1865 THE UNIVERSITY OF MAINE

Cooperative Forestry Research Unit

2019 Annual Report

Cooperative Forestry Research Unit
CFRU

Cooperative Forestry Research Unit
2019 Annual Report

Edited by Samantha M. Anderson & Meg Fergusson

About the CFRU

Founded in 1975, the CFRU is one of the oldest industry/university forest research cooperatives in the United States. We are composed of 32 member organizations including private and public forest landowners, wood processors, conservation organizations, and other private contributors. Research by the CFRU seeks to solve the most important problems facing the managers of Maine's forests. The CFRU is a core research program of the Center for Research on Sustainable Forests at the University of Maine.

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Cover illustration: Biomass Growth Index map for Maine and New Brunswick, courtesy Rahimzadeh-Bajgiran, P., Weiskittel, A., & Hennigar, C. Section photos provided by project scientists and are credited within reports.

The CFRU is an applied scientific research organization. As scientists, we favor metric units (e.g., cubic meters, hectares) in our research; however, the nature of our natural resources business frequently dictates the use of traditional North American forest mensuration English units (e.g., cubic feet, cords, acres). We use both metric and English units in this report. Please consult any of the conversion tables that are available on the internet if you need assistance.

Cooperative Forestry Research Unit
A Core Program of the Center for Research on Sustainable Forests
5755 Nutting Hall, Rm 263
Orono, Maine 04469-5755
umaine.edu/cfru

CFRU Highlights

- The CFRU engaged thirty-three members representing 8.15 million acres of Maine's forestland this year. CFRU members contributed $541,465 to support research activities during Fiscal Year 2019-20.
- Nearly 40 members attended the fall field tour visiting four sites in Kibby Township on Weyerhaeuser forestland. Topics and sight visits covered the latest CFRU research at the interface of forestry and wildlife habitat.
- CAFS funding supported two projects led by University of Maine researchers (Understanding and Modeling Competition Effects on Tree Growth and Stand Development Across Varying Forest Types and Management Intensities and Modeling the Influence of Spruce Budworm on Forest Productivity).
- Three students were awarded funding grants from the Center for Undergraduate Research to work on CFRU projects this year.

Silviculture & Productivity

- Both seedlings (sexual reproduction from seed) and layers (asexual reproduction from branches that root to the ground) are common in white-cedar-dominated lowlands. Co-PI Wason determined that mode of white-cedar regeneration can be identified by microscopic examination of cross sections from excavated regeneration.

- Though few if any direct effects of soils were found on winter harvesting productivity and costs for a white cedar stand at the PEF, tree species composition was an influential factor and is itself related to soils.

- Weymouth Point Study: The long-term impacts of whole-tree harvesting has been completed; results may inform development sustainable forest management standards in northern New England.

- The evaluation of timber harvesting operations on soil revealed that the cost of BMP implementation was directly influenced by extant and the severity of the sensitive zone within the harvest zone, and less impacted by the skidding distance. BMP implementation can be incorporated into a mainstream harvesting operation without much affecting the economic feasibility.

- Data analyses of our fieldwork for quantifying the long-term ecological outcomes and in alternative riparian buffer designs is being finalized, but initial results indicate that ecological communities reflect a legacy of riparian management approaches 17 years after initial harvest occurred.

Growth & Yield Modeling

- In 2018 and 2019 (before and after timber harvesting), soils were collected in northern hardwood stands. The study areas support a diverse range of species including sugar maple, red maple, yellow birch, American beech, spruces, and balsam fir. The forest management practices that will evaluated for their influence on soils include irregular shelterwood cutting, crop tree release, partial harvesting, and control (no cutting in 2018).
- Data from repeat measurements of crop trees on the Penobscot Experimental Forest Rehabilitation Study and the SI Comp experiment are being analyzed. The measurements and findings from both studies will be used to develop tree growth and yield models for early successional hardwood and mixed-wood stands.
- 21 variables including 9 single spectral bands and 12 spectral vegetation indices (SVIs) with combination of other variables were used to predict tree volume/ha (GTV) and tree height. The results showed a 10–12% increase in out of bag r2 when Sentinel-2 variables were included in the prediction of total volume in combination with Biomass Growth Index (BGI).
- A comprehensive, flexible and efficient workflow was developed for building, applying and evaluating enhanced forest inventory prediction maps using an area-based approach.
- LiDAR-based flow-channel, depression and wet-areas mapping initiative were presented at a series of meetings and workshops to inform how geomorphic features such as flow channels, depressions, cartographic depth-to-water and related seasonal variations can be emulated based on digital elevation models.

Wildlife Habitat

- Ground telemetry efforts in 2018 and 2019 yielded 964 American marten locations, contributing to an overall dataset of 7,009 telemetry locations on 153 resident marten. Future work will integrate these data with a time series of habitat data developed from satellite and aerial imagery to investigate marten responses to three decades of habitat change.
- Research continues on Rusty Blackbird nesting and fledgling habitat selection and survival in intensively managed forests in Maine and New Hampshire. Birds during the 2019 field season were confirmed nesting in wetlands, naturally regenerating stands, and stands that had undergone pre-commercial thinning.
- The CFRU research team looking at Bicknell's thrush successfully tracked 24 individuals to obtain 27 home ranges among the 2018 and 2019 breeding seasons at two study sites: Kibby Mountain (harvested landscape; 15 home ranges) and Mt. Redington (non-harvested landscape; 12 home ranges). Habitat selection analysis is underway.

Contents

Monarch Butterfly. Photo by Pam Wells. Used with Permission.

Chair's Report

This year CFRU provided approximately $280,000 to help fund 17 different projects in our core interest areas. Additionally, for the 2019-20 fiscal year budget, the membership has approved $250,000 in funding for 15 projects. Some of these projects are a continuation of multi-year research efforts while others are entirely new projects. Particularly gratifying to me is not only the diversity of these projects, but also the diversity of the researchers themselves, a few of whom are receiving CFRU funding for the first time. These projects, many of which are highlighted in the pages of this report, range from the continued development of CFRU's long-term adaptive silviculture network (MASN) to the habitat needs of species of special concern. In addition, CFRU was able to partner and help fund ongoing projects such as Spruce budworm L2 monitoring and statewide LiDAR data acquisition.

Although our 2018-19 plans included a new 5-yr prospectus to guide our research efforts, and a strategy session with the membership was held in July, it was decided to postpone those development efforts until discussions with University leadership regarding CFRU's position with the University have been finalized.

My term as Chairman of the CFRU Advisory Committee has ended and I will be transitioning to the Financial Officer position in 2019-20. It has been a true honor to serve in this capacity. While I regret our not being able to finalize our financial support agreement with the University, I do believe that it will be resolved in the coming months. Throughout this uncertainty, I have come to appreciate even more the dedication of the membership to the CFRU mission.

I would like to recognize and thank the staff of CFRU and CRSF for their dedication and hard work during challenging circumstances this past year. Finally, I would like to recognize my colleagues on the Executive Committee for their counsel and wisdom. The committee is in good hands with our incoming Chairman, Ian Prior. I would also like to thank Greg Adams and Kenny Fergusson for serving an extra year to their term. They have provided many years of service not only to the Advisory Committee but also more recently to the Executive Committee.

Sincerely,

Gordon Gamble

Gordon Gamble
CFRU Executive Committee Chair

Director's Report

This FY 2018-19 Annual Report details the results of fifteen CFRU projects addressing our member's needs in the areas of silviculture & productivity, growth & yield modeling, and wildlife habitat. Our membership, productivity, and funding remain strong as we work with our members to meet the most pressing challenges they face in sustainably managing Maine's commercial forestlands. As CFRU cooperators and the University work to create a long-term plan to build on the successful union of the past four decades, we continue to provide critical leadership on key issues facing Maine's forestland managers in the region and country.

Many thanks go to all of our CFRU members, staff, Project Scientists, as well as the graduate and undergraduate students who made another successful year possible. Special thanks go to our CFRU Executive Committee **Gordon Gamble** (Chair), **Ian Prior** (Vice Chair), **Greg Adams** (Financial Officer), and **Kenny Fergusson** (Member-at-Large) for their leadership and support over a transitional couple of years; their efforts will provide an excellent basis for the incoming Executive Committee: **Ian Prior** (Chair), **Eugene Mahar** (Vice Chair), **Gordon Gamble** (Financial Officer**), Elizabeth Farrell** (Member-at-Large). Finally, I would like to extend a special note of appreciation to **Dr. Brian Roth**, who served the CFRU as Associate Director and Program Leader since 2013.

As demonstrated in the following 2019 CFRU Annual Report, the unit continues to deliver a wide array of relevant research findings that contribute to the sustainable management of Maine's working forests.

Aaron Weiskittel
CRSF Director

Membership

FOREST LANDOWNERS / MANAGERS

American Forest Management
Appalachian Mountain Club
Baskahegan Company
Baxter State Park, SFMA
BBC Land, LLC
Clayton Lake Woodlands Holding, LLC
Downeast Lakes Land Trust
EMC Holdings, LLC
Fallen Timber, LLC
Frontier Forest, LLC
Irving Woodlands, LLC
Katahdin Forest Management, LLC
Maine Bureau of Parks and Lands
Mosquito, LLC
New England Forestry Foundation
Prentiss and Carlisle Company, Inc.
Presley Woods LLC
Rangeley Lakes Heritage Trust
Robbins Lumber Company
Sandy Gray Forest, LLC
Seven Islands Land Company
Solifor Timberland, Inc.
Sylvan Timberlands, LLC
The Nature Conservancy
Wagner Forest Management
Weyerhaeuser Company

WOOD PROCESSORS

Sappi North America

CORPORATE / INDIVIDUAL MEMBERS

Acadia Forestry, LLC
David B. Field
Forest Society of Maine
Huber Engineered Woods, LLC
LandVest
Si Balch
The Forestland Group

ADVISORY COMMITTEE

Chair

Gordon Gamble *Wagner Forest Management*

Vice Chair

Ian Prior *Seven Islands Land Company*

Financial Officer

Greg Adams *Irving Woodlands, LLC*

Member-at-Large

Kenny Fergusson *Huber Resources Corp. [Fallen Timber, LLC; Sylvan Timberlands, LLC; North Woods ME Timberlands, LLC; St. John Timber, LLC; Solifor Timberland, Inc.]*

Members

Kyle Burdick *Baskahegan Company*
Tom Charles *Maine Bureau of Parks and Lands*
Frank Cuff *Weyerhaeuser Company*
David Dow *Prentiss and Carlisle Company, Inc.*
Elizabeth Farrell *BBC Land, LLC*
Alec Giffen *New England Forestry Foundation*
Scott Joachim *Katahdin Forest Management, LLC*
Eugene Mahar *LandVest [Frontier Forest, LLC; Clayton Lake Woodlands Holding, LLC; EMC Holdings, LLC, Mosquito, LLC, The Tall Timber Trust]*
Brittany Mauricette *Downeast Lakes Land Trust*
Jacob Metzler *Forest Society of Maine*
Dan Pelletier *Huber Engineered Woods, LLC*
Jim Robbins, Jr. *Robbins Lumber Company*
Matthew Sampson *The Forestland Group, LLC*
Nancy Sferra *The Nature Conservancy*
Eben Sypitkowski *Baxter State Park*
Steve Tatko *Appalachian Mountain Club*
Nathaniel Vir *Sappi North America*

Research Team

Staff

Aaron Weiskittel (PhD), Center for Research on Sustainable Forests (CRSF) Director

Brian Roth (PhD), CFRU Program Leader

Leslee Canty-Noyes (MIS), CFRU/CRSF Administrative Specialist

Meg Fergusson (BA), CRSF Outreach and Communications Specialist

Project Scientists

Paul A. Arp (PhD), Forestry & Enviromental Management, University of New Brunswick

Russell D. Briggs (PhD), State University of New York – Environmental Science and Forestry

John Campbell (PhD), Northern Research Station, U.S. Forest Service

Ivan Fernandez (PhD), School of Forest Resources, University of Maine

Shawn Fraver (PhD), School of Forest Resources, University of Maine

Carol Foss (PhD), New Hampshire Audubon

Kate Gerndt (MS), Research Assistant & Data Manager, Penobscot Experimental Forest

