the first year of the project; the focus of this second and final year was on documenting and presenting findings as well as preparing follow-up research grant proposals.

Wildlife Habitat

Population Dynamics of Spruce Grouse in the Managed Forest Landscapes of Northern Maine

Joel M. Tebbenkamp, Erik J. Blomberg, and Daniel J. Harrison, University of Maine

Year 3 Progress Report Summary

Spruce grouse rely extensively on conifer-dominated forests throughout the year and frequently use forest stands with a history of clearcutting, herbicide application, and precommercial thinning for both breeding and brood rearing. Reproductive success and survival of spruce grouse inhabiting intensively-managed forests, however, remain unknown. To assess habitat relationships and link demographic responses of spruce grouse to commercial forest management, we have radio-marked and monitored 114 (66 female, 48 male), spruce grouse in Piscataquis County, Maine during 2015 – 2017. We have located and monitored success of 22 nests, and monitored locations and survival of 27 broods. Based on nest survival models, the probability of a nest successfully hatching was 0.56, and increased with greater visual concealment and decreased with greater basal area of saplings. This suggests that, on average, more than 50% of hens nest successfully each year (a relatively high value for a ground-nesting bird) and that females can increase their likelihood of success further by choosing nest sites with greater structural complexity. Apparent brood success was 74%, and the majority (5 of 7) of brood failures were due to females being killed by predators during brood rearing. We are currently in the process of evaluating how structure, composition, and harvest

Bobcat. *Photo courtesy Pam Wells, Oakleafs Studios.*

treatments affect probability of brood success and adult survival.

Landscape-Level Evaluation of Deer Wintering Habitat in Northern Maine

Mindy S. Crandall, Amber Roth, Karen N. Bothwell, Erin Simons-Legaard, Daniel Hayes, Anthony Guay, University of Maine; Brian Roth, CFRU

Year 1 Progress Report Summary

The goal of this project is 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 winter habitat and a quantitative evaluation of that habitat's distribution (Figure 4). Results confirmed 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. In addition, through the combination of digital data acquisition and the development and analysis of existing data, we have begun development of habitat maps that incorporate historical information, expert opinion, and the best available technology (EFI and LiDAR).

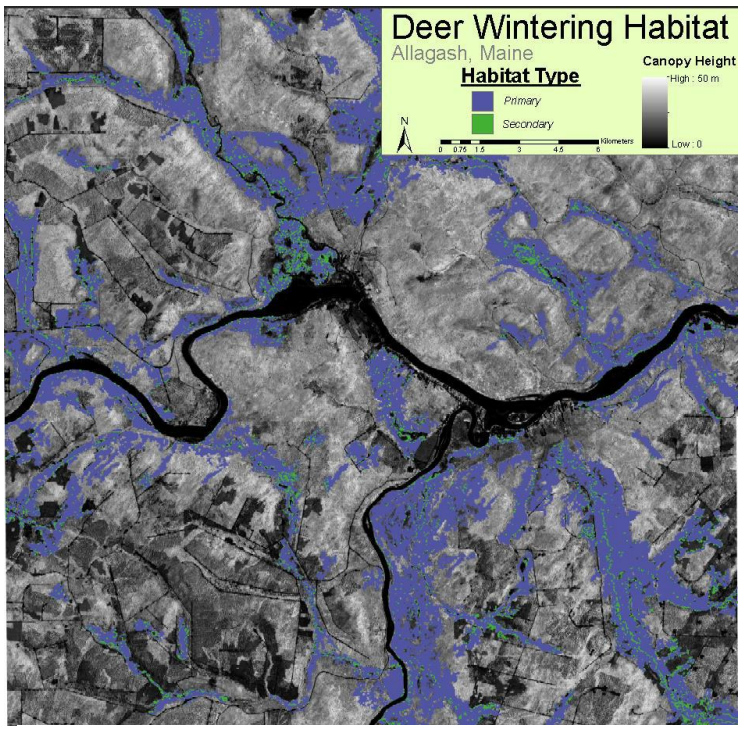


Figure 4. Preliminary analysis from LiDAR data of deer wintering habitat, using information for Allagash Township, Maine.

FOR/ MAINE

The Forest Opportunity Roadmap/Maine (FOR/Maine) is a unique cross-sector collaboration between industry, communities, government, education, and non-profits, 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 petro-chemicals), 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.

FOR/ MAINE

Strong forest. Strong economy. Strong communities.

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**.

FOR/Maine Strategic Planning Workshop: Forest Industry Sub-Sector Analysis

Sandra De Urioste-Stone, Brooke Hafford MacDonald, Lydia Horne, Jane Haskell, Linda Silka, Aaron Weiskittel

Committee Scope
The team members from the University of Maine working on the sub-sector analysis are: (1) undergraduate students Nathaniel Burke, Asha DiMatteo-LePape, and Hope Kohtala; (2) Graduate students Brooke Hafford MacDonald and Lydia Horne; and (3) Professors Sandra De Urioste-Stone, Jane Haskell, Linda Silka, and Aaron Weiskittel.

Work Completed to Date
The research team has conducted 5 focus groups and 13 semi-structured interviews with industry stakeholders. Responses from focus groups and interviews have been transcribed and analyzed using NVivo 12 (computer software used to analyze audio and text data from interviews and focus groups). To date, 50 individuals have participated in the study, representing the following industry subsectors: (1) Land managers – those who manage timber lands; (2) Land owners – those who own timber lands; (3) Loggers – those who work to harvest timber; (4) Transportation – those who transport timber and timber products; (5) Sawmills – those who own or work in a sawmill; (6) Pulp and paper mills – those who own or work in a pulp and paper mill; (7) Bioenergy – those who own or work in biomass/bioenergy plants; (8) Professional services – those who work in mapping or surveying; and (9) Professional groups – those who lead or work in professional groups or non-profit organizations. Additionally, we have collected information from a small sample of policy makers, foresters from government agencies, and capital investors.

Challenges experienced: we have found it challenging to identify and gain entry with capital investors. We have used multiple strategies (i.e., asking feedback from key stakeholders, requesting suggestions during interviews and focus groups, reaching out directly to some investors). We plan to use an anonymous questionnaire as our last strategy to try to collect information from a larger sample of investors.

Facilitators of the process: gatekeepers and existing collaborative platforms have allowed our team to reach out and recruit participants for focus groups and interviews. The extensive support provided by Sarah Curran and the FOR/MAINE Executive Committee has been instrumental to gain entry and build trust with stakeholders. Further, an enthusiastic and highly trained team has allowed for the systematic and rigorous data collection process.

Major Findings
The key ideas that have emerged from the subsector analysis have been grouped under three main themes: strengths of the Maine forest resources industry; challenges experienced by industry stakeholders; and future opportunities.

Strengths: Strong **collaboration** across sub-sectors; recognition that the **industry is important** for Maine and many rural communities in the state; availability of **technology** that makes operations more efficient; **connected** forest landscape; **diversity** of species, forest products, and businesses; **field-center**ed nature of the industry that appeals to people that love the outdoors and are passionate about the forest and forestry.

Challenges: **Aging population** that leads to a lack in quantity of labor force; **younger labor force** that is perceived as less reliable and of "less quality" than the older labor force; **physical strain** of the job that makes recruitment of labor force harder; **non-competitive wages** and lack of incentives (e.g., health insurance, and other benefits); managing for **multiple** and at times **conflicting uses** of the land (e.g., recreation and tourism along with forestry operations); **limited** and low quality of **infrastructure** (roads, railroads) in several areas in the state that decreases efficiency; **high energy costs and taxes** in comparison to other regions in the US and abroad; finding a **sustainable market** for low-grade products.

Opportunities: **Technological** advances; **adding value** to sell products in international markets; take advantage of **proximity** to large markets; expanding **collaboration** with UMaine to take advantage of advances in wood technology and science.

Priority Projects/Strategies

According to study participants, strategies that could foster the success of the forest industry into the future, while ensuring community vitality and sustainability of the industry (forest resources and businesses), include the following:

- Invest in **outreach** activities to enhance the relationship between the industry and "the public" (communities, recreation users, visitors, etc.) to maintain a "social license" (approval from the public) to conduct forest operations.
- Conduct **educational** activities with **k-12** students in Maine to encourage the youth to pursue forest resources related careers. Participants reiterated the importance of starting "early" the recruitment process—they emphasized that High School was too late to build strong interest.
- Use of **new technology** to develop and sell new products using low-value materials.
- Utilize **integrated planning** to reduce conflicts among different industries (i.e., forestry, recreation, tourism, etc.).

Next Steps

During summer and fall 2018 the research team plans to

- Facilitate additional focus groups and interviews with stakeholders (e.g., small woodlot owners, government agencies, non-governmental organizations).
- Conduct thematic data analysis.
- Integrate information from newspaper articles, and prior studies on transportation challenges in Maine to the data we are currently generating via focus groups and interviews.
- Develop and apply a capital investor questionnaire to further understand the challenges and opportunities experienced by potential/current groups to invest money in forest resources oriented ventures.

FOR/Maine Strategic Planning Workshop: Wood Supply

Aaron Weiskittel and Peter Triandfillou,Co-Chairs

Committee Scope

Conduct a statewide wood supply analysis to attract new markets. This primarily has focused on forecasting Maine's forest growth and harvest levels by species, grade, and geography. Committee members include: Peter Triandafillou (Co-Chair), Huber Resources; Aaron Weiskittel (Co-Chair), University of Maine; Pat Strauch, Maine Forest Products Council; Tom Doak, Maine Woodland Owners Ken Laustsen, Maine Forest Service; Ian Prior, Seven Islands land Company; Anthony Lyons, Catalyst Jim Contino, Verso

Work Completed to Date

The committee drafted a RFP for a Phase I wood supply, which is focused on broad-level (megaregion) and short-term (25-30 years) trends. A vendor was selected and a final report has been issued in May. Future work will focus on understanding regional trends in wood supply as well as developing improved tools and methods for future wood supply analyses in Maine, which will include revised yield curves and improved product breakout.

Major Findings

The Phase I wood supply suggested that Maine's forest resources remains highly diverse and sustainably managed. Across the state's different megaregions and forest types, several species have moderate to strong resource potential. In particular, the supply outlook for spruce-fir forest type looks very strong throughout most of the state.

Priority Projects/Strategies

The Phase I wood supply is an important contribution as the previous analysis was dated and built on limited data. The results of the current analysis needed to be broadly communicated and marketed. The follow-up analyses identified below will help to refine the initial findings o

Next Steps

Focus will be on two additional analyses, which include:

1) Regional Wood Supply Assessment

   Wood flows across Maine's borders, so we need to expand our understanding of trends in New England and Canada. The Regional Wood Supply Assessment would examine short-term (20-30 years) trends in wood supply by broad forest types throughout the Northern Forest region.

2) Refined Yield Curves.

   Refined Yield Curves for Maine can be used for future modeling to keep our data current going forward. The current analysis used existing yield curves and lots of changes in modeling capabilities have occurred since their original construction. These include the development of the Acadian Variant of FVS and taper equations, which would help with product merchandising. In this project, species- and product-specific yield curves would be developed that addressed current stand structures/compositions, management practices, and merchantability specs.

Partnerships and Initiatives

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 initiatives and 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 Tree Foundation** and the **Maine Forest Service**.

In addition to the aforementioned stakeholders, this year CRSF participated in the following strategic partnership and initiatives:

FBRI Forest Bioproducts Research Institute

SSI maine's sustainability solutions initiative

Center for Advanced Forestry Systems

NSF

Maine EPSCoR

NSRC Northeastern States Research Cooperative

Forests for Maine's Future

Center for Advanced Forestry Systems

This year saw the completion of the fourth 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.

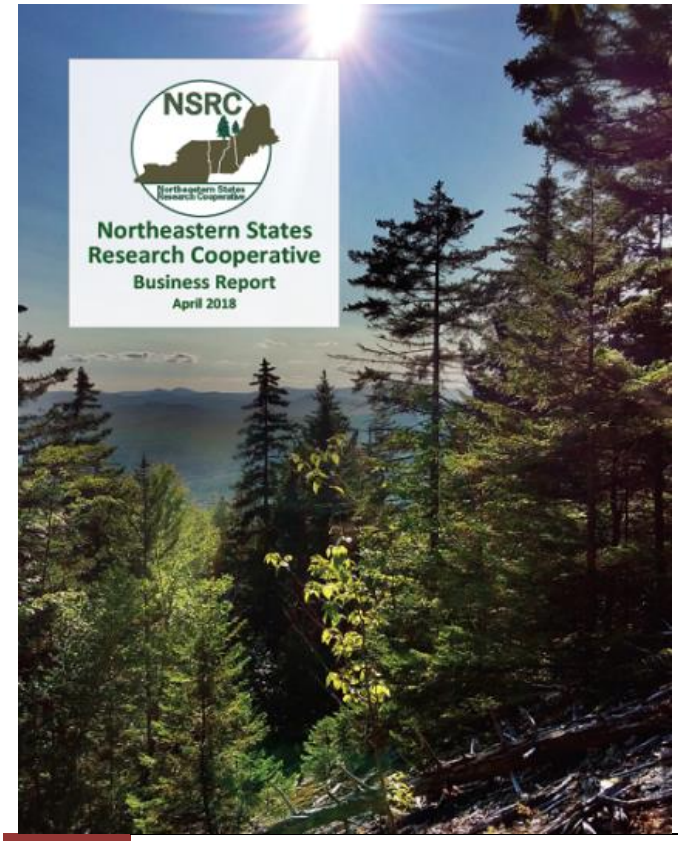
During the 5-year span of Phase II the NSF contributes $60,000 per year to the center as long as CFRU members contribute a minimum of $350,000 per year to support the work of the site. This past year of CAFS funding supported two projects led by UMaine (Understanding and Modeling Competition Effects on Tree Growth and Stand Development Across Varying Forest Types and Management Intensities; The Rise of Commercially Less Desirable Species in Maine: Identification, Characterization, and Associated Driving Factors).

In 2017, the University of Maine became the lead institution for CAFS and CRSF Acting Director Weiskittel was approved as Director. In addition, the CRSF organized the annual Industry Advisory Board meeting held in Burlington, Vermont. Thirty 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 Vermont's Northeast Kingdom to visit operations on Weyerhaeuser and state-managed lands, and a tour of the Maple Guild's sugaring operations and syrup facility.

The Northeastern States Research Cooperative

Since its inception in 2001, the Northeastern States Research Cooperative (NSRC) has been a critically important source of funding for applied forest research and outreach efforts throughout the Northern Forest. The program 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 course of its 16-year history, the U.S. Forest Service Northern Research Station (USFS-NRS) has awarded the NSRC nearly $24 million in support of more than 335 individual projects from 50 organizations across diverse topics and issues relevant to the Northern Forest.



