



Annual Report 2016

**Center for Research on Sustainable Forests
University of Maine**



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), the 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. Going forward, the CRSF will prioritize developing, integrating, and applying these emerging technologies 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 Pamela Wells

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Clouded Sulphur Butterfly (Photo by Pamela Wells)

DIRECTOR'S REPORT

The Center for Research on Sustainable Forests (CRSF) had another productive year during 2015-16, but it was a year of transition given **Dr. Bob Wagner's** retirement and **Dr. Aaron Weiskittel** taking over as Acting Director in September 2016.

Center programs continued to be successful in a variety of key areas. The Commercial Forests Research Program, headed by **Drs. Bob Wagner** and **Brian Roth**, led several stakeholder-driven research projects for 35 member organizations through the Cooperative Forestry Research Unit (CFRU). A particularly important CFRU project development this past year was the initiation of the Maine's Adaptive Silviculture Experimental Network (MASEN), which will include several operational-scale installations across the state to evaluate alternative mid-rotation management strategies. **Dr. Rob Lillieholm** retired from the university in May 2016, but continued to promote and support the Maine Futures Community Mapper tool for the Conservation Lands Research Program. In the Family Forests Research Program, **Dr. Jessica Leahy** continued to work closely with the Small Woodland Owner Association of Maine (SWOAM) to assist family forest owners on a number of key issues. **Dr. Sandra De Urioste-Stone** led a statewide effort to better understand visitor preferences at key locations (Bar Harbor, Millinocket, and Bethel) and evaluated the role of weather patterns on their spending.

Dr. Shawn Fraver and research associates **John Lee** and **Holly Hughes** continue making automated greenhouse gas, eddy covariance (flux), and numerous other atmospheric measurements at Howland Forest, which is part of the national Ameriflux Network and one of the longest running sites in the network. **Dr. Arun Bose** continued to coordinate several research projects associated with the National Science Foundation's Center for Advanced Forestry Systems (CAFS) as a Post-doctoral Research Fellow with particular focus on addressing the influence of American beech on forest structure and composition.

In addition to these accomplishments, the CRSF led several key initiatives in 2015–16. Following a close, two-year collaboration with both the Maine Forest Products Council and the Maine Forest Service, the Maine Spruce Budworm Task Force report was released and has been well received throughout the region. A website to facilitate outbreak communications was also launched: <http://www.sprucebudwormmaine.org/>. Two additional CRSF-supported websites focused on stakeholder engagement were launched. The Northeast Forest Information Source (NEFIS; <http://www.nefismembers.org/>) is an interactive repository that allows open-access submission and retrieval of research-related documents, while the Maine Forest Spatial Tool (MFST; <http://mfst.acg.maine.edu/>) allows users to access numerous key spatial layers from prior CRSF research projects. The spatial layers include data from two recently completed CFRU projects (improved depth-to-water table mapping and the biomass growth index), which provide an estimate of potential forest productivity throughout the region. In a partnership with the Maine

Library of Geographic Information, the CFRU helped to coordinate the statewide acquisition of LiDAR data, which is radically altering how forests are inventoried and managed. This acquisition will continue over the next few years with the CFRU providing key logistical support and coordination with landowners.

2015–16 was a significant year for the CRSF as it marked our tenth anniversary and included several key transitions. In the coming year, CRSF staff will work to complete a comprehensive review of past center accomplishments and devise its future direction. Regardless, the overall success of the CRSF this year was due in large measure to the hard work of the many scientists, graduate students, and summer technicians who worked on CRSF research projects. Their hard work and accomplishments are described in the following report.



Aaron Weiskittel

Aaron Weiskittel

CRSF Acting Director



UMaine Forest, Orono

PEOPLE

Leadership & Staff

Robert Wagner, *Director*

Aaron Weiskittel, *Assistant Director*

Brian Roth, *Commercial Forests Program
Leader & CFRU Associate Director*

Jessica Leahy, *Family Forest Program Leader*

Sandra de Urioste-Stone, *Nature-Based
Tourism Program Leader*

Rob Lilieholm, *Conservation Lands Program
Leader*

John Lee, *Research Associate, Howland
Research Forest*

Holly Hughes, *Research Associate, Howland
Research Forest*

Arun Kantibose, *CFRU Post-Doctoral Research
Scientist*

Meg Fergusson, *CRSF Administrative Assistant*

Cynthia Smith, *CFRU Administrative Assistant*

Cooperating Scientists

Daniel Harrison (*CFRU*)

Aaron Weiskittel (*CFRU, NSRC*)

Project Scientists

Mohammad Bataineh, *University of Arkansas
(NSRC)*

Eric Blomberg, *Univ. of Maine (CFRU)*



Ladyslipper (Photo by Pamela Wells)

Sophan Chhin, *Michigan State University
(NSRC)*

Anthony D'Amato, *Univ. of Vermont (NSRC)*

Michael Day, *Univ. of Maine (NSRC)*

Mark Ducey, *Univ. of New Hampshire (NSRC)*

Jereme Frank, *Univ. of Maine (NSRC)*

Shawn Fraver, *Univ. of Maine (NSRC, CFRU)*

Todd Gabe, *Univ. of Maine (Tourism)*

Eric Gustafson, *USFS-NRS (NSRC)*

Chris Hennigar, *Univ. of New Brunswick
(CFRU, NSRC)*

Patrick Hiesl, *Clemson University (CFRU)*

David Hollinger, *USDA Forest Service
(Howland)*

Jennifer Hushaw, *INRS, LLC. (NSRC)*

Laura Kenefic, *USFS-NRS (NSRC, CFRU)*

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

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

David MacLean, *University of New Brunswick (NSRC)*

Spencer R. Meyer, *Highstead Foundation (NSRC)*

Bethany Muñoz, *USDA-NRS (NSRC)*

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

Bill Parker, *Ontario Forest Research Institute (NSRC)*

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

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

Ben Rice, *LandVest (NSRC)*

Robert Seymour, *Univ. of Maine (NSRC)*

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

Susan Stein, *USFS-NRS (NSRC)*

Crista Straub, *Univ. of Maine (Family Forests)*

Brian Sturtevant, *USFS-NRS (NSRC)*

Michael Ter-Mikaelian, *Ontario Ministry of Natural Resources (NSRC)*

Jeremy Wilson, *Harris Center for Forest Conservation (NSRC)*

Graduate Students

Mark Castle (*CFRU, NSRC*)

Cen Chen (*NSRC*)

Garth Dixon (*NSRC*)

Jon Doty (*NSRC*)

Todd Douglass (*NSRC*)

Stephen Dunham (*CFRU*)

Lydia Horne (*Conservation Lands, Tourism*)

Michelle Johnson (*Conservation Lands, NSRC*)

Andrew Kennedy (*NSRC*)

Cody Lachance (*CFRU*)

C. J. Langley (*NSRC, CFRU*)

Bethany Muñoz (*NSRC*)

Michael A. Pouch (*NSRC*)

Allison Price (*NSRC*)

Brian Rolek (*CFRU*)

Matthew Scaccia (*Tourism*)

Paul J. Szwedo (*NSRC*)

Bina Thapa (*NSRC*)

Joel Tebbenkamp (*CFRU*)

Emily Wilkins (*Tourism*)

Nathan Weseley (*CFRU*)

FINANCIAL REPORT

Budget details for the CRSF during FY2015-16 are shown in Table 1. Income supporting the center came from programs administered by or that support the general operations of the CRSF (\$953,612), UMaine competitive sources (\$56,779), as well as extramural grants supporting specific research projects (\$373,200) that were received by CRSF scientists from outside agencies. These extramural grants made up 27% of funding for the center. Total funding of the CRSF for FY 2015-16 was \$1,383,591 million.

As shown in Figure 1, 65% of the total funding allocated to research programs making up the CRSF was allocated to Commercial Forests, 7% to Nature-Based Tourism, 11% to Howland Research Forest, and 18% to the Northeastern States Research Cooperative. Nearly 70% of the funding received by CRSF went directly to support the research projects described in this report. The remaining funds supported personnel salaries (14%) and center operating expenses (18%), with the later primarily being used to support the layout, design, and hosting of four new CRSF websites.

A key source of financial support for the CRSF is provided by the Maine Economic Improvement Fund (MEIF). The \$167,580 investment from MEIF helped leverage \$786,032 from other CRSF sources, \$56,779 from UMaine competitive sources, and \$373,200 in extramural grants for a total leverage of \$1,216,011 (or \$7.26 for every dollar of MEIF funding) of additional research funding.

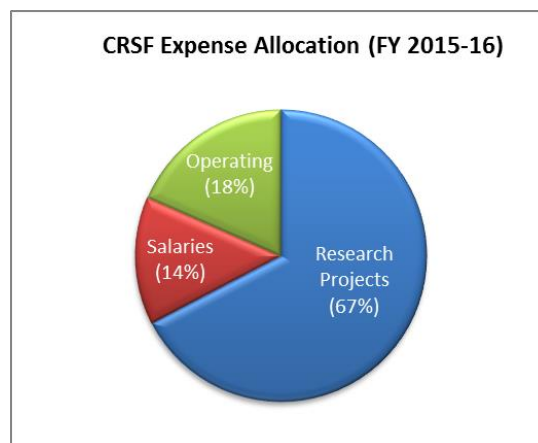
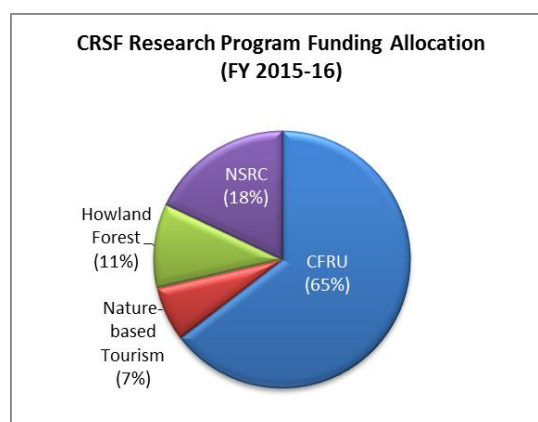
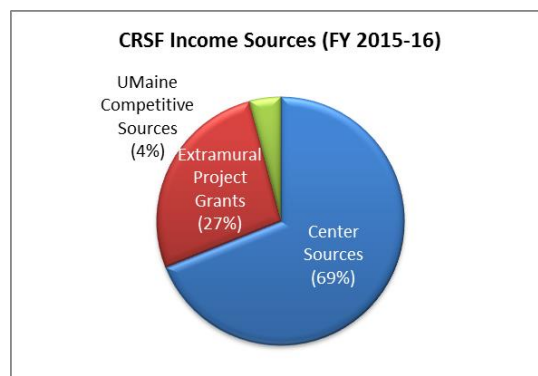


Figure 1 - Income sources, research program allocation, and expense allocation for CRSF during FY 2015-16.

Table 1 - FY2015-16 Budget for Center for Research on Sustainable Forests.

INCOME			
Center Sources:	Funding Source	PI	Amount
Cooperative Forestry Research Unit (CFRU)	CFRU	Wagner	\$ 508,239
US Forest Service-Northeastern States Research Cooperative Theme 3 (NSRC)	USDA	Wagner	\$ 210,108
Maine Economic Improvement Fund	MEIF	Wagner	\$ 167,580
National Science Foundation - Center for Advanced Forestry Systems Phase 2	NSF	Wagner / Weiskittel	\$ 60,000
CRSF Gift Fund	Gift	Wagner	\$ 1,500
UMaine Munsungan Fund	Gift	Wagner	\$ 6,185
		Center Total	\$ 953,612
UMaine Competitive Sources	Various UM	Various	\$56,779
Extramural Project Grants:			
Campuses for Environmental Stewardship (CES)	Educational	De Urioste-Stone	\$ 4,000
data at the Howland Forest Site	USFS	Fraver	\$ 40,000
CFRU Extramural Funds	CFRU	Cooperating Scientists	\$ 242,433
Support of AmeriFlux Research at the Howland Research Forest	USDA NFS	Fraver	\$ 86,767
		TOTAL	\$ 373,200
		Total Income	\$ 1,383,591
ALLOCATION			
Salaries & Benefits:			
Director, Associate Director, Program Leaders, and Scientists			112,461
Support staff + grad students			77,729
		Salaries & Benefits Total	190,190
			248,200
		Salaries, Benefits, & Operating Total	\$ 438,390
Research Projects:	Funding Source	PI	Amount
CFRU:			
CTRN Commercial Thinning Research Network: Continued Measurements and New Opportunities	CFRU	Wagner et al.	\$ 32,695
The Effects of Mechanized Harvesting Operations on Residual Stand Condition	CFRU	Benjamin et al.	\$ 33,043
Identifying Attributes that Distinguish Old-and Second-Growth Northern White-Cedar Stands for Forest Management and Planning	CFRU	Wagner et al.	\$ 12,000
Strategies for rehabilitating beech-dominated stands	CFRU	Wagner et al.	\$ 19,415
Assessing the Influence of Tree Form and Damage	CFRU	Benjamin et al.	\$ 24,191
Linking Site Quality to Tree Growth and Survival in the Acadian Forest	CFRU	Weiskittel	\$ 27,759
Maine Statewide Light Detection and Ranging (LiDAR) Data Acquisition Project	CFRU	Roth	\$ 10,000
Identifying relationships between spruce budworm larval density, moth abundance, and	CFRU	Weiskittel	\$ 36,094
Development an application of early detection and monitoring of SBW defoliation using	CFRU	Weiskittel	\$ 16,374
Populations Dynamics Spruce Grouse	CFRU	Young	\$ 29,829
Moose Density and Forest Regeneration Relationships in Maine	CFRU	Castonguay	\$ 21,890
Bat Ecology in Commercial Forests	CFRU	Harrison	\$ 23,455
Economic Impacts of Wildlife Regulations on Forest Management and Industry	CFRU	Harrison	\$ 17,160
CFRU Extramural Grants from Cooperating Scientists	Various	Coop Sci	\$ 242,433
		Commercial Forests Project Total	\$ 546,338

Table 1 continued...

ALLOCATION			
NSF CAFS Phase 2	NSF	Wagner & Weiskittel	\$ 60,000
Family Forests:			
Family Forests Project Total			\$ -
Nature-Based Tourism:			
Campuses for Environmental Stewardship (CES)	Davis Educational Foundation	De Urioste-Stone	\$ 4,000
Community Resilience and Quality-of-Place in Maine: The Penobscot River Bay-to-Baxter Corridor Initiative	Maine Margaret Chase Smith Policy Center	De Urioste-Stone	\$ 4,000
Economic Impact Study for Maine's Tourism Industry	UMaine's Office of the President	De Urioste-Stone	\$ 32,039
Mining in Maine: Exploring public perceptions	Senator George J. Mitchell Center for Sustainability Solutions	De Urioste-Stone	\$ 15,000
Developing a Community Resilience Index	Senator George J. Mitchell Center for Sustainability Solutions	De Urioste-Stone	\$ 2,840
Nature-Based Tourism Project Total			\$ 57,879
Conservation Lands:			
Conservation Lands Project Total			\$ -
NSRC Theme 3:			
Productivity, regeneration patterns, and precommercial treatment options of two ecologically based silvicultural systems: 20 year results	NSRC	Seymour	\$ 39,985
Classifying and evaluating partial harvests and their effect on stand dynamics in northern Maine	NSRC	Kuehne	\$ 77,371
Learning from the past to predict the future: validation of the spruce budworm disturbance model	NSRC	Sturtevant	\$ 34,502
NSRC Project Total			\$ 151,858
Howland Forest:			
Understanding the forest carbon cycle	USFS	Fraver	\$40,000
Pilot study of forest bat use of the Penobscot Experimental Forest	Penob. Exp For	Fraver & Blomberg	\$ 2,900
Support of AmeriFlux research at the Howland Research Forest	USDA NFS	Fraver	\$ 86,767
Howland Project Total:			\$ 89,667
Research Project Total			\$ 905,742
Total Allocation			\$ 1,344,132

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 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



Broadwing Hawk (Photo by Pamela Wells)

Huber Engineered Woods, LLC
Irving Woodlands, LLC
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	Snowshoe Timberlands, LLC
Maine Office of Tourism	St. John Timber, LLC
Maine Tree Foundation	Sylvan Timberlands, LLC
Mosquito, LLC	Social and Economic Sciences
National Science Foundation	Research Center, Washington State
Natural Resources Conservation	University
Service	The Forestland Group, LLC
New Brunswick Department of	The Nature Conservancy
Natural Resources	Timbervest, LLC
New England Forestry Foundation	UMaine Cooperative Extension
North Woods Maine, LLC	University of Massachusetts-Amherst
Nova Scotia Department of	University of New Brunswick
Natural Resources	University of New Hampshire
PenBay Regional Land Trust	University of Vermont, Rubenstein
Pennsylvania State University	School of Environment and
Penobscot Experimental Forest	Natural Resources
Plum Creek Timber Company, Inc.	UPM Madison Paper
Prentiss & Carlisle Company, Inc.	USDA Forest Service, Northern
Professional Logging Contractors	Research Station
of Maine	USDA Forest Service, Family
ProFOR Consulting	Forest Research Center
Quebec Ministry of Natural Resources	USGS Maine Cooperative Fish &
ReEnergy Holdings, LLC	Wildlife Research Unit
Robbins Lumber Company	USGS West Virginia Cooperative Fish
SAPPI Fine Paper	& Wildlife Research Unit
Seven Islands Land Company	Wagner Forest Management
Simorg North Forest, LLC	West Virginia University
Small Woodland Owners Association	Woods Hole Research Center
of Maine	

CRSF Research Programs



2015-16 Organizational Structure



NATURE-BASED TOURISM

The Nature-Based Tourism Program of the CRSF was established in 2014 and has quickly gained momentum. Tourism plays a vital role in the culture, economy, and future 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, constrained integrated tourism planning and development, and extreme weather events/natural disasters. By regularly gathering, analyzing, and communicating information about the economic impact and trends of tourism in Maine we expect to increase the efficiency of and opportunities for Maine's tourism industry.