Hamish Greig (PhD), School of Biology and Ecology, University of Maine

Marie-Cécile Gruselle (PhD), Friedrich-Schiller University, Germany

Anthony Guay (MS), The Wheatland Lab, University of Maine

Amanda Klemmer (PhD), School of Biology and Ecology, University of Maine

Daniel Harrison (PhD), Department of Wildlife, Fisheries, and Conservation Biology, University of Maine

Daniel Hayes (PhD), School of Forest Resources, University of Maine

Chris Hennigar (PhD), University of New Brunswick

Project Scientists

Keith Kanoti (MS), University Forests Office, University of Maine

Laura Kenefic (PhD), Northern Research Station, U.S. Forest Service

Anil Raj Kizha. (PhD), School of Forest Resources, University of Maine

Christian Kuehne (PhD), School of Forest Resources, University of Maine

Adrienne Leppold (PhD), Maine Department of Inland Fisheries and Wildlife

Alessio Mortelliti (PhD), Department of Wildlife, Fisheries, and Conservation Biology, University of Maine

Robert Northington (PhD), Husson University

Joshua Puhlick (PhD), School of Forest Resources, University of Maine

Parinaz Rahimzadeh (PhD), School of Forest Resources, University of Maine

Andrew Richley (MF), School of Forest Resources, University of Maine

Amber Roth (PhD), School of Forest Resources and Department of Wildlife, Fisheries, and Conservation Biology, University of Maine

David Sandilands (MS), The Wheatland Lab, University of Maine

Erin Simons-Legaard (PhD), School of Forest Resources, University of Maine

C. T. (Tat) Smith (PhD), Department of Geography & Planning, University of Toronto

Inge Stupak (PhD), Department of Geosciences and Natural Resource Management, University of Copenhagen

Jay Wason (PhD), School of Forest Resources, University of Maine

Research Scientists

Ethel Wilkerson (MS), Manomet

Patricia Wohner (PhD), Cuckoo Conservation Initiative

Graduate Students

Libin T Louis (PhD, Forestry UMaine)

Alex George (PhD, Forestry UMaine)

Harikrishnan Soman (MS, Forestry UMaine)

Kirstin Fagan (Ph.D., WLE UMaine)

Tyler Woollard (M.S., WLE UMaine)

Luke Douglas (MS Forest Resources, UMaine)

Carl Pohlman (MS Forest Resources, UMaine)

Kaitlyn Wilson (MS Wildlife Ecology, UMaine)

Samantha Anderson (MF, Forestry, UMaine)

Michael Redante (MF, Forestry, UMaine)

Jeanette Allogio (MS, UMaine)

Bryn Evans (PhD, Wildlife, UMaine)

Tyler Woollard (MS, Wildlife Ecology, UMaine)

Margaret Mansfield (MS, Forestry, UMaine)

Undergraduate Students

Noah Coogen (BS student, UMaine)

Skye Cahoon (BS Zoology, UMaine)

Aashish Dhungana (BS, Forest Resources, UMaine)

Jack Ferrara (BS student, UMaine)

Joshua Goldsmith (BS, Forest Resources, UMaine)

Undergraduate Students

David Holmberg (BS, Wildlife Ecology, UMaine)

Lauren Keefe (BS, Forest Resources, UMaine)

Michaela Kuhn (BS, Parks, Recreation and Tourism, UMaine)

Hateya Levesque (BS, Forestry, UMaine)

Kyle Lima (BS, Wildlife Ecology, UMaine)

Aaron Malone (BS, Forest Resources, UMaine)

Evan Nahor (BS student, UMaine)

Emma Payne (BS student, Cornell University

Emily Roth (BS, Forest Resources, UMaine)

Emily Tomak (BS Ecology & Environmental Science, UMaine)

Mike Turso (BS Wildlife Biology, UMaine)

Emma Payne (BS student, Cornell University

Emily Roth (BS, Forest Resources, UMaine)

CFRU Summer Field Crew

Noel Lienert

Casey Dumont

Ethan Olson

Ethan Jacobs

William Thomas

Marshal Bertrand

Noah Coogan

Jon Rheinhardt

Technical Assistant

Alex Barnes

Financial Report

The CFRU engaged thirty-three members representing 8.15 million acres of Maine's forestland this year. CFRU members contributed $541,465 to support research activities during Fiscal Year 2019-20. In addition to our industry and individual members, the State of Maine and Maine Bureau of Parks and Lands continue to be very supportive to the CFRU and we appreciate their continued engagement. By the end of FY2019, the CFRU had received nearly 100% of expected contributions. We thank all of our members for their financial and in-kind contributions, as well as the trust in the CFRU and UMaine that these contributions represent.

Sound fiscal management by CFRU scientists and staff resulting spending $85,330 (13.5%) less than the $630,840 that was approved by the Advisory Committee for this fiscal year (Table 2). Funds allocated in FY18 and rolled into FY19 were applied to a retroactive salary increase for the Program Leader, skewing the percentage of monies spent on the administrative budget versus research projects for this year (Figure 1). CFRU research expenses by category this year included 31% on seven Silviculture & Productivity projects, 32% on six Growth & Yield Modeling projects, and 37% on five Wildlife Habitat projects (Figure 2).

Figure 1. CFRU Expenses FY2018-19

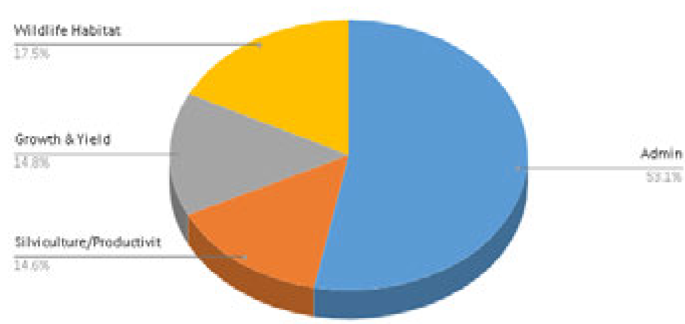


Figure 2. CFRU Research Expenses FY2018-19

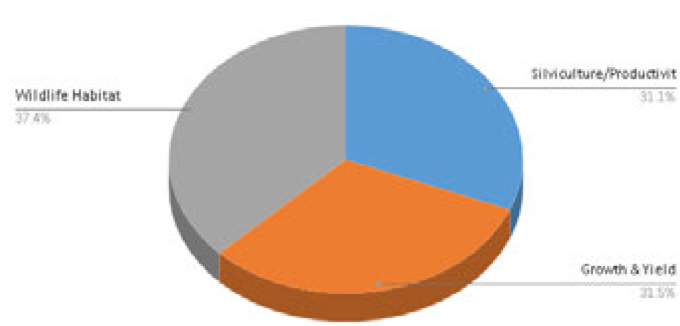


Table 1. CFRU Member Contributions Received FY 2018-19 (for allocation in 2019-20)

CFRU Member	Contributions for FY19-20*
FOREST LANDOWNERS / MANAGERS:	
Irving Woodlands, LLC	$68,804
Wagner Forest Management	$56,464
BBC Land, LLC	$54,320
Weyerhaeuser Company	$47,204
Clayton Lake Woodlands Holding, LLC	$44,363
Prentiss and Carlisle Company, Inc.	$43,093
Seven Islands Land Company	$42,354
Maine Bureau of Parks & Public Lands	$75,277
Katahdin Forest Management, LLC	$17,528
The Nature Conservancy	$9,269
Fallen Timber, LLC	$7,468
Solifor Timberland Inc.	$6,970
Baskahegan Company	$6,898
Sandy Gray Forest, LLC	$5,841
Sylvan Timberlands, LLC	$5,521
Appalachian Mountain Club	$4,315
Frontier Forest, LLC	$3,115
Downeast Lakes Land Trust	$3,266
EMC Holdings, LLC	$2,363
Baxter State Park, SFMA	$1,725
North Woods Maine, LLC	
Robbins Lumber Company	$1,564
Presley Woods, LLC	
St. John Timber, LLC	
Mosquito, LLC	$1,000
The Forestland Group, LLC**	
Blue Hill Heritage Trust	
Rangeley Lakes Heritage Trust	$286
New England Forestry Foundation	$1,000
TOTAL	$510,008
WOOD PROCESSORS:	
SAPPI Fine Paper	$25,557
TOTAL	$25,557
CORPORATE and INDIVIDUAL MEMBERS:	
ReEnergy Holdings, LLC	
James W. Sewall Company	
Huber Engineered Woods, LLC	$1,000
The Forestland Group	$3,000
Forest Society of Maine	$1,000
Si Balch	$500
LandVest	$200
David B. Field	$100
Acadia Forestry, LLC	$100
TOTAL	$5,900
GRAND TOTAL (members):	$541,465
*Contributions received as of 10/16/2019.	
**The Forestland Group no longer owns timberland in Maine, but contributes as a	
	Contribution Received
	Contribution Pending
	New Member
	Member Withdrew

Table 2. CFRU Expenses Incurred During FY2018-019

PROJECT	Principal Investigator	Approved Amount	Spent End of FY19	Balance Remaining	% Balance Remaining
Total Administration		$290,818.36	$274,155.91	$16,662.45	5.70%
Research Projects					
Silviculture and Productivity:		$138,367.49	$75,365.91	$50,884.41	36.80%
Maine's Adaptive Silviculture Network (MASN)	Roth	$46,216.98	$30,522.17	$11,493.27	24.90%
Long-term Impacts of Whole Tree Harvesting: Weymouth Point Study	Smith/Roth	$49,366.98	$17,013.32	$27,865.75	56.40%
Evaluating the Effects of Timber Harvesting Operations on the Soil	Kizha	$11,089.98	$9,884.13	-$0.56	0.00%
Silvicultural and Operational considerations for Lowland Northern White-Cedar	Kenefic/Fraver	$6,609.53	$5,883.97	$124.69	1.90%
Quantifying the ecological and economic outcomes of alternative riparian	Greig	$11,328.01	$4,519.81	$5,778.38	51.00%
Quantifiying Regeneration Outcomes and Logging Residues in MASN	Rogers	$8,677.31	$0.00	$544.18	6.30%
Beech bark disease 40-year results	Kenefic/Livingston	$5,078.70	$0.00	$5,078.70	100.00%
Growth & Yield Modeling		$97,543.99	$76,139.70	$13,582.40	13.90%
Developing a Dynamic Site Productivity Map by linking BGI and RS Variables	Rahimzadeh	$29,750.00	$22,734.44	-$122.43	-0.40%
Development of Approaches for HW Response to Forest Management	Puhlick	$17,467.00	$15,879.03	$0.00	0.00%
Spruce Budworm	Roth	$9,549.99	$8,681.81	$0.00	0.00%
Measurements, Modes and maps: large-area forest inventory from Lidar	Hayes	$13,273.00	$9,865.23	$2,201.13	16.60%
Cartographic Depth to water mapping	Arp/Roth	$16,000.00	$16,000.30	-$0.30	0.00%
Assessing and monitoring soil productivity, carbon storage and conservations on MASN	Puhlick	$11,504.00	$0.00	$11,504.00	100.00%
Wildlife Habitat:		$104,110.80	$90,445.31	$4,200.85	4.00%
Bicknells Thrush	A. Roth	$22,275.99	$22,152.94	$123.05	0.60%
Large Scale Monitoring of Carnivores	Mortelliti	$6,632.00	$5,344.74	$684.33	10.30%
Response of Marten Population 30 years Later	Harrison	$47,433.31	$42,626.82	$494.37	1.00%
Rusty Blackbird Use of Commnercially-managed Spruce-fir forests	A. Roth	$3,531.00	$1,080.10	$2,129.90	60.30%
Watershed-scale drivers of temperature and flow of headwater streams in Northern Maine	N. Thompson	$24,238.50	$21,265.80	$769.20	3.20%
Total		**$630,840.64**	**$516,106.83**	**$85,330.11**	**13.50%**
Control Account	**Roth**	**$969,539.47**			
Fleet Account	Roth	$25,127.29		$40,982.63	
CAFS 2 @10%	Weistkittel	$240,000.00	$236,788.40	$3,211.60	1.30%