In early 2017, after years of declining congressional funding for the program, project funding was suspended. The NSRC leadership and the USDA Forest Service Northern Research Station continue to work together to determine the future of NSRC. A comprehensive business report covering key accomp-lishments and contributions to the region's unique working landscape was released in March 2018. The report is available online (**www.nsrcforest.org**). In January 2018, a facilitated NSRC

stakeholder meeting was convened with more than 30 participants from a range of organizations. This meeting indicated that the primary concerns of participants included: (1) understanding environmental change effects on local ecological and economic systems and (2) better connecting science to the public via outreach and communications. Key future priority research areas outlined were: (1) rural and forest-based socioeconomics; (2) invasive species; (3) effective science linkages to policy; (4) sustainable forest management; (5) regional patterns in land use and effects of fragmentation; and (5) ecosystems services, particularly energy and carbon. Based on this feedback, NSRC continutes to explore potential partnerships with the University of Vermont's Forest Ecosystem Monitoring Cooperative (FEMC) and the Northern Borders Regional Commission (NBRC).

Past NSRC research topics have in-cluded forest products (e.g., maple syrup production, wood products), land and resource management, models predicting changes in Northern Forest ecosystems, recreational values and opportunities (e.g., public access to private lands, forest-based tourism), and threats to forest health. The research has provided opportunities for the Northern Forest research community to work with land owners and managers, conservation groups, agency staff, and private citizens on issues of mutual interest and concern. These collaborations have resulted in original data, predictive tools, and clear recommendations to manage, protect, and monitor essential natural resources in a regional culture and economy that depends on healthy, working forests.

The structure and organization of the NSRC has evolved over the years, with a shift in 2008 toward greater integration of the four research themes managed by each state. Projects are currently organized into 14 core research interest areas across four broad themes: (1) sustaining productive forest communities, (2) sustaining ecosystem health in northern forests, (3) forest productivity and forest products, and (4) biodiversity and protected area management.

Theme 3 at CRSF

NSRC Theme 3 is managed by the CRSF and supports research that will quantify, improve, and sustain productivity of the products-based economy of the Northern Forest. Aspects of primary interest include underlying biological processes, management practices, and methods of prediction that will influence future wood supplies and forest conditions. Dr. Aaron Weiskittel and Meg Fergusson manage the NSRC within CRSF.

During FY 2017–18, CRSF continued to support ongoing NSRC projects granted in past years. Summaries of the final reports from projects completed this year and progress reports from current Theme 3 projects follow (full reports are available on the NSRC web site at nsrcforest.org).

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

Parinaz Rahimzadeh (Principal Investigator), School of Forest Resources, UMaine; Aaron Weiskittel, School of Forest Resources, UMaine; Daniel Kneeshaw, Department of Biological Sciences, UQAM, Quebec; David MacLean, Forestry and Environmental Management, University of New Brunswick, Canada

Year 2 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 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 and comprehensive 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 km^2) was located in the northern part of Maine (Figure 5). This region is part of New England Acadian forests that are a transition zone between boreal spruce-fir forests to the north and deciduous forests to the south. It is relatively flat with low mountains and abundant lakes, ponds and streams. 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 and SBW-induced defoliation were the major landscape-scale causes of change in the region. Later in the 1990s, management practices shifted to clear cutting with protection of advance regeneration [Legaard et al. 2015]. The last outbreak in Maine was particularly severe. 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 m^3 of fir [Maine Forest Service, 1993], and intensive salvage logging.

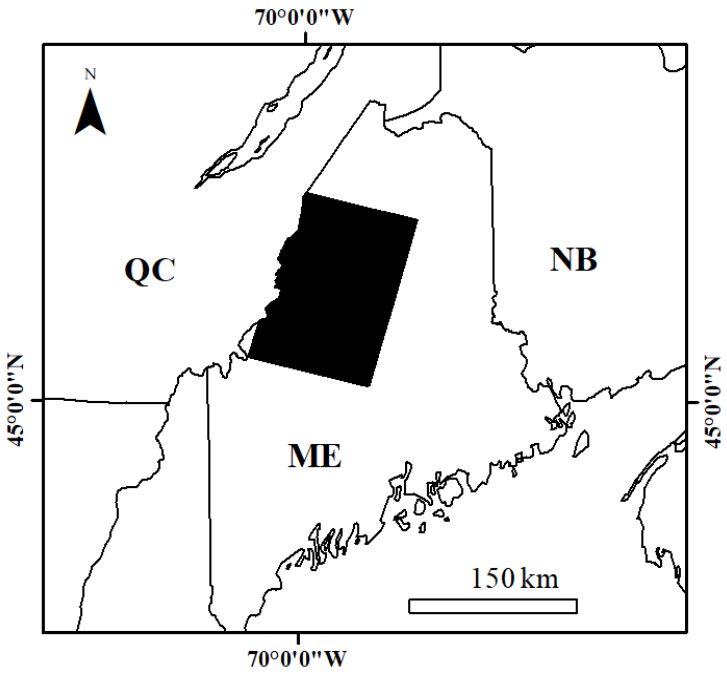


Figure 5. Location of the study areas in Maine, USA. The study area (~100*150 km2) was located in Landsat-MSS scene 13/28

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 6).

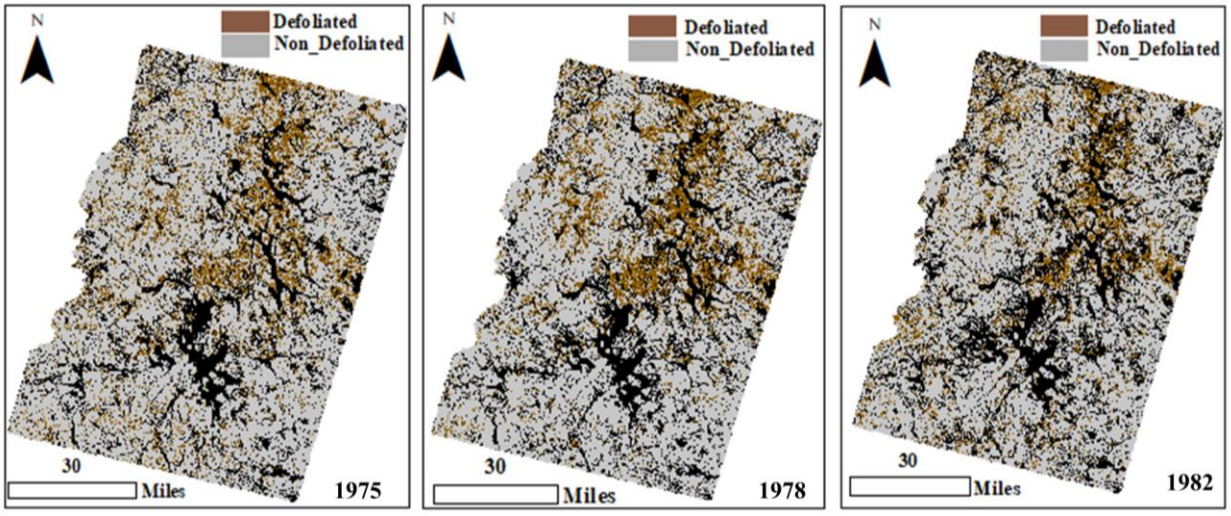


Figure 6. Landsat-MSS SBW defoliation occurrence maps at 60 m spatial resolution.

Future Plans

- Study effect of site factors on SBW defoliation patterns/method improvement.

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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

Marie-Cécile Gruselle (Principal Investigator), School of Forest Resources, UMaine; Ivan J. Fernandez, School of Forest Resources and Climate Change Institute, UMaine; Shawn Fraver, School of Forest Resources, UMaine; Christian Kuehne, School of Forest Resources, UMaine; Cheryl J. Spencer, School of Forest Resources, UMaine; Michaela Kuhn, School of Forest Resources, UMaine; Elyse Daub, Bangor High School; Audrey Garcia, School of Forest Resources, UMaine; Devon Rossignol, School of Forest Resources, UMaine

Year 2 Progress Report

Summary

The main goal of this project is to better understand the influence of elevated N input on downed wood debris dynamics. Staff continued the implementation of the downed coarse and fine woody debris (CWD and FWD, respectively) sampling as well as a standard wood 'decay stake' experiment at the Bear Brook Watershed in Maine (BBWM). Since 1989, the BBWM is a manipulative whole-ecosystem and paired-watershed experiment with one watershed receiving N fertilizer and another one remaining untreated. 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 ^{15}N 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 ^{15}N recoveries in standard 'decay stakes' of sugar maple and red spruce between watersheds in a field decomposition experiment.

- Test the influence of watershed N status, decay stake characteristics (tree species, initial wood density and chemistry), and local drivers of decomposition on C and N dynamics and ^{15}N recoveries of sugar maple and red spruce wood 'decay stakes' in a field decomposition experiment.

Approach

- This study combines a descriptive and an experimental approach and capitalizes on the well-established infrastructure and existing long-term ecosystem data from the BBWM.
- In the ***descriptive approach***, CWD, FWD were sampled in both watersheds as well as outside of the reference East Bear Watershed between June and October 2017 for chemical analysis (C, N, 15N). Sampling of downed coarse and fine dead wood pieces outside the BBWM but in the research area was performed to accurately estimate the 15N recovery, hence fate of N, in decomposing fine and coarse woody debris. The chemical analysis for C, N and tracer N (15N) coupled with biomass data will allow us to calculate C, N and 15N recoveries in CWD and FWD components that ultimately will be compared between watersheds (i.e. ecosystem N status).
- In the ***experimental approach***, the field decomposition experiment using standard red spruce and sugar maple wood 'decay stakes' continued. We now have two years of decomposition since the installation of the stakes in July 2016. The decay-stake method allows us to follow wood decomposition and the fate of N in decomposing wood materials in the field by making use of pre-existing whole watershed 15N pulse-chase labeling experiments at the BBWM. It will also enable us to compare the wood decay rate and 15N recoveries between sugar maple and red spruce at the same site. Lastly, this experiment will allow us to test whether the shorter the distance between the decay stakes and the decaying log of the same species, as the source of the decaying fungi, enhances the decomposition of the decay stakes (see proposal for detailed description of the stakes installation scheme).

Key Findings / Accomplishments

- Between July 1, 2017 and June 30, 2018, there was a change of lead-PI as Dr. Gruselle left UMaine. Dr. Fernandez is lead-PI since January 1, 2018. Moreover, since June 1, 2018, the project is in the phase of no-cost extension as approved by Dr. A. Weiskittel on November 3, 2017.
- During the 2017 growing season, a sampling scheme for FWD was devised to sample FWD classes (diameter: 0-1 cm, 1-2.5 cm, 2.5 to 5.0 cm and 5.0 to 10.0 cm) in accordance to their frequency (i.e. larger total sampling area for FWD of class 5.0 to 10.0 cm than for the class < 1.0 cm).
- Suitable locations were found to collect reference samples of woody detritus for 15N background levels by watershed. The reference CWD and FWD samples were taken from the lower A plots of Eckhoff and Wiersma (2002), which are situated east and outside of the boundaries of the reference watershed.
- Sampling of CWD cross-sectional disks (174 collected) and FWD samples (281 collected) is completed. In the last 12 months, part of the CWD disks and the FWD samples have been processed (milling) for chemical analyses by 4 student workers (Michaela Kuhn, Elyse Daub, Audrey Garcia, and Devon Rossignol). The processing is not completed but significant progress towards timely completion has been achieved.
- A set of 12 CWD samples were sent to the UC Davis Stable Isotope Facility for expedited analysis to get a better estimate of (1) the mass of sample to send for analysis to get accurate C and N and dual isotope concentrations, and (2) 15N enrichment by tree species (American beech, maple spp., and red spruce) by decay class. Enrichment results, expressed as δ15N, are presented in Table2. These very preliminary results show a strong isotopic enrichment in red spruce of decay class 3 (least decomposed stage in Table 2). Based also on these results, a maximum of 9.0 mg of

powdered samples should be used for all species and decay class combinations of CWD to get both accurate δ15N and δ13C values. A similar test will be done on FWD samples early on during the present no-cost extension.

- A stump, snags and overstory inventory has been performed between 13th and 22nd September 2017 at the same locations as the ones used for CWD and FWD inventory. This inventory was performed in order to relate stand characteristics to the abundance of downed woody debris. In total, 642 trees, stumps, and snags have been measured (height and diameter). In summer 2018, PI Fraver will perform a sapling inventory at the same locations across both watersheds because this research component was not part of the inventory of September 2017.
- Red spruce and sugar maple standard wood 'decay stakes' were installed in the field in July 2016 (320 stakes in total). These stakes were checked during the summer/fall 2017. A conversation with the PIs is taking place to plan the collection of half of the stakes in the fall of 2018.

	Reference watershed			Treated watershed		
Species	DC3	DC4	DC5	DC3	DC4	DC5
A. Beech	n.d.	7.11	14.12	n.d.	14.96	n.d.
Maple spp.	n.d.	n.d.	-0.08	n.d.	n.d.	2.60
R. Spruce	118.94	2.75	7.03	112.37	10.02	2.97

Table 2. Isotopic composition ($\delta^{15}N$, ‰) of CWD samples from decay class (DC) 3 to 5 by tree species and watershed at the BBWM. Expedited set was 12 samples in total (n = 1 per cell). n.d.: not determined.

Future Plans

- Completing the Wiley and ball milling of the remaining CWD and FWD samples in the laboratory in Deering Hall and their subsequent preparation and submission to the UC Davis Stable Isotope Facility for C, N, and 15N analyses. The Wiley milling of the wood samples is slow, as expected, and the data turn-around at UC Davis SIF is around 4 to 8 weeks. Thus, this aspect of the project will occupy a large part of the no-cost extension year of the project.
- 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, 15N) of the 'decay stakes'.
- Submitting the processed decomposed decay stakes to UC Davis Stable Isotope Facility for C, N, and 15N analyses.
- Writing a publication on the influence of ecosystem N status and local drivers of decomposition on mass loss, chemistry, and 15N recoveries of sugar maple and red spruce wood 'decay stakes'.

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

Mark Ducey (Principal Investigator), University of New Hampshire; John Gunn, University of New Hampshire and Spatial Informatics Group Thomas Buchholz, Spatial Informatics Group; with support from Ethan Belair, University of New Hampshire

Summary
Within the next several years, an outbreak of eastern spruce budworm (SBW; *Choristoneura fumiferana*) will impact the Northern Forest Region. This new outbreak will affect product flows and yields as well as carbon storage. This new outbreak comes just as emerging carbon markets are beginning to show benefits for Northern Forest landowners. 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 stand- and landscape-level risk, and capturing carbon in wood-in-use pools from at-risk and dying trees that would otherwise be lost.

We are 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 attack. The results will provide guidance on the best strategy for risk management, to minimize the impact of spruce budworm on both timber and carbon values in the forest.

Project Objectives
- Develop projections of future forest and wood-in-use C pools for FIA plots and remeasured 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.
- 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 has been completed.
- 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 has been completed for all scenarios, for all plots in the study area. Example results are shown in Figure 7.
- 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. A screen capture of the web site is shown in Figure 8.