Schoodic Point, Acadia National Park

In its second year, the program received an additional \$76,719 in research funding and launched five sustainable tourism-related research projects: (1) mailed 2,300 surveys to wildlife viewers, anglers, and hunters in Maine to understand their views on lead fishing and common loon conservation; (2) interviewed 2,036 visitors to estimate the economic impact of tourism in Maine; (3) surveyed 883 visitors to understand perceptions on climate change impacts and travel behavior; (4) mailed 2,500 questionnaires to understand Maine resident perceptions about metallic mineral mining; and (5) interviewed tourism businesses in Western Maine to explore climate change risk perceptions and adaptation strategies.



Sand Beach, Acadia National Park (Photo by Pamela Wells)

Analyzing the Economic Impact of Tourism in Maine

Sandra De Urioste-Stone, Caroline Noblet, and Todd Gabe

University of Maine

Final Report

Summary

The travel and tourism industry plays a key role in Maine's economy, and the economic development of many communities in the state. By most measures, tourism is considered one of the largest industries in the state (Maine Development Foundation, 2004). Over 33 million visitors¹ traveled to/in Maine in 2015 (DPA, 2016). In 2012, the industry accounted for an estimated 17% of state tax revenue (Maine Revenue Services, 2013). In 2015, the Maine tourism industry was responsible for generating over 15% of jobs in the State (DPA, 2015). Limited information exists on the economic activity generated by tourism in Maine. This study contributes to the ongoing efforts by the Maine Office of Tourism to estimate the economic impact of the industry. The study included two phases: (1) a pilot visitor survey (June 2014–April 2015) to establish an effective and reliable methodology; and (2) a mixed-mode visitor survey (intercept and online) conducted in the state to understand travel behavior and spending.

Project Objectives

- Inform existing efforts by the Maine Office of Tourism to estimate the economic impact of the travel and tourism industry in the state.
- Develop an economic impact assessment methodology responding to Maine's needs and context.
- Contribute to the development of instruments to estimate the economic impact of tourism at the state level.

Approach

- Surveyed 2,036 Maine visitors to understand general travel behavior.
- Selected visitors using a two-stage cluster probability sampling design (Scheaffer, Mendenhall III, Ott, & Gerow, 2012) at tourist attractions, airports, visitor centers, national and state parks, camping areas, and selected chambers of commerce across Maine.

¹ Visitors include non-residents and residents that engage in recreation and tourism activities.

- Conducted an online survey of 883 Maine visitors using Dillman’s Tailored Design method (Dillman, Smyth, & Melani, 2014) to estimate spending and overall travel behavior.

Key Findings / Accomplishments

Based on the visitor survey data, 7% of visitors were visitors classified as residents of Maine, 6% as visitors on daytrips, 51% as overnight visitors from outside the state who stayed in hotels, cabins, bed and breakfasts and other overnight paid accommodations, 7% as overnight visitors from outside the state who camped, and 29% as overnight visitors from outside the state who did not incur any lodging expenses (Table 2). Average visitor group size ranged from 1.9 to 3.0 people across the five visitor type segments. Overall, 72% percent of visitors indicated that “vacation” was the primary reason for their trip to the state of Maine.

Table 2 - Selected visit/trip characteristics by segment, 2015

Characteristic	Local	Day trip	Hotel	Camping	Non-paid	Total
Visitor Segment Share (number of survey respondents)	7% (58)	6% (52)	51% (458)	7% (58)	29% (257)	100% (883)
Average visitor group size	2.3	1.9	2.7	3.0	2.2	2.5
Length of stay (days or nights)	1.0	1.0	5.7	5.0	6.6	5.2

Visitor Spending

The Maine visitor spending survey collected data about expenditures of visitor groups during their trip in the state. Spending averages were computed on a visitor group trip basis for each visitor segment. The average visitor group spent \$1100.93 in Maine during their trip (Table 3). On a visitor group trip basis, average spending for visitor groups staying in hotels was \$1992.74, while visitor groups that camped spent \$626.34. Day trip visitor groups spent an average of \$83.19, while non-paid overnight visitor groups spent \$310.83. The local visitor segment spent an average of \$230.48 per visitor group trip.

Table 3 - Average spending by segment (dollars per visitor group trip).

Expenditures	Local	Day trip	Hotel	Camping	Non-paid	All visitors*
Hotels	\$0.00	\$0.00	\$876.69	\$0.00	\$0.00	\$414.97
Camping	\$0.00	\$0.00	\$0.00	\$175.17	\$0.00	\$9.45
Restaurant & bars	\$62.17	\$29.52	\$388.82	\$95.90	\$86.18	\$223.94
Groceries	\$45.34	\$6.08	\$83.06	\$98.47	\$80.84	\$74.63
Gas & oil	\$25.09	\$14.90	\$75.41	\$95.26	\$49.37	\$59.83
Other transportation	\$30.97	\$1.73	\$183.57	\$22.64	\$23.23	\$98.00
Admissions & fees	\$29.03	\$4.04	\$94.90	\$68.76	\$22.91	\$58.45
Souvenirs & other expenses	\$37.88	\$26.92	\$290.29	\$70.14	\$48.30	\$161.66
Total	\$230.48	\$83.19	\$1992.74	\$626.34	\$310.83	\$1100.93

*Weighted by percent visitor group trips.

The estimated visitor spending attributable to tourism visitation that brings new economic activity into the state of Maine excludes both spending by in-state-residents and by those visitors who did not identify vacation as their primary reason for visiting Maine. The estimated spending is 8.7 billion. Overnight visitors who stayed in hotels accounted for 90% of this spending. Spending on hotels (40%), restaurants & bars (20%), and souvenirs & other expenses (14%) made up the largest proportions of expenditures.

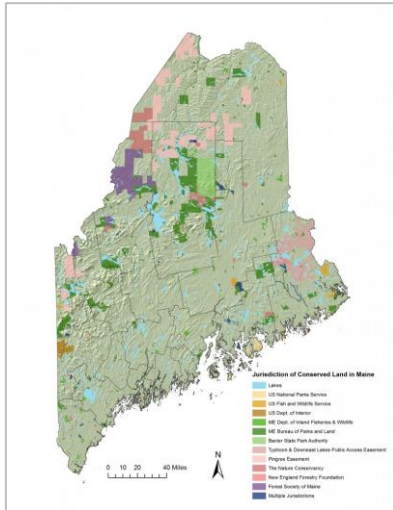
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Schoodic Point (Photo by Pamela Wells)

CONSERVATION LANDS AND PUBLIC VALUES



Conserved Lands in Maine.

Source: [Maine Forest Dashboard](#).

Maine has led the nation in the development and application of innovative land conservation tools, especially when it comes to private lands and the protection of working forests. Maine currently has over 4 million acres of land protected from development. These lands provide a host of public and private benefits, ranging from parks and working forests to timber, wildlife habitat, and biodiversity protection. Together, these protected areas provide both recreation and ecosystem services for current and future generations of Mainers, and have been protected through the combined efforts of federal (e.g., USDA Forest Legacy program), state (e.g., Land for Maine’s Future), and a host of municipal and nongovernmental groups, including early 100 land trusts.

The landscape mosaic of developed and undeveloped lands in the northeastern U.S. has progressively changed at various spatial scales in response to land use and development pressures, socioeconomic influences, expansion of transportation networks, and non-uniform state and local regulatory frameworks. As ongoing processes of urbanization have transformed open spaces and agricultural property into developed land uses, there has been a remarkable counter-balancing expansion of



Carriage Trails in Acadia National Park
(Photo by Meg Fergusson)

public and private land conservation activities aimed at protecting biodiversity, scenic values, working forest lands, ecosystem services, recreational opportunities, and special natural areas in the remaining undeveloped land base. Because land use changes and conservation efforts in the region have occurred incrementally at multiple scales and in a variety of jurisdictions, it is challenging to assess the aggregate impacts of these cumulative land use decisions on environmental quality, resilience, and long-term sustainability across the overall landscape.

CRSF’s research program on Conservation Lands & Public Values has sought to assist decision makers and planners as they look to the future and increasingly think strategically about balancing land conservation, working lands protection, and land development activities. Program activities were designed to: (1) help develop a clear understanding of the current status, extent, and landscape patterns of conserved lands across the region; (2) determine what kinds of values and

conditions are represented in conserved parcels; (3) account for the dominant processes and criteria driving conservation activities across the different states of the Northeast; and (4) develop tools that help a wide range of stakeholders understand land use change and explore alternative future development paths.

Understanding how these lands are ultimately protected, managed, and valued by current and future generations will significantly affect the sustainability of Maine’s communities and related forest-based industries, including forest processors and the recreation and tourism sector. The Maine Futures Community Mapper – an award-winning online tool for assessing land use for forestry, agriculture, conservation and development across two large watersheds covering 4.4 million acres in Maine – is an important tool in realizing these goals. To learn more, visit:

MaineLandUseFutures.org.

Maine Woods Dashboard: Documenting the Economic, Ecological, and Social Impacts of Maine’s Forest Resource

Robert J. Lillieholm
University of Maine

Final Report

Summary

The Maine Forest Service (MFS) leads efforts to report on key measures of forest management throughout the state. Specifically, Maine statute requires MFS to periodically report on: (1) forest resource assessment; (2) forest sustainability; (3) the state of Maine’s forests; (4) wood processor activity, including imports and exports; and (5) silvicultural activities. In addition, MFS also reports on forest inventory and best management practices. These and other state and federal activities provide valuable information to a host of stakeholders, making timely and accurate reporting paramount. Unfortunately, the dispersed nature of these data—including its limited availability in periodic printed reports as opposed to real-time datasets and analyses—hinders the capacity for long-term planning and productivity enhancements. This project leverages developments in database and web technologies to create a website where detailed and customized data queries about all aspects of Maine’s forests can be generated to assist forest sector businesses and planning in the face of increasingly complex global markets.



Tree Fungus
(Photo by Pamela Wells)

Project Objectives

- Create a Maine Woods Data Portal (MWDP) that will house publically available data related to Maine’s forests and forest sectors.
- Develop a Maine Woods Dashboard (MWD) that will allow users to readily access, analyze, and display data within the MWD.

Approach

- Phase I: The Maine Woods Data Portal (MWDP) – The MWDP will provide access to all publicly available, relevant forest resources information. It will combine all available biophysical and socioeconomic information related to forest management (see MFS

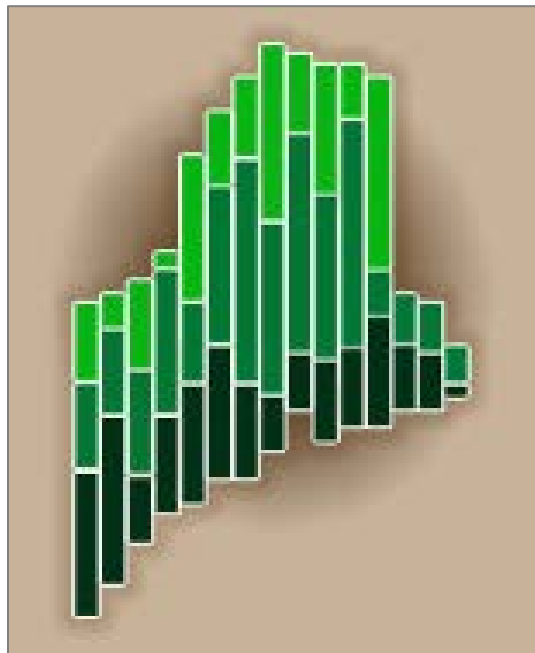
reporting requirements above). Data will be available for download through this portal, increasing accessibility to currently inaccessible information.

- Phase II: The Maine Woods Dashboard (MWD) – The MWD will be an outreach tool based on metrics housed in the MWDP, delivering timely, scientifically credible information about the economic, social, and environmental conditions and impacts of Maine’s forests. MWD will host relevant information for a wide range of audiences, from the general public to business leaders, researchers to students. MWD will allow for the creation and presentation of data summaries (e.g., graphs, tables, infographics, etc.) in an easy-to-use graphical interface.

Key Findings / Accomplishments

- The MFS forest-related databases have been secured. Input of data on timber harvests and processing into the system is ongoing. This dataset is the basis for the suite of analysis and display tools that are available to users on the website (www.maineforestdashboard.com), which was officially launched in 2016.

MAINE FOREST DASHBOARD



FAMILY FORESTS

The Family Forests Program serves the estimated 120,000 private, individual forest landowners who own 5.7 million acres of forest land in Maine. The mission of the Family Forests Program has been to conduct applied scientific research and outreach that contributes to the sustainable management of Maine's family forests for desired products, services, and conditions in partnership with Maine's family forest stakeholders. These stakeholders include the Small Woodland Owner Association of Maine (SWOAM), USDA Family Forest Research Center, UMaine Cooperative Extension, American Tree Farm System (ATFS), Maine Forest Service (MFS), Natural Resources Conservation Service (NRCS), USDA State and Private Forestry, American Consulting Foresters (ACF), other consulting foresters, Professional Logging Contractors of Maine, and forest management firms offering services to family forest owners (e.g., Prentiss and Carlisle, LandVest, etc.).

The Family Forests Program has pursued two lines of research and outreach over the last year: Developing and implementing succession planning models for aging landowners; and surveying the knowledge, attitudes, and behaviors of landowners toward invasive forest pests such as the emerald ash borer and Asian long-horned beetle.



Understanding and Informing Family Forest Owner Decisions of Intergenerational Land Transfer to Ensure Working Forested Landscapes

Jessica Leahy
University of Maine

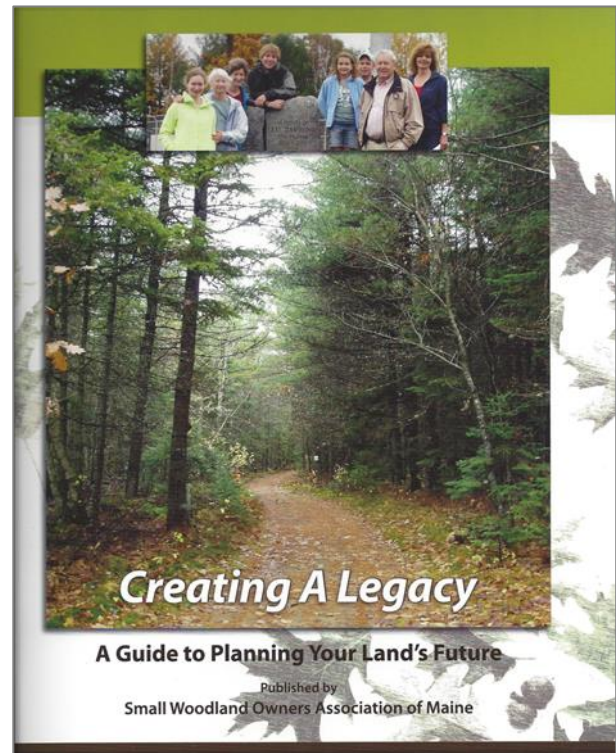
Final Report

Summary

Family-owned tree farms, known simply as "family forest lands" provide tremendous amounts of wood products and ecosystem services in the U.S, particularly in the northeast where 52% of the land is held by family forest owners (FFOs). Due to an aging landowner population, in the coming years, almost half of the FFOs in the U.S. will be deciding the future of their land (i.e., convert to another use, parcelize, conserve). These decisions will be the most important determinants of the viability of working forests, because forest cover loss and parcel size reductions eliminate or lessen forest management opportunities. Stabilizing the forest land base by stemming the tide of conversion and parcelization is critical to ensuring a future of viable and competitive working forested landscapes. The project team, made up of the Universities of Massachusetts, Maine, Vermont, and Cornell aim to help stabilize the forested land base by working to ensure that a significant proportion of FFO lands are passed from one generation of landowners to the next with minimal amount of forest conversion and parcelization. The research component of this project will use landowner interviews and a mail survey to better understand how FFOs make decisions about the future of their land. These research findings will inform regional extension programs that use peer network and train-the-trainers approaches to help inform FFO decisions. By working to stabilize the land base in this way, this project will assist in maintaining a viable forest industry, and, ultimately, vibrant rural communities.

Project Objectives

- Gain a better understanding of the timing and influences of bequest decisions in the northeast region.



Jessica Leahy, co-author

- Use research findings to develop effective conservation-based estate planning extension resources and programs.
- Amplify the reach of extension efforts through the development and training of a network of professionals and peer landowners.
- Inform the land bequest decisions of family owned tree farms and help them move forward in the conservation-based estate planning process by providing them with links to more experienced peers and knowledgeable professionals.

Approach

This research involved cognitive interviews to gain a more in-depth understanding of landowner thought processes regarding bequest and for survey development and pre-testing. We used draft survey questions to hold a series of cognitive interviews with FFOs living and owning land in the previously defined priority areas of the four northeastern states. Feedback from an initial round of testing enabled us to review and modify the questionnaire.

In addition to developing a survey instrument, the cognitive interviews involved asking semi-structured questions to probe our understanding of landowner motivations for bequest (traditional and conservation bequests), barriers to bequeathing land, the estate planning decision process, and issues that were identified in previous extension and research.

Having developed and tested our survey instrument, a mail survey was implemented in the priority landscapes of the four states with FFOs owning at least 10 acres of land. FFO survey recipients in Maine, Massachusetts, Vermont, and New York were randomly identified. We used the Dillman's Tailored Design Method (Dillman et al. 2009) as a method for administering the survey.

The final research step involved developing and analyzing a state-of-the-art behavioral model of bequest motivation grounded in economic theory.

Key Findings / Accomplishments

- A screener and full survey were developed and administered across all four states.
- Results showed that there was a distribution of succession and estate planning actions taken by landowners. There was no detected non-response bias. Analysis is ongoing.
- 100% of the qualitative interviews were completed.
- The interviews led to new understanding about how the trans-theoretical model applies to succession and estate planning.

Future Plans

The research portion of this project is now complete; peer-reviewed publications based on this research are in the works. A master's thesis by Hallie Schwab at the University of Vermont is in progress.



Showy Lady Slippers (Photo by Pamela Wells)

COMMERCIAL FORESTS (CFRU)



Dr. Robert Wagner, who served 18 years as the CFRU's director, relocated to Indiana to lead the Forestry & Natural Resources Department at Purdue University in 2016. During his tenure he led the CFRU through significant challenges, including restructuring the unit, major land divestitures, and ever changing forest management, and leaves the CFRU with a much expanded membership. He was instrumental in bringing highly qualified and engaged scientists to the unit. "I believe that the CFRU is the best invention of UMaine's forestry program since it was

founded over a century ago. The CFRU is a national model of stakeholder-driven research that has provided critical information to improve forest management and policy across the state and region. The CFRU also has made UMaine more relevant by helping create students and faculty with expertise on the most important forest resource issues and challenges of the day," Wagner stated in his final report as Director.