Fall Field Tour

Woods, Wildlife and Wind Power

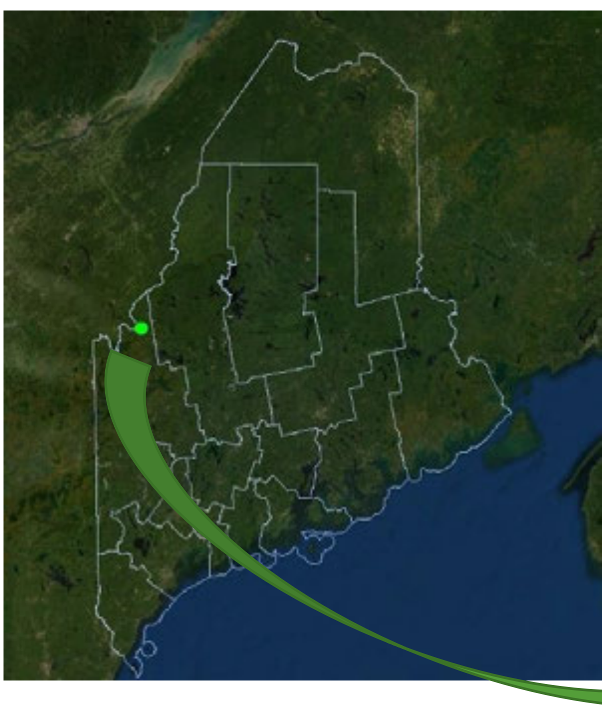
Overview

Field tour attendees spent the day visiting four sites in Kibby Township on Weyerhaeuser forestland. Topics and sight visits covered the latest CFRU research at the interface of forestry and wildlife habitat. CFRU members can access the field tour book on the CFRU members website under the field tour tab.

2019 CFRU Fall Field Tour attendees gather on Kibby Township.

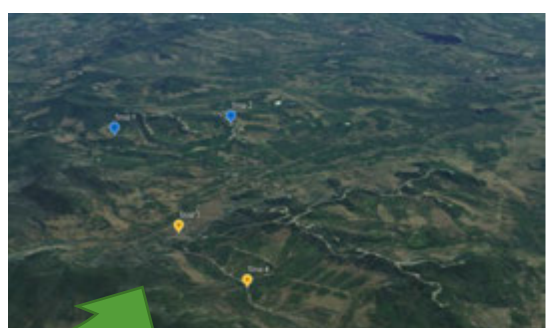
Topics Covered

- Riparian Management
- Carnivore Monitoring
- Deer Habitat Modeling from LiDAR
- Bicknell's Thrush Habitat Use
- Rusty Blackbird Habitat Use
- Wind power Development



Presenters

- Mitchell Paisker, University of Maine
- Bryn Evans, University of Maine
- Dr. Amber Roth, University of Maine
- Kaitlyn Wilson, University of Maine
- Luke Douglas, University of Maine
- Mike Darienzzo, Kibby Mountain Wind Project
- Dr. Brian Roth, CFRU, University of Maine



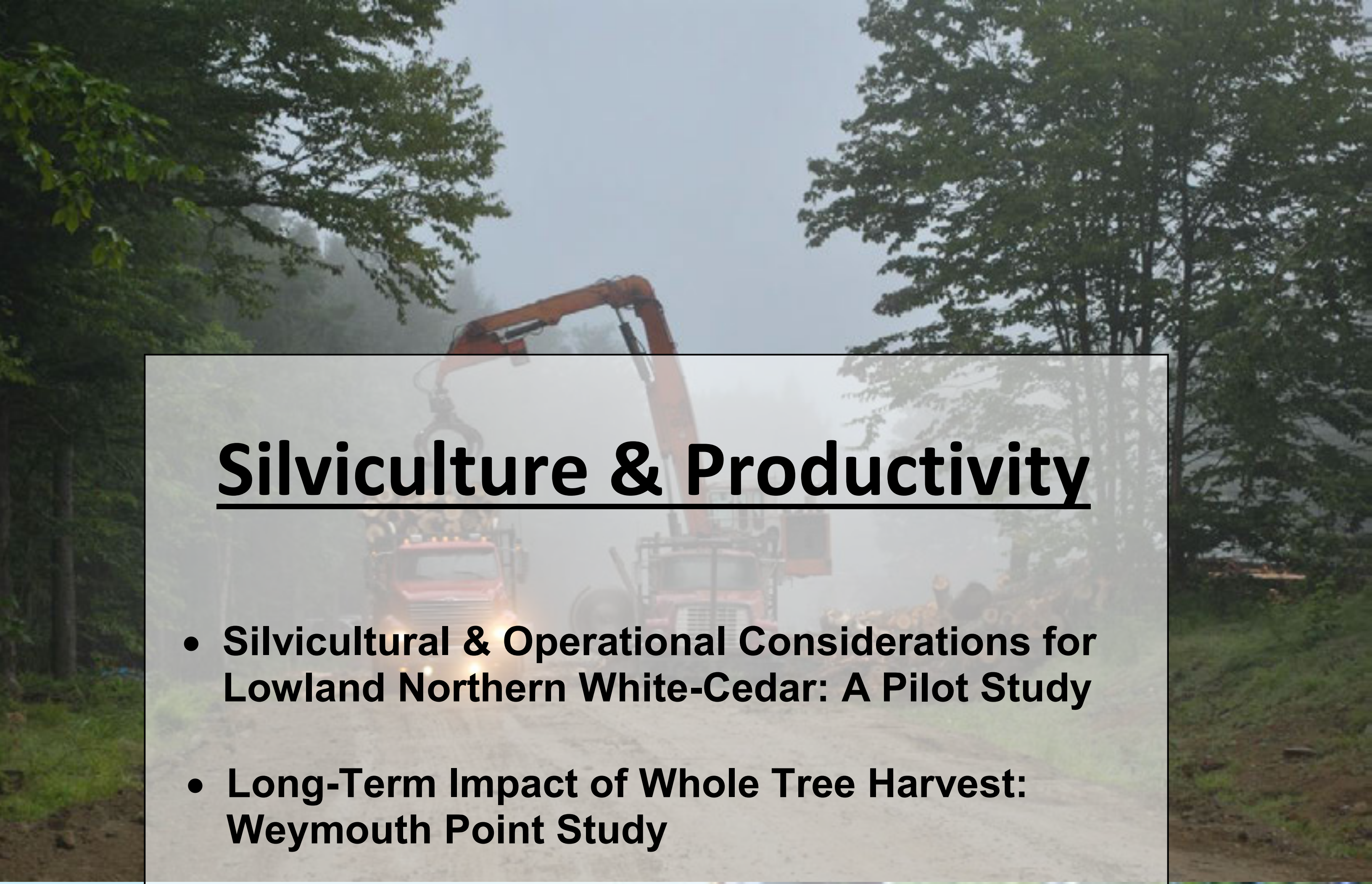
Center for Advanced Forestry Systems

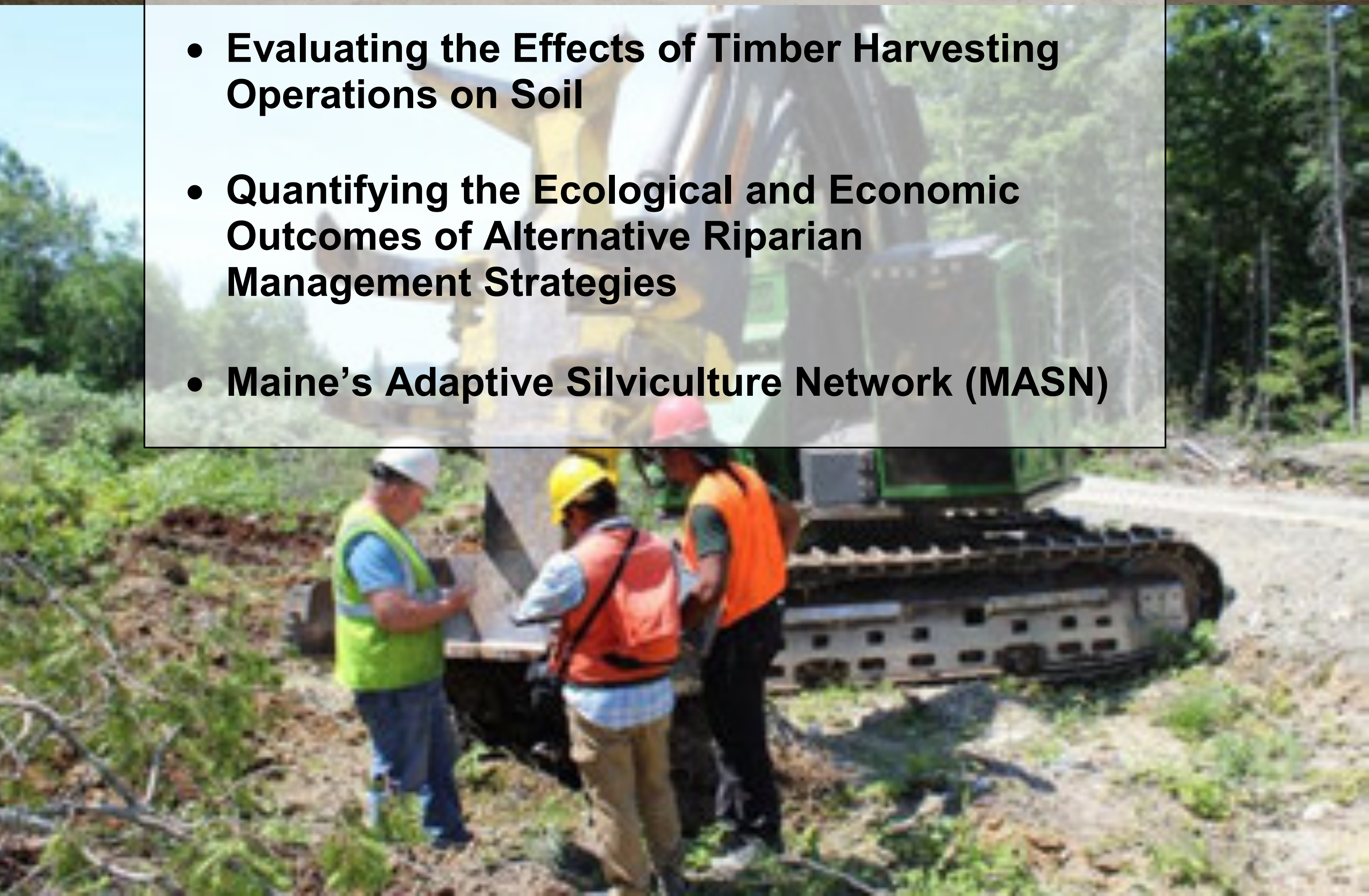
This year saw the completion of the final year of Phase II for the UMaine site under the **Center for Advanced Forestry Systems** (CAFS). CAFS is funded by the National Science Foundation (NSF) Industry/University Cooperative Research Centers Program (I/UCRC) in partnership with CFRU members. CAFS is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

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

CAFS Field Tour south of Athens, GA, June 2019.

Research Project Reports





Silviculture & Productivity

- Silvicultural & Operational Considerations for Lowland Northern White-Cedar: A Pilot Study
- Long-Term Impact of Whole Tree Harvest: Weymouth Point Study
- Evaluating the Effects of Timber Harvesting Operations on Soil
- Quantifying the Ecological and Economic Outcomes of Alternative Riparian Management Strategies
- Maine's Adaptive Silviculture Network (MASN)

Silviculture and Operations in Northern White-Cedar Lowlands

Laura Kenefic[1], Anil Raj Kizha[2], Shawn Fraver[2], Amber Roth[2], Jay Wason[2], and Keith Kanoti[2]

[1]U.S. Forest Service, Northern Research Station
[2]University of Maine, School of Forest Resources

Photo 1. *The harvest at the PEF removed 12 cords acre-1 of white-cedar and 4 cords acre-1 of other species. This reduced stocking of trees ≥6 inches dbh by about 36%.*

Status: Year 2 of 3

Abstract

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

Project Objectives

- Assess changes in structure, composition, and stocking resulting from silvicultural treatment in lowland white-cedar.
- Quantify cost and productivity of timber harvesting operations in lowland white-cedar.
- Determine site impacts (e.g., area in trails, hydrologic changes) from harvesting operations.
- Make preliminary recommendations for management of white-cedar lowlands, expanding the scope of the existing Silvicultural Guide (Boulfroy et al. 2012).