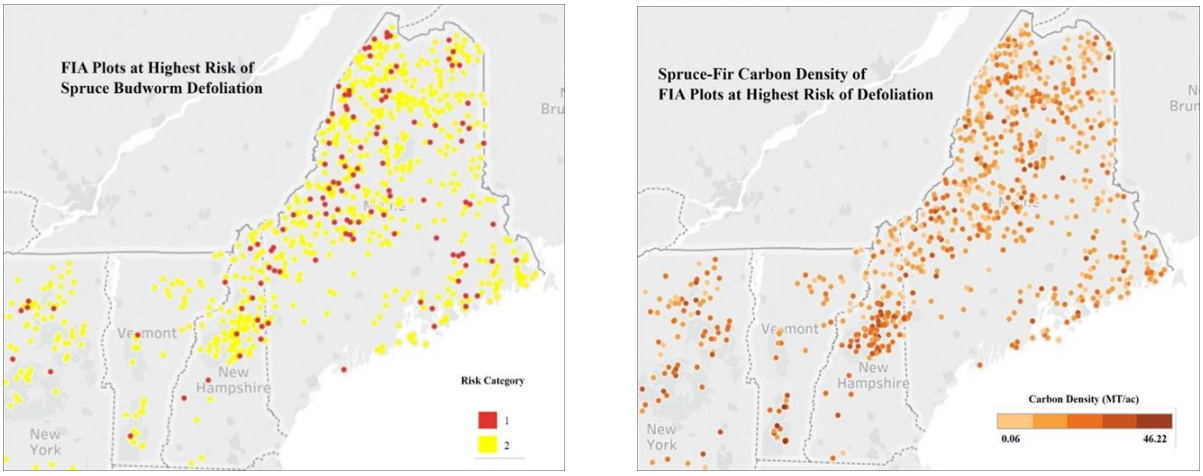

Figure 7 (Left) Map of highest-risk FIA plots for SBW attack in the study region. (Right) Carbon at risk from SBW attach on FIA plots with the highest risk rating.

- We are using the estimated standing C pools and harvested C from the simulation alternatives (Figure 9) and tracking forest sector life-cycle emissions using the ForGATE tool developed for the Northern Forest region. The tool allows for life-cycle forest-sector GHG accounting from stump to mill gate and final disposition. GHG accounts include: 1) storage in above- and below-ground live biomass and dead organic matter components; 2) storage in forest products in use and in landfills; 3) forest-sector emissions by harvest, transport, and mills or avoided emissions (substitution; bioenergy), as well as 4) landfill methane fluxes. This work is in the final stages.
- We have developed the framework for analysis of decision alternatives, and will be poised to complete the synthesis as soon as the final results of the life cycle analysis are complete.
- In the original proposal, we anticipated using a carbon offset pro forma analytical tool to evaluate the implications of SBW avoidance or mitigation strategies for offset project feasibility. There are carbon consequences both of SBW attack, and of mitigation strategies. However, based on the preliminary results of the life cycle analysis, the carbon benefits of aggressive spruce budworm mitigation do not appear to be large enough to represent a viable offset, unless bundled over very large areas of high-risk spruce-fir stands. Should this result be confirmed once the final LCA (including all wood-in-use pools) is complete, we will incorporate that finding in our final recommendations.

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 we expect to submit to a peer-reviewed journal within the month.Twenty business-as-usual and alternative harvesting scenarios have been modeled for 40 years, distilled, and formalized for subsequent life cycle assessment of forest products, including energy.

Future Plans

- We expect to submit a manuscript on the current stocking of forests in Northern New England, including specific discussion of pest risk, climate resilience, and greenhouse gas consequences, within the month.

- Final LCA analysis will be completed this summer, with synthesis into landowner recommendations and the development of two outreach publications by October.

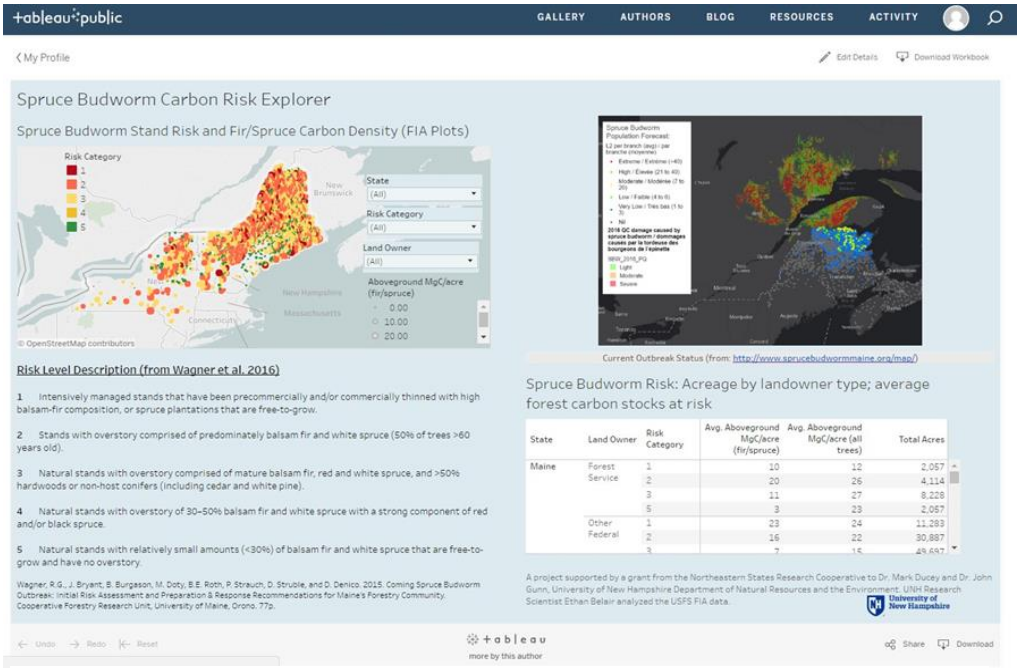

Figure 8. Web portal for interactive query and display of FIA data and simulation results.

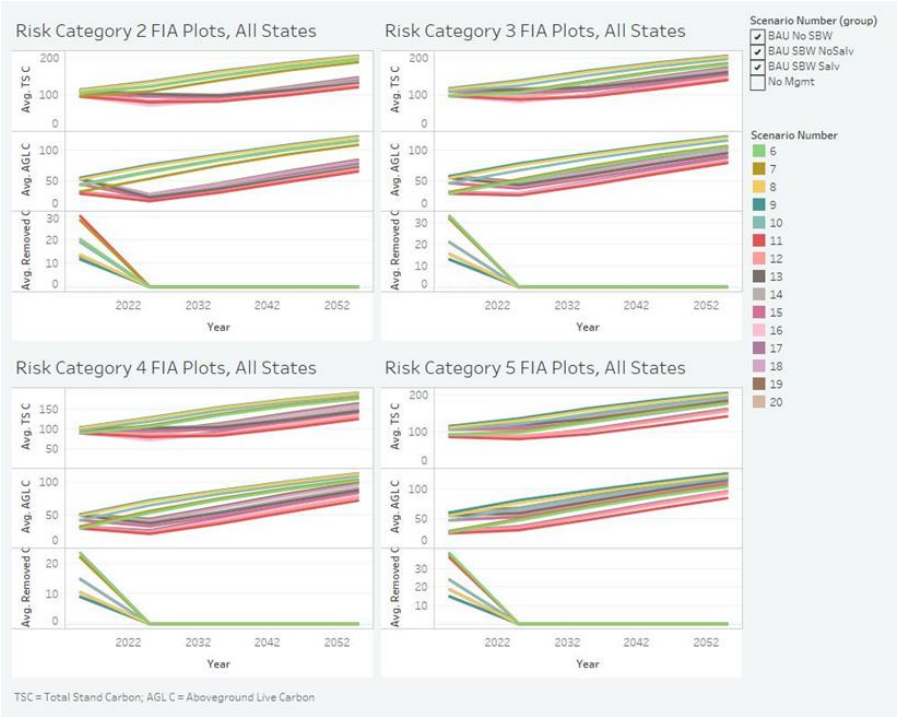

Figure 9. Raw outputs of Forest Vegetation Simulator harvest and growth simulations for 20 scenarios.

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.*

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

Laura Kenefic (Principal Investigator), USDA Forest Service, Northern Research Station; Bethany Muñoz, USDA Forest Service, Northern Research Station and School of Forest Resources, UMaine; Aaron Weiskittel, School of Forest Resources, UMaine; Ivan Fernandez, School of Forest Resources, UMaine; Jeffrey Benjamin, Bangor Christian Schools; Shawn Fraver, School of Forest Resources, UMaine

Year 4 Progress Report

Summary

Though whole-tree harvesting has become increasingly common in the Northeast, concerns remain about site productivity impacts of biomass removal. This project quantified productivity in the oldest known study of biomass harvesting in temperate forests worldwide, at the Penobscot Experimental Forest in Maine (Figure 10). Beginning in 2014, permanent sample plots (PSPs) were installed to quantify growing stock, composition, and soil and foliar nutrients in three treatments applied in 1964-65: whole-tree harvesting (WTH), stem-only harvesting (SOH), and stem-only harvesting with prescribed burning (SOHB). Fifty years after treatment, we found that neither WTH nor SOHB reduced productivity relative to SOH as expressed by structure, stocking, or soil and foliar nutrients. Differences in composition were observed, but attributed to site disturbance associated with whole-tree skidding or burning rather than effects on inherent site productivity. The site was re-harvested this winter (Table 3) and will be re-burned this summer.

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
- 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

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

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 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 (i.e., each tree had one cation and one anion IERM strip placed side by side, at a distance ~10x 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

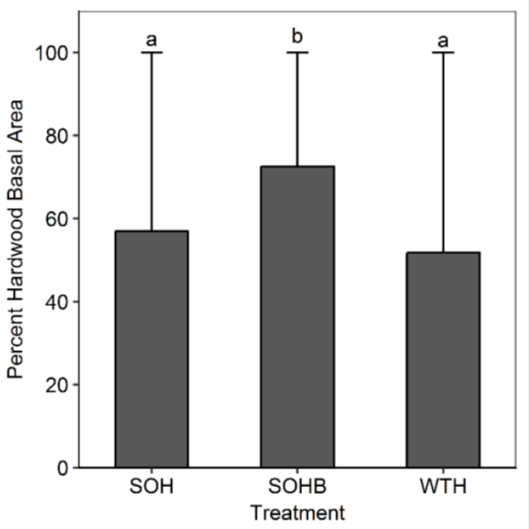

Figure 10. Least-squares means and standard errors of hardwood basal area by treatment, for trees with a dbh ≥ 1.3 cm. Different lower-case letters indicate a significant difference in least-squares means.

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**

Table 3. Summary of products removed in the 2018 winter harvest on C33, by species-specific product

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). *Photo courtesy Bethany Muñoz*.

- 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)
- Presentation of Chapter 1 and 2 findings during doctoral defense: "*Long-term Sustainability of Northern Mixedwood Management: Spatial and Temporal Aspects of Forest Productivity*" (November 28, 2017)

Future Plans

- Compare fuels and deadwood structure across SOH, SOHB, WTH (prescribed burn anticipated summer 2018), in collaboration with University of Massachusetts
- Woody plant regeneration research (repeating that on the site by Rinaldi (1970)) and wildlife utilization study (deer exclosure installation summer 2018)
- Measure soil solution chemistry (pH included) > 1 year following harvest, followed by subsequent measurements
- Collect NIR imagery of C33 for long-term evaluation of change in productivity over time in collaboration with University of Maine, Barbara Wheatland Geospatial Laboratory
- Collect 0-360 degree imagery and video of burn units to be used in survey evaluating social perception of prescribed burning northern mixedwood stands, in collaboration with USDA Forest Service, Northeast Climate Hub

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

Christian Kuehne (Principal Investigator), School of Forest Resources, UMaine; Kasey Legaard, School of Forest Resources, UMaine; Aaron Weiskittel, School of Forest Resources, UMaine

Year 3 Progress Report

Summary

Three years into this project, we have made further progress in the preparation and analysis of both field measurements and remote sensing data sources, needed for quantitative characterization of harvesting trends across northern Maine. Initial analyses were completed, and substantial

methodological improvements were made. As a result of the ongoing growth and yield model improvements and the resulting postponement of the stand development projections, another 1-year no-cost extension was requested. An extension based on the collaboration with the University of Maine System Advanced Computing Group will enable a statewide expansion of remote sensing and spatial analyses based on new, more efficient software implementations of our algorithms. Results from this collaboration will be available soon. Thus, work planned for year 4 will complete project objectives, with multiple important improvements over the work originally proposed.

- Refine and evaluate the distribution of partial harvest conditions in northern Maine.
- Map incremental changes in partial harvest conditions across a ~10 million acre study area and a ~30 year time period.
- Project the development and quantify the shift in species composition and structure of residual stands created following the most commonly used types of partial harvest identified in objective #1.
- Group these projections into a new set of average stand development trajectories based on past harvest actions which will serve as the basis for an updated classification scheme.

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 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.

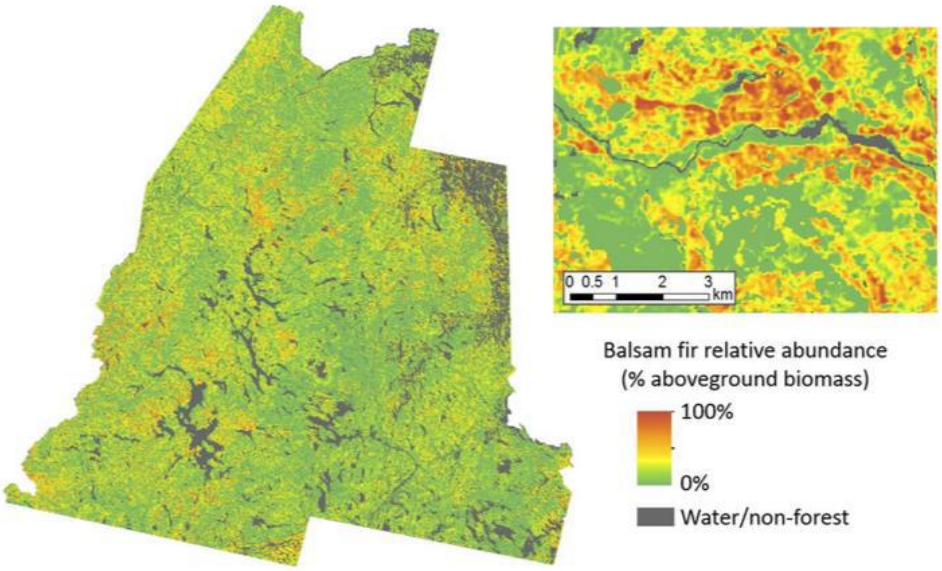

Figure 11. Example of satellite-derived map of forest conditions using machine learning techniques that effectively reduce undesirable systematic error as part of the ongoing collaboration with the UMS Advanced Computing Group.