Dr. Brian Roth, Acting Director of the CFRU, and Dr. Aaron Weiskittel, Acting Director of the CRSF, will carry on the great work being done by the 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).

The mission of the CFRU is to *"conduct applied scientific research that contributes to the sustainable management of Maine's forests for desired products, services, and conditions."* Currently composed of 35 private and public forestland management organizations, wood processors, conservation organizations, and other members, the CFRU guides and supports research on key issues facing Maine's forest landowners and managers. These members represent nearly 8.3 million acres, or half of Maine's forestland. The CFRU is one of the oldest industry/university forest research cooperatives in the United States, and serves as a model for stakeholder-driven research at the University of Maine.

This year, the CFRU raised \$508,239 in member contributions and leveraged an additional \$371,913 in extramural grants and in-kind support. An additional \$1,423,153 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. A significant addition this year was welcoming James W. Sewall Company as a new corporate member of the CFRU.

Research from the past year focused on three primary areas: silviculture & productivity, growth & modeling, and wildlife habitat. Project highlights include a new research project to quantify the compositional and structural characteristics of **old-growth Northern White-Cedar** dominated stands and to identify which attributes best differentiate old- from second-growth stands; a one-year project to **revisit Maine's historic tree improvement trials** identified and measured over a dozen field trials that were still intact and useful for growth & yield, climate change and forest productivity research; a three-year plan **to acquire Statewide LiDAR data** has been implemented with the first year's data to be completed in 2016; a multi-year project examining the **relationships among forest harvesting, snowshoe hares, and Canada lynx in Maine** has been completed, and it is apparent that the extent and distribution of high quality hare habitat will drive the long-term dynamics of hares and lynx across the broader landscape; and results from the first year of a three-year project examining **the link between commercial forest management, forest habitat characteristics and population performance of spruce grouse** indicate that selection by adult females at the sub-stand includes lower tree densities, taller trees, greater QMD, and higher densities of saplings during the brooding season.



CFRU MEMBERS



Appalachian Mountain Club
Baskahegan Corporation
Baxter State Park, SFMA
BBC Land, LLC
Canopy Timberlands Maine, LLC
Clayton Lake Woodlands
 Holding, LLC
Downeast Lakes Land Trust
EMC Holdings, LLC
Field Timberlands
Forest Society of Maine
The Forestland Group, LLC
Frontier Forest, LLC
Huber Engineered Woods, LLC
Irving Woodlands, LLC
James W. Sewall Company
Katahdin Forest Management, LLC
LandVest
Maine Bureau of Parks &
 Public Lands
Mosquito, LLC
The Nature Conservancy
New England Forestry Foundation
North Woods Maine, LLC
Plum Creek Timber Company, Inc.
Prentiss & Carlisle Company, Inc.
ReEnergy Holdings, LLC
Robbins Lumber Company
SAPPI Fine Paper
Seven Islands Land Company
Simorg North Forest LLC
Snowshoe Timberlands, LLC
St. John Timber, LLC
Sylvan Timberlands, LLC
Timbervest, LLC
UPM Madison Paper
Wagner Forest Management

CFRU PROJECT SUMMARIES

SILVICULTURE & PRODUCTIVITY

Commercial Thinning Research Network (CTRN)

Christian Kuehne, Aaron Weiskittel, Robert Wagner, and Brian Roth

University of Maine

Progress Report, Year 3 of 4

Summary

The Commercial Thinning Research Network (CTRN) examines commercial thinning (CT) responses in Maine spruce-fir stands. There were two experiments established in 2000 with additional ones beginning in 2011. The initial experiments consisted of 12 study sites across Maine examining response in pre-commercially thinned (PCT) balsam fir stands (6 sites) and mature spruce-fir stands not receiving PCT (6 sites). The PCT study quantified the growth and yield responses from the timing of first CT (i.e., now, delay five years, and delay 10 years) and level of residual relative density (i.e., 33% and 50% relative density reduction). The no-PCT study is designed to quantify the growth and yield response from commercial thinning methods (i.e., low, crown, and dominant) and level of residual relative density (i.e., 33% and 50% relative density reduction). Beginning in 2011, the CTRN was expanded to include previously established thinning studies, such as the Early Commercial Thinning (ECT) and Austin Pond Third Wave projects. These experiments also have the advantage of unit area replication within locations, which is absent in the first three experiments. Key findings this year: Individual tree-level thinning treatment response functions for spruce-fir stands were developed and evaluated and were shown to significantly improve predictions of annual stand-level basal area growth and mortality. When the developed thinning modifiers were included in standard individual-tree growth models, a significant improvement in prediction over baseline models was achieved, yet the individual-tree approach was superior for predicting long-term response to various thinning treatments (Figure 2).



PCT Brush Saw (Photo by Pamela Wells)

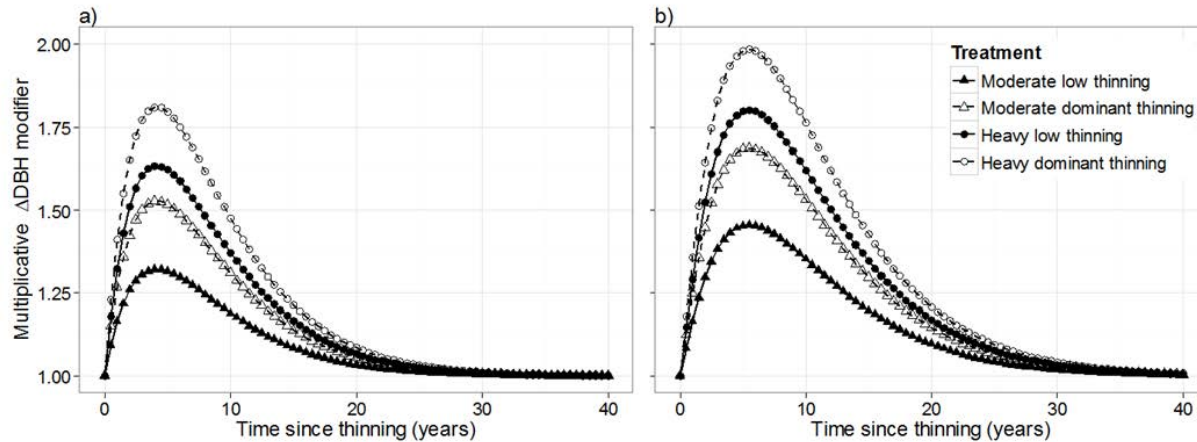


Figure 2 - Individual tree-level annual DBH increment (Δ DBH) thinning-response functions for exemplary moderate and heavy (25% or 50% basal area removal, respectively) low or dominant thinnings (QMD ratio = 0.7 or 1.1, respectively) for (a) balsam fir

Identifying Attributes that Distinguish Old and Second-Growth Northern White-Cedar Stands for Forest Management and Planning

Laura Kenefic,¹ Shawn Fraver,² and Aaron Weiskittel²

¹U.S. Forest Service, Northern Research Station, ²University of Maine

Progress Report, Year 1 of 2

Summary

Northern white-cedar (NWC) has received limited research attention and land managers are confronted with challenges in the management of this species. This includes the recognition of old-growth (OG) characteristics and the differentiation between OG and second-growth (SG) stands. The goal of this project is to quantify the compositional and structural characteristics of OG NWC-dominated stands and identify which attributes best differentiate OG from SG stands. To accomplish this, known OG stands were located and sampled along with SG stands that have experienced a range of intensities of partial harvesting. Thirty-one plots were installed in five locations across Maine and New Brunswick. With 8 additional plots at Big Reed Forest Reserve collected as part of an earlier study, we now have 39 plots in the dataset. Roughly half of the plots were considered old-growth and half were considered second-growth. Data summary and analysis are underway.

Revisiting Maine's Tree Improvement and Plantation Trials

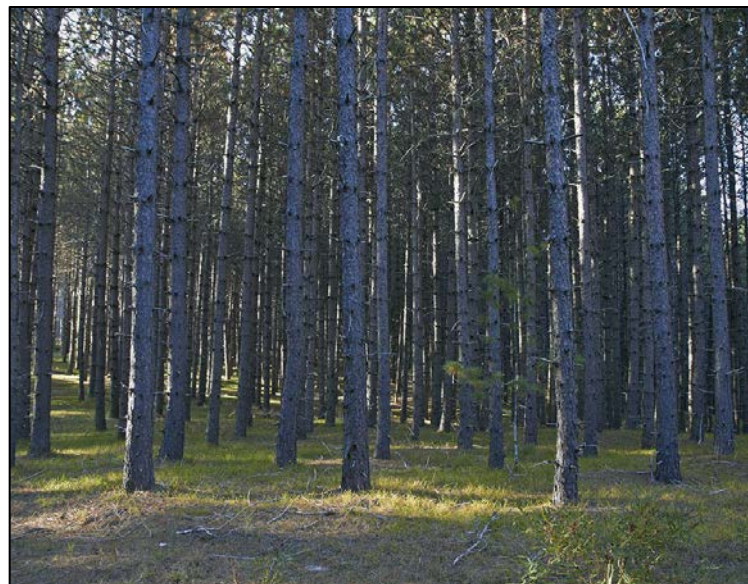
Brian Roth,¹ Aaron Weiskittel,¹ and Laura Leites²

¹University of Maine, ²Pennsylvania State University

Final Report

Summary

In the 1980s there was a concerted effort to increase the productivity of Maine's forested land base in response to a predicted shortfall of merchantable spruce-fir due to an unbalanced age structure as a result of the spruce budworm outbreak in the 1970s. To gain information on which species and seed sources were best suited for planting in Maine, a variety of species, provenances and genotypes were established in field tests across the state using optimum silvicultural treatments. These tests were measured periodically up until the late 1990's, but measurements stopped abruptly during a period of drastic change in land ownership and management objectives. While interest in establishing plantations in Maine has waned, a subset of these tests continue to hold immeasurable value as a source of data for the improvement of growth & yield models as well as predicting forest response to a changing climate. This project revisited over 3 dozen historic tree improvement and plantation trials in Maine of which around one third were still intact and useful. Plot boundaries were monumented in the field and GIS shapefiles were sent to landowners/managers to protect these stands through rotation.



Red Pine Plantation (Photo by Pamela Wells)

Effects of Mechanized Harvesting Operations on Residual Stand Conditions

Robert Wagner,¹ Brian Roth,¹ Cody Lachance,¹ and Jeffery Benjamin²

¹University of Maine, ²Bangor Christian Schools

Progress Report, Year 2 of 3

Summary

The spruce-fir forest type is one of Maine's most abundant forest types and has immense ecological and economic value to the state. Mechanized harvesting operations can lead to detrimental residual stand conditions including soil disturbance and residual stem damage. The goal of this study is to investigate the impacts of mechanized harvesting at two long-term experimental sites. The Austin Pond study site will be used to test whether commercial thinning operations have an impact on residual stem damage. The Weymouth Point study site will be used to assess how soil disturbance following whole-tree harvesting influenced long-term tree growth and species composition. Results from this study will help forest managers better understand the relation between logging disturbance and the long-term impact on future stand growth, quality, and value.



Skidder Soil Disturbance (Photo by Pamela Wells)

GROWTH & YIELD MODELING

Evaluating the Influence of Stem Form and Vigor on Product Potential, Growth, and Mortality for Northern Commercial Hardwood Species

Aaron Weiskittel, Jereme Frank, and Mark Castle

University of Maine

Progress Report, Year 1 of 2

Summary

Compared to softwood species, northern hardwoods display a wide variety of stem forms and defects whose presence are not accounted for in most volume/biomass equations or even growth and yield models. To account for these deficits, the primary goals of this project were to quantify the influence of form and defects on biomass, merchantable volume, diameter increment, and survival of northern commercial hardwood species. To accomplish these goals, intensive tree measurements incorporating form and damage protocols were taken on standing and felled trees across several sites in Maine and New Hampshire. Preliminary work suggests that the probability that rot occurs varies between species, while growing stock acceptability and diameter are significant factors when predicting the proportion of tree rot. Further analyses will: 1) predict occurrence of stem defects and their impacts on biomass/merchantable volume and 2) evaluate the influence of stem form and damage on individual tree growth and mortality.

Linking Site Quality to Tree Growth and Survival in the Acadian Forest

Chris Hennigar,¹ Aaron Weiskittel,² and Lee Allen³

¹University of New Brunswick, ²University of Maine, ³ProFOR Consulting

Final Report

Summary

Stand growth and dominant tree height-age (i.e., site tree) measurements from ~10,900 plot locations were compiled from Maine, Nova Scotia (NS), New Brunswick, and Prince Edward Island to

predict and map forest productivity for the Acadian forest region as a function of climate, lithology, soils, and topographic metrics. Forest productivity was defined here as the theoretical maximum above-ground biomass survivor growth rate (BGI; kg/ha/yr). Regionally, 65% of the variation in biomass survivor growth was explained as a function of mean growing season temperature, frost free days, bedrock type, soil depth to root restriction, soil % coarse fragments, slope, and depth to water in combination with stand structure and species predictors. BGI was mapped on a 20m grid holding stand structure and species constant. BGI explained 0-30% of spruce-fir site index variability depending on dataset, and showed similar predictive performance ($\pm 5\%$) when compared to existing land productivity classifications (LC) in each province. Lack of a responsive site index dataset in Maine limited validation for this state. When the NS LC was combined with BGI to predict site index, error explained increased relatively by $\sim 40\%$ for NS compared to LC or BGI used independently. Limitations and future improvements to soils and topographic metrics are discussed.

Maine Statewide Light Detection and Ranging (LiDAR) Data Acquisition

Joseph Young,¹ Brian Roth,² and Daniel Walters³

¹Maine Office of GIS, ²University of Maine, ³U.S. Geological Survey

Final Report

Summary

LiDAR data and Geographic Information Systems (GIS) have brought the capability for making large scale accurate assessments of forest resources. Software options are increasing and it is becoming easier for forestry professionals to take advantage of the power of this 3D GIS technology. GIS analysis has proven to be a reliable method for analyzing, quantifying and graphically illustrating forest resources. These resources include; biomasses, canopy height, stem diameter, basal area, gross merchantable volume, gross total volume and stem density. Now prior to walking any particular forest plot a forester can have a working knowledge of the topography and forest biometrics, thus improving overall efficiency of professional time spent in the field. 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.

WILDLIFE HABITAT

Relationships among Forest Harvesting, Snowshoe Hares, and Canada Lynx in Maine

Sheryn Olson and Daniel Harrison

University of Maine

Final Report

Summary

This year we completed fieldwork on a 15-year study of temporal dynamics in snowshoe hare populations across regenerating conifer stands, as well as comparing over-winter hare densities across a range of forests harvesting treatments. This was part of a larger study of the inter-relationships between forest harvesting,



Snowshoe Hare (Photo by Pamela Wells)

Canada lynx, snowshoe hares, habitat structure, forest succession, and natural population cycles conducted from 2001-2015. Results on lynx food habits, resource selection by lynx across multiple spatial scales, and on effects of forest structure and seasons on habitat selection by hares have been presented each year in CFRU Annual Reports from 2008 - 2014. As such, this report focuses on the 15-year trends in over-winter hare populations across our 38 stands located within our 2,516 km² study area in Piscataquis and Aroostook counties, northern Maine.

Hare densities were highest in regenerating conifer stands (REGEN) with a previous history of clearcut harvesting, followed by herbicide application to suppress competing deciduous hardwoods. These stands provided superior habitat for a period from 15 - 40 years post-harvest due to dense conifer regeneration ranging from 2,200 - 13,000 stems ha⁻¹ (stems defined as >1.0 m height), which suppressed stand growth rate and maintained high cover value for hares. Hare densities ranged from 2.3 times higher in REGEN than in uncut mature stands (MAT) during 2014, to 4.3 times higher in REGEN compared to MAT in 2008. Across the period 2008 to 2015, MAT stands averaged 0.25 hares ha⁻¹ (range 0.20 - 0.33), partial harvest stands averaged 0.43 hares ha⁻¹ (range 0.31 - 0.59), and REGEN stands averaged 0.86 hares ha⁻¹ (range 0.77 - 0.99).

Our REGEN stands were monitored over a longer period to assess evidence for natural cyclic dynamics in hare populations, as has been reported for northern boreal study sites in Alberta, Northwest Territories, Yukon Territories, and Alaska. It has been speculated that hares do not cycle near the southern portion of their geographic range, but longitudinal empirical studies are absent for this region. We documented that hares maintained relatively high and stable densities in REGEN

stands across a consecutive 6-year period from 2001 - 2006 when annual densities averaged 1.98 hares ha^{-1} (range 1.79 - 2.22). Hares transitioned to intermediate densities of 1.19 ha^{-1} during a decline year in 2007 and then stabilized at a relatively lower annual density averaging 0.86 ha^{-1} (range 0.77 - 0.99) across the final 8 years of our study spanning 2008 - 2015. Our data do not suggest the presence of 10-year cycles typical of northern hare populations, but suggest long-term stable equilibria where densities vary approximately 2.3-fold and where density transitions from a stable high period to a lower density phase across only a single year. Although we cannot rule out a cycle of longer periodicity (i.e. >20 years) based on our data, it is apparent that hares in Maine do not cycle with the frequency and at the magnitude (e.g., 5- to 25-fold) observed in northern boreal populations. This has significant implications for management of Canada lynx, which exhibit greatly decreased reproduction, declining survival, expanded home ranges, and decaying spatial structuring at the nadir of hare cycles in the north. Changes in home range area, habitat selection, and spatial behavior by lynx were not observed during the range of hare densities that we observed.