Approach

- Conduct operational-scale silviculture experiment in white-cedar-dominated lowlands (≥ 60% of BA) at three sites, each with one or more treated stand(s) and a reference (control)
- *Measure edaphic (soil) and hydrologic features such as thickness of the organic horizon and depth to water table at each site.*

- *Establish a network of permanent sample plots and transects to quantify stand composition and structure, tree quality, regeneration density and stocking, deadwood, and microtopography pre- and post-harvest.*
- Determine mode of regeneration of white-cedar seedlings in lowlands through excavation and microscopic assessment of cell structure to determine seed or vegetative (layer) origin across multiple sites.
- Collect harvest productivity and cost data to assess operational impacts and feasibility of partial harvests on low-productivity sites.

Silviculture Treatments

1. Irregular shelterwood conducted with a cut-to-length (processor, forwarder) system in Eddington, Maine at Penobscot Experimental Forest and in Danforth, Maine in collaboration with Baskahegan Company:
    - *Establish and release white-cedar regeneration by creating small (one to two tree-height) canopy gaps*
    - *Favor the growth of the best residual pole- and small sawtimber white-cedar through crop tree release (crown thinning) between gaps*
    - *Conduct mechanical (brushsaw) post-harvest control of regeneration in a subset of gaps*
2. Cut from above conducted with a whole-tree (feller-buncher, grapple skidder) system in Downeast Maine in collaboration with Wagner Forest Management:
    - *Remove all merchantable white-cedar ≥ 10 inches dbh*
    - *Remove all merchantable hardwoods and fir ≥ 6 inches butt diameter and spruce ≥ 7 inches dbh.*

Key Findings and Accomplishments

- In winter 2019, harvesting was completed on the Penobscot Experimental Forest. Delay-free cycle times and predictor variables were recorded for the processor and forwarder using detailed time-motion study techniques. Harvested wood timber volume was estimated from scaling data and scale tickets. Machine rate calculations to determine hourly production cost were made based on information from the forest management company. Post-harvest inventory was completed in summer 2019.

- Stand layout and pre-harvest measurements were completed in summer 2019 in the stands managed by Baskahegan (*n*=2, one harvest and one control) and Wagner (*n*=3, two harvest and one control). The Baskahegan site was marked for harvest; the operator will select trees to harvest based on the stand prescription at Wagner. Harvesting is scheduled for winter 2020 and time-motion studies are planned for the Baskahegan site. Post-harvest measurements are planned for summer 2020.

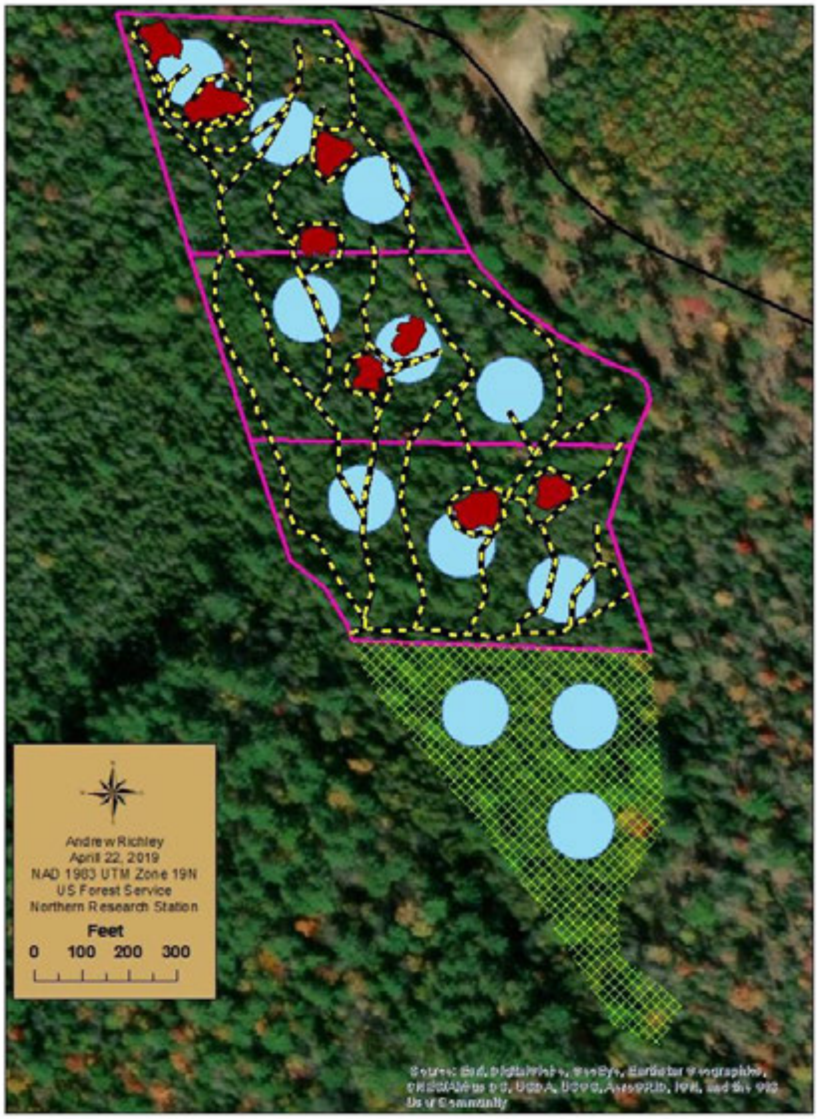


Figure 1. *The approximately 11-acre harvest area at the PEF is outlined in pink. Permanent sample plots (one-fifth acre) are shown in light blue. Harvest gaps (one to two tree-heights wide) are red and skid trails are yellow and black. Skid trails were designated and did not cross gaps located on pockets of advance regeneration. Post-harvest area in trails was approximately 25%.*

- The scope of work was expanded in 2019 to provide additional information about white-cedar regeneration based on preliminary observations of the importance of microtopography (pits and mounds) for regeneration and growth in stands with seasonally high water table, and of the prevalence of regeneration by layering in lowland white-cedar stands. Additional work includes:

    - *Experimental planting of white-cedar seedlings on pits, flats, and mounds in the Penobscot Experimental Forest, in collaboration with co-PI Fraver, completed in spring 2019. These seedlings are being monitored for survival and growth.*

- *Excavation of regeneration at additional sites across the range of white-cedar in summer 2019, including Downeast Maine, Vermont, and Michigan, to determine whether the high proportion of white-cedar layers observed in central Maine is representative of regional trends. Additional study sites include two stands at the Dukes Experimental Forest on the Upper Peninsula of Michigan, one stand owned by the Vermont Land Trust and one family forest in northern Vermont, and one stand each managed by Baskahegan and Wagner in Downeast Maine.*

Preliminary findings for stand structure and composition:

- Volumes of deadwood are high in unharvested white-cedar-dominated lowlands, likely due to slow rates of decay.
- White-cedar regeneration benefits from deadwood substrate; the proportion of regenerating stems growing on deadwood is high.
- Water table data collected by co-PI Fraver show shallow depth to water, particularly in the fall and spring.
- Locations of regenerating stems and trees in white-cedar-dominated lowlands suggest that tree establishment and growth are better on elevated microsites.
- Saplings of other species (e.g., balsam fir, alder) often compete with white-cedar in the understory.

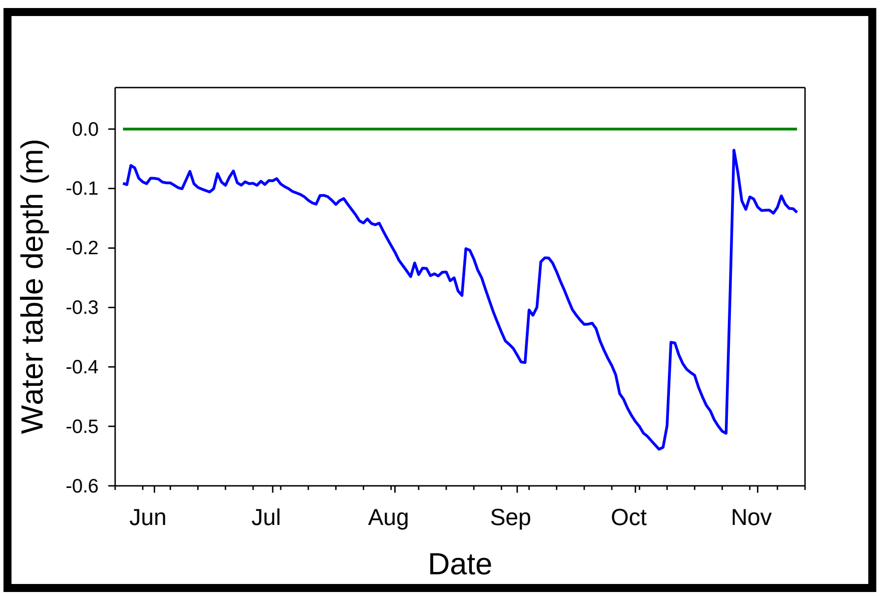


Figure 2. *We monitored water table depth from May to November over 2 years prior to harvest on the PEF using HOBO sensors. The mean data across 5 plots in 2017 are shown here. We observed that the water table is as few as 4 inches below the surface (shown as a green line) throughout much of the year. Post-harvest data are in preparation; we anticipate that the water table has risen. University Forester Keith Kanoti observed a beaver swimming though the stand during spring 2019.*

***Photo 2**. Buffalo Forwarder piling white-cedar logs at the landing on the PEF.*

***Photo 3.** Undergraduate student Lauren underplanting white-cedar for investigation of survival and growth on pits, flats, and mounds.*

Preliminary findings for mode of regeneration:

- Both seedlings (sexual reproduction from seed) and layers (asexual reproduction from branches that root to the ground) are common in white-cedar-dominated lowlands.
- Co-PI Wason determined that mode of white-cedar regeneration can be identified by microscopic examination of cross sections from excavated regeneration. Because the above-ground portions of the stems have pith cells but the roots do not, the presence of pith cells in the underground portion of a regenerating stem suggests that it is a buried branch (layer). University students are using this methodology to determine the proportion of regeneration that is from layers in our study sites.
- Layers can originate from tree branches resting on the ground, but also from established seedlings and saplings pressed down by snow and ice loads. As many as 18 stems of regeneration were found attached to a single buried stem in the present study.