- Extend and update the Acadian Variant of the Forest Vegetation Simulator (FSV-ACD) by incorporating new submodels (so-called thinning modifiers) projecting individual tree growth and mortality after various types of partial harvest
- Project the development of residual stands created from common classes of partial harvest using the updated Acadian Variant of the Forest Vegetation Simulator.
- Evaluate short- and long-term projected shifts if species composition and forest structure induced by common classes of partial harvesting
- Develop a new set of stand development pathways representing current harvest practices and anticipated silvicultural outcomes by grouping projected stand conditions.

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) may cause apparent regional differences in harvest 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 should result in tangible improvements to maps.
- By extending this project into a fourth year, we will capitalize on outcomes of other projects to expand spatial data statewide. 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 will overcome computation and data management barriers that have thus far limited work to a northern Maine study area. A statewide expansion of mapping objectives will provide a comprehensive accounting of harvest trends needed for a statewide spatial wood supply analysis.
- We developed individual tree-level forest treatment response functions for the two most important conifer species of the study area (red spruce and balsam fir) and incorporated these treatment modifiers into FVS-ACD.
- We have partially leveraged this project and obtained additional funding for the upcoming fiscal year that will further 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).
- 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).

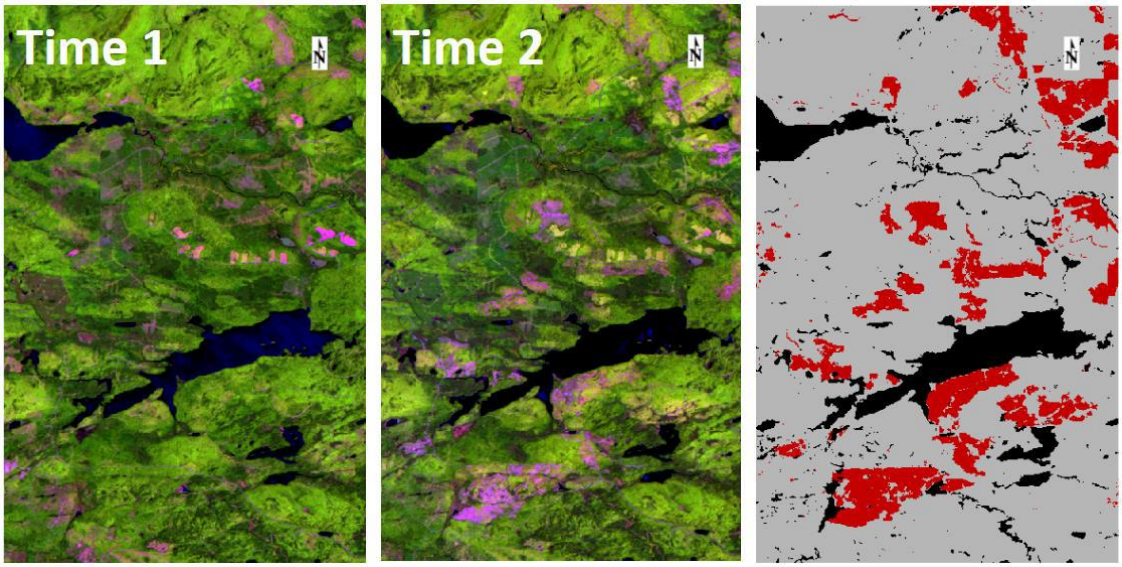

Figure 12. Sample of preliminary forest change detection outcomes generated from a new machine learning and remote sensing workflow developed in collaboration with the UMS Advanced Computing Group. This machine learning approach effectively eliminates bias in maps of forest disturbance, enabling more consistent estimation of disturbance characteristics and more reliable detection of temporal trends.

Future Plans

- We are well positioned to complete proposed objectives during the next year. In a number of cases, this will include significant improvement over the work we originally planned.
- 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.
- Using the 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.

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

Brian R. Sturtevant (Principal Investigator), USFS, Northern Research Station; Eric J. Gustafson, USFS, Northern Research Station; Kasey Legaard, University of Maine

Year 3 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. 1973* 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 (Figure 13), 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.

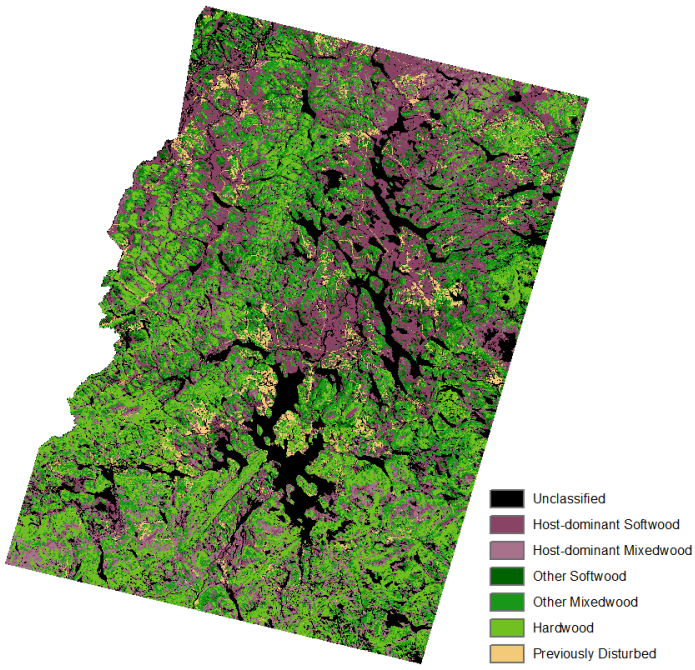

Figure 13. Map of 1975 forest conditions differentiating host-dominant softwood and mixedwood from other forest types. We have produced multiple maps depicting different spruce-fir distributions in order to evaluate the sensitivity of simulation outcomes to uncertainty in host species distributions. 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.

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 CFRU.
- 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.

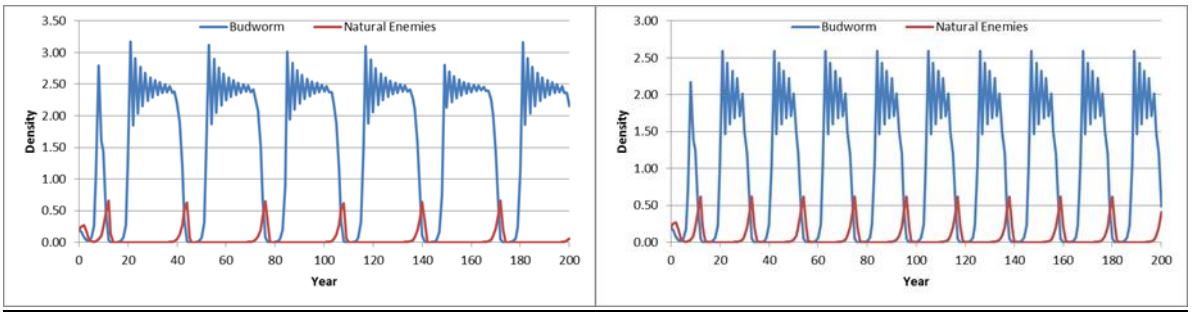

Figure 14. Simulated spruce budworm population dynamics within A. pure host forest, versus B. mixed forest (0.6 host conifers and 0.4 nonhost hardwoods). Critical features include both high frequency (i.e., "sawtooth" at high density) and low frequency (i.e., broad oscillation between endemic and outbreak densities) populations; lower frequency outbreak cycles under pure host conditions, due to comparatively slower response of natural enemies (see Sturtevant et al. 2015). In this case, a non-host effect was controlled by an input parameter.

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, we obtained plot coordinates for a large set of historic plot measurements made by the FIA program.
- 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 1973.

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 (Figure 14). 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.

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):

- 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.

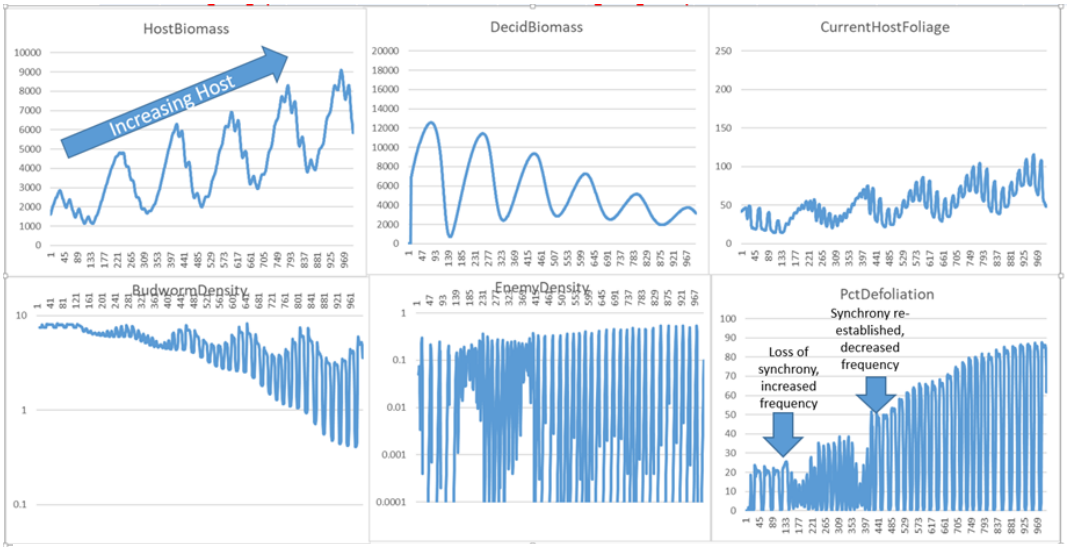

Figure 15. Forest landscape dynamics of budworm host (white spruce), nonhost (trembling aspen), spruce budworm populations and natural enemy "populations." Outbreak dynamics are an emergent property of spatiotemporal feedbacks between budworm and landscape forest conditions.

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 (Figure 15). 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 (Figure 16). 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.

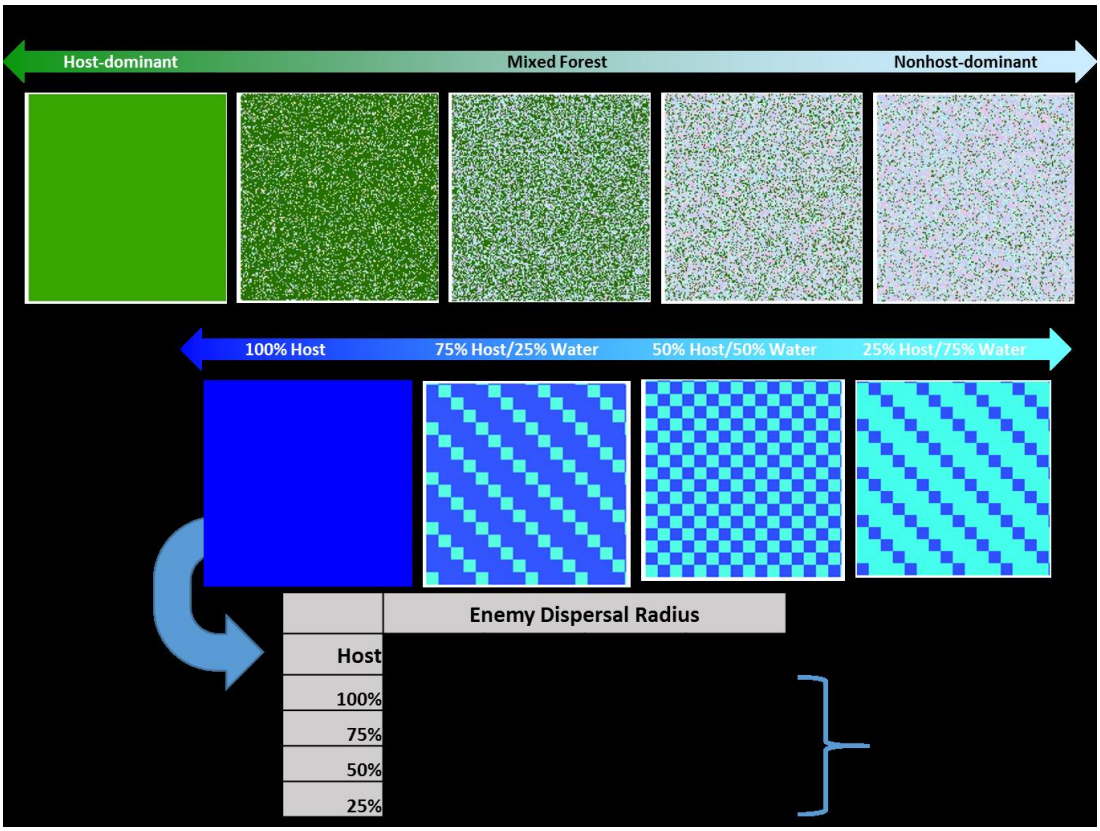

Figure 16. Example neutral landscapes used as initial conditions for evaluating budworm population response to host abundance and configuration. Top panel shows an example of a gradient in host and nonhost types, with fine-scaled fragmentation. Bottom panel shows a gradient in host vs nonforest ("water"), with coarse-scaled fragmentation. Table inset shows how outbreak periodicity is sensitive to both the enemy dispersal radius (a calibrated parameter) and the proportion of host (an emergent property of the simulations).

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Productivity, Regeneration Patterns, and Pre-Commercial Treatment Options of Two Ecologically Based Silvicultural Systems: 20-Year results from the AFERP Study

Robert S. Seymour (Principal Investigator, University of Maine; Shawn Fraver (Co-PI), University of Maine; Paul Szwedo (MF/MS candidate), Margaret Mansfield (MS)

Year 4 Progress Report

Summary
The Acadian Forest Ecosystem Research Project (AFERP, established on the Penobscot Experimental Forest, Maine) represents a 20-year ongoing effort to test an ecologically based silvicultural system in a mixed-species forest type representative of much of the Northern Forest. We have been working to evaluate the silvicultural performance (regeneration, growth, mortality) of two variants of natural disturbance-based expanding gap silviculture installed in the AFERP study. Throughout the time period of July 1, 2017 to June 30, 2018 we completed understory vegetation measurements on all research areas; RAs 8 and 9 were completed in 2018, others were done in 2017, by Margaret Mansfield. All vegetation quadrats were reassessed using protocols identical to those used on four prior occasions, most recently in 2011.

Project Objectives

- Extend the short-term (10-year) results from earlier work (NSRC 2007; Arsenault and Saunders 2011) by quantifying 20-year stand development patterns (regeneration, growth, and mortality) in terms of conventional stemwood volumes and carbon stocks, focusing on the productivity tradeoffs among matrix forests, regeneration, and permanent reserve trees
- Examine within-gap regeneration patterns to isolate the effects of harvest timing, location within gap, and proximity to reserve trees
- Compare regeneration patterns and stemwood productivity by silvicultural treatment (large gap, small gap, unharvested matrix, unharvested control) and quantify statistically significant differences
- Install a new study of stand-tending intermediate treatment options for the regenerating gaps.