Across our various studies, the extent and distribution of high quality hare habitat (i.e., conifer-dominated stands 15 -40 years post stand-replacing disturbance) will drive the long-term dynamics of hares and lynx across the broader landscape. In the future, these processes will be most influenced by forest harvesting and silvicultural practices (e.g., clearcut versus partial harvesting, herbicide application versus natural regeneration, plantations) and by natural processes (e.g., spruce-budworm) that influence forest successional patterns across the Acadian forest landscapes occupied by hares and lynx. In the longer term, climate change may also affect the southern range limit for some conifer tree species, snowshoe hares, and Canada lynx and may influence snow characteristics affecting competitive interactions between lynx and other mesopredators (e.g., fishers, bobcats, coyotes, red foxes) that also consume hares.

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

Joel Tebbenkamp, Erik Blomberg, Daniel Harrison, and Stephen Dunham
University of Maine

Progress Report, Year 1 of 3

Summary

During the 2015 field season we monitored 44 radio-marked spruce grouse, including 30 females and 14 males in northern Maine. We obtained approximately 225 locations from these birds to locate nests, track brood success, and evaluate habitat use. All females radio-marked prior to the breeding season initiated nests, and apparent nest success was 50% (4/8). We monitored 11

broods, and apparent brood success was 73% (8/11). We conducted vegetation sampling at nests and areas used by females post-nesting (both brooded and non-brooded), and also collected similar data at random locations. Additionally, we completed measurement at sites of use by 28 female spruce grouse monitored by telemetry during 2012 - 2014 and compared to random sites within the stands where the birds were captured. During June and July 2015 we located females approximately once per week and conducted vegetation sampling at the use and 1 dependent random location resulting in a total of 116 (58 use and 58 random) vegetation plots from the 15 females monitored during this time period. In future years we will focus on increasing our sample sizes and expanding analyses of demographic responses and habitat selection in relation to various forms of forest management.

Bird Communities of Coniferous Forests in the Acadian Region: Habitat Associations and Responses to Forest Management

Brian Rolek,¹ Daniel Harrison,¹ Cynthia Loftin,² and Petra Wood³

¹*University of Maine,* ²*USGS Maine Cooperative Fish & Wildlife Research Unit,* ³*USGS West Virginia Cooperative Fish & Wildlife Research Unit, West Virginia University*

Final Report

Summary

Several bird species of concern are found in the coniferous forests of Northern New England. Cape May (*Setophaga tigrina*) and Bay-Breasted Warbler (*Setophaga castanea*) have been declining within the Acadian Region since region-wide monitoring began with the USGS Breeding Bird Survey in 1966, whereas, species such as Blackburnian Warbler (*Setophaga fusca*) are increasing (Sauer *et al.* 2012). The United States Federal government has the authority to manage these species under the U.S. Migratory Bird Treaty Act. Maine contributes up to 96% of breeding habitat (e.g., Bay-Breasted Warbler, M. Hartley, USFWS, unpublished data) for some of these spruce-fir associated species in the United States, and the apparent population declines of some species are not well understood. The coniferous forests where these species reside are heavily managed by the timber industry with a variety of silvicultural and industrial prescriptions. Habitat requirements for these species are not well-defined, nor are the species' responses to forest management.

We sampled birds across sites located within the Acadian Forest Region, which coincides roughly with Bird Conservation Region 14 in the United States. In 2013, we established survey points in the North Maine Woods (Clayton Lake and Telos), Baxter State Park, and four National Wildlife Refuges (Nulhegan Basin Division of Silvio Conte, Umbagog, Moosehorn, and Aroostook). We tested for bird

community response to management with non-metric multidimensional scaling to group bird species within forest management types and across common vegetation measurements representing the structure and composition of stands. Preliminary analyses suggest that both Bay-breasted and Cape May Warblers were associated with regenerating and pre-commercially thinned treatments, along with dense canopy cover, high proportion of spruce-fir composition, and mid-successional stand structure.

Moose Density and Forest Regeneration Relationships in Maine

Peter Pekins,¹ Sabrina Morano,² and Fred Servello²

¹University of New Hampshire, ²University of Maine

Progress Report, Year 1 of 2

Summary

High moose density that can influence forest composition, growth, and regeneration, and is a management concern in Maine. This study was designed to assess composition, regeneration, and damage in 5-10, 10-15, 15-20, and >30 year old cuts in 2 harvest regimes (clear-cut, partial harvest) within 3 forest types (softwood, hardwood, mixed wood). In summer 2015, 64 younger-aged (5-20 years) stands were measured with a milacre plot protocol; 4 stands >30 years old were measured via standard forestry inventory. The dominant stem in the majority of plots regardless of forest type, age class, or harvest type was a commercial species without damage; relative damage (light crook) was consistently higher in hardwood plots and declined with age. The majority (~80%) of trees in the >30 year old plots were commercial species, undamaged, and of Form 1 or 2 (single stem) and of vigor R1 or R2 (96%) indicating that trees were commercially valuable.



Moose Calf (Photo by Pamela Wells)



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 provided leadership this year as part of the Spruce Budworm Task Force as it developed and launched a website and related social media that focuses on all aspects of 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 the **Howland Research Forest**, which is part of the national Ameriflux network measuring the atmospheric flux of carbon dioxide, and a partner in **Forests for Maine's Future**, which provides a social media and website connection on important forest resource issues to the general public.

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



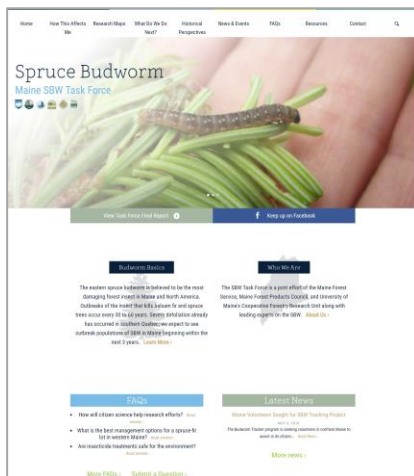
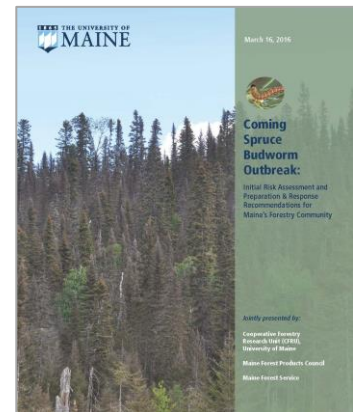


SPRUCE BUDWORM

About 40 years ago, the spruce budworm (SBW) was devastating spruce-fir forests across northern Maine. This outbreak was a regional event covering more than 130 million acres across Quebec, Northern New England, and the Maritime Provinces of Canada. That outbreak lasted about 15 years

(1970-85) and shaped the forest, forestry politics, and careers of most foresters during this period. It was during this period that the CFRU also was formed to help forest landowners work together with the University of Maine to meet the challenges associated with the SBW.

Returning on a natural 30-60 year cycle, the next outbreak is now at Maine's doorstep. The current outbreak began in Quebec around 2008 and has spread to cause severe defoliation on over 10 million acres of spruce-fir forest. Insect traps in northern Maine and New Brunswick have captured steadily increasing SBW moth counts over the past several years, and defoliation of spruce-fir stands is within a few miles of Maine's northern border. Therefore, Maine is likely only a few years away from seeing the first defoliated trees. To help Maine prepare for the coming outbreak, the CFRU, Maine Forest Service, and Maine Forest Products Council formed a joint SBW Task Force in 2013. More than 65 experts contributed to task teams to address: Monitoring strategies, Forest management strategies, Protection options, Policy, regulatory & funding issues, Wildlife habitat issues, Public communications & outreach, and Research priorities.



The findings of the Task Force were published in March 2016. The report includes a detailed risk assessment and nearly 70 recommendations for how Maine's forestry community can begin preparing for and responding to the coming outbreak. On the heels of the report, CRSF staff developed and launched **sprucebudwormmaine.org**, a website dedicated to providing accurate, in-depth, and timely resources and links for landowners, forest managers, educators, legislatures, researchers, and the public. This website will serve as the primary communications outlet once the outbreak commences in Maine.

Citizen scientists throughout the state have become an invaluable resource to the Maine Forest Service and UMaine's Cooperative Forestry Research Unit's efforts to monitor the rise and spread of the spruce budworm. In late fall, branches and sample plot data are collected throughout the working forests of Maine for lab analysis to determine budworm larvae (second instar larvae, or L2) populations. The L2 numbers reveal trends for the area under study and help to forecast budworm density for the following year.

To keep up with the latest news regarding the spruce budworm outbreak status in Maine, as well as information on the current outbreak in Quebec and New Brunswick, follow our Facebook page: **Spruce Budworm Maine**.



Private Landowner Hanging Spruce Budworm Trap



CENTER FOR ADVANCED FORESTRY SYSTEMS (CAFS)

Bob Wagner and Aaron Weiskittel

This year saw the completion of the first 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. The mission of CAFS is *to optimize genetic and cultural systems to produce high quality raw forest materials for new and existing products by conducting collaborative research that transcends species, regions, and disciplinary boundaries*. 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.

Phase II of CAFS contributes \$60,000 per year for 5 years 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 Dr. Arun Bose's efforts to better understand regional regeneration patterns and most influential factors, particularly with respect to American beech.



CFRU staff and several Advisory Committee members represented the Maine CAFS site at the Eighth Annual CAFS Industrial Advisory Board (IAB) meeting held April 26-28, 2016, in Pensacola Beach, FL. The meeting was well attended by scientists, graduate students, and forest industry representatives who met to review and approve all CAFS projects nationwide. CFRU looks forward to the next four years of collaboration with the NSF I/UCRC through CAFS.



Split Gilled Fungus (*Photo by Pamela Wells*)



THE NORTHEASTERN STATES RESEARCH COOPERATIVE

The Northeastern States Research Cooperative (NSRC) is a competitive grant program funded by the USDA Forest Service that supports cross-disciplinary, collaborative research in the Northern Forest—a 26-million acre working landscape that is home to more than one million residents and stretches from eastern Maine through New Hampshire and Vermont and into northern New York. The NSRC addresses the importance of the Northern Forest to society and the need for research to have relevance and benefit to the people who live there, work with its resources, use its products, visit it, and care about it.

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.

Since 2001, the NSRC has awarded over 295 research grants, totaling over \$22 million, to researchers throughout the region. Each year, the NSRC supports Northern Forest research that fits into four research themes:

Theme 1 (Vermont): *Sustaining Productive Forest Communities: Balancing Ecological, Social, and Economic Considerations*

Theme 2 (New Hampshire): *Sustaining Ecosystem Health in Northern Forests*

Theme 3 (Maine): *Forest Productivity and Forest Products*

Theme 4 (New York): *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 2015-16, three new project proposals on the Northern Forest were approved for funding through Theme 3, while CRSF continues to support over a dozen ongoing NSRC projects granted in past years. Progress reports from current Theme 3 projects as well as summaries of Theme 3 projects completed in 2015-2016 follow (full reports are available from the NSRC website at nsrcforest.org)

NSRC PROGRESS REPORTS

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

PI: Robert S. Seymour, University of Maine

Co-PI: Shawn Fraver, University of Maine

Progress Report, Year 1

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, 2015, to June 30, 2016, we completed overstory and sapling permanent plot measurements of research areas 1, 2, 3, 5, 6, 7, and 9. All overstory trees and saplings within the nested plot design were stem mapped, given new tags, and trees were re-marked with a bark scribe and tree paint at breast height. In February 2016, the second replicate (research areas 5/6) were marked for harvest with operations concluding in March 2016.

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



Advance pine regeneration in research area 6 (large expanding-gap) post-harvest March 2016.
(Photo by Joshua Puhlick)

- 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 precommercial 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).



Pine and spruce legacy trees marked for retention post-harvest March 2016
(Photo by Josh Puhlick)

Key Findings / Accomplishments

- Complete re-measurement of 140 permanent plots in research areas 1, 2, 3, 5, 6, 7, 9.
- Overstory trees measured $n = 5821$
- Sapling trees measured $n = 4060$
- Total trees measured $n = 9881$
- New plot center posts installed marked overhead with flagging
- All old tags, nails, staples removed
- New tags stapled vertically, breast height re-marked with bark scribe and tree marking paint (Photo 1)
- All trees stem mapped
- Harvest layout, implementation RA 5/6 completed
- Post-harvest inventory RA 5/6 completed
- Preliminary growth analysis RA 1/2
- Comprehensive analysis of reserve-tree growth and mortality (David Carter MS Thesis); one paper published, another in revision.

Future Plans

- Complete permanent plot inventory for the remaining research areas (4/8) (July – September 2016)
- Establish (July 2016 – October 2016) 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 precommercial composition and density control treatments (Objective 4).

- Perform harvest layout and implement the third harvest entry for research areas 7 and 9 (winter 2016/2017)
- Convert 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)
- 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)
- 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 (winter/spring 2017)
- 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.

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

PI: Aaron Weiskittel, University of Maine

Co-PIs: Gaetian Pelletier, Northern Hardwoods Research Institute; Jereme Frank, University of Maine; Mark Castle, University of Maine

Progress Report, Year 1 of 2

Summary

We are currently in the process of analyzing data and preparing manuscripts using the data collected during the 2015 and 2016 field seasons. To date we have taken intensive tree measurements incorporating form and risk protocols for 7016 hardwood species across PSPs in the

following locations: (1) Austin Pond Research Forest, (2) Demerit University Forest, (3) Dixmont Community Forest, (4) The Holt Research Forest, (5) Kingman Farms Research Forest, Madbury, (6) The Penobscot Experimental Forest, (7) and The Scientific Forest Management Area (SFMA). Current results indicate that stem form and risk have important implications on potential sawlog recovery (Figure 3) and diameter growth (Figure 4) for several northern commercial hardwood species. Analysis using destructively sampled trees suggest that risk classifications can also be used to improve predictions of the occurrence of internal stem decay (Figure 5).

Project Objectives

- Assess differences in stem form and risk across several prominent northern commercial hardwood species
- Quantify the influence of stem form and damage on potential sawlog recovery, diameter increment, and probability of survival
- Develop revised framework for classification system that could be used for hardwood management in the Northeast
- Use destructively sampled trees to (1) examine the influence of commonly measured tree metrics such as size, taper, risk class and crown ratio on a tree's susceptibility to decay, and (2) assess whether decay varies between species

Approach

- Standing measurements were taken on hardwoods of varying tree form and vigor across PSPs in Maine and New Hampshire; These data were used to analyze the influence of stem form and risk on product potential, diameter growth and survival.
- On adjacent sites, destructively sampled trees with poor form/ high damage were collected to assess decay proportion, volume and biomass deductions.
- Generalized linear mixed effects models were used to predict the occurrence of stem form and risk across species. Subsequent beta regression models were used to predict sawlog recovery as a function of a tree's size, stem form and risk.
- Nonlinear mixed effects models were developed to quantify annualized diameter increment and survival using stem form and risk as covariates.
- Evaluated several different kinds of modelling frameworks and explanatory variables for predicting the probability and proportion of internal stem decay
- Incorporate resultant equations and modifiers into FVS - ACD

Key Findings / Accomplishments

- Potential sawlog recovery was lower for trees that demonstrated excessive sweep or lean, multiple stems, significant forks, or severe/extensive damage
- Annual diameter increment was about 8% lower for trees considered to be high risk
- Key predictors of decay included taper, crown ratio and species.
- Risk class significantly improved classification of decay occurrence by 5%.

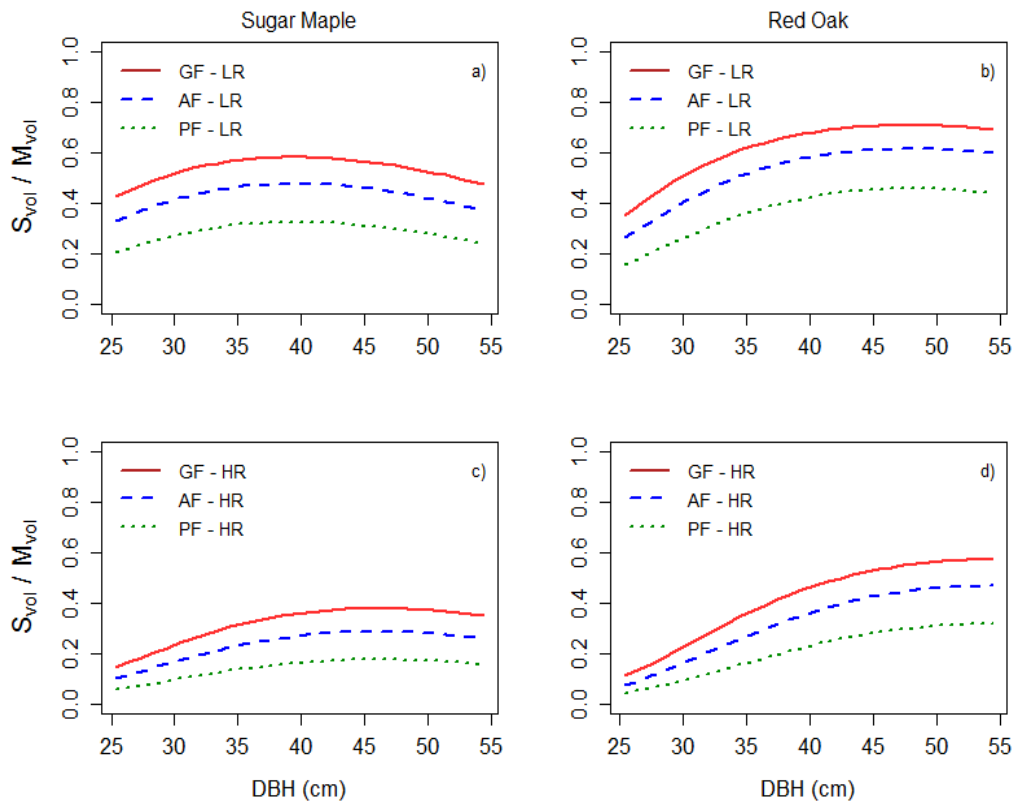


Figure 3 - Predictions of the proportion of sawlog volume to merchantable volume (S_{vol}/M_{vol}) in an individual tree stem across DBH, form (AF, GF, PF), and risk classes (LR and HR) for sugar maple (a and c) and red oak (b and d). AF, GF and PF correspond to acceptable form (tree with multiple stems, sweep or significant lean), good form (tree with single straight stem) and poor form (tree with at least 1 significant fork on first 5 m of stem) respectively. LR and HR correspond to low risk (trees with little or no damage) and high risk trees (trees with extensive or severe damage) respectively.