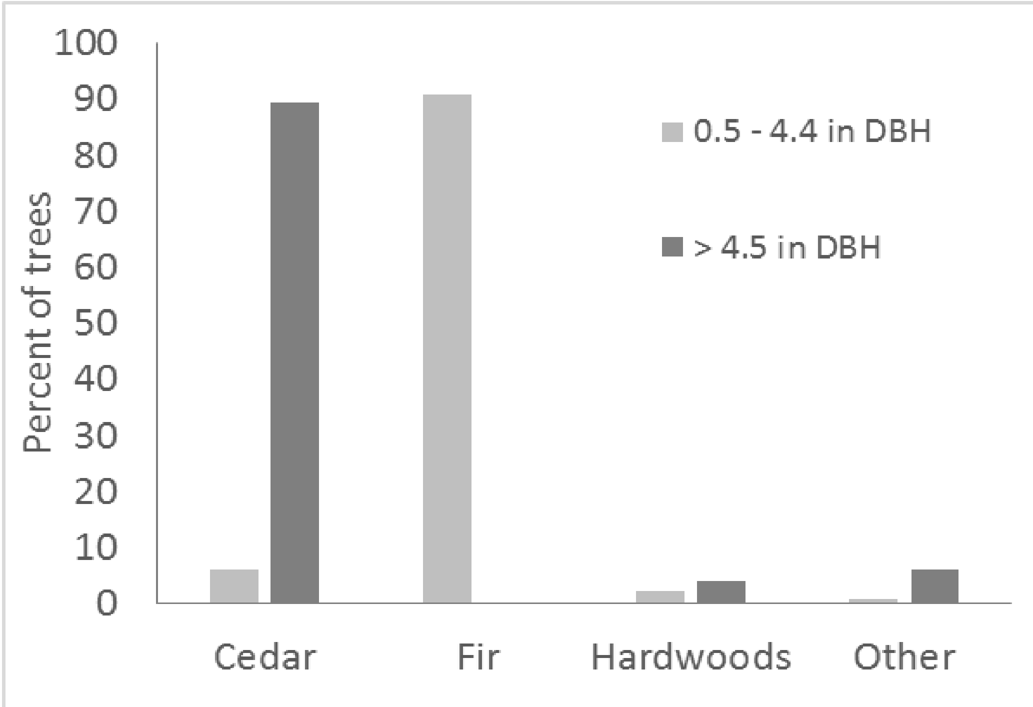


Figure 3. *Stand composition prior to harvest at the PEF showed overstory white-cedar and understory fir; similar compositions were observed at other study sites.*

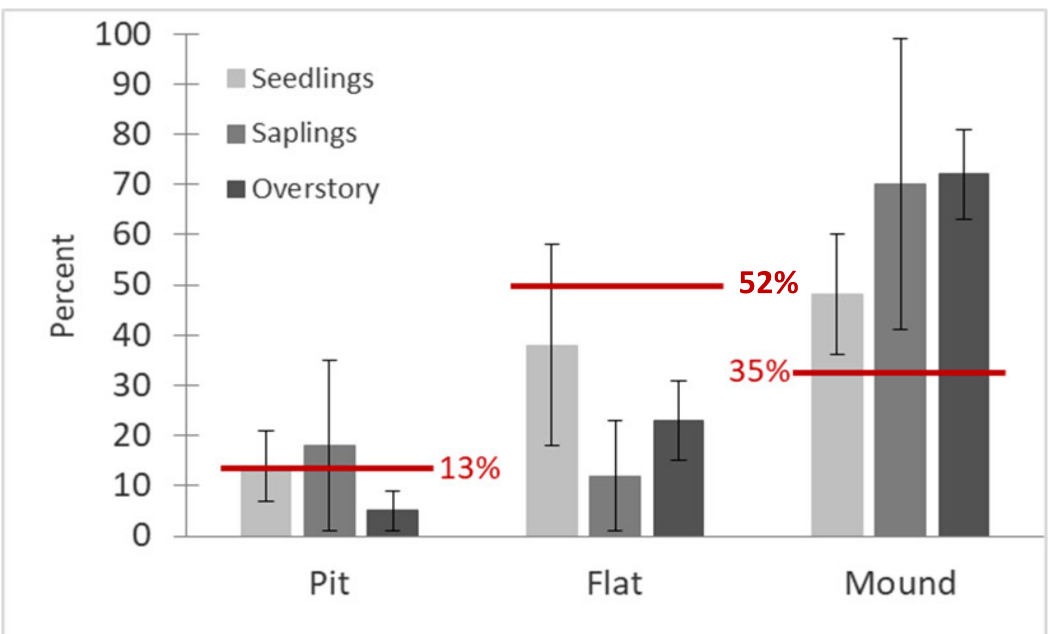


Figure 4. *Percent of white-cedar seedlings, saplings, and overstory trees (≥4.5 inches dbh) on mounds is high relative to the percent of stand area occupied by mounds at the PEF. Red lines show percent of stand occupied by each category.*

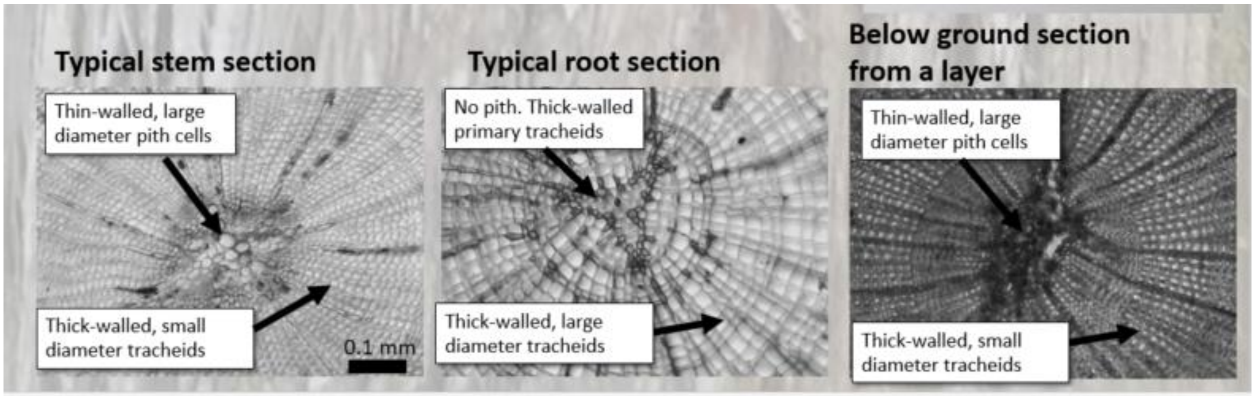


Figure 5. *Different cell structure in shoots and roots allows student researchers to determine how much of the regeneration arose from seed, and how much from layers.*

Preliminary findings for experimental planting of white-cedar seedlings:

- Mortality rates during the first growing season varied with microtopographic position. Mortality of seedlings planted in pits was five times greater than that of seedlings planted in other positions. Mortality rates did not differ between seedlings planted on flats and mounds.

Preliminary findings for harvest productivity and cost from co-PI Kizha and University doctoral student Alex George:

- The cost of the operation was higher for the white-cedar stand (81% white-cedar) (US \$31.93 m^{-3}) than an adjacent non-cedar stand (10% white-cedar) (US \$24.27 m^{-3}) on the Penobscot Experimental Forest. The former is regarded as a "sensitive soil" site and the latter a "sturdy soil" site for the purpose of this assessment.
- Apportioning methods showed that the cost of felling and processing white-cedar (US \$6.35 m^{-3}) was higher than hardwoods (US \$6.09 m^{-3}) or other softwoods (US \$5.66 m^{-3}).
- Sensitivity analysis showed that increases in butt-end diameter, distance between trees, and number of cuts per cycle increased the delay-free cycle time of the harvester.
- In the case of the forwarder, length and diameter of the log were inversely proportional to delay-free cycle time, whereas an increase in forwarding distance and number of pieces increased delay-free cycle time.
- Overall, the smaller dbh and greater number logs per handle in the white-cedar stand, distance between the decks, and time for segregating different products influenced productivity and cost. Also of note, the tapered form of white-cedar logs requires the operator to deliberately orient the butt ends when loading.
- Though few if any direct effects of soils were found on winter harvesting productivity and costs, tree species composition was an influential factor and is itself related to soils.

Table 1. *Cost and productivity of different operational phases in white-cedar and non-cedar stands. Values in parentheses show cost and productivity to extract wood to a hypothetical landing adjacent to the stand (excluding distance to the actual landing, which varied between the two stands). Source: George et al. 2019.*

Operational phase	Cost (USD m^{-3})		Productivity (m^3 PMH^{-1a})	
	Cedar	Non-cedar	Cedar	Non-cedar
Felling and Processing	9.98	8.03	20.64	25.60
Extraction	20.47 (13.58)	14.76 (8.75)	5.89 (8.88)	8.16 (13.78)
Loading[b]	1.48		61.21	
Total	**30.45**	**22.79**		

[a] PMH- productive machine hour

[b] Products from both treatments were combined at the landing.

Photo 4. *Graduate student Alex George learns about product specifications for white-cedar from Charles Tardif at the Maibec mill yard in St. Theophile, Quebec.*

Photo 5. *Forester Andrew Richley in a white-cedar lowland at the Dukes Experimental Forest in Michigan, where additional replicates of the irregular shelterwood treatment are proposed.*

Future Plans

- Harvest irregular shelterwood replicate at Baskahegan in winter 2020, collect data for calculation of harvest productivity and cost.
- Harvest cut-from-above stands at Wagner in winter 2020.
- Conduct post-treatment inventory of harvested stands Downeast (Baskahegan and Wagner) summer 2020.
- Complete laboratory analysis re: of mode of regeneration for all sites (*n*=8).
- Though the period of CFRU funding has ended, the project is continuing using leveraged funds from the U.S. Forest Service, Maibec, and the University of Maine. Additional work to be conducted includes:
    - M.S. student will analyze harvesting impacts on the lowland cedar stands as well as ecophysiology of northern white-cedar. Start date: summer 2020, co-PIs: Kenefic and Wason.
    - U.S. Forest Service scientist Christel Kern will replicate the irregular shelterwood treatments in three lowland white-cedar stands at the Dukes Experimental Forest on the Upper Peninsula of Michigan. These stands are similar in composition and structure to those in the present study, but have a greater proportion of sawtimber. Stand layout and permanent sample plot installation were completed in summer 2019; harvesting is pending approval through the National Environmental Policy Act process and will be overseen by staff of the Hiawatha National Forest within 5 years.

References

Boulfroy, E.; Forget, E.; Hofmeyer, P.V.; Kenefic, L.S.; Larouche, C.; Lessard, G.; Lussier, J-M.; Pinto, F.; Ruel, J-C.; Weiskittel, A. 2012. Silvicultural guide for northern white-cedar (eastern white cedar). Gen. Tech. Rep. NRS-98. Newtown Square, PA: Dept. of Agric., Forest Service, Northern Research Station. 74 p.

George, Alex Kunnathu; Kizha, Anil Raj; Kenefic, Laura. 2019. Economic feasibility of timber harvesting in lowlands. In: Czupy, Imre, ed. Exceeding the vision: forest mechanisation of the future. Proceedings of the 52nd International Symposium on Forestry Mechanization. Sopron, Hungary: University of Sopron Press: 379-393.

Photo 6. *PI Kenefic at the study site with undergraduate students hired for data collection in winter 2019: Aaron, David, and Lauren.*

Acknowledgements

We thank staff of the University of Maine Forests Office, Wagner Forest Management, and Baskahegan Company for their assistance. We also thank the Cooperative Forestry Research Unit; U.S. Forest Service, Northern Research Station; Penobscot Experimental Forest, Research Operating Team; University of Maine, School of Forest Resources; Maine Agricultural and Forest Experiment Station; and Maibec for funding.

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

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Status: Final Report

Abstract

Research at Weymouth Point was designed to evaluate impacts on forest ecosystem nutrient (N, P, K, Ca and Mg) and carbon (C) pools of whole-tree harvesting (WTH) and stem-only harvesting (SOH) compared to an unharvested reference (REF) forest. REF and clearcut watersheds were sampled in 2016, 35 years after clearcutting in 1981. Living aboveground forest accumulated 70 Mg C ha^{-1} (60%) versus 116 Mg C ha^{-1} in the pre-harvest forest. The REF forest contained 16 Mg C ha^{-1} deadwood versus 5-7 Mg C ha^{-1} in WTH-SOH, and, correspondingly, 120 versus 112-136 Mg C ha^{-1} in mineral soil to 100 cm depth. Forest floor lost 10-26 Mg C ha^{-1} since clearcutting. Ecosystem C pools modelled with a carbon budget model (CBM-CFS3) overestimated dead organic matter C pools compared with empirical estimates; living biomass C was modelled accurately. These results may inform development sustainable forest management standards in northern New England.

Project Objectives

- Quantify trends in ecosystem C and nutrient pools 35 years after clearcutting a balsam fir-red spruce forest at Weymouth Point Study Area (WPSA).
- Compare 35-year ecosystem C pool dynamics with C dynamics predicted by an IPCC-relevant forest C budget model (CBM-CFS3 was proposed).
- Inform development of criteria and indicators of sustainable forest management (SFM) in forest policy and certification systems adopted for balsam fir-red spruce forests in northern New England.