Approach

- To characterize general long-term growth and composition trends and provide baseline comparisons between treatment types and control areas, a permanent plot network of nested, fixed-area overstory, sapling, and regeneration plots have been measured every five years since 1995 (Saunders et al. 2012). Trees >9.5 cm dbh are stem-mapped on 20 0.05-ha plots per research area; saplings are measured on nested 0.01-ha plots. We have been working to remeasure these plots prior to harvest entries, and again after completion, to complete a 20-year record. Data include species, dbh, status, height (total and crown base), crown stratum, and Bechtold's (2003) light exposure class.

- We will establish an intensive sample of regeneration plots within harvest gaps, and use these data to (1) document 20-year regeneration patterns, and (2) inform the prescription of precommerical composition and density control treatments (Objective 4).
- We will use the data from objectives (1) and (2) to further stratify results by silvicultural treatment to determine the effect of harvest prescription on stand dynamics and development. This will be accomplished by assessing the significance of gap size, position within gap, time since harvest, and proximity to retention trees.
- We will use the results of the vegetation clustering from Objective (2) to create specific crop-tree release and precommercial thinning prescriptions. Treatments will focus on shifting species composition to higher-value, longer-lived, and locally uncommon species where possible. Each managed research area will be split in half, such that the permanent plots and areas in harvest gaps are represented as equally as possible. Treatments will be applied by trained workers to the sapling regeneration in a randomly chosen half of each research area, using a combination of herbicide basal sprays (for hardwood sprout clumps) and motor-manual cutting. The treatments will be applied during the first growing season following the third harvest entry (2017).
- Vegetation quadrats (4 per overstory plot) will be remeasured in 2017/2018.

Key Findings / Accomplishments

- Harvest layout, implementation RA 7/9 completed
- Post-harvest inventory RA 7/9 completed.
- Preliminary stand development analysis all Research Areas
- Comprehensive analysis of reserve-tree growth and mortality (David Carter MS Thesis); Second paper on growth published.
- We established (July 2017 – October 2017) an intensive sample of regeneration plots within harvest gaps, and use these data to (1) document 20-year regeneration patterns, and (2) inform the prescription of precommerical composition and density control treatments (Objective 4).
- We converted stem mapping data from permanent the plot inventory (azimuth and distance from established plot center) to X Y coordinates in R 3.2.1 (R Project, 2015) and import into ArcGIS 10.4.1 to create a geodatabase for spatially explicit analysis (winter 2017)
- We used the results of the vegetation clustering from Objective (2) to create specific crop-tree release and precommercial thinning prescriptions. Treatments focus on shifting species composition to higher-value, longer-lived, and locally uncommon species where possible. RA 1 was so treated during winter/spring of 2017.
- Some progress was made on quantifying long-term stand development metrics but more analysis needs to be completed.

Future Plans

- Treat RA5 and 9 with PCT treatments. RA 1 completed in May 2017.
- Quantify 20-year stand development patterns (regeneration, growth, and mortality) in terms of conventional stemwood volumes and carbon stocks, focusing on the productivity tradeoffs among matrix forests, regeneration, and permanent reserve trees (winter/ spring 2017)
- We will analyze and stratify results of all permanent plots in R 3.2.1(R Project, 2015) by silvicultural treatment to determine the effect of harvest prescription on stand dynamics and development. This will be accomplished by assessing the significance of gap size, social position within gap, time since harvest, and proximity to retention trees.

Assessing the Influence of Tree Form and Damage on Commercial Hardwoods Growth, Volume and Biomass in Maine

Aaron Weiskittel (Principal Investigator), School of Forest Resources, UMaine; Gaetian Pelletier, Northern Hardwoods Research Institute; Jereme Frank, School of Forest Resources, UMaine; Mark Castle, School of Forest Resources, UMaine

Final Report

Summary
Northern hardwood species display a wide variety of stem forms and defects which can considerably reduce stem quality and complicate the management objectives of these species. Although commonly cited as limiting attributes of hardwood species, the influence of both stem form and damage remain largely unaccounted for in volume/biomass equations, assessments of internal wood quality, or even growth and yield models. In addition, the limited integration of these attributes in quantitative applications has left the efficacy of current tree classification systems used to manage these species untested. The purpose of this study was to determine the influence of stem form and damage on product potential, growth, survival, future sawlog value, and internal stem quality for prominent northern commercial hardwood species. The findings from these analyses will be used to propose a framework for a tree classification system that can be used to facilitate management of hardwood species in the northeast region.

Project Objectives

1. Assess the prevalence of different stem forms and damage across several prominent commercial hardwood species.
2. Quantify potential saw log product recovery as a function of a tree's size, stem form, and risk (stem damage).
3. Incorporate stem form and risk into predictions of annual diameter growth, survival and future sawlog value.
4. Link tree, site, and species level variables to predictions of the occurrence and extent of internal stem decay.
5. Use findings from analyses to provide a recommendation for a tree classification system.

Data Collection

- Standing tree measurements were taken across five continuous forest inventory networks.
- Destructively sampled trees spanning 3 distinct geographic regions were used to assess internal stem decay.
- Destructively sampled trees were obtained from ongoing biomass sampling efforts, product recovery assessments conducted by the Northern Hardwood Research Institute (NHRI, New Brunswick), and past USFS biomass studies.

Data Analysis

Objective 1: Binomial regression was used to assess the probability of occurrence of different stem forms and damage across red maple, red oak, sugar maple, and yellow birch.

Objective 2: Beta regression was used to model the ratio of sawlog to merchantable stem volume on an individual tree basis as a function of a tree's size, stem form, and risk.

Objective 3a: Nonlinear regression models were developed to test the effect of stem form and risk on predictions of annualized diameter growth and survival.

Objective 3b: Sawlog volume, growth, and survival modifiers were incorporated into FVS-ACD to assess the influence of form and risk on long term projections of stand level sawlog value.

Objective 4: Using destructively sampled trees, the occurrence and extent of internal stem decay were quantified using several different modelling frameworks.

Key Findings / Accomplishments

Potential sawlog recovery was found to be significantly lower for trees demonstrating multiple sweeps or stems, significant lean, significant forks on the lower portion of the bole, or extensive damage relative to trees of ideal stem form. Annual diameter growth was found to be 21% lower for trees with severe or extensive damage compared to those with little or moderate damage. The annual probability of survival was shown to be significantly lower for trees with multiple sweeps or stems compared to those with ideal form. Long term simulations using FVS-ACD indicated that forecasted stand level sawlog value was 16 – 28% lower when stem form and risk were accounted for depending on the percentage of non-ideal hardwood stems in a stand. Decay was 1.8 times more likely to occur in trees with signs of damage that were perceived have a moderate to high probability of mortality. The most influential factors for predicting the probability that decay would occur were tree taper and crown ratio.

Implications and Applications in the Northern Forest Region

- Tree classification systems can be used to facilitate hardwood management in the Northeast Region by being able to differentiate between trees of varying product potential and vigor.
- Inclusion of stem form and risk in growth and yield models can enhance forecasting of forest resources by improving predictions of product potential, growth, and survival.
- Long term simulations indicated that projections of future stand value could be biased if stem form and risk are not accounted for in growth and yield models.

Future Plans

- USFS FIA is currently implementing proposed tree classification framework on 20% of state wide inventory. Collected data will be used to further validate models developed in the current study.
- When possible, destructive sampling will continue. Data will be used to refine models of decay and biomass in trees of varying risk and form.
- The focus will shift from destructive sampling to using remote sensing technologies to assess tree form and improve estimates of tree volume. Terrestrial LiDAR scans (TLS) from the Harvard Forest are currently being processed. Upon completion, TLS will be evaluated as a tool for measuring stem volume and form. A field campaign is planned for the Acadia Research Forest this summer to obtain additional data.

Forest Productivity & Forest Products: Improving Regional Growth and Yield Simulators and Decision-Support Systems for Large-Scale Pest Outbreaks

Mohammad Bataineh (Principal Investigator), School of Forestry & Natural Resources, University of Arkansas at Monticello; Aaron Weiskittel, School of Forest Resources, University of Maine; Robert Seymour, School of Forest Resources, University of Maine; David MacLean, Faculty of Forestry and Environmental Management, University of New Brunswick; Brian Roth, Cooperative Forestry Research Unit, University of Maine; Laura Kenefic, Northern Research Station, U.S. Forest Service; Cen Chen, School of Forest Resources, University of Maine

Year 4 Progress Report

Summary

Following our previous investigation on the influence of spruce budworm (SBW) defoliation on stand and individual-tree growth and mortality, the variation and temporal development of individual-tree defoliation caused by SBW were evaluated and modeled using data of over 47,000 individual-tree observations of defoliation collected in Maine and New Brunswick. Our results demonstrated that the majority of explained variation in individual tree defoliation was attributed to host species, while considering a variety of tree and stand characteristics. Meanwhile, defoliation of both balsam fir and red/black spruce was found to develop towards converged trajectories over time despite differences in initial defoliation, stand and site conditions, and geographical locations. These findings were consistent between Maine and New Brunswick despite their differences in past forest management and SBW outbreak histories. Overall, the developed modeling framework should be extendable to other forms of defoliation.

Table 4. Akaike Information Criterion (AIC) and changes in AIC (ΔAIC) of models predicting individual tree defoliation with various covariates by region, where DEF_P is plot defoliation (%); SPP is species (balsam fir, red/black spruce, and white spruce); BA and BA_{SW} are basal area and that of softwood trees in a plot (m^2 ha^{-1}), respectively; ABD is relative species abundance in a plot; DBH is diameter at breast height (cm); HT is height (m); MHT_{SW} is mean height of softwood trees in a plot (m); BAL is basal area of trees larger than the subject tree in DBH in a plot(m^2 ha^{-1}); and CR is crown ratio. The results indicate that species is the single most important predictor of individual tree defoliation at given plot defoliation level, while all the other potential covariates do not have as much influence individually or in combination.

	Maine (n = 42 349)		New Brunswick (n = 5 519)	
Model	AIC	ΔAIC	AIC	ΔAIC
Null	14904	--	241	--
DEF_P	-10614	-25518	-4151	-4392
DEF_P, SPP	-18711	-8097	-4868	-717
DEF_P, SPP, BA_{HW}/BA	-20191	-1480	-5086	-218
DEF_P, SPP, BA_{HW}/BA, ABD, DBH, HT, HT/MHT_{SW}, BAL, CR*	-21320	-1129	-5418	-332

* For New Brunswick, HT and MHT_{SW} were initial values measured at the beginning of the study, and CR was not available.

Project Objectives

- Assess spruce budworm impact on individual-tree growth, mortality, and ingrowth and develop modifiers to adjust the current FVS-ACD equations
- Develop a relationship between stand-level mean defoliation to within-stand variation in defoliation
- Compare the newly developed modifiers to those currently used in the spruce budworm decision support system for New Brunswick (Table 4)
- Incorporate the newly developed modifiers into FVS-ACD and project growth and yield of various compositional and structural archetypes under various defoliation and forest protection scenarios

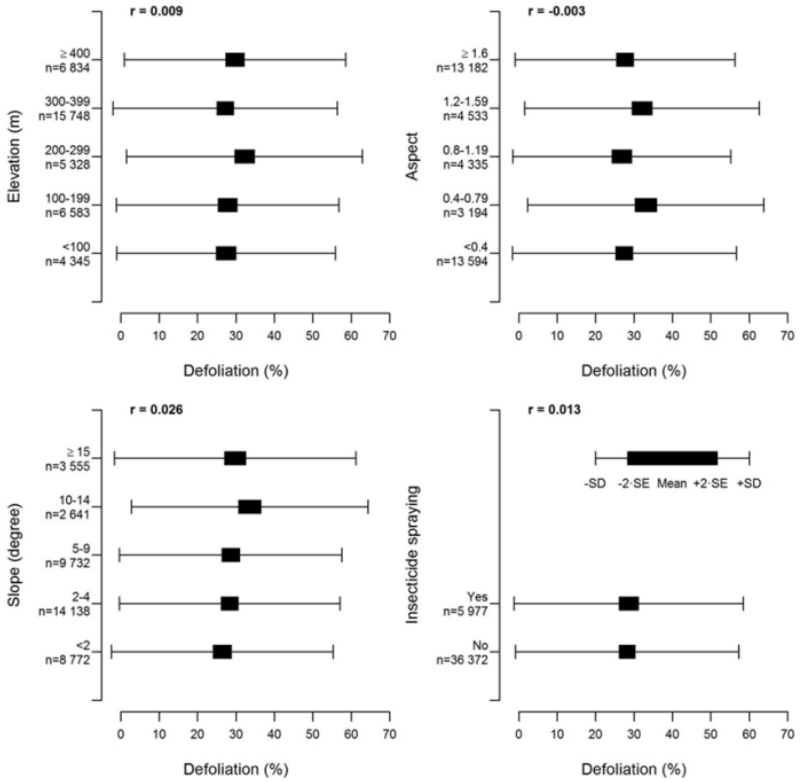


Figure 17. Relationships between individual-tree defoliation and topographic as well as insecticide spraying attributes, where aspect is computed as cos(45º – aspect in degree) + 1. As indicated by the correlation coefficients (r), these relationships are only nominal.

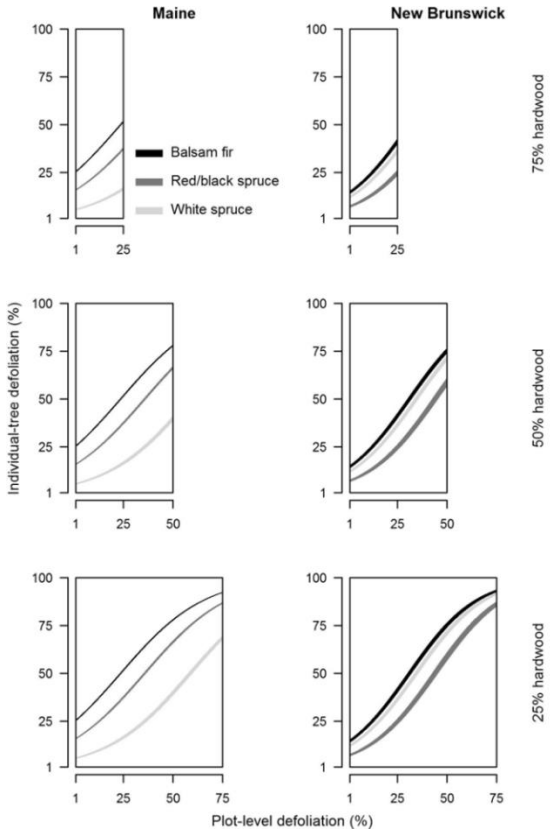


Figure 18. Predictions of individual tree defoliation (%) with 95% credible intervals as a function of plot defoliation (%; with all the other covariates at their means) by percentages of hardwoods in a plot and region.