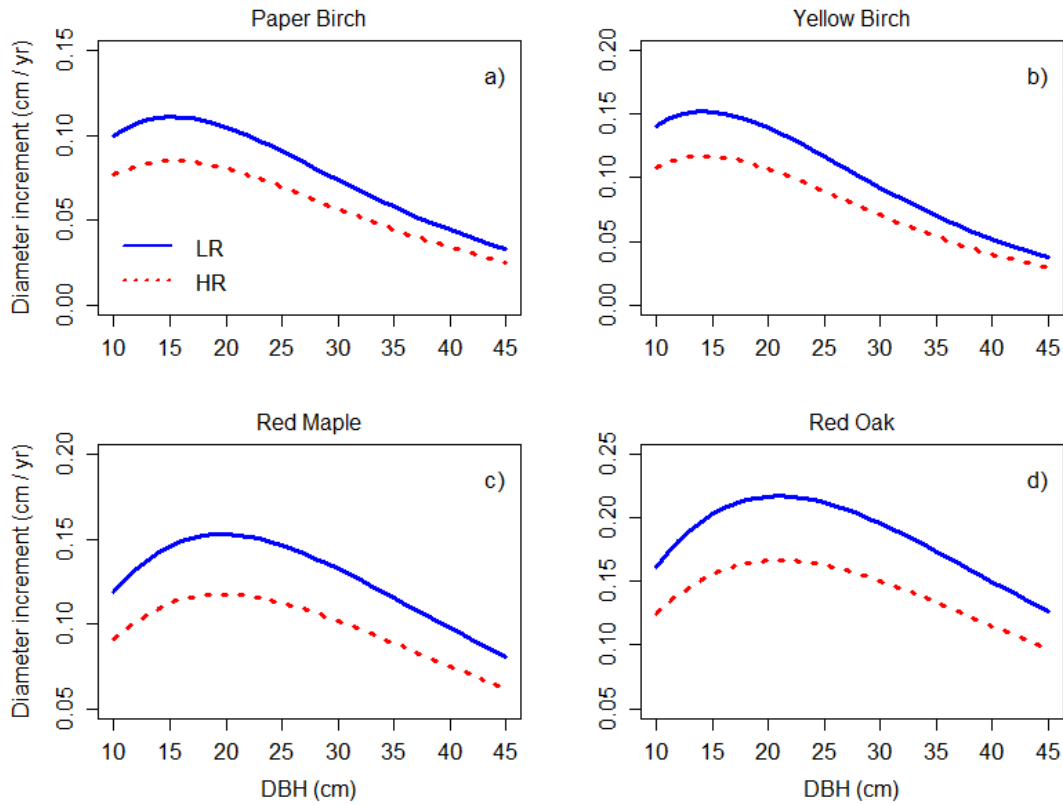


Figure 4 - Predictions of the annual diameter increment across DBH and risk class for paper birch (a), yellow birch (b), red maple (c) and red oak (d). LR and HR correspond to low risk (trees with little or no damage) and high risk trees (trees with extensive or severe damage) respectively.

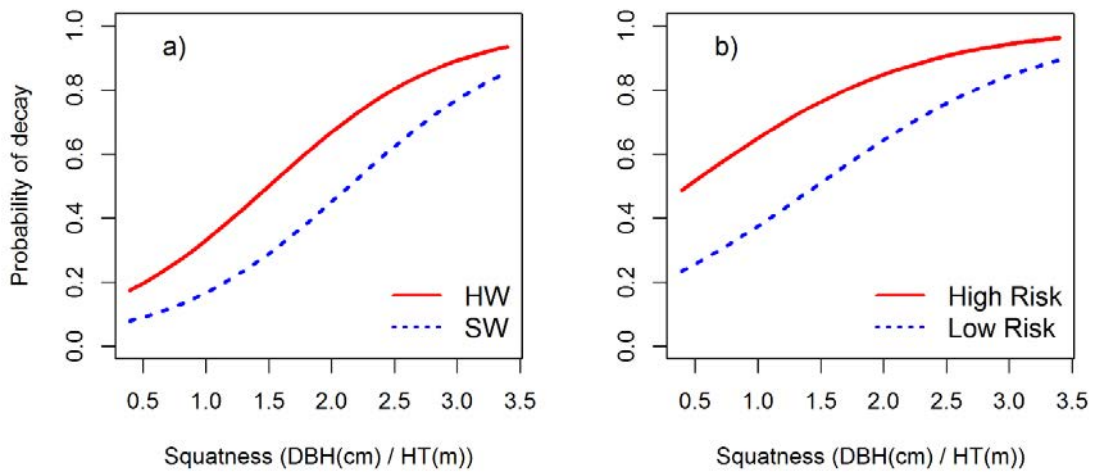


Figure 5 - Predictions of the probability of internal stem decay across tree squatness, for evergreenness (a), and risk class (b).

Future Plans

- Further analysis and continued preparation of manuscripts
- Work with FIA to incorporate form and risk classification protocols into statewide inventory in Maine

Potential Impacts of Alternative Future Land Uses on Forest Management and Wood Supply across Maine

PI: Spencer R. Meyer, Highstead Foundation

Co-PIs: Robert Lillieholm, University of Maine

Progress Report Year 5 of 5

Summary

Maine is the most heavily forested state in the United States, with 95% of its forests in private ownership. These forests support rural economies across the state through forest-based manufacturing as well as outdoor recreation and tourism. Maine's rural character, attractive quality-of-place, and relatively low land cost continues to encourage development, which in turn places pressure on private forest resources. The likely prospect of future development poses a risk to the wood supply upon which Maine's forest products economy relies. In this project, we are using a mixed-methods approach that combines land use planning with an assessment of the wood supply that could be affected by future development patterns. Using Bayesian belief networks (BBN), we integrated geospatial data and expert opinion to develop land suitability models for four land uses (development, forestry, conservation and agriculture) across two major watersheds. Initial projections of future development suggest limited impact on timber supplies. Land parcelization, however, is likely to be more of a concern in the short-run.

Project Objectives

- Create spatial maps of future development in selected locations in Maine.
- Summarize current development impact on forests.
- Project future forest cover and volume.
- Evaluate trends and spatial patterns of impacts of future development on forests.

Approach

- Focus groups were used to solicit stakeholder input on landscape/parcel factors affecting suitability for four key land uses – development, forestry, conservation and agriculture.
- Bayesian belief networks (BBN) were co-developed with stakeholders from the focus groups. These networks combined expert knowledge with over 100 geospatial datasets to spatially identify areas of suitability for our four land uses.
- All stakeholders were convened to review and comment on BBN output. At these workshops, we also solicited a set of alternative future development scenarios.
- An agent based model was used to apply stakeholder-derived scenarios under varying assumptions across our two study areas.
- The intersection between likely future development and productive forestland will be used to estimate future timber supply impacts.

Key Findings / Accomplishments

- Stakeholders were able to serve a critical role in developing land use specific BBNs for our two Maine watersheds. The all-stakeholder workshop led to a successful set of future scenarios.
- Scenario generation is difficult. Most scenarios envision slight changes to the status quo. In our case, the Penobscot River Watershed has lost several major pulp and paper mills. The magnitude of the change in processing capacity far outweighed anything our stakeholders might have envisioned. A lesson learned is that “unrealistic” scenarios that forecast significant change have a role to play in futures analyses.

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

PI: Laura Kenefic, USDA Forest Service, Northern Research Station

Co-PIs: Bethany Muñoz, USFS Northern Research Station; Aaron Weiskittel, Ivan Fernandez, Jeff Benjamin, and Shawn Fraver, University of Maine

Progress Report, Year 2 of 2

Summary

Beginning summer 2014, 23 permanent sample plots (PSPs) were installed in Compartment 33, located within the Penobscot Experimental Forest (Figure 6). Treatments include an unharvested reference, whole-tree harvesting (WTH), stem-only harvesting (SOH), and post-harvest prescribed burning (SOHB). For the treated areas, we estimated trees per hectare (trees ha⁻¹), tree regeneration (stems ha⁻¹), total basal area (m² ha⁻¹), mean dominant height (m), and hardwood basal area (percent of total basal area). For aboveground carbon stock, we estimated total aboveground live-tree, snag, and down woody material carbon content (Mg ha⁻¹). Though suggestive evidence of reduced site productivity on SOH sites with high O horizon thickness was found, neither WTH nor SOHB appear to reduce site productivity. Results were presented at both national conferences and field tours.

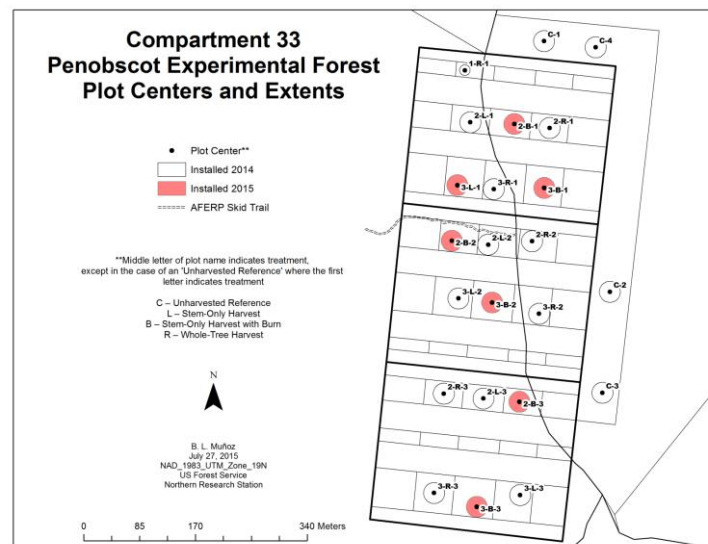


Figure 6 - Map of Compartment 33 plot centers and extents.

Project Objectives

- Quantify site productivity (soil and foliar nutrients) and stand attributes (biomass and composition) 50 years after treatment in a designed experiment of clearcutting with WTH and SOH
- Determine the effect, if any, of incremental (SOH vs WTH) biomass removal on productivity
- Synthesize our findings with those from other studies of WTH in the Northern Forest to provide insight for future sustainable biomass harvesting guidelines

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

- Treatment, site condition, or an interaction of the two did not have an effect on live-tree density, mean dominant height (m), overall percent hardwood composition, or dead wood carbon stock
- Suggestive evidence of lower basal area, live and total carbon stock on SOH treated areas with high O horizon thickness (Figure 7)

- At the species-level, aspen basal area was lowest on poorly-drained sites within treatments (Figure 8)
- Neither WTH nor SOHB reduced northern mixedwood site productivity 50 years after harvest, as reflected by stand structure or composition

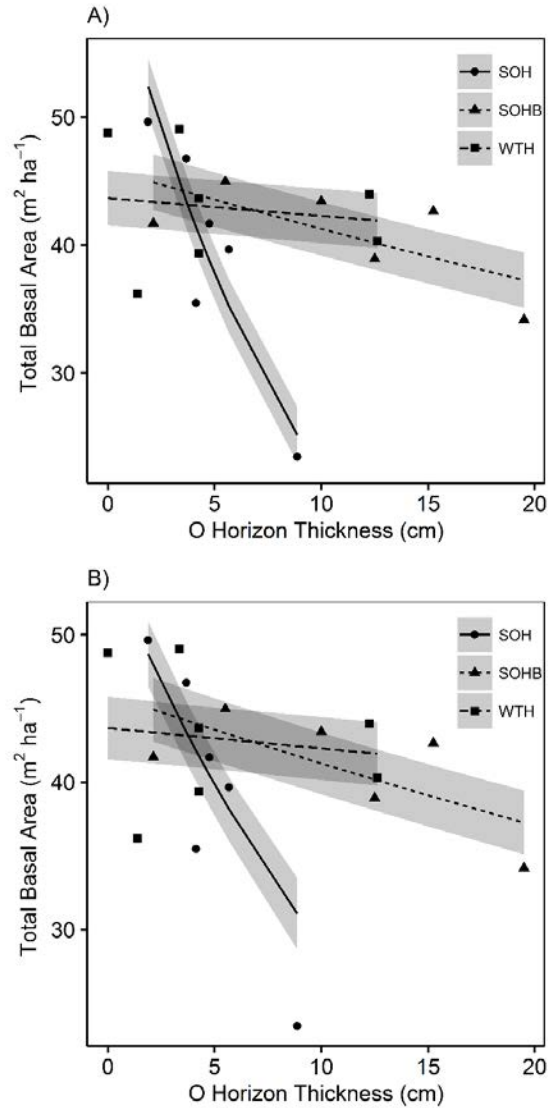


Figure 7 - Predicted (line) and observed (point) total basal area with O horizon thickness, for trees ≥ 1.3 cm dbh. Plot a) displays the predicted line for SOH with the influential point and b) displays the predicted line for SOH without the influential point. Gray shading around predicted lines represents 95% confidence bands.

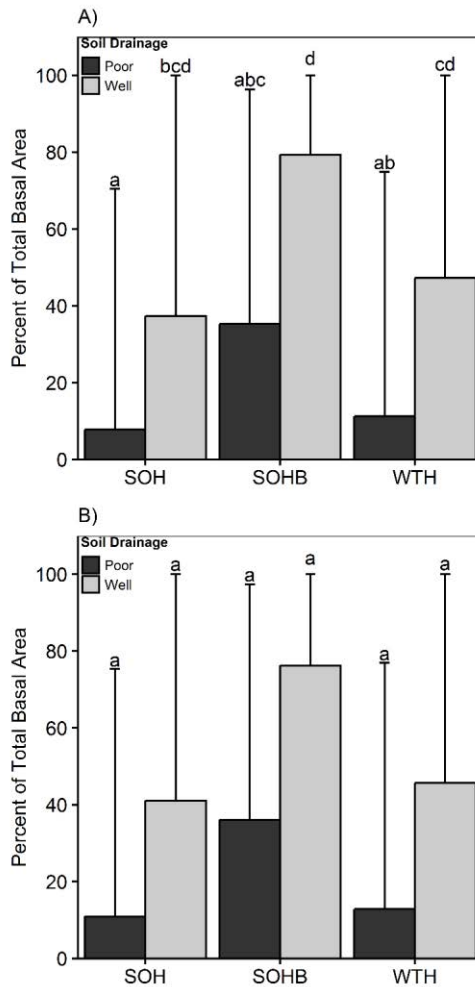


Figure 8 - Aspen basal area (% of total basal area) least-squares means by treatment and drainage type, for trees ≥ 1.3 cm dbh. Plot a) displays least-squares means for SOH with the influential plot and b) displays least-squares means for SOH without the influential plot. Treatments are as follows: SOH = stem-only harvest; SOHB = stem-only harvest with burn; WTH = whole-tree harvest. Different lower-case letters indicate significant differences.

Future Plans

- December 2016 – October 2017: Muñoz will complete data analysis, producing two chapters in her dissertation dedicated to this project
- Chapters will be submitted for publication, targeting Forest Ecology and Management and other natural resource journals
- Chapter 1: Northern mixedwood site productivity 50 years after whole-tree harvesting and stem-only harvesting with and without prescribed burning

- Chapter 2: Foliar and mineral soil nutrient availability 50 years after whole-tree and stem-only harvesting in a northern mixedwood forest
- November 2017: Presentation of all results at Muñoz dissertation defense

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

PI: Brian Sturtevant, USFS Northern Research Station

Co-PIs: Eric J. Gustafson, USFS, Northern Research Station;

Kasey Legaard, University of Maine

Progress Report, Year 1 of 2

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 the LANDIS-II environment have produced the range of anticipated budworm behaviors and consequent impacts under simplified (i.e., homogenous) scenarios, even when spatial processes were explicitly simulated. Future work will focus on the backcasting of 1985 Maine forests to pre-outbreak conditions *circa* 1973, simultaneous calibration of the spruce budworm disturbance extension to the Border Lakes Landscape (i.e., border country of Minnesota & Ontario), and finally Maine applications necessary for model validation by comparison with a historic outbreak.

Project Objectives

- *Map forest conditions ca. 1973* using previously developed maps, historic plot data, and new remote sensing analyses
- *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 acquired in 1985, and then backdate pre-outbreak spruce-fir distributions to 1973 using a previously developed time series of forest disturbance maps.
- Digitize the locations of a large set of plots measured by private companies in 1985, from hand-written records maintained by the U. Maine Cooperative Forestry Research Unit.
- Develop a new predictive modeling algorithm capable of (1) using either occurrence-only data or occurrence data mixed with unlabeled data, and (2) providing alternative mapped distributions differing in spruce-fir acreage.

Objective 2

- Develop parameters for the Spruce Budworm Population disturbance extension for LANDIS-II that reproduce observed outbreak behaviors for the Border Lakes Landscape (BLL) of NE Minnesota and adjacent Ontario.
- Apply the above parameters to simulations of budworm outbreak dynamics in space and time using the forest conditions of northwestern Maine in 1973 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 1970s and 1980s.

Key Findings / Accomplishments

Objective 1

- 178 historic spruce-fir plot locations were digitized from hand-written records.
- Topo-climatic attributes and Landsat images were compiled and pre-processed for predictive modeling and mapping.
- We have extended the utility of the biased support vector machine (SVM; Liu et al. 2002) by embedding it within a multi-objective genetic algorithm (Deb et al. 2002) that generates multiple, alternative solutions with optimal classification performance at varying levels of class prevalence.
- Comparison of our multi-objective biased SVM algorithm with an analogous 2-class SVM algorithm has demonstrated that contemporary spruce-fir distributions can be predicted

with very similar accuracy (approx. 85% accuracy with mapped acreage matching reference acreage provided by USFS FIA field plot data).

Objective 2

- Initial population parameters have been developed to produce the range of critical outbreak behaviors observed within the Border Lakes region (Robert et al. 2012) parameters. (e.g., see Figure 9):
- Critical outbreak behaviors have been reproduced according to hypothesized relationships with hardwood content of the forest (Figure 1).
- Demonstrated realistic responses in terms of damage experienced by forests, and the consequent response of the forest via succession in LANDIS-II.
- Critical outbreak behaviors have been reproduced under spatialized modeling environments, where dispersal and Moran effects (Royama 1992) are simulated explicitly.