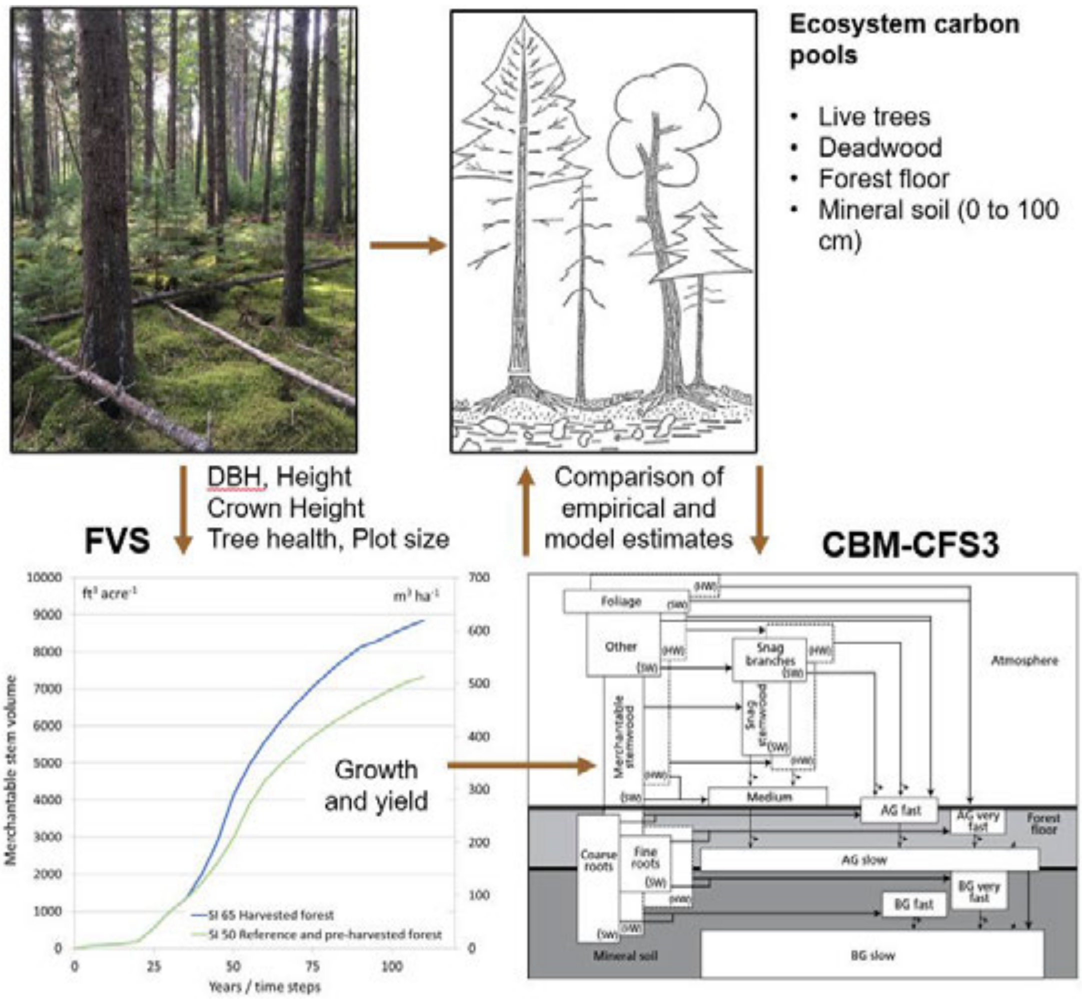

Figure 1. *Overview of methods selected to estimate tree growth and ecosystem carbon and nutrient pool responses to harvesting and delimbing residue management treatments in the forest, and to compare empirical estimates of C pools with predictions derive.*

Approach

- Methodology for the overall project was selected to determine tree growth and ecosystem carbon and nutrient pool responses to harvesting and delimbing residue management treatments, and to compare empirical estimates of C pools with predictions derived from the CBM-CFS3 model (Kull 2019) (Figure 1).
- USDA Forest Vegetation Simulator Northeast Variant (FVS-NE) (USDA 2018) simulation of growth and yield curves was based on forest inventory data from 2016, and site index (SI) defined as tree height in feet at breast-height age 50 years: SI 50 for pre-harvest and reference forest, based on height measurements and stem disks from 1980; SI 65 for natural regeneration after harvesting was based on height measurements and stem cores from 2018.

- CBM-CFS3 simulation of the development in forest ecosystem carbon pools was based on input of FVS-NE growth and yield estimates. Pseudo-initialization included 100 years of growth after an afforestation event after reset of the MAKELIST pools. Next, spruce budworm (SBW) outbreaks were simulated every 60 years for 840 years (year 940 corresponding to calendar year 1916, time step -65 for WTH and SOH and time step 0 for REF).
- CBM-CFS3 scenarios WTH, SOH and REF were simulated with the time steps signifying time after disturbance: WTH and SOH (blue line in Figure 6) simulated from time step -65 to 100 as defined for the WTH and SOH (corresponding to calendar years 1916-2081), with a WTH and SOH clearcut disturbance in time step 0 (1981). Simulations for time step -65 to 0 for WTH and SOH is not shown. REF (green line in Figure 6) was simulated from time step 0 to 100 as defined for REF (corresponding to calendar years 1916-2016), with a SBW outbreak disturbance in time step 0 (1916).

Key Findings / Accomplishments

Key findings from empirical work:

Tree growth: 35 years after WTH does not differ from tree growth after SOH (Figure 2), cf. also 2017 CFRU report. Site index estimates indicated Forest Vegetation Simulator Northeast Variant (FVS-NE) (USDA 2018) simulations of stand growth and yield should assume SI 50 for the Reference watershed plots and SI 65 for WTH and SOH treated plots (Figure 3).

Element concentrations in soil: Concentrations of total C and N appear to be somewhat higher in harvested watershed soils (WTH and SOH treatments) than Reference watershed soils (REF) at 0–10 and 25–50 cm depths, but less Bray-P and exchangeable Ca, cf. also 2018 CFRU report.

Element concentrations in biomass: N, P, K, Ca and Mg concentrations were generally higher or similar in tree biomass in the harvested watershed 35 years after harvest, compared to concentrations in 1980, prior to harvest, indicating that soil nutrient availability has not been degraded. Balsam fir biomass generally had higher nutrient concentrations than red spruce (Figure 4).

Deadwood C: Dead woody debris in the unharvested forest (REF) was about three times that observed in harvested watershed treatments (Figure 5), cf. also 2018 CFRU report.

- *Forest floor C:* Forest floor, including post-harvesting residues, after WTH and SOH lost 38-61 Mg C ha^{-1} and mineral soil gained 2-37 Mg C ha^{-1} 35 years after harvesting (Figure 5), cf. also 2018 CFRU report.
- *Mineral soil C:* Mineral soil C appears to be sustained by both residue treatments (SOH and WTH). Further research is required to clarify the extent to which loss of forest floor C is related to net gains in mineral soil and/or decomposition with release of CO_2 to the atmosphere.
- *Total ecosystem C*: Total ecosystem C had, at age 35 years, reached about 79% of the pre-harvested forest C pool.

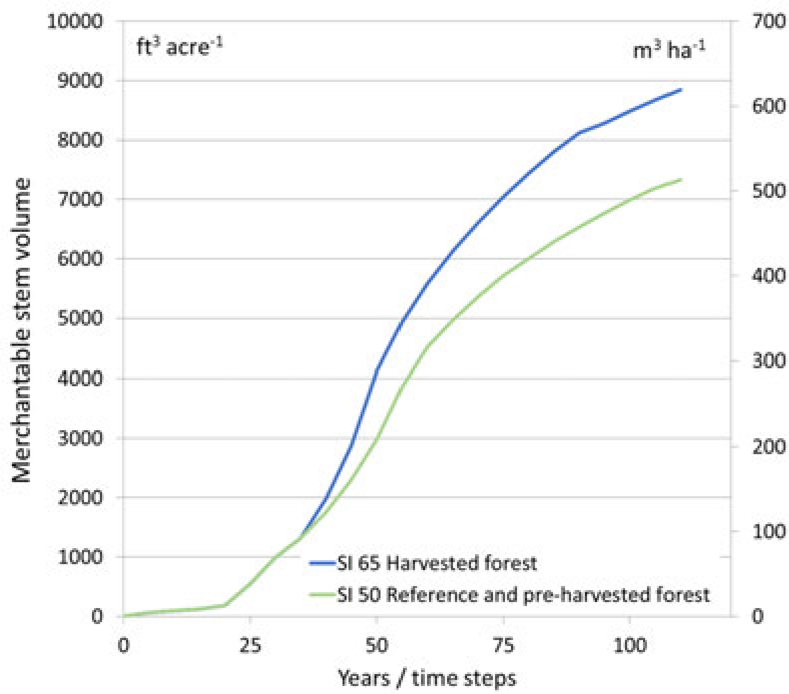

Figure 2. *Growth and yield curves of gross merchantable volume developed for the harvested watershed (SI 65) (WTH and SOH) and the reference watershed (SI 50) (REF), based on FVS-NE modeling of each watershed.*

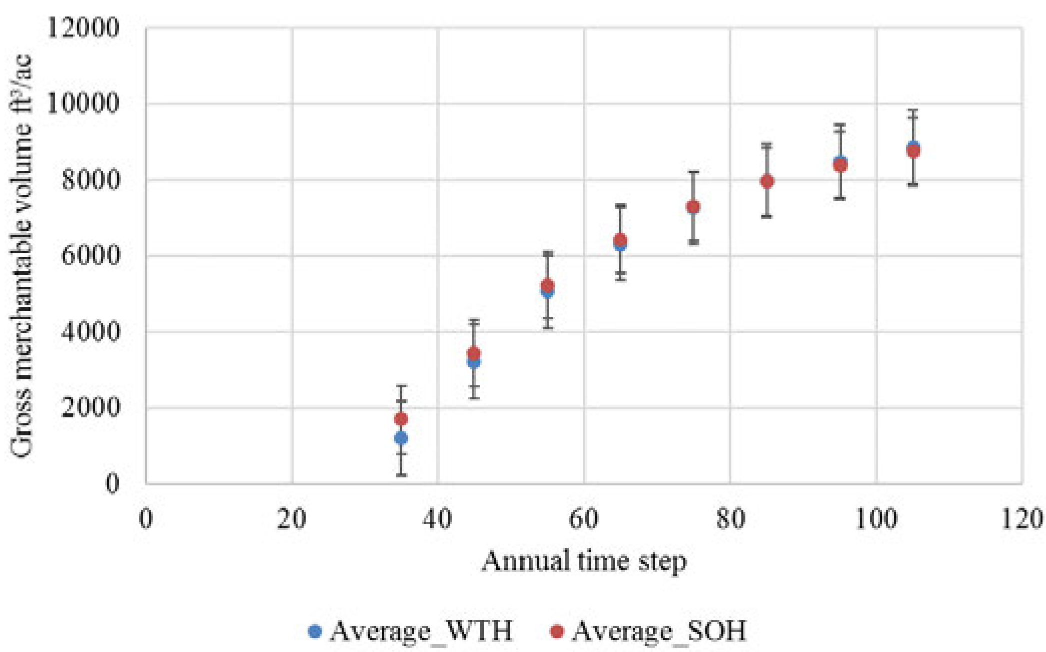

Figure 3. *Average merchantable stem volume with standard error (whiskers), based on FVS-NE modeling of each plot with site index 65. Modeling was based on data from WTH and SOH plots from the forest inventory done in 2016. There was a total of 13 and 5p.*