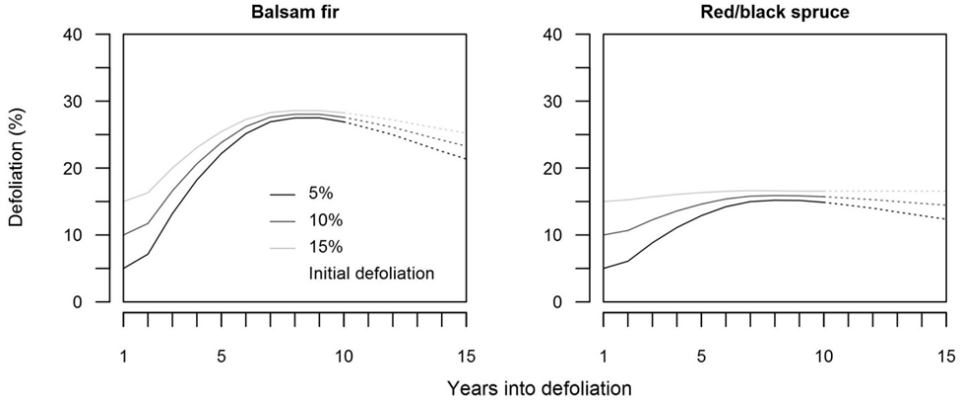


Figure 19. Predictions of the temporal development of individual tree defoliation (%) as a function of time (year) at various levels of initial (first year) defoliation (%) by species. Dotted lines are extrapolations of these predictions.

Approach

- Derived information on individual-tree and plot defoliation, host species and plot species composition, tree dimension, stand structure, site topography, and insecticide spraying status from data containing over 47,000 individual-tree observations collected at 560 permanent sample plots in the 1970s-1980s in Maine, USA and New Brunswick, Canada (Figure 17-19).
- Bayesian models based on Markov chain Monte Carlo technique were developed to model individual-tree defoliation in relation to plot defoliation and temporal development of individual-tree defoliation based on its initial observation using the most important variables selected from the above attributes.
- Perform the above modeling and evaluation in Maine and New Brunswick, which differ in forest management and spruce budworm outbreak histories, to better verify the robustness and consistency of our findings.

Key Findings / Accomplishments

- The majority of explained variation in individual tree defoliation was attributed to host species, while considering a variety of tree and stand characteristics.
- Defoliation was lower in pure stands than in mixed stands of the host species.
- Defoliation of both balsam fir and red/black spruce was found to develop towards converged trajectories over time despite differences in initial defoliation, stand and site conditions, and geographical locations

Future Plans

- Evaluating the influence of spruce budworm defoliation on forest dynamics at landscape level, while assessing how the dynamics of defoliation itself are affected by the connectivity and patchiness of forest landscapes.
- Design a sampling procedure better capturing the influences of stand structure and composition, management history, and site quality on growth responses to defoliation, while taking into consideration the population dynamics of spruce budworm.
- Design and conduct an experimental study to investigate the effectiveness of insecticide spraying on reducing the influence of spruce budworm defoliation on forest growth and mortality.

Howland Research Forest

The CRSF is home to the Howland Research Forest. The Howland Forest is a continuously operating forest ecosystem research site estab-lished in 1986 by University of Maine researchers with the cooperation of International Paper. It is located approximately 30 miles north of Orono, Maine, and situated within an expansive low elevation conifer/northern hardwood transitional forest.

Initially funded to conduct biogeochemical cycling and acid rain research, Howland Forest has since been host to various model and sensor development efforts as well as numerous studies focusing on nutrient cycling, forest ecology, ecosystem modeling, acid deposition, remote sensing, climate change, and carbon sequestration. Howland Forest, with its long fetch and low surface roughness, is an ideally situated tower research site for micro-meteorological measurements. With infrastructure in place and a comprehensive data train of ecological monitoring from below the soil to above the tree canopy, the site continues to attract scientists from around the globe associated with numerous universities, independent research organizations, and federal agencies (such as the USDA Forest Service, NOAA, NASA, EPA, DOE, and DOD).

Already a member of several research networks, Howland Forest became the first base site for the Ameriflux network in 1996. The current research focus is based around our ability to measure the flux of carbon dioxide (i.e. the forest-atmosphere exchange). This, along with the many ancillary ecological and atmospheric data measurement systems, provides

valuable information about how the landscape breathes and grows, and is the foundation for related research to further our understanding of how the environment works. Howland Forest is managed by the Environmental Physics group of the University of Maine, and is currently funded by the Department of Energy through its Ameriflux program and the USDA Forest Service through its Global Change Program.

2017-18 Research Update: US Forest Service Joint Venture Agreement to Support AmeriFlux Researchat the Howland Forest

Dr. Shawn Fraver, Assistant Professor, University of Maine; John Lee, Research Associate, University of Maine; Holly Hughes, Research Associate, University of Maine; Erin Fien, University of Maine

Collaborators: Dave Hollinger, US Forest Service, Northern Research Station, Durham, NH; Andrew Richardson, Harvard University, Cambridge, MA; Kathleen Savage, Woods Hole Research Center, MA; Eric Davidson, Appalachian Laboratory, Frostburg, MD; Northeast Wilderness Trust, Montpelier, VT.

Summary

The AmeriFlux network is a nation-wide set of research sites measuring fluxes of CO_2, 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 CO_2 flux, meteorological, soil flux, and ecological activities associated with the Howland Forest AmeriFlux site, (2) assisting with sensor calibration, telecommunications, flux calculations, data processing, and ecological measurements, (3) Ensure adequate communication between the University of Maine and Forest Service personnel regarding project status, (4) sharing data freely with the AmeriFlux Management Project, and various AmeriFlux data repositories, and (5) providing general upkeep and safety of the Howland Forest site, including liaising with the Howland Forest landowner.

Approach

The project objectives are met through the work of two full-time Research Associates, John Lee and Holly Hughes. In addition, the infrastructure and continuous, long-term data at Howland Forest provide an ideal framework for graduate student research, which is conducted through the School of Forest

Resources. Such research allows us to address additional questions complementary to the core Ameriflux mission, thereby expanding the project's reach and scope. Recent graduate students associated with this project include Erin Fien (MS) and Jeanette Allogio (MS).

Key Findings / Accomplishments

The Howland Forest site has had continuous atmosphere-forest canopy CO_2 flux data since 1996, making it the second longest running flux site in North America.

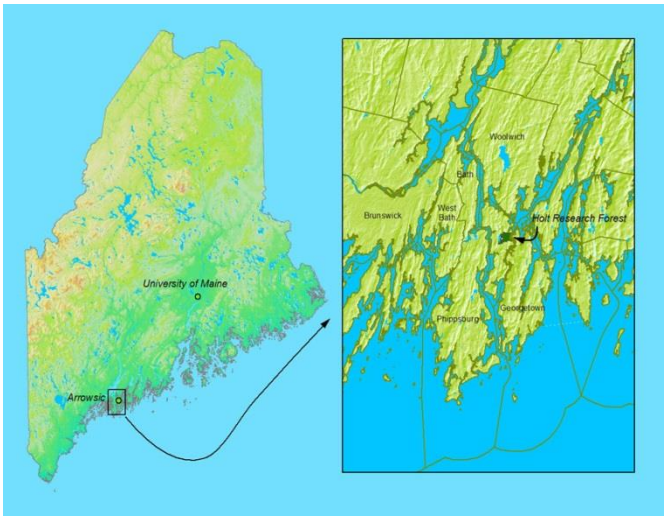
Future Plans

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

Holt Research Forest

The CRSF welcomed Holt Research Forest (HRF) into its fold in 2016. 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. 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 Holt Woodland Research Foundation, established specifically to support this project, provided the vast majority of the funding until 2014 when the foundation was merged into the Maine TREE Foundation, which continues to support the site.

Located in Arrowsic, an island town in the Kennebec Estuary, HRF is approximately 100 miles southwest of Orono. The site is situated between a fresh water pond and an estuarine river and includes approximately 300 acres of forest and 50 acres of wetlands, mostly salt marsh. This region has the greatest woody plant species richness in the state in part because it falls within the transition between the Northeastern coastal forest to the west and south and the New England/Acadian forest to the east and north.



Research and Management

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. In concert with these goals, the HRF endeavors to provide a continued economic return from the sale of forest products; maintain and improve the diversity and abundance of wildlife; and maintain and improve the aesthetic appeal of the forest.

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

Furthermore, the HRF is located in the part of the state that has the greatest human population density and fastest growth. Land management in this region requires a balance between human habitat needs and ecological values. HRF is well situated for public outreach and to convey the importance of sustainable forest management to a large audience.

Rare sighting of Canada Mayflower (Maianthemum canadense) *flowering at HRF. Located atop a winthrown root mound, a refugia from deer. Photo courtesy Jack Witham.*

The primary study area is 40ha overlaid with a well-marked grid system. The 25 x 25 m resolution study grid has allowed for the development of an extensive spatial database of many components including oak-pine ecosystem types, 20ha of stemmed mapped trees, high intensity soils maps, forest canopy gaps, bird territories, and more. Areas of study include these components as well as yearly seed and seedling data, sapling counts and mapping, plant species distribution and coverage, salamander and small mammal abundance, 100% tree tallies, and other ecologically important components.

Working with several graduate students through the Barbara Wheatland Geospatial Lab at the University of Maine, new high resolution imagery and HRF stemmed map data is being utilized to help ground truth the data. In addition, NASA has tested its new Goddard's LiDAR, Hyperspectral & Thermal Imager (G-LiHT) portable imaging system for the second time at the Holt Research Forest, with the most recent flight being in the early summer of 2015.

The Holt Research Forest has hosted numerous cooperating researchers, a variety of training opportunities for graduate and undergraduate students, and several public service and outreach activities to the community. Graduate and undergraduate students have made up a significant portion of the work force, carrying out much of the field work that forms the 35 year database. To date, more than 20 research scientists have studied here or used Holt Research Forest data, over 100 students have had career building work experience, and some 1,000 people including natural resource professionals, small woodlot owners, and the interested public have attended workshops and other educational programs here.

Holt Research Forest holds promise as a site to examine many relevant current and emerging issues in Maine's forest community. Recent accomplishments include an NSF - Field Station and Marine Lab planning grant which is being used to develop a strategic plan to layout research, management, and outreach and education goals for the second 35 years.

From forest dynamics as it relates to climate change, public health issues with vector-borne diseases, forest and landscape fragmentation, as well as the continuing issue of integrating commodity production with maintaining ecological integrity which has always motivated research activities at the HRF, and will continue to do so.

2017-18 Research Update

Jack W. Witham, Research Forester, University of Maine

Holt Research Forest (HRF) saw continued progress on many fronts. The focus for this year has been utilizing the NSF FSML grant to work on a strategic plan for HRF. A significant portion of the background data has been collected, several workshops have been conducted, and a review by a Board of Visitors is completed. Additional field work has helped to maintain many of the most important long-term datasets. We continued progress on the documentation and management of the long-term data including submission of data to a US Forest Service data archive and the Forest Ecosystem Monitoring Cooperative.

Objectives

- Long-term monitoring of forest ecosystem
- Complete data management and make data sets available for use
- Host educational programs for forest landowners and natural resource professionals
- Complete HRF Strategic Plan
- Begin work on updated research plan

Approach

- Work with collaborators to increase use of HRF for research
- Share data to increase interest in HRF research program
- Continue monitoring and collect key data sets
- Work with partners for educational programming
- Key Findings / Accomplishments:
- Completed data collection for 35th field season, began 36th field season
- Progress on data management process
- Hosted Board of Visitors for three days with report completed

Holt Forest Workshop, October 5, 2017

The workshop was held in conjunction with a Board of Visitors evaluation of Holt Research Forest. Thirty-five attendees joined the group at the Patten Free Library in Bath, Maine. The following presentations and posters were included:

- *Ecological Significance of Kennebec Estuary*
  Mitch Hartley, North Atlantic Coordinator, Atlantic Coast Joint Venture, US Fish&Wildlife Service
- *Land Protection in the Kennebec Estuary*
  Andy Cutko, Director of Science, The Nature Conservancy, Maine Chapter
- *Holt Research Forest Overview*
  Mac Hunter, Department of Wildlife, Fisheries, and Conservation Biology, UMaine
- *Research and Data* at Holt Research Forest
  Jack Witham, School of Forest Resources, UMaine
- *Forest Dynamics at Holt Research Forest*
  Aaron Weiskittel, School of Forest Resources, UMaine
- *Of voles and seeds: Demographic mechanisms linking tree seeds and rodent population fluctuations*
  Alessio Mortelliti, Department of Wildlife, Fisheries, and Conservation Biology, UMaine
- *Long-term numerical and spatial response of birds to a group-selection timber harvest in Maine*
  Steve Campbell, Conservation Biologist, Albany Pine Bush Preserve Commission

Report to Maine Tree Foundation Board of Directors

October 2017

Holt Research Forest (HRF) saw continued progress on many fronts. The focus for this year has been utilizing the NSF grant to begin work on a strategic plan for HRF. A significant portion of the background data has been collected, several workshops have been conducted, and a review by a Board of Visitors is nearly completed. Additional field work has helped to maintain many of the most important long-term datasets. We continued progress on the documentation and management of the long-term data including submission of data to a US Forest Service data archive and the Forest Ecosystem Monitoring Cooperative.

Photo courtesy Jack Witham.

Field Work – Most field work scheduled for 2017 was completed. This was the 35th field season for our long-term forest ecosystem study.

Table 5. 2017 Small Mammal Captures

Species	# Caught
Short-tailed Shrew (*Blarina brevicauda*)	1
Southern Flying Squirrel (*Glaucomys volans*)	3
White-footed Mouse (*Peromyscus leucopus*)	943
Red-backed Vole (*Clethrionomys gapperi*)	41
TOTAL	988

- Birds – Twelve visits were made during the breeding season (late May – early July) all bird encounters were recorded on maps of the study area.
- Seed traps – Collections were completed in May before red maple seed fall began. This collection represents the 2016 tree seed production.
- S-1s – Every 5th S-1 plot was visited (n=120, area=1m^2) and seedling counts were done for each plot.
- Small mammals – Eight nights of trapping were conducted in early August. Table 5 summarizes the captures. Numbers of total captures were the 3rd highest ever recorded for white-footed mice (943, so 42.9 captures per 100 trap nights). Only 3 other species were captured which is the lowest species diversity we've found. The number of southern flying squirrels was the lowest since 2004 when there was only 2 captures (2 individuals).

Mosquito boxes near red maple swamp. *Photo courtesy Jack Witham.*

Other Field Work

Joanne Sharpe, an independent scientist, completed her measurements of over 700 individuals marked ferns (*Dryopteris marginalis* and *Dryopteris intermedia*) for the 17th year. She presented a poster entitled "*Holt Research Forest Fern Observations (2000-2016)*" at the HRF Research Workshop.