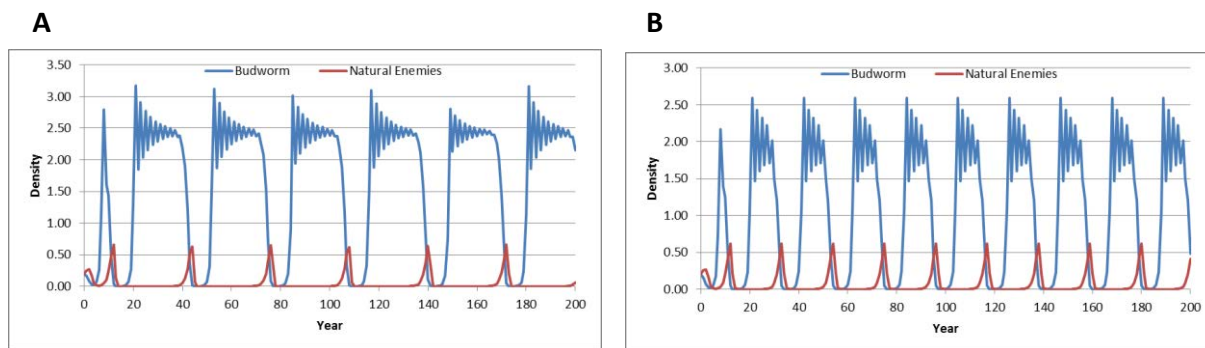


Figure 9 - Simulated spruce budworm population dynamics within A. pure host forest, versus B. mixed forest (0.6 host conifers and 0.4 nonhost hardwoods). Critical features include both high frequency (i.e., “sawtooth” at high density) and low frequency (i.e.,

Future Plans

Objective 1

- We will soon apply our new classification algorithm to the prediction of ca. 1985 spruce-fir distributions, and backdate derived maps to 1973 using available forest disturbance maps depicting spruce-fir salvage logging from 1973-1985.
- Backdated spruce-fir maps will be merged with available forest type maps (ca. 1975) to depict relevant host and non-host class distributions at the onset of the last outbreak.
- Compare and contrast our new multi-objective biased SVM algorithm with other one-class algorithms in common use (e.g., Support Vector Data Description, MaxEnt).

Objective 2

- Simulations of outbreak dynamics under the actual forest conditions of the Border Lakes region are now underway
- Complete strategic calibration of model parameters under “real world” conditions
- Move simulations to Maine pending reasonable parameterization of population dynamics for the Border Lakes region, and the initial conditions circa 1973 from Objective 1.

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

PI: Christian Kuehne, School of Forest Resources, UMaine

Co-PIs: Kasey Legaard and Aaron Weiskittel, University of Maine

Progress Report, Year 1 of 2

Summary

One year into this two-year project, we have made significant progress in the preparation and analysis of both field measurements and remote sensing data sources, needed for quantitative characterization of harvesting trends across a 10 million acre northern Maine study area. Given the sweeping changes in partial harvest practices that occurred in the early and mid-1990s, we are focusing our efforts on methods of harvest classification and characterization that can be consistently applied to both field measurements and the ~30 year Landsat image archive. We will soon complete initial analyses and primary mapping objectives, and are well positioned to pursue stand development projections during year 2. This will culminate in a new set of stand development trajectories and silvicultural pathways that better reflect predominant harvesting practices, and new spatial data products needed to better characterize the cumulative effects and projected impacts of the contemporary harvesting regime.

Project Objectives

- 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.
- Project the development of residual stands created from common classes of partial harvest using the new Acadian Variant of the Forest Vegetation Simulator.
- Evaluate short- and long-term projected shifts in species composition and forest structure induced by common classes of partial harvesting, and compare with FIA field measurements to improve projection model calibration.
- Develop a new set of stand development pathways representing current harvest practices and anticipated silvicultural outcomes by grouping projected stand conditions.
- Refine satellite-derived harvest maps to represent stand development pathways, and conduct a spatially explicit analysis of stand development trends associated with ~30 years of mapped harvest history.

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.
- We have considered various strategies for modifying the harvest classification system to capture greater detail in either silvicultural practices or residual stand characteristics, but have concluded that none are likely to support extension of plot-level analyses to Landsat-based mapping objectives. Because the sweeping changes in partial harvest practices that occurred in the early and mid-1990s lie within the window of Landsat observation but not that of the contemporary FIA program, we have elected to focus

our efforts on a harvest classification scheme that can be directly transposed onto the Landsat archive.

- 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.
- Inspection of available map data indicated several aspects of spatial error or uncertainty that could be improved upon, with significant potential benefit to project outcomes. We are specifically investigating methods to improve estimation along harvest boundaries, to reduce cloud- and haze-induced artifacts, and to refine methods of linking pre- and post-harvest image acquisitions with pre- and post-harvest FIA measurements. We have also implemented a new methodology for harvest mapping from Landsat image time series that explicitly controls error patterns in consecutive harvest maps to ensure consistent estimation and spatial representation of harvest area (i.e., unbiased estimation of harvest area).
- We have partially leveraged this project to obtain additional funding that will further support refinement of remote sensing, spatial modeling methods, and predictions of stand dynamics.

Improving Regional Growth and Yield Simulators and Decision-Support Systems for Large-Scale Pest Outbreaks

PI: Mohammad Bataineh, University of Arkansas at Monticello

Co-PIs: Aaron Weiskittel, Robert Seymour, Brain Roth, and Cen Chen, University of Maine; David MacLean, University of New Brunswick; Laura Kenefic, USFS Northern Research Station

Progress Report, Year 2 of 2

Summary:

Statistical models were built to investigate individual-tree and stand growth influenced by spruce budworm (SBW) defoliation using data collected in Maine and New Brunswick during the last SBW outbreak, aimed to improve regional growth and yield simulators and decision-support systems for large-scale pest outbreaks. The influence of defoliation was evaluated for various individual-tree and stand growth components and compared between the regions along with corresponding growth responses. Significant influence of defoliation was found on all growth components

investigated, largely dependent on species (composition) while less affected by site conditions. This influence was largest on mortality and height increment while moderate on stand net growth and diameter increment, and varied considerably within and between the regions with New Brunswick being less affected. It was also found that the influence of defoliation was generally smaller in scale comparing to those reported before. In addition, no noticeable effect of insecticide spraying was found.

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.
- 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.

Approach

- Derived information on individual-tree and stand growth, mortality, ingrowth, stand structure and composition, and SBW defoliation from data previously collected at 424 sample plots during 1975-1985 in Maine, USA and from 127 sample plots during 1986-1991 in New Brunswick, Canada.
- Compiled and related geographic, topographic, insecticide spraying, and site condition information to the above observed individual-tree and stand growth.
- Developed statistical models for various individual-tree and stand growth components under the influence of SBW defoliation.
- Evaluated the influence of SBW defoliation on the above growth components and compared differences in these influences as well as various growth responses between Maine and New Brunswick.

Key Findings / Accomplishments

- Large amount of variation existed in SBW defoliation and in various growth responses to defoliation within and between the two study regions with New Brunswick being generally less affected (Figure 10).
- These influences of defoliation were generally moderate, largely dependent on species (composition), and less affected by site conditions (Figure 11).
- Mortality and height increment were affected by defoliation at much larger scales than stand net growth and diameter increment (Figure 12).
- The effect of insecticide spraying in reducing the influence of defoliation was not detected from the data, and may require a thorough investigation in the future (Figure 13).

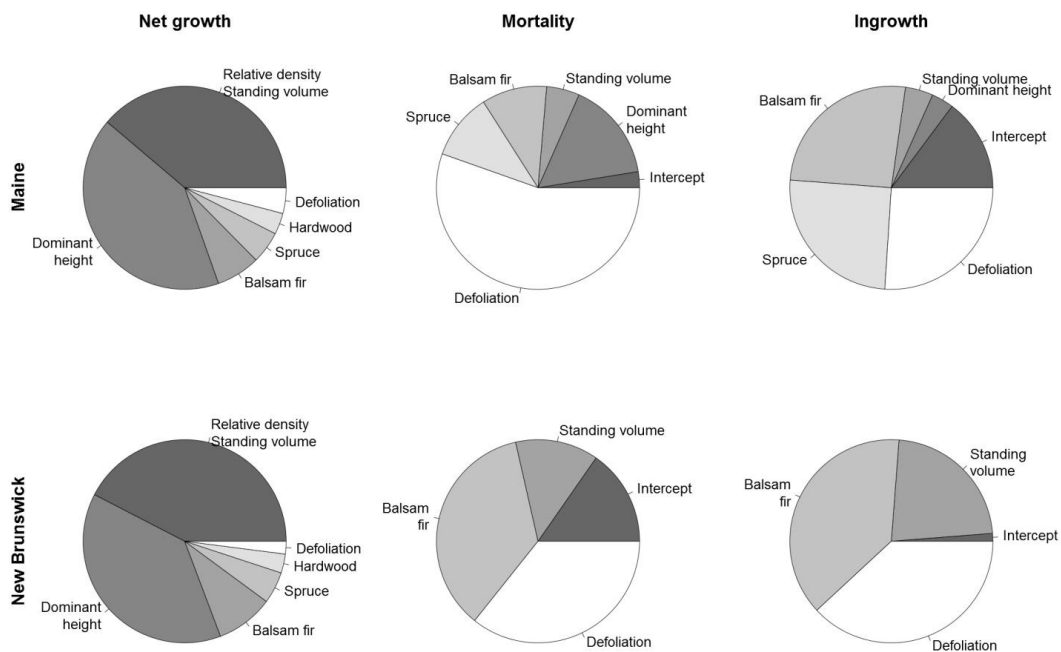


Figure 10 - Relative importance of various variables (at their mean values) on different stand growth components by region.

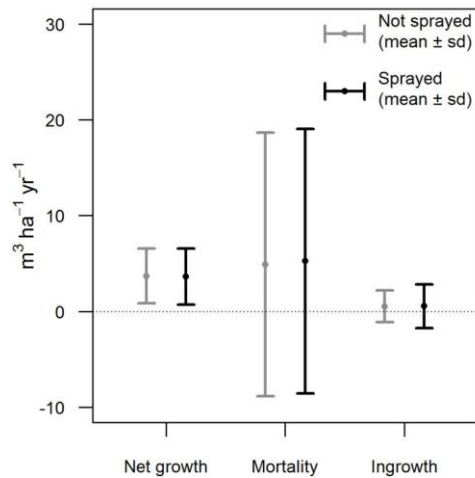


Figure 11 - Comparisons of the effects of spraying on different stand growth components in Maine.

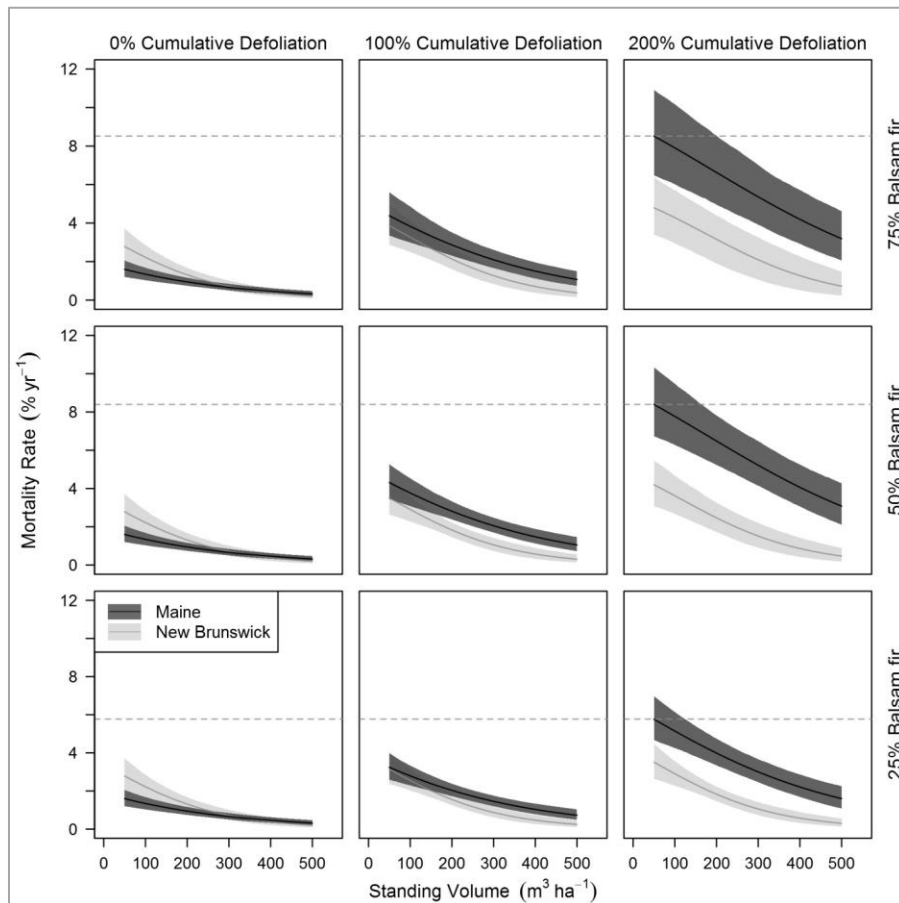


Figure 12 - Predictions of volume mortality rate (% yr⁻¹) as a function of standing volume (m³ ha⁻¹) under different levels of cumulative defoliation and balsam fir content by region. While 0% cumulative defoliation served as a reference of normal growth, 100% and 200% cumulative defoliation represented medium and high levels of defoliation, respectively, within the measurement periods. All the other covariates were set at their mean values. The observed mortality was closest to that shown in the lower-left graph. Dashed lines that pass the maxima of the curves in the third column from left are used to help show the differences in mortality rate under different levels of defoliation. The shaded areas are the 95% confidence interval of the predictions.

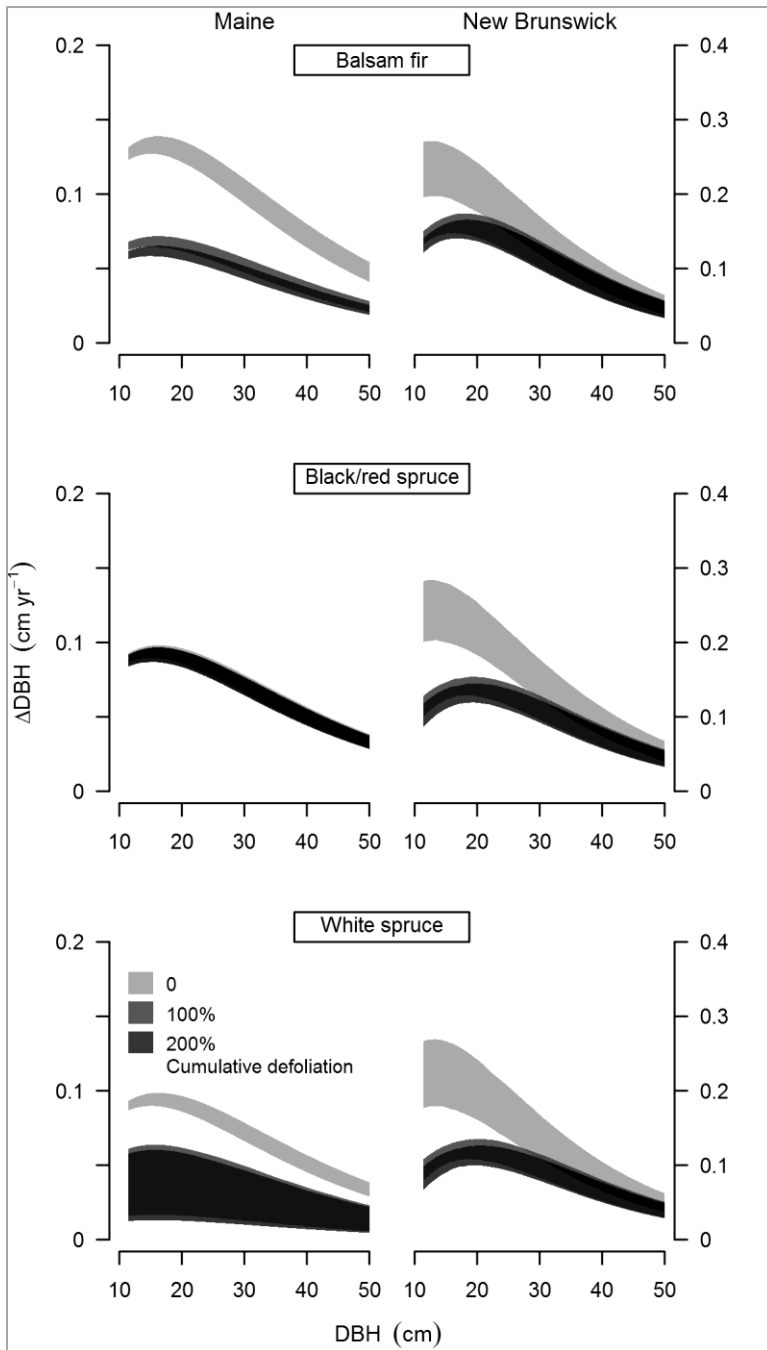


Figure 13 - Predictions of annual diameter increment (Δ DBH; cm yr^{-1}) as a function of initial DBH (cm) under 0, 100% (moderate), and 200% (severe) cumulative defoliation with all the other covariates set at their mean values by species for Maine and New Brunswick. Shaded areas represent 95% confidence intervals of these predictions.

Future Plans

- Design and conduct a rigorous experimental study to investigate the effectiveness of insecticide spraying on reducing the influence of SBW defoliation on forest growth.
- Build a relationship between defoliation data obtained through remote sensing and individual-tree defoliation.
- Design a sampling procedure better capturing the influences of stand structure and composition, management history, and site quality on growth responses to defoliation, as well as taking into consideration the dynamics of SBW population.