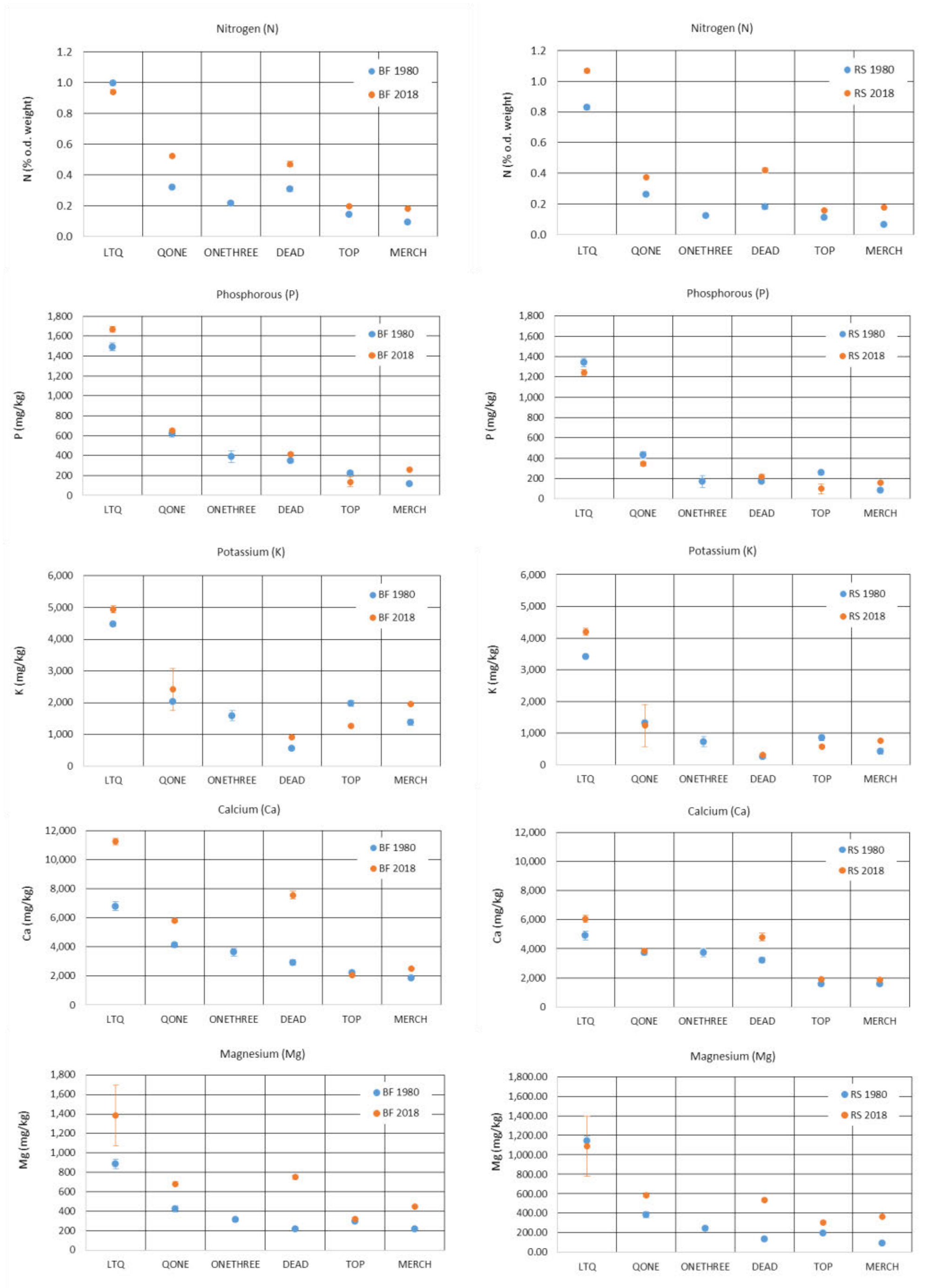

Figure 4. *Concentrations of N, P, K, Ca and Mg in living biomass components of balsam fir (BF) and red spruce (RS) in 1980 (see Appendices 8a-9e, Smith 1984) and 2018 on harvested watershed plots. Tree components sampled in 2018 were defined identically to those sampled in 1980 to develop biomass equations and estimate forest nutrient content prior to harvest; LTQ (< 1/4 inch (0.6 cm) branches plus foliage), QONE (1/4-1 inch (0.6-2.5 cm) branches plus foliage), ONETHREE (1-3 inch (2.5-7.6 cm) branches plus foliage), DEAD branches, TOP (unmerchantable stem < 10 cm diameter) and MERCH (merchantable stem >10 cm diameter) (Smith et al. 1986). Means and standard errors are plotted.*

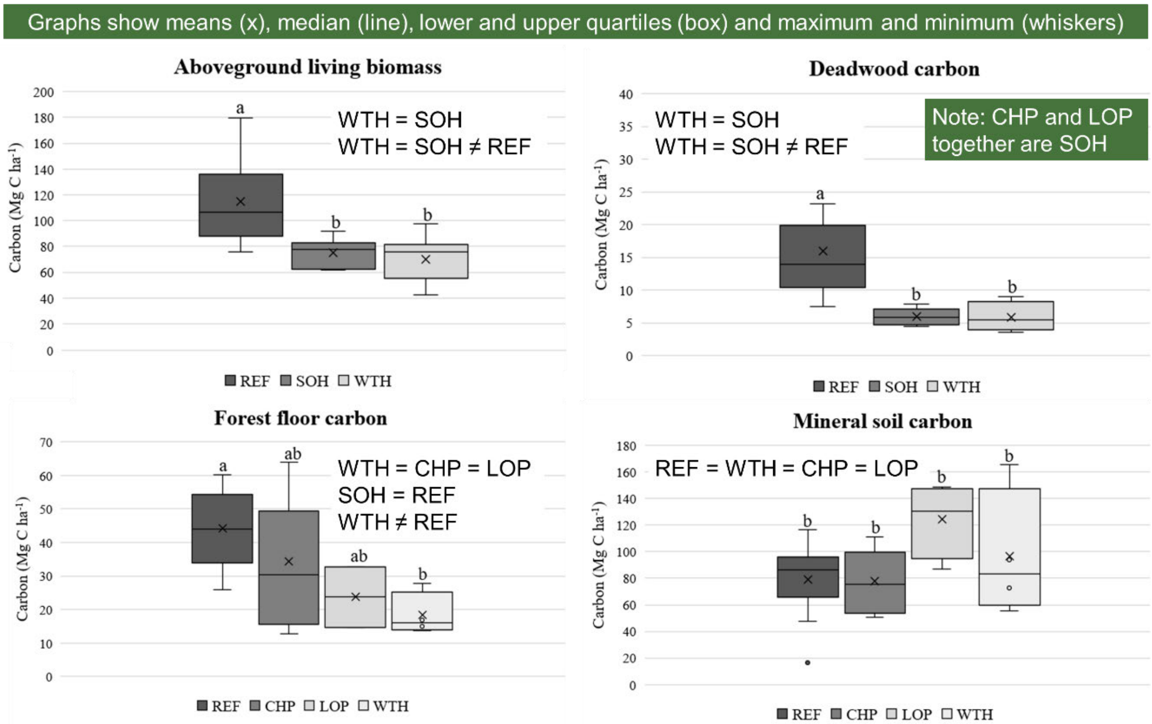

Figure 5*. Carbon content of aboveground living biomass, deadwood, forest floor and mineral soil (0-100 cm depth) pools for the treatments REF, CHP, LOP, and WTH, where LOP is stem-only harvesting with return of lopped residues LOP and CHP is stem-only harvesting with return of residues to the site , and SOH being CHP and LOP lumped together. Graphs portray average (x), median (horizontal line), upper and lower quartiles (maximum and minimum of the box), which represents 50% of the data, and maximum and minimum values (whiskers). Scatter plot is an outlier minimum value. Treatments with different letters are significantly different, α = 0.05.*

Key findings from CBM-CFS3 modeling work:

- Measured and modeled values did not agree in absolute value (Tables 1-3), particularly for soil and deadwood pools, although trends in CBM-CFS3 curves are similar to trends over time in empirical estimates (Figure 6).
- Initial model estimates for dead organic matter (DOM) C pools in forests historically subject to a partial disturbance regime (such as spruce budworm) rather than stand-replacing wildfire are more uncertain.
- Additional development is required for modeling DOM C dynamics where stand replacing wildfire is not presently a disturbance regime, as is the case for Weymouth Point.

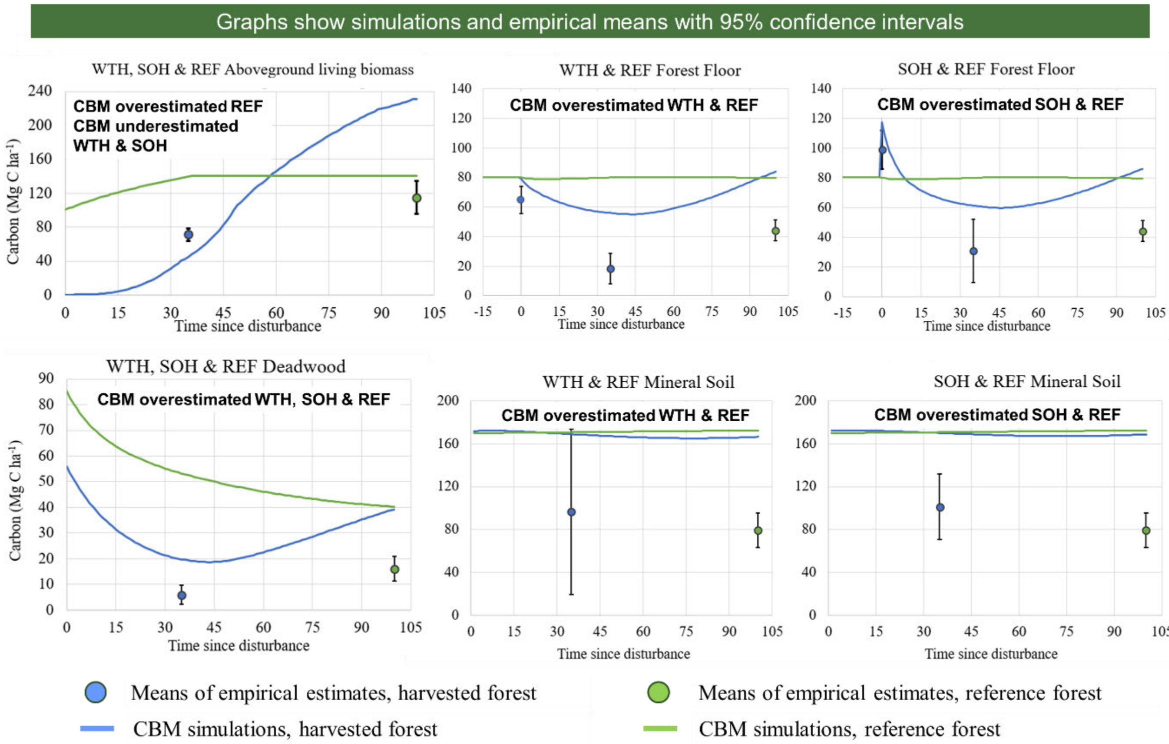

***Figure 6**. Simulated development in C pools of aboveground living biomass, deadwood, forest floor and mineral soil (0-100 cm depth) in the harvested and reference watersheds compared with 2016 empirical estimates (mean and 95% confidence interval).*

***Table 1**. Comparison of C stock pools modeled with CBM-CFS3 (growth and yield assuming Site Index 50) with empirical pools obtained by measurement and sampling of the reference watershed (REF) plots in 2016.*

Modeled C pools		Empirical pools		Difference
Component	Mg C ha^{-1}	Component	Mg C ha^{-1}	%
Merchantable stemwood	91.5	Merchantable stemwood	81.8	12
Other wood[1]	34.3	Other wood[1]	15.6	120
Foliage	14.6	Foliage	10.5	39
AB Biomass	**140.4**	**AB Biomass**	**114.9**	**22**
Fine roots	2.5	Fine roots	2.5	0
Coarse roots	28.7	Coarse roots	22.6	27
BG Biomass	**31.2**	**BG Biomass**	**25.1**	**24**
Total Biomass	**171.6**	**Total Biomass**	**140.1**	**22**
Large snags	14	Large snags	4.6	204
		Small snags	0.2	
		Dead stump	3.3	
Snag branches[2]	2.3	Small snags + dead stump	3.5	-34
Snags & stumps	16.3	Snags & stumps	8.1	101
CWD & FWD	23.9	CWD & FWD	7.9	203
Deadwood	**40.2**	**Deadwood**	**16**	**151**
Forest floor	79.7	Forest floor	44.2	80
Mineral soil	172.4	Mineral soil	75.7	128
Soil	**252.1**	**Soil**	**119.9**	**110**
Total DOM	**292.3**	**Total DOM**	**135.9**	**115**
Total Ecosystem	**463.9**	**Total Ecosystem**	**276**	**68**

[1]Other wood C pool is composed by submerchantable trees (<12.7 cm DBH), branches and living stumps.
[2]Snag branch C pool is composed by dead branches, small snags (<9.1 cm DBH) and dead stump.