Lyme & Vector-Borne Disease Laboratory, part of the Maine Medical Center Research Institute has continued to accept ticks from HRF small mammals for identification and testing. This year they began collecting mosquitos at HRF with light traps at the salt marsh and resting boxes in the forest. Elizabeth

Henderson presented a poster at the HRF Research Workshop entitled *"Mosquito Diversity at Two Southern Maine Coastal Sites – York and Sagadahoc Counties, 2017."* Susan Elias (former HRF staff) presented a poster "Tick Changes" based on 20 years of tick observations at HRF.

NSF Planning Grant

The Board of Visitors was here for the events scheduled for October 4-6, 2017. Mark Aston, Yale University; Brian Kloeppel, Highlands Research Station; Jennifer Seavey, Shoals Marine Lab; Bill Schuster, Black Rock Forest; and Hilary Swain, Archbold Biological Station were in attendance. David Foster, Harvard Forest had to cancel at the last minute. The base of operation for the meetings was at Hampton Inn in Bath with Patten Free Library as the location for the research workshop. An initial meeting with the Board of Visitors occurred on October 4th with Bruce Wiersma and Kevin McCarthy, both representing Maine TREE Foundation and Mac Hunter, Aaron Weiskittel, and Jack Witham representing University of Maine. The discussion included site review goals and objectives, HRF history, overview of Maine TREE Foundation, perspectives on HRF, open discussion, and a HRF site visit and tour. On October 5th the research workshop was held. Workshop attendance was 35 with seven presentations and 4 posters, considerable time was provided between presentations to allow for questions and comments. Pdf versions of the presentations are available on line. MTF Board members Barrie Brusilla and Kevin McCarthy were at the workshop. A visit to HRF followed with about 20 people venturing into the study area. Many thoughtful discussions occurred throughout the day. The final day of the visit the Board of Visitors met to review the information they had gathered and begin the preparation of a report. Aaron, Mac, and Jack sat in on much of the discussion and answered any lingering questions. The meeting lasted nearly 5 hours before the Board of Visitors departed. A draft report was submitted to us and comments went back to them. We do not currently have a time frame on when a final report will be delivered.

Another research workshop was held on December 13 at UMaine. Twenty five people, mostly faculty from UMaine, attended. Background information about HRF was presented via a much shortened version of the October 5th program. Following the presentations (about 1 hr.), people were divided up into working groups for discussion of the research potential at HRF and any research interest of participants that might align with HRF.

Much of the discussion at these meetings has centered on the value of the long-term data. The perspectives emerging from these meetings are that the strategic plan should include collection of data continuing into the future, ways that the data can be utilized for analysis and publication, and to guide new research that may develop.

To make a strategic plan successful, the role and thoughts of all stakeholders must be considered. This has included an educator's workshop held in August, discussions with foresters and others associated with private nonindustrial landowners, with Maine TREE board and former board members and with potential partners for education or research. Additional work is still needed on this front.

Data Management

The first HRF data set is now active at the USFS Research Data Archive. (Witham, Jack W. 2017. Holt Research Forest regeneration data. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2017-0024) Work continues on updates to metadata and data sets for inclusion on the USFS archive. Additional improvements and manipulations are underway on numerous data sets.

Work with the Advanced Computing Group on the Orono campus has led to the creation of a data backup system and a data sharing site. Using the Seafile server and software, all data is now stored on a drive at HRF which is backed up to Orono with automated syncing of changes.

A relatively new facility at the University of Vermont is being utilized for most data sharing. Several data sets have been uploaded and will be ready for sharing soon. The Forest Ecosystem Monitoring Cooperative (FEMC) is a "regionally focused collaborative that synthesizes and utilizes forest ecosystem information, facilitates networks and provides tools to understand and monitor the health and management of forested ecosystems across the region". To view the website go to http://www.uvm.edu/femc/.

This site is a DataONE node which means it meets strict protocols for data sharing. DataONE is a global effort that enables universal access to data and also facilitates researchers in fulfilling their need for data management and in providing secure and permanent access to their data.

Note: The window faces toward Sewell Pond.

HRF (UMaine) received a $15,000 gift to support updating/creating a GIS program for inputting bird territory mapping, hire students to input data, and Jack's time for data analysis. The writing of a GIS program for inputting bird territory mapping is underway with a consultant currently under contract.

Educational Programs – Outdoor Classroom

Jack met with Kevin Doran to discuss programming at HRF. There have been requests for additional workshops to be held at HRF. They are considering a series of landowner workshops similar to the *Sustainable Forests for Midcoast Maine* held over several years (10± years ago) at HRF and are looking for partners.

Final work on the outdoor classroom was completed with the exterior boards and trim, and benches being stained, a wall constructed on the northeast corner, three (8'x8') platforms finished, and the outhouse put in place as required to meet plumbing standards. The outdoor classroom is ready for use. A grant to fund kiosks and signage in the 'Nature Education Area' submitted to Ed Meadows Conservation Fund by TNC was successful. We have $2900 to utilize for this purpose.

Other

Collaborations with our small mammal data sets have continued. We assisted Ryo Ogawa, Alessio Mortelliti, and Erik Blomberg (graduate student and Department of Wildlife, Fisheries, and Conservation Biology professors) by providing data and help with analysis on white-footed mice (*Peromyscus leucopus*) and red-backed vole (*Myodes gapperi*) demographics at HRF.

A paper was recently published this year in the peer-reviewed Journal of Mammalogy. The citation and a

Graduate Students

Two masters thesis were completed this year, both using data from HRF. Elias Ayrey is utilizing HRF data for his PhD work. He is developing an algorithm to segment 3-D tree shapes from LiDAR data, then implement it to predict carbon content of each individual tree in the forest. He hopes to improve his individual tree detection algorithm developed during his MS project. He is utilizing image data provided by *Bruce Cook*, NASA scientist at Goddard Space Flight Center, taken with NASA's G-LiHT Imager [http://gliht.gsfc.nasa.gov/].

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 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.

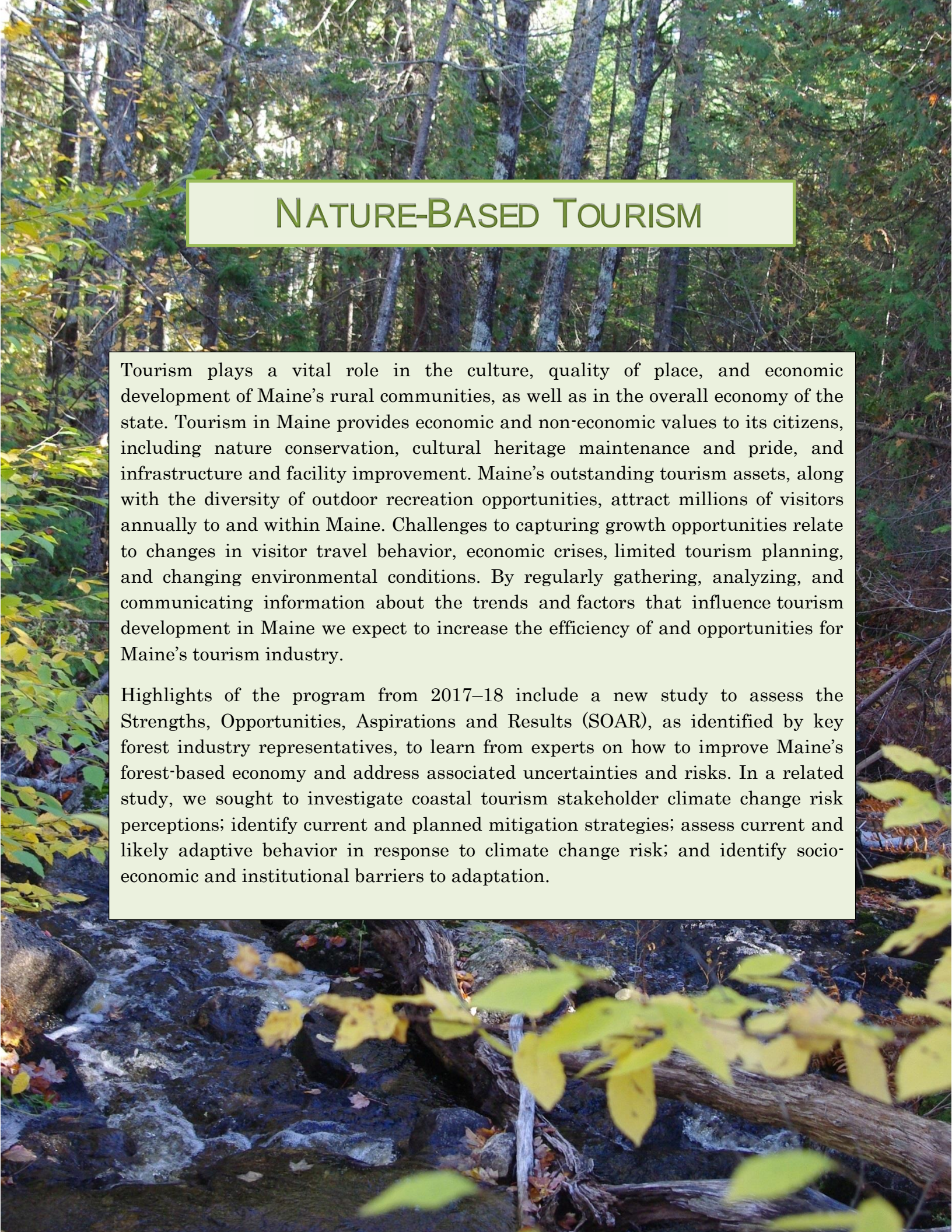
Research

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 present), contributing to sustainable management of working forests in Maine and elsewhere. The Center for Research on Sustainable Forests has partnered with the Forest Service to maintain their large-scale silviculture experiments across 1,000 acres of the PEF. This work includes the Management Intensity Demonstration (1950-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.

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.



Nature-Based Tourism

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.

Highlights of the program from 2017–18 include a new study to assess the Strengths, Opportunities, Aspirations and Results (SOAR), as identified by key forest industry representatives, to learn from experts on how to improve Maine's forest-based economy and address associated uncertainties and risks. In a related study, we sought to 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.

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 1 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 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.

Project Objectives

- This study uses a *Forest Industry Sub-Sector Analysis* to assess the Strengths, Opportunities, Aspirations and Results (SOAR) as identified by key forest industry representatives, selected communities, and capital investors in Maine.
- The purpose of this analysis is to learn from experts on how to improve Maine's forest-based economy and address associated uncertainties and risks.

Approach

- We have conducted five focus groups and 13 semi-structured interviews with industry stakeholders at locations convenient for participants.
- Responses from focus groups and interviews have been transcribed, and analyzed using NVivo 12. To date, 50 individuals have participated in the study, representing the industry subsectors: (1) Land managers–those who manage timber lands; (2) Land owners–those who own timber lands; (3) Loggers–those who work to harvest timber; (4) Transportation–those who transport timber and timber products; (5) Sawmills–those who own or work in a sawmill; (6) Pulp and paper mills–those who own or work in a pulp and paper mill; (7) Bioenergy–those who own or work in biomass/bioenergy plants; (8) Professional services–those who work in mapping or surveying; and (9) Professional groups–those who lead or work in professional groups or non-profit organizations.

Key Findings / Accomplishments

- The terms most frequently used by participants included forest, people, products, management, wood, Maine (Figure 20).
    - Stakeholders perceive the interconnectedness between the forest, the resources and products it provides, the management decisions made by different industry sub-sectors, and the role of people (including how people are impacted by, and how they impact the forest and its management).
    - The term *forest* was usually utilized in combination with the terms resources, industry, and management, suggesting that participants see the forest in terms of the resources that businesses use and transform, and how the forest is managed across the landscape.

- When using the term *industry,* participants most often referred to the forest resources being managed by industry stakeholders, how the industry itself is organized as a cluster, and the role of the industry in utilizing "good" management practices.
- When mentioning *Maine,* participants frequently referred to the positioning and uniqueness of the Maine forest and industry in comparison to other states, the challenges faced by the industry, and the opportunities and challenges in Northern Maine.

Figure 20. Words most frequently mentioned by study participants during focus groups and interviews.

- The key ideas that have emerged from the subsector analysis have been grouped under three main themes: strengths of the Maine forest resources industry; challenges experienced by industry stakeholders; and future opportunities.
  - *Strengths*: Strong collaboration across sub-sectors; recognition that the industry is important for Maine and many rural communities in the state; availability of technology that makes operations more efficient; connected forest landscape; diversity of species, forest products, and businesses; field-centered nature of the industry that appeals to people that love the outdoors and are passionate about the forest and forestry.
  - *Challenges*: Aging population that leads to a lack in quantity of labor force; younger labor force that is perceived as less reliable and of "less quality" than the older labor force; physical strain of the job that makes recruitment of labor force harder; non-competitive wages and lack of incentives (e.g., health insurance, and other benefits); managing for multiple and at times conflicting uses of the land (e.g., recreation and

tourism along with forestry operations); limited and low quality of infrastructure (roads, railroads) in several areas in the state that decreases efficiency; high energy costs and taxes in comparison to other regions in the US and abroad; finding a sustainable market for low-grade products.

- *Opportunities*: Technological advances; adding value to sell products in international markets; take advantage of proximity to large markets; expanding collaboration with UMaine to take advantage of advances in wood technology and science.

Future Plans

- Facilitate additional focus groups and interviews with stakeholders (e.g., small woodlot owners, government agencies, non-governmental organizations).
- Conduct thematic data analysis.
- Integrate information from newspaper articles, and prior studies on transportation challenges in Maine to the data we are currently generating via focus groups and interviews.
- Develop and apply a capital investor questionnaire to further understand the challenges and opportunities experienced by potential/current groups to invest money in forest resources oriented ventures.
- Submit at least one more scholarly journal article

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

Sandra De Urioste-Stone (Principal Investigator), Parinaz Rahimzadeh-Bagjiran (Co-PI), Lydia Horne (PhD student)

Year 1 Progress Report

Map of tourism areas under study.

Summary

Climate change is impacting global nature-based tourism industries. 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 nature-based tourism assets, 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 in Maine. The extent to which tourism destinations are able to anticipate, respond, and adapt to climate change threats and take advantage of opportunities determines resilience in light of climate change uncertainty. 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 destination.
- 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

This study uses a three-phase comparative case study design with a mixed methods approach.

- Phase 1 assesses climate change risk perceptions and behavior via in-depth semi-structured interviews with tourism stakeholders in coastal Maine.
- Phase 2 includes a visitor survey to evaluate tourist risk perceptions of climate change, along with a geo-spatial vulnerability hotpot assessment that incorporates both biophysical and social vulnerability indicators to determine areas of high risk within each destination.
- Phase 3 integrates results from phases 1 and 2, and includes a series of participatory planning workshops with tourism stakeholders.