NSRC FINAL REPORT SUMMARIES

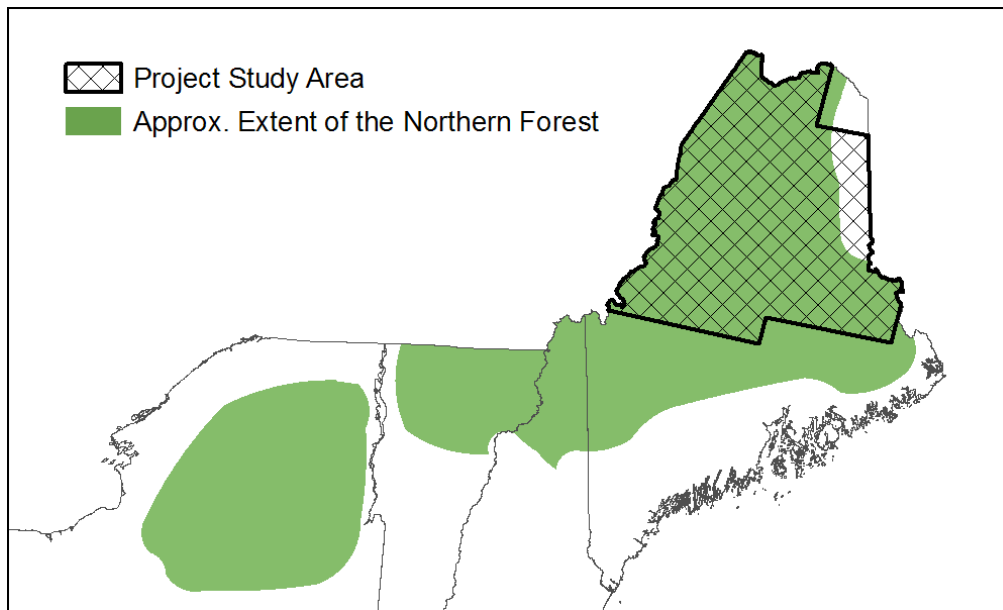
Future Distribution and Productivity of Spruce-Fir Forests under Climate Change

PI: Erin Simons-Legaard, University of Maine

Co-PIs: Anthony D'Amato, University of Vermont; Kasey Legaard, University of Maine; Brian Sturtevant, USFS Northern Research Station; Aaron Weiskittel, University of Maine

Summary

Already at its southern range limit, the ecologically- and economically-important eastern spruce-fir forests are expected to be highly susceptible to the negative effects of climate change. Predictions based on coarse-scale climate envelope models suggest that suitable climate conditions for balsam fir and spruce *sp.* will be eliminated throughout much of their current range in the U.S. Such predictions, however, necessarily overlook the influence of fine-scale variation in environmental conditions that may allow for local persistence and important interactions with other disturbance agents (e.g., land use). We used bioclimatic envelope models and a forest landscape model to improve understanding of how climate change will impact spruce-fir forest directly and indirectly. Within this framework, moderate resolution (30 meter) projections of species distributions and productivity under varying climate and simulations of future forest dynamics responding to different disturbance regimes (including climate change, timber harvesting, and spruce budworm) allowed for an evaluation of system sensitivity to disturbance, as well as identification of areas of potential climate refugia.



The study area encompassed approximately 10 million acres of commercial forestlands in Maine.

Major Findings

Selection of important variables in the bioclimatic models was similar for all species, indicating that areas which are snowier and colder in winter than average characterize suitable habitat for balsam fir and spruce *sp.* (black, red, and white). Maps based on projected climate change suggest that although suitable climate conditions will decline as a result of less snow and warmer winter temperatures, patches of suitability will remain in the Northeast ca. 2090 for all but white spruce. Forest landscape projections further suggest that without a significant increase in the “natural mortality” of mature fir and spruce trees due to climate change (e.g., via thermal stress), ecosystem resilience will likely ensure the distribution of spruce-fir forest in Maine remain largely unchanged over at least the next 50 years.

Implications for the Northern Forest Region

Coarse-scale climate envelope models may overstress the effects of climate change on spruce-fir forest in the Northeast over the next century. In our study, timber harvesting had a larger effect on future forest composition than climate change in Maine.

Evaluating and Predicting the Regional Effects of Silviculture and Site Factors on Established Regeneration in the Northern Conifer Forest

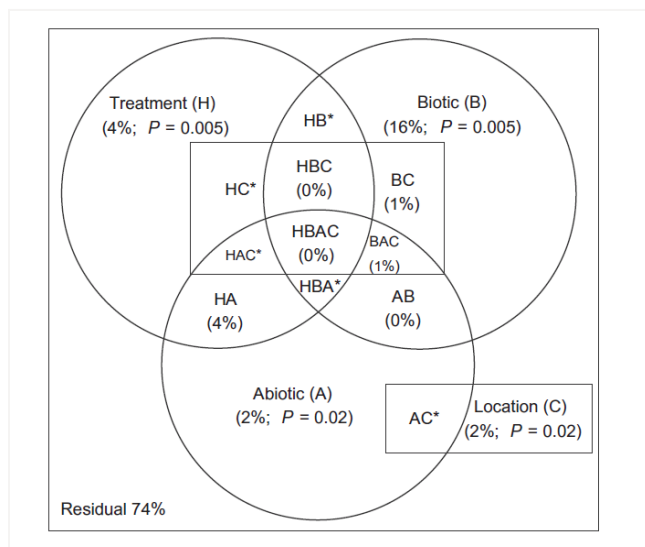
PI: Mohammad Bataineh, University of Arkansas

Co-PIs: Arun K. Bose, University of Maine; Aaron Weiskittel, University of Maine; Laura Kenefic, USFS Northern Research Station; Ben Rice, LandVest; Robert Seymour, University of Maine

Summary

Natural regeneration remains the dominant method for the development of new stands in the Northern Forest. This trend is expected to continue in the future in light of the growing prominence of partial harvesting. Limited understanding of how partial harvesting practices, and biotic and abiotic factors influence regeneration composition (species) and abundance (number of regeneration) restricts our ability to evaluate management alternatives and project future wood supply. The objectives of this project were to: 1) quantify the relation between overstory, site, and understory characteristics; 2) identify key factors and constraints associated with regeneration of desired species; and 3) develop predictive models that can be incorporated into the Acadian Variant of FVS. The objectives were evaluated both at the stand- and the landscape-level using the long-term measurement plots of Penobscot Experimental Forest and the US Forest Service Forest Inventory and Analysis dataset, respectively.

At the stand-level, the regeneration abundance was primarily associated with the local site factors, including overstory composition and soil attributes. Harvesting treatments were less influential in explaining the pattern of natural regeneration abundance and composition relative to biotic (e.g., overstory structure and composition) at the stand-level. Our results showed, mean annual temperature and overstory tree-size diversity were the most important abiotic and biotic variable, respectively to explain the abundance and composition of natural regeneration at the landscape-level. Our results indicate, the moderate growing condition and moderate overstory tree-size diversity incorporate higher number of species as well as higher number of regeneration than productive/poor growing conditions or uniform/highly diverse overstory. Our models are ready to incorporate into the Acadian Variant of FVS. The overall results suggest low intensity partial harvesting will not be enough to change the regeneration composition (e.g., balsam fir to red spruce or American beech to sugar maple). Site preparation treatments including soil scarification, controlling browsing pressure, and controlling the regeneration of aggressive species (e.g., American beech) are necessary.



Venn diagram of regeneration composition and abundance variance partitioning among treatment (H), biotic (B), abiotic (A), and location (C) predictor matrices. Treatment, biotic, abiotic, and location matrices contained 3, 6, 5, and 2 factors, respectively. Starred values are <math><0.05</math>.

Implications and Applications in the Northern Forest Region

- Our results of both the stand- and the landscape-level analysis showed that relative to harvesting treatments, biotic (e.g., overstory structure and composition) and abiotic factors (e.g., temperature, soil attributes) were more influential in explaining the pattern of natural regeneration at both stand- and landscape-scale.
- Low intensity partial harvesting will not be enough to change the regeneration composition (e.g., balsam fir to red spruce or American beech to sugar maple). Site preparation treatments including soil scarification, controlling browsing pressure, and controlling the regeneration of aggressive species (e.g., American beech) is necessary.

Analysis of Wood Resource Availability in the Northeastern United States

PI: Jennifer Hushaw, Innovative Natural Resource Solutions, LLC

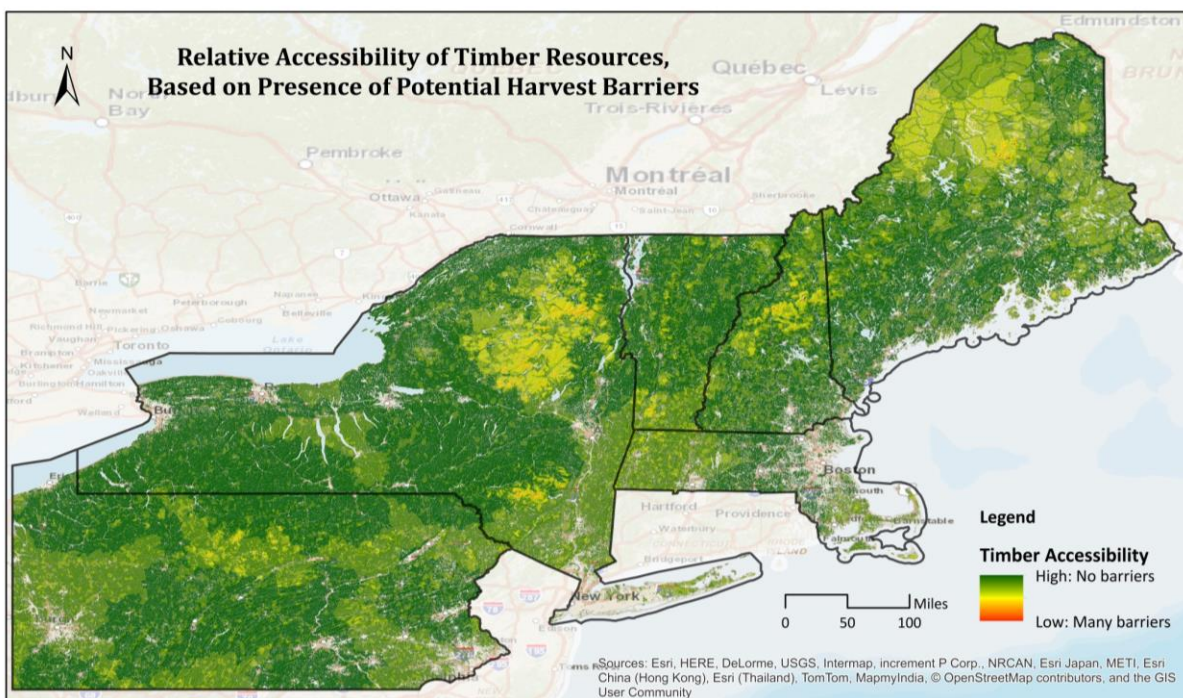
Co-PI: Mark Ducey, University of New Hampshire

Summary

Forests are an important part of the cultural and economic fabric of the Northern Forest region, but new demand for wood-use within the renewable energy sector has raised concerns about sustainability of the forest resource. Accurate estimates of available wood supply are a critical

starting point for decision-making and evaluations of forest sustainability. However, decision-makers do not have reliable and consistent estimates of wood supply in the Northeast because research studies vary in scope, scale, and methodology. In particular, the Northeast lacks region-wide, consistent datasets that quantify accessibility of wood supply in terms of environmental, legal, social, or logistical constraints to harvesting.

NSRC researchers will fill this data gap by creating new datasets and synthesizing other data sources into a centrally located series of datasets that quantify various factors contributing to the likelihood of harvesting in a given area, such as distance from roads, stream buffers, small parcel size, and existing harvest demand. In addition, researchers will create comprehensive documentation and spatial analysis tools that will allow the generated datasets to be updated easily in the future.



Data will be made publically available online and will be integrated into an existing wood supply modeling tool. These datasets will improve accuracy of wood supply analysis in the region and increase utility of wood supply assessment tools that require these types of user inputs. Ultimately, these data will provide policy-makers, researchers, forest managers, and the general public with information they need to assess the realistic capacity of the forest resource and to make informed decisions regarding sustainable use of our forests.

Examining the Influence of Spatial Structure on Forest Growth and Stand Dynamics

PI: Aaron Weiskittel, University of Maine

Co-PIs: Christian Kuehne, University of Maine; Shawn Fraver, University of Maine

Summary

Using a series of regional, comprehensive, multi-year, replicated, and fully stem mapped commercial thinning studies of the spruce-fir (*Picea-Abies*) forests of the Acadian Region we examined the effect of various thinning treatments on forest structure, how overall stand and individual-tree growth correlate with changes in forest structure, and the influence of distance from the forwarder trails on individual-tree growth.

Major Findings

- Irrespective of the method, thinning mostly reduced stand structural heterogeneity compared to the non-thinned control which was at least partly attributable to increased post-treatment mortality rates.
- The spatial arrangement of trees changed from fully random (control) to a more clustered (dominant) or regular distribution (low thinning) while thinning-induced changes in forest structure were often reflected in tree size diversity.
- Overall stand growth exhibited varying trends across the treatments and in the course of the study with increasing (control, low thinning) or decreasing growth dominance of large trees (crown thinning).
- Forwarder trails added another important structural element to the thinned stands and increased basal area growth of individual trees up to a trail distance of approximately 5 m.

Implications for the Northern Forest Region

- Commercial thinning can substantially alter within-stand dynamics and these alterations may vary with thinning method and intensity.
- Medium-aged suppressed and intermediate balsam fir and red spruce trees released in the dominant thinning treatments proved to be highly responsive.

Extending the Acadian Variant of the Forest Vegetation Simulator to Managed Stands

PI: Jeremy Wilson, Harris Center for Conservation Education

Co-PI: Aaron R. Weiskittel, University of Maine; Chris Hennigar, University of New Brunswick

Summary

Using a series of regional, comprehensive, multi-year, and replicated commercial thinning studies of the spruce-fir (*Picea-Abies*) forests of the Acadian Region to develop annual thinning response modifiers for stand-level basal area growth, dominant height increment, and mortality; establish annual and species-specific thinning response modifiers for individual-tree diameter, height, and height to crown base increment as well as mortality; and evaluate predictions of commercial thinning response across a range of treatments using both the stand- and individual tree-level modifiers

Major Findings

- Stand-level thinning treatment response functions for spruce-fir stands were shown to significantly improve predictions of annual stand-level basal area growth and mortality.
- Additional improvement was demonstrated for species-specific, individual tree-level annual diameter increment, height to crown base increment, and mortality functions.
- When the developed thinning modifiers were included in stand- and individual-tree growth models, a significant improvement in prediction over baseline models was achieved, yet the individual-tree approach was superior for predicting long-term response to various thinning treatments.

Implications for the Northern Forest Region

- Derived individual tree thinning response functions were implemented in the Acadian Variant of FSV and are ready-to-use.
- Additional testing of the developed growth modifiers also showed improved growth model prediction accuracy after pre-commercial thinning.

Influence of Commercial Thinning on Resistance to and Recovery from Defoliation in Spruce-Fir Forests

PI: Michael E. Day, University of Maine

Co-PI: C.J. Langlely, University of Maine

Summary

Eastern spruce budworm has plagued spruce-fir ecosystems for centuries, causing widespread defoliation, loss of productivity and mortality. To manage this type of stress trees have developed two strategies, tolerance and defense, and survival depends on the appropriate balance between these two strategies. A tree's capacity for recovery after consecutive years of defoliation typical of spruce budworm outbreak is linked to the pool of nonstructural carbohydrates available to stimulate growth of latent buds and recover leaf area. While commercial thinning treatments have the potential to increase NSC pools, studies during past outbreaks have shown that thinning has a complicated effect on outbreak severity and duration. Secondary defensive compounds, such as soluble phenolics may provide resistance to defoliation caused by the spruce budworm and other herbivores. This study evaluates the eco-physiological responses of red spruce) and balsam fir to stand-level thinning and artificial defoliation treatments across three experimental locations throughout the state of Maine. In contrast to carbohydrate allocation theory, the results of this study suggest that stand level thinning treatments lower the NSC available to both species. This could leave trees within thinned stands vulnerable during an outbreak. The production of secondary defensive compounds was not found to be affected by the artificial defoliation treatment.

Interestingly, balsam fir was found to maintain higher concentrations of nonstructural



Defoliation damage during the 1980s spruce budworm outbreak. (Photo courtesy Maine Forest Service)

carbohydrates and tannic acid equivalence than red spruce. The results reported in this study should mean that balsam fir is better adapted to withstand defoliation caused by the spruce budworm, however this is not the trend that has been reported historically when defoliation and mortality of the species are compared.

Implications for the Northern Forest Region

- Commercial thinning shifts carbon allocation patterns from storage reserves to growth in both red spruce and balsam fir, decreasing their ability to produce new foliage and increasing their susceptibility to mortality and loss of productivity in spruce budworm outbreaks.
- Defoliation does not enhance resistance to defoliators by increasing phenolic content of needles in either species

Future Directions

While this study suggests that commercial thinning increases the susceptibility to damage from spruce budworm in red spruce and balsam fir, the design and available sites did not permit evaluation of effects due to thinning intensity and time since treatment. Other possible herbivore defense mechanisms, both constitutive and induced, should be evaluated.

A Long-Term Monitoring Program to Assess the Northern Forests Logging Industry Health

PI: Jeffrey G. Benjamin, University of Maine

Summary

The forest resources industry is an integral part of the economy, ecology, and culture of the Northern Forest region of New York, Vermont, New Hampshire, and Maine. The forest products manufacturing industry provides over 92,000 jobs and \$14.4 billion to the region (NEFA 2007). The logging sector of the forest resources industry provides significant employment to rural communities in addition to harvesting and transporting this valuable and renewable resource to processing facilities. Despite the importance of the logging sector, there have been relatively few studies in recent years that focus on logging businesses, and as noted by Egan et al. (2006), there are many hidden costs in timber harvesting and barriers to production. A labor shortage and an aging workforce have been projected for the logging industry, and numerous studies have been conducted to address recruitment (Pan Atlantic/Ireland Group 1999, Egan & Taggart 2004, Egan 2005, Egan 2009). Based on a survey of logging business owners across the states of the Northern Forest, this report will describe business attributes and harvest operation details with an emphasis on existing logging infrastructure. This study is a baseline for future, periodic surveys that can be used to analyze trends in the logging industry, and a tool for logging contractors, policy makers, or professional organizations to identify areas for improvement in forest operations.

Implications for the Northern Forest Region

Business Attributes and Business Owner Demographics

- Logging businesses tend to be small companies and the business owners tend to be in a mature demographic. Across all states in this study 86% of logging businesses had five or fewer employees, 60% of business owners were greater than 50 years old, and over 50% of business owners have been in the logging industry for at least 30 years.
- Approximately 40% of business owners entered the industry without any familial attachment to logging and 20% of logging businesses were established since 2000.
- Business owners have a strong desire for independence and they enjoy their work, although many cited significant challenges associated with managing people and making a living in the logging industry. They judged their performance by their reputation in the industry, the quality of their work, and satisfaction of their clients.

Harvest Production and Capacity

- Tree-length harvest systems (chainsaw, cable skidder) are the most common system throughout the region in terms of frequency, but they rank last in total production.
- Production by harvest system is not uniform across the region. For example, 77% of production in Maine is by whole-tree systems compared to only 12% in New York.

Harvest Production and Capacity

- Average weekly production, in tons, was found to be significantly different among all three harvest methods (Tree- Length <100, Cut-to-Length >250, Whole-Tree >300) across all four states.
- Weather conditions were overwhelmingly cited as the most important limitation to achieving maximum production across all states and all business sizes. There was close agreement in regard to other top-rated limitations such as market price, mechanical breakdowns, road conditions, and mill closures and quotas.

Equipment Infrastructure

- Some logging businesses have made significant capital investments in new logging equipment, but on average harvesting machines have close to 7,000 hours and primary transportation equipment have over 10,000 hours.
- Using an optimistic estimate of 2,000 productive hours per year, it is clear this means that a lot of equipment in the industry is at least four to five years old.
- Repair and maintenance costs for logging equipment are highly variable and they are a function of more than simply machine hours.



Biomass pile from clear cut harvest block cut by feller-buncher. (Photo courtesy of Jeff Benjamin)



HOWLAND RESEARCH FOREST

The CRSF is home to the Howland Research Forest. The Howland Forest is a continuously operating forest ecosystem research site established in 1986 by University of Maine researchers with the cooperation of International Paper. 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 micrometeorological 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.



**Publications and
Presentations**

CRSF scientists disseminated results from their research in a wide variety of ways this year. They delivered 8 journal publications, 17 research reports, and 3 theses. In addition, they participated in 2 conferences and 38 presentations (including posters, field tours, media presentations, and workshops).

Refereed Journal Publications

Bose, A. K., Weiskittel, A., Wagner, R. G., & Kuehne, C. 2016. Assessing the factors influencing natural regeneration patterns in the diverse, multi-cohort, and managed forests of Maine, USA. *Journal of Vegetation Science*, 27, 1140-1150.

De Urioste-Stone, S. M., Le, L., Scaccia, M., & Wilkins, E. 2016. Nature-based tourism and climate change risk: Visitors' perceptions in Mount Desert Island, Maine. *Journal of Outdoor Recreation and Tourism*. doi: 10.1016/j.jort.2016.01.003

Kuehne C., Weiskittel A. R., Fraver S., & Puettmann, K. J. 2015. Effects of thinning induced changes in structural heterogeneity on stand growth, ingrowth, and mortality in secondary Douglas-fir forests. *Canadian Journal of Forest Research*, 45, 1448-1461.

De Urioste-Stone, S. M., Scaccia, M., & Howe-Poteet, D. 2015. Exploring visitor perceptions of the influence of climate change on tourism at Acadia National Park, Maine. *Journal of Outdoor Recreation and Tourism*, 11, 34-43. doi: dx.doi.org/10.1016/j.jort.2015.07.001

Fefer, J., De Urioste-Stone, S. M., Daigle, J., & Silka, L. 2016. Using the Delphi technique to identify key elements for effective and sustainable visitor use planning frameworks. *Sage Open*. doi: 10.1177/2158244016643141.

Kuehne C., Weiskittel A. R., Wagner R. G., & Roth, B. E. 2016. Development and evaluation of individual tree- and stand-level approaches for predicting spruce-fir response to commercial thinning in Maine, USA. *Forest Ecology and Management*, 37, 84-95.

Scaccia, M. D., & De Urioste-Stone, S. M. 2016. Resident perceptions of sustainable tourism in Maine. *International Journal of Sustainable Development and Planning*, 11, 375-384. doi: 10.2495/SDP-V11-N3-375-384

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- Bunn, C., Cumming, J., Goplerud, E., Horne, L., Howe-Poteet, D., Mauricette, I., Marsh, S., Moore, J., Zhlke, J., & De Urioste-Stone, S. M. 2016. Sustainable tourism strategic plan: Collaboration, management and marketing in Western Maine. Technical report submitted to Northern Forest Center, Bethel Chamber of Commerce, Maine West, and Western Maine Economic Development Council.
- De Urioste-Stone, S. M. 2016. Assessing community resilience and quality of place. Summary Report. Margaret Chase Smith Policy Center. 2pp.
- De Urioste-Stone, S. M. 2016. Economic impact of nature-based tourism in Maine. Technical report submitted to University of Maine Office of the President. 35pp.
- De Urioste-Stone, S. M. 2016. Economic impact of forest-based recreation in Maine. Technical report submitted to University of Maine Office of the President and the Forest Council of Maine. 26pp.
- De Urioste-Stone, S. M. 2016. Economic contributions of Acadia National Parks visitors. Technical report submitted to Acadia National Park. 8pp.
- De Urioste-Stone, S. M. 2015. Resilience of the nature-based tourism to climate change in Maine. Technical Report. ADVANCE-RISING TIDE.
- De Urioste-Stone, S. M. 2015. Resilience of rural Maine communities to climate change: A pilot study of the nature-based tourism industry. Pre-tenure Research and Creative Activity Fellowship Program. Annual Report. Vice-President for Research. 7pp.
- De Urioste-Stone, S. M., Gabe, T. & Noblet, C. 2015. Progress report on visitor spending and visitation in Maine. Submitted to: University of Maine Office of the President.
- Kuehne C., Weiskittel A., Wagner R., & Roth, B. 2016. Development and evaluation of stand and individual tree-level growth and mortality modifiers for thinned spruce-fir (*Picea-Abies*) forests of the Acadian Region. In B. E. Roth (Ed.), Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME. p. 21-23.
- Weiskittel A., Hennigar, C., & Kershaw, J. 2015. Extending the Acadian variant of FVS to managed stands. In R. G. Wagner (Ed.), Cooperative Forestry Research Unit: 2014 Annual Report. University of Maine. Orono, ME. 94 p.
- Wilkins, E., Morgan, A., & De Urioste-Stone, S. M. 2016. Katahdin visitor characteristics, travel behavior, and perceptions of tourism. Annual report. Baxter State Park. 14pp.
- Wilkins, E., Morgan, A., & De Urioste-Stone, S. M. 2016. Acadia National Park research summary report: Visitor characteristics and perceptions of the impact of weather and climate change on tourism. Annual report. Acadia National Park. 18pp.

Wilkins, E., Morgan, A., & De Urioste-Stone, S. M. 2016. Maine Visitors' Centers research summary report: Visitor characteristics, travel behavior, and perceptions of the impact of weather and climate change on tourism. Annual report. Maine Tourism Association. 16pp.

Wilkins, E., Morgan, A., & De Urioste-Stone, S. M. 2016. Bangor International Airport research summary report: Visitor characteristics, travel behavior, and perceptions of tourism. Annual report. Bangor International Airport.

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Wilkins, E., Morgan, A., & De Urioste-Stone, S. M. 2016. Bethel Chamber of Commerce research summary report: Visitor characteristics, travel behavior, and perceptions of the impacts of climate change on tourism. Annual report. Bethel Chamber of Commerce.

Wilkins, E., Morgan, A., & De Urioste-Stone, S. M. 2016. Katahdin visitor characteristics, travel behavior, and perceptions of tourism. Annual report. Baxter State Park. 14pp

Theses

Andrews, C. 2015. Modeling and Forecasting the influence of current and future climate on eastern North American spruce-fir (*Picea-Abies*) forests. M.S. Thesis, University of Maine, Orono.

Carter, D. 2015. Survival and Growth Of Reserve Trees in an Expanding-Gap Silvicultural System 20 Years After Establishment. MS Thesis, University of Maine School, Orono. 132 p.

Langley, C. J. 2016. Influence of Commercial Thinning on Resistance to and Recovery from Defoliation in Spruce-Fir Forests. M.S. Thesis, University of Maine, Orono.

Conferences

Bose, A. K., Weiskittel, A., & Wagner, R. G. 2016. Climate driven landscape-level changes in key hardwood species occurrence and abundance over the last three decades in forests of Northeastern USA. ECANUSA, University of Vermont, Burlington, VT.

Bose, A. K., Weiskittel, A., Wagner, R. G., & Kuehne, C. 2015. Predicting regional patterns in natural regeneration. Northeastern Mensurationists Organization Annual Meeting, Burlington, VT.

Presentations / Workshops / Meetings / Field Tours

- Castle, M., & Weiskittel A. R. Nov. 2015. Influence of stem form and damage on product potential, growth, and mortality for northern commercial hardwood species. Presentation to the Northeastern Mensuration Meeting, Stowe, VT.
- Castle, M., & Weiskittel, A. R. 2016. Evaluating the influence of stem form and vigor on volume, product potential and growth for northern commercial hardwood species. Presentation, Wood QC 2016: Modelling wood quality, supply, and value chain networks, Quebec City, Quebec, Canada.
- Catanzaro, P., Zimmer, R., Markowski-Lindsay, M., Allred, S., Sissock, M., & Leahy, J. 2015. Understanding and informing family forest owner decisions of land transfer. Society of American Foresters National Convention, November, Baton Rouge, LA.
- Chen, C. 2015. Assessing and modeling the influence of spruce budworm on forest stand dynamics in Maine, USA and New Brunswick, Canada. Northeastern Mensurationist Organization annual meeting, November, Stowe, VT.
- Day, M. E., & Langley, C. J. Oct. 2015. Influence of commercial thinning on recovery from defoliation in spruce-fir forests. Cooperative Forest Research Unit Fall Field Tour, Irving Woodlands T6R6 WELS, ME.
- De Urioste-Stone, S. M. 2015. Nature-based tourism and climate change risk: Assessing visitor perceptions at Acadia National Park, Maine. Acadia Science Symposium, October 7, Winter Harbor, ME.
- De Urioste-Stone, S. M. 2015. Promoting sustainable tourism in Maine: A research strategy. Maine Woods Consortium, September 22, Bangor, ME.
- De Urioste-Stone, S. M., Dixon, D., Isenhour, C., Klein, S., McGreavy, B., & Sullivan, C. 2015. Where service learning meets sustainability: Connecting classrooms with communities for stewardship and civic engagement. Mitchell Center Seminar Series, October 26, Orono, ME.
- De Urioste-Stone, S. M., & Scaccia, M. 2015. Stakeholder perceptions of nature-based tourism and climate change in Maine. International Union of Forest Research Organizations Annual Conference, October, Salt Lake City, UT.
- De Urioste-Stone, S. M., Le, L., Wilkins, E., & Scaccia, M. 2015. Climate change risk: Perceptions of visitors to Acadia National Park, Maine. International Congress on Coastal and Marine Tourism, November 10–13, Hawai'i.
- De Urioste-Stone, S. M., Scaccia, M., Daigle, J., & Anderson, M. May 2016. Resident perceptions of sustainable tourism in Maine. Abstract submitted to 7th International Conference on Sustainable Tourism, Valencia, Spain.

- De Urioste-Stone, S .M., Wilkins, E., & Scaccia, M. 2015. Climate change vulnerability and risk perceptions: Views from visitors to Acadia National Park". SAF National Convention, November 3-7, Baton Rouge, LA.
- Frank, J., & Weiskittel, A. R. 2015. Advancing individual tree biomass prediction: assessment and alternatives to the component ratio method. Presentation at the Northeastern Mensuration Meeting, November, Stowe, VT.
- Frank, J., & Weiskittel, A. R. 2016. Combining measures of standing hardwood tree form with existing data to improve estimates of internal wood properties across the Acadian Region. Presentation, Wood QC 2016: Modelling wood quality, supply, and value chain networks, Quebec City, Quebec, Canada.
- Hennigar, C. 2015. Design and performance of an Acadian forest site productivity index. Canadian Woodlands Forum, October, Fredericton, New Brunswick.
- Kuehne C., Weiskittel A. R., Pommerening A., & Wagner R. G. 2016. Temporal and spatial variability in stand structure and individual-tree growth for 10 years following commercial thinning in spruce-fir forests of northern Maine. Western Mensurationists Annual Meeting, Stevenson, WA.
- Kuehne C., Weiskittel A., & Wagner, R. 2015. Growth and mortality modifiers for thinned spruce-fir stands of the Acadian Forest. 2015 Northeastern Mensurationists Organization (NEMO) Annual Meeting, Stowe VT.
- Langley, C. J., Day, M. E., & Roth, B. Oct. 2016. Capacity for recovery, influence of commercial thinning and resistance to defoliation in spruce-fir forests. Accepted oral presentation for the ECANUSA Forest Science Conference, Burlington, VT.
- Langley, C. J., & Day, M. E. 2016. Capacity for recovery, influence of commercial thinning and resistance to defoliation in spruce-fir forests. Oral presentation. Annual Winter Meeting of the New England Society of American Foresters, March, Sturbridge, MA.
- Langley, C. J., & Day, M. E. 2015. Capacity for recovery from defoliation in commercially thinned spruce-fir forests. Acadia Science Symposium. Schoodic Institute, October, Winter Harbor, ME.
- Lilieholm, R. J. 2015. Measuring willingness to adopt conservation-oriented behaviors in buffer zone communities surrounding Chitwan National Park, Nepal. Poster presentation, Society of American Foresters Annual Convention, Salt Lake City, UT and Society for Human Ecology Annual Meeting, October, Bar Harbor, ME.
- Lilieholm, R. J., Cronan, C., & Weil, K. 2015. Effects of watershed characteristics on stream vulnerability to degradation: Implications for the future of streams in Maine, USA. Society for Human Ecology Annual Meeting, October, Bar Harbor, ME.
- Le, L., De Urioste-Stone, S. M., & Holmes, N. 2016. Exploring meanings of heritage site: A case study of George Washington Carver National Monument. 28th Annual Ethnographic and Qualitative Research Conference, February 1-2, Las Vegas, NV.

- Muñoz, B. 2016. Stand structure, composition, and carbon stock 50 years after whole-tree and stem-only harvesting in a northern mixedwood forest. Field tour for ADS, PL, and University of Maine collaborators, Penobscot Experimental Forest, May, Bradley, ME.
- Rolek, B. W., Loftin, C., Harrison, D., & Wood, P. 2015. Effects of Forest Management on Avian Abundance in Spruce-fir Forests of New England. Joint Meeting of the Canadian Ornithological Society, Association of Field Ornithologists, and Wilson Ornithological Society, July, Wolfville, CA.
- Rolek, B. W., Loftin, C., Harrison, D., & Wood, P. 2015. Methods, Data, Analysis, and Future Directions of the Northern New England Forest Birds Project. Workshop, USFWS Migratory Bird Division, October, Hadley, MA.
- Scaccia, M., De Urioste-Stone, S. M., & Wilkins, E. 2015. The future of destination selection in a changing climate: Implications for visitation to Acadia National Park, Maine. Acadia Science Symposium, October 7, Winter Harbor, ME.
- Schlager, E., & De Urioste-Stone, S. M. Resident perceptions of community resilience in the Penobscot River Watershed, Maine. Abstract submitted to 22nd International Symposium on Society and Natural Resource Management (ISSRM): Transitions, towards sustainable relationship in a different world, June 22–26, Houghton, MI.
- Seymour, R. 2016. Exploring silvicultural strategies in our changing forests II – Acadian spruce-fir. Invited Webinar, February, Univ. of Vermont, Burlington, VT (host).
- Simons-Legaard, E., Legaard, K., & Weiskittel. 2015. Predicting forest aboveground biomass in diverse landscapes: A global sensitivity analysis of the LANDIS-II model. 9th International Association of Landscape Ecology World Congress, July, Portland, OR.
- Sturtevant, B. R., Miranda, B. R., & Cooke, B. J. 2015. Modeling insect outbreaks as emergent consequences of forest condition and climate. [Abstract]. In 9th IALE World Congress, July, Portland OR.
- Sturtevant, B. R., Robert, L.-E., James, P.M.A., Cooke, B. J., Fortin, M.-J., Townsend, P. A., Wolter, P. T., & Kneeshaw, D. 2016. Landscape structure damps and desynchronizes cyclic outbreak behavior in spruce budworm. Heart of the Continent Partnership, 1st Science Symposium, March, International Falls, MN.
- Wagner, R. G. 2015. The coming spruce budworm outbreak: Are we prepared? The Forest Society of Maine, Director's Circle Luncheon, September, Brunswick, ME.
- Wagner, R. G. 2015. Results from commercial thinning and vegetation management research. CFRU forestry field tour for Seven Islands Land Company Forestry Staff, Bingham, ME.
- Wilkins, E., De Urioste-Stone, S. M., Weiskittel, A., & Gabe, T. 2016. The effects of changing weather on Maine's nature-based tourism industry. Abstract submitted to 22nd International Symposium on Society and Natural Resource Management (ISSRM): Transitions, towards sustainable relationship in a different world, June 22–26, Houghton, MI.

- Wilkins, E., De Urioste-Stone, S. M., Weiskittel, A., & Gabe, T. 2016. The impact of weather and climate change on nature-based tourism: A segmentation analysis of tourist groups to Maine, USA. Abstract submitted to 22nd International Symposium on Society and Natural Resource Management (ISSRM): Transitions, towards sustainable relationship in a different world, June 22–26, Houghton, MI.
- Wilkins, E., De Urioste-Stone, S. M., Weiskittel, A., & Gabe, T. 2015. The effects of past weather and a changing climate on nature-based tourism on Mount Desert Island, Maine. International Congress on Coastal and Marine Tourism, November 10–13, Hawai'i.
- Wilkins, E., De Urioste-Stone, S. M., Weiskittel, A., Horne, L., Cooper, A., Scaccia, M., & Gabe, T. 2015. The effects of changing weather: Impacts on tourism-related spending on Mount Desert Island, Maine. Acadia Science Symposium, October 7, Winter Harbor, Maine.