Key Findings / Accomplishments

- Preliminary findings from the pile sort suggest that when participants think about climate change, they are concerned about the drivers of climate change and resulting impacts specific to their locale. Distinguishing between naturally occurring and human-caused phenomenon is important for participants, as are the solutions to climate change, most often identified as mitigation, adaptation, building resilience, and infrastructure investments.
- Participants have overall demonstrated high awareness and concern for climate change impacting coastal Maine.

Undergraduate student research assistants preparing to survey visitors at Acadia National Park. From left to right: Nathaniel Burke, Asha DiMatteo-LePappe, Hope Kohtala. *Photo courtesy Lydia Horne.*

- 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.
- Other climate change impacts of high concern are increased storms, especially for sailing businesses and low-lying infrastructure, changes in the wildlife that attracts visitors to the coast, and negative changes to Maine's fishing industry, especially the lobster fishery.
- Participants who are closely connected to the natural resource base (i.e., for their nature-based tourism business) are most concerned about climate change impacts to their livelihoods. Though these participants often claim to not have a "scientific" understanding of these environmental changes, their first-hand experience depending on these natural resources paints a clear picture of the changes coastal Maine communities are experiencing.
- Obstacles that prevent adaptive behavior include lack of funding and time, and uncertainty about future climate change impacts.
- Participants are aware of ongoing pro-environmental work in their respective locations; however, few business owners are incorporating mitigation into their business plan.

Future Plans

During year 2 of this grant the research team plans to:

- Continue interviewing nature-based tourism stakeholders from all sites with a focus on Camden and business owners.
- Perform visitor surveys during summer and fall 2018
- Conduct thematic data analysis of interviews, and analyze survey data using SPSS 25.
- Compare newly developed social indicators with biophysical GIS layers to create a vulnerability hotspot map to use for collaborative planning meetings with tourism stakeholders.
- Integrate data from phases 1 and 2.
- Submit two scholarly journal articles, and present at two scientific conferences.
- Facilitate participatory meetings with stakeholders.

Climate Change Perceptions and Tourism

Sandra De Urioste-Stone (Principal Investigator), Lydia Horne (MS),and Leah Beck (MS)

Final Report

Summary

Assessing stakeholder climate change risk perceptions is crucial for understanding motivations or barriers to engage in climate change mitigation and adaptation behaviors. Therefore, the goal of this study is to understand climate change risk perceptions and likely behavioral responses amongst nature-based tourism stakeholders in Western Maine using a qualitative approach. The Maine Lakes and Mountains Region has been selected as a study site because of its high dependence on winter outdoor recreation and the importance tourism has in supporting community resilience.

Project Objectives

- Understand climate change risk perceptions of tourism stakeholders in Western Maine.
- Explore group cognition associated with climate change risk among tourism stakeholders.
- Determine facilitators and barriers to the implementation of climate change adaptation and mitigation strategies.

Approach

- A phenomenological study was done using semi-structured interviews (20 participants) with key stakeholders in the Maine Lakes and Mountains Region of Maine in 2016.
- A pile sort exercise (33 cards) was conducted with 19 tourism stakeholders in the Maine Lakes and Mountains Region of Maine in 2016
- Interpretative Phenomenological Analysis was used to generate categories and themes.
- Multidimensional scaling was used to analyze data from the pile sorts.

Hiking along Champlain Mountain in Acadia National Forest. *Photo courtesy Meg Fergusson.*

- Funding was secured through the Mitchell Center to conduct a recreation user survey to assess climate change risk perceptions in the region.

Key Findings / Accomplishments

- A key theme that emerged throughout the study was that of uncertainty of the causes of climate change, impacts to the region, which climate change communication sources to trust, and whether or not experienced environmental changes were related to climate change. Uncertainty hindered participants' abilities to implement adaptation and mitigation behaviors.
- Providing climate change information specific to the study region communicated by scientists or through the local newspaper could help empower participants to adopt more mitigation and adaptation strategies, thus bolstering the resilience of the tourism destination.
- Stakeholders believed climate change to be a psychologically distant phenomenon and perceptions of uncertainty hindered participants' abilities to devise and implement adaptation actions to increase destination resilience.

PUBLICATIONS AND PRESENTATIONS

Refereed Journals (15)

Bose, A. K., A. R. Weiskittel, R. G. Wagner. 2017. Occurrence, pattern of change, and factors associated with American beech-dominance in stands of the northeastern USA forest. Forest Ecology and Management 392: 202-212.

Bose, A. K., A. Weiskittel, and R. G. Wagner. 2017. A three decade assessment of climate-associated changes in forest composition across the north-eastern USA. Journal of Applied Ecology 54(6): 1592-1604.

Bose, A. K., R. G. Wagner, B. Roth, and A. Weiskittel. 2018. Influence of browsing and overstory on American beech and sugar maple regeneration nine years following understory herbicide release in central Maine. New Forests 49(1): 67-85.

Carter, D.R., R. S. Seymour, S. Fraver, and A. Weiskittel. 2017. Effects of multiaged silvicultural systems on reserve tree growth 19 years after establishment across multiple species in the Acadian Forest of Maine, USA. Canadian Journal of Forest Research 47(10):1314-1324.

Castle, M.E., Weiskittel, A.R., Ducey, M.J., Wagner, R.G., Frank, J. and Pelletier, G., 2018. Evaluating the influence of stem form and damage on individual tree diameter increment and survival in the Acadian Region: Implications for predicting future value of northern commercial hardwood stands. Can. J. For. Res. Accepted for publication.

Castle, M., A. Weiskittel, R. Wagner, M. Duvey, J. Frank, and G. Pelletier. 2017. Variation in stem form and risk of four commercially important hardwood species in the Acadian Forest: Implications for potential sawlog volume and tree classification systems. Canadian Journal of Forest Research. 47(11): 1457-1467.

Frank, J., Castle, M.E., Westfall, J.A., Weiskittel, A.R., MacFarlane, D.W., Baral, S.K., Radtke, P.J. and Pelletier, G., 2018. Variation in occurrence and extent of internal stem decay in standing trees across the eastern US and Canada: evaluation of alternative modelling approaches and influential factors. Forestry. https://doi.org/10.1093/forestry/cpx054.

Hiesl, P., M.S. Crandall, A.R. Weiskittel, and A.R. Kizha. 2017. Assessing alternative silvicultural prescriptions for mid-rotation, unthinned, spruce-fir stands in Maine. Forests 8 (370): 1:15

Horne, L.*, **De Urioste-Stone, S.M.,** Daigle, J. & Noblet, C. (2018). Using pile sorts to understand perceptions of climate change. *WIT Transactions of Ecology and the Environment, 227*, 175-183. doi: 10.2495/ST180171

Koirala, A., A. R. Kizha., and S. De Urioste-Stone. 2017. Policy recommendation from stakeholders to improve Maine's forest trucking enterprises: A qualitative research approach. Forests. 8(11): 434. doi:10.3390/f8110434.

Koirala, A., A. R. Kizha, and B. E. Roth. 2017. Perceiving major problems and potential resolutions in forest products transportation by trucks and trailers. European Journal of Forest Engineering. 3(1):23-34.

MacDonald, B., Horne, L., De Urioste-Stone, S.M., Haskell, J. & Weiskittel, A. (2018). Collaborative leadership is key for Maine's forest products industry. *Maine Policy Review, 27*(1), 90-98.

Ogawa,R., Mortelliti, A., Witham, J. W., and Hunter, M. L. Jr. 2017. Demographic mechanisms linking tree seeds and rodent population fluctuations: insights from a 33-year study. doi: https://doi.org/10.1093/jmammal/gyw200

Rahimzadeh-Bajgiran, P., Weiskittel, A.R., Kneeshaw, D. and MacLean, D.A. 2018. Detection of Annual Spruce Budworm Defoliation and Severity Classification Using Landsat Imagery. Forests 2018, 9(6), 357. doi.org/10.3390/f9060357.

Teets, A., S. Fraver, D. Hollinger, A. Weiskittel, R.S. Seymour, and A. Richardson. 2018. Linking annual tree growth with eddy-flux measures of net ecosystem productivity across twenty years of observation in a mixed conifer forest. *Agricultural and Forest Meteorology* 249: 479-487.

Book Chapters (1)

Horne, L.*, **De Urioste-Stone, S.M**., Daigle, J., Noblet, C., Rickard, L. Kohtala, H.+, & Morgan, A.* (Forthcoming). 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*.

Research Reports (2)

De Urioste-Stone, S.M., Horne, L., & Rahimzadeh-Bajgiran, P. (2018). Fostering coastal community resilience in Maine: Understanding climate change risk and behavior. Technical report submitted to NOAA. Orono, Maine. 11pp.

De Urioste-Stone, S.M., MacDonald, B.*, Horne, L.*, Silka, L., Haskell, J., & Weiskittel, A. (2018). Maine forest industry sub-sector analysis. Final report submitted to FORMAINE Executive Committee, Orono, Maine. 10pp.

Theses (5)

Bothwell, K. N. 2017. Economic and Spatial Impacts of a Wildlife Habitat Policy on Forest Management. M.S. thesis, University of Maine, Orono. 98 p.

Castle, M. 2017. Evaluating the Influence of Stem Form and Vigor on Product Potnetial, Growth, and Survival for Northern Commercial Hardwood Species. M. S. thesis, University of Maine, Orono. 85 p.

Koirala, A. 2017. Forest trucking industry in Maine: Opportunities and challenges. Masters in Forestry. University of Maine. 120 p.

Muñoz, B. 2017. Long-term sustainability of northern mixedwood management: Spatial and temporal aspects of forest productivity. PhD thesis, University of Maine, Orono, ME.

Sandilands, D. 2017. An assessment of aerial survey acquisition methods for generating forest inventory models. M.S. thesis, University of Maine, Orono.

Research Reports and Conference Papers / Posters (2)

Koirala, A., A. R. Kizha., and S. De Urioste-Stone. Improving Maine's forest trucking enterprises: A qualitative approach. 40th Annual Meeting of the Council on Forest Engineering, July 30 to August 2, 2017, Bangor, ME.

Rahimzadeh-Bajgiran, P., A. Weiskittel, D. Kneeshaw, and D. A. MacLean. A multi-index Landsat-derived model for spruce budworm defoliation detection and quantification: Examples of past and current outbreaks (1970s and 2000s). ASPRS-Pecora Memorial Remote Sensing Symposium, November 2017, Sioux Falls, SD.

Presentations/Workshops/Field Tours (15)

Cooke, B.J., B.R. Sturtevant, L.-E. Robert, and D.K. Kneeshaw. 2018. Fragmentation of forest host disrupts cycling behavior of defoliator outbreaks: Evidence from spruce budworm and forest tent caterpillar in a heterogeneous mixedwood landscape. Annual Symposium of the International Association of Landscape Ecologists, Chicago, IL, April.

Fraver, S. Ecological attributes of woody debris in New England's forests (invited). NESAF, March 28, 2018, Nashua New Hampshire

Gunn, J.S., M.J. Ducey, and E.P. Belair. 2017. Quantifying and Mapping Risk of Spruce Budworm Damage in New England. New England Society of American Foresters, Bangor, Maine, March 8-10.

Holt Forest Research Workshop, in conjunction with a Board of Visitors evaluation of Holt Research Forest. 2017. Patten Free Library, October 5.

Horne, L., De Urioste-Stone, S.M., Noblet, C., & Rickard, L. (2018). Using risk perceptions and message framing to explore climate change engagement. Tourism Naturally Conference. May 16-18, Kaprun, Austria.

Horne, L., De Urioste-Stone, S.M., Daigle, J., & Noblet, C. (2018). Using pile sorts to understand perceptions of climate change. Sustainable Tourism Conference. May 2-4, Vienna, Austria.

Horne L., De Urioste-Stone, S.M. (2018). Climate change communication. National Outdoor Recreation Conference (NORC). April 23-26, Burlington, Vermont.

Howard N., Colella N., Legaard K., Nellutla S., McCoy E., Whitsel L., Wilson C. Segee B. 2018. Adventures of two student research computing facilitators. Practice and Experience in Advanced Research Computing Conference Series, Pittsburgh, PA. July 22-26.

Muñoz, B., 2017. Long-term sustainability of northern mixedwood management: spatial and temporal aspects of forest productivity. Doctoral defense, November 28, 2017, University of Maine, Nutting Hall (Plum Creek Room).

Kenefic, L. et al, 2018. Long-term U.S. Forest Service research at the Penobscot Experimental Forest: Silvicultural Institute Field Tour, Compartment 33. Penobscot Experimental Forest, une 14.

Rahimzadeh-Bajgiran, P., Weiskittel, A., Kneeshaw, D., 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, Fredericton, NB, Canada, March 13-14.

Rahimzadeh-Bajgiran, P., Weiskittel, A., Kneeshaw, D., MacLean, D.A. 2017. A multi-index Landsat-derived model for spruce budworm defoliation detection and quantification: Examples of past and current outbreaks (1970s and 2000s). ASPRS-Pecora 20 Memorial Remote Sensing Symposium, Sioux Falls, SD, U.S.A, November 13-16.

Rahimzadeh-Pajgiran, P.,2017. Spruce budworm-induced forest defoliation and remote sensing opportunities, Atmospheric Transport Model working group meeting in Quebec, Sept 27.

Seymour, R. S., Kenefic, L., and others. 2018. Northeast Silviculture Institute – Spruce-fir forestsThis study (AFERP) was a key feature on the field trips on both occasions, June..

Thapa, B., P. Wolter, B. Sturtevant, and P. Townsend. 2018. Reconstructing historical boreal forest structure by using archived Landsat and national forest inventory. Annual Symposium of the International Association of Landscape Ecologists, Chicago, IL, April 11.

Webinars / Conference Hosting & Support (4)

CFRU Webinar Series: Spruce Budworm: Monitoring and Early Intervention Strategies, February 14, 2018, 2:00 p.m.

CFRU Webinar Series: Monitoring Maine's Birds, April 25, 2018, 2:00 p.m.

Center for Advanced Forest Systems Annual IAB Meeting, Burlington, VT, June 12-13, 2018.

Seminar: Maria Janowiak, USFS, Nutting Hall, April 10, 2019.

Newspapers / Periodicals / Television / Web (6)

Forest mapping: When the budworms come to dinner (https://www.mghpcc.org/forest-mapping-when-the-budworms-come-to-dinner/)

A web page has been developed to allow users to interactively query and explore the FIA data and simulation results from the NSRC project *Silvicultural Strategies for Mitigating Northern Forest Carbon Reversal Due to Spruce Budworm*, using the Tableau interface for maps and graphics: (https://public.tableau.com/profile/john.gunn#!/vizhome/SpruceBudwormRiskMapv2/Dashboard)

The three decade assessment of climate-associated changes in forest composition study by CRSF-affiliated researchers Dr. Arun Bose (WSL Institute), Dr. Aaron Weiskittel (UMaine), and Dr. Robert Wagner (Purdue University) published in the *Journal of Applied Ecology* received extensive media coverage in the *Washington Post, Newsweek*, North Country Public Radio, and Boston.com.

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