***Table 2**. Comparison of C stock pools modeled with CBM-CFS3 (growth and yield assuming Site Index 65) with empirical pools obtained by measurement and sampling of the whole-tree harvested (WTH) plots in 2016.*

Modeled C pools		Empirical pools		Difference
Component	Mg C ha^{-1}	Component	Mg C ha^{-1}	%
Merchantable stemwood	22.1	Merchantable stemwood	20.3	9
Other wood[1]	18.3	Other wood[1]	34.5	-47
Foliage	4.7	Foliage	8	-41
AB Biomass	**45.1**	**AB Biomass**	**69.8**	**-35**
Fine roots	1.8	Fine roots	4.3	-58
Coarse roots	8.3	Coarse roots	11.5	-28
BG Biomass	**10**	**BG Biomass**	**15.8**	**-37**
Total Biomass	**55.1**	**Total Biomass**	**85.6**	**-36**
Snags stemwood	1	Large snags	0.6	67
		Small snags	1.2	
		Dead stump	1.9	
Snag branches[2]	0.9	Small snags + dead stump	3.1	-71
Snags & stumps	1.9	Snags & stumps	3.7	-49
CWD & FWD	17.7	CWD & FWD	2.2	705
Deadwood	**19.6**	**Deadwood**	**5.8**	**237**
Forest floor	56	Forest floor	18.4	204
Mineral soil	168.8	Mineral soil	96.8	74
Soil	**224.8**	**Soil**	**115.2**	**95**
Total DOM	**244.4**	**Total DOM**	**121.1**	**102**
Total Ecosystem	**299.5**	**Total Ecosystem**	**206.6**	**45**

[1]Other wood C pool is composed by sub merchantable trees (<12.7 cm DBH), branches and living stun
[2]Snag branches C pool in composed by dead branches, small snags (<9.1 cm DBH) and dead stump.

***Table 3.** Comparison of C stock pools modeled with CBM-CFS3 (growth and yield assuming Site Index 65) with empirical pools obtained by measurement and sampling of the stem-only harvested (SOH) plots in 2016.*

Modeled C pools		Empirical pools		Difference
Component	Mg C ha^{-1}	Component	Mg C ha^{-1}	%
Merchantable stemwood	22.1	Merchantable stemwood	28.9	-24
Other wood[1]	18.3	Other wood[1]	30.1	-39
Foliage	4.7	Foliage	8	-41
AB Biomass	**45.1**	**AB Biomass**	**75.2**	**-40**
Fine roots	1.8	Fine roots	4.5	-60
Coarse roots	8.3	Coarse roots	13.4	-38
BG Biomass	**10**	**BG Biomass**	**17.9**	**-44**
Total Biomass	**55.1**	**Total Biomass**	**93.1**	**-41**
Snags stemwood	1	Large snags	0.3	233
		Small snags	1.4	
		Dead stump	2.1	
Snag branches[2]	0.9	Snags small + dead stump	3.5	-74
Snags & stumps	1.9	Snags & stumps	3.8	-50
CWD & FWD	17.7	CWD & FWD	2.2	705
Deadwood	**19.6**	**Deadwood**	**6**	**227**
Forest floor	61.4	Forest floor	30.9	99
Mineral soil	173.4	Mineral soil	98.8	76
Soil	**234.8**	**Soil**	**129.7**	**81**
Total DOM	**254.4**	**Total DOM**	**135.7**	**87**
Total Ecosystem	**309.5**	**Total Ecosystem**	**228.8**	**35**

[1]Other wood C pool is composed by sub merchantable trees (<12.7 cm DBH), branches and living stum
[2]Snag branches C pool in composed by dead branches, small snags (<9.1 cm DBH) and dead stump.

Future Plans

Manuscripts planned and in progress:

- Preece et al. Response of tree and stand growth to whole-tree and stem-only harvesting. Manuscript in progress.
- Smith et al. Ecosystem nutrient pool response to whole-tree and stem-only harvesting. Manuscript in progress.
- Barusco et al. Ecosystem carbon pool response to whole-tree and stem-only harvesting. Manuscript in progress.
- Barusco et al. Forest carbon pools development over 35-years in a balsam fir-red spruce forest in northern central Maine after stem-only and whole-tree harvesting – model validation. Manuscript in progress.
- For inclusion in Smith et al.: Complete analysis of data from chemical analyses of bryophyte, forest floor and mineral soil subsamples collected from 25 0.5 m^2 quantitative soil pits and 25 morphological soil pits to determine differences in C, N, P, K, Ca and Mg concentrations and pools among the unharvested reference watershed (REF) and residue treatments (WTH, LOP and CHP).

References

Kull, S.J., Rampley, G.J., Morken, S., Metsaranta, J., Neilson, E.T. and Kurz, W.A. 2019. Operational-Scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3). Northern Forestry Center: Natural resources Canada. Victoria.

Smith, C. T. Jr. 1984. Nutrient removals and soil leaching from a whole-tree harvest of a red spruce (*Picea rubens* Sarg.) - balsam fir (*Abies balsamea* (L.) Mill.) Stand In North Central Maine. Ph.D thesis. University of Maine at Orono.

Smith, C.T., Jr., M.L. McCormack, Jr., J.W. Hornbeck and C.W. Martin. 1986. Nutrient and biomass removals from a red spruce   balsam fir whole tree harvest. Canadian Journal of Forest Research 16:381 388.

United States Department of Agriculture. 2018. Northeast (NE) Variant Overview Forest Vegetation Simulator. [online] Available at: https://www.fs.fed.us/fmsc/ftp/fvs/docs/overviews/FVSne_Overview.pdf [Accessed 01.05 2019].

Acknowledgements

Sincere thanks to Katahdin Forest Management and specifically Marcia McKeague and Dave Wilson for all that they have contributed to the Weymouth Point study since 1979. Thanks also are extended to colleagues Aaron Weiskittel and Jenna Zukswert at the University of Maine, and to Juha Metsaranta, Stephen Kull, and Werner Kurz with Natural Resources Canada, Canada for their support of research underpinning the M.Sc. thesis of Bruna Barusco and Agnė Grigaitė.

Evaluating the Effects of Timber Harvesting Operations on Soil

Anil Raj Kizha[1], Brian Edward Roth[2]

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[2]Cooperative Forestry Research Unit

Photo 1. *Recording inputs for machine rate calculation.*

Status: Final Report

Abstract

This controlled field experiment was developed to examine the difference in operational cost and potential soil disturbance (compaction and rutting) between two ground-based timber harvesting scenarios. The second objective was to evaluate the residual stand damage following different partial timber harvest silvicultural prescriptions and harvesting methods. The BMP cost was calculated using two methods – as a percentage of the skidders' productive machine hour (\$153.87 PMH^{-1}) devoted to BMP implementation and the cost per cubic meter of wood generated. In the residual stand damage study, bole wounds were the major form of damage. In terms of silvicultural prescription, higher intensity of harvest resulted in a larger amount of residual stand damage. The harvesting method also had a profound influence on the damages, with the Hyb CTL inflicting lesser damage to residual trees compared to WT.

Project Objectives

- Estimate and compare the cost of operation for a timber harvesting designed to minimize soil disturbance (Treatment A) and the current operational practices (business as usual, Treatment B).
- Compare and evaluate the effects on soil compaction by the treatments
- Assess residual stand damage in varying silvicultural prescription and harvesting methods

Approach

- Stand inventory
- Detail time and motion study
- Evaluating rut depth
- Recorded soil penetration forces
- Transect survey to estimate residual stand damage

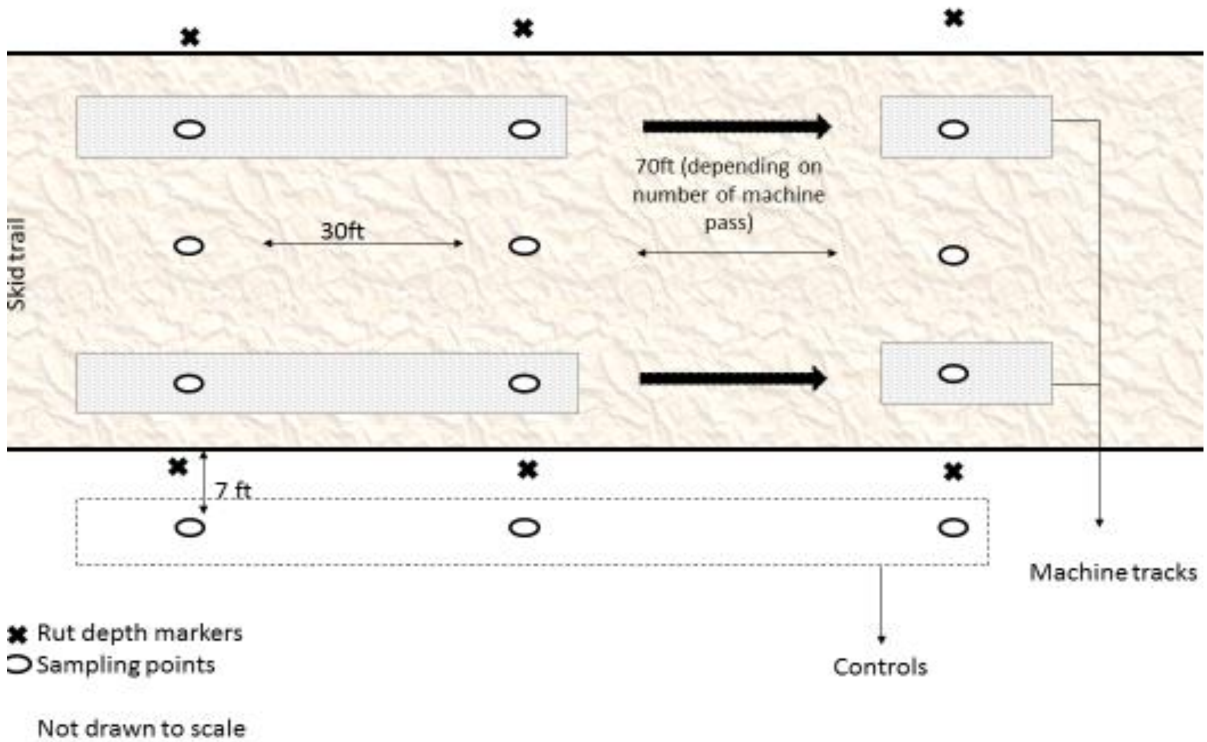

***Figure 1**. Study design adopted for collecting samples for measuring soil compaction and rut.*

Key Findings / Accomplishments

- One peer-reviewed article has been published and one is under preparation; One thesis defended and two capstone projects completed; several presentations and field demonstrations
- The field-based study was conducted on two MASN sites.
- The average time dedicated for picking slash at the landing and handling slash ranged from 1.1–3.8 min and accounted for 7–32% of skidder's DFC.
- The cost of implementing BMPs per cubic meter of wood produced ranged from $1.00–$3.70.
- The cost of BMP implementation was directly influenced by extant and the severity of the sensitive zone within the harvest zone, and less impacted by the skidding distance.
- BMP implementation can be incorporated into a mainstream harvesting operation without much affecting the economic feasibility.
- Other than the pressure exerted by machines, skidding direction and skid trail slope was also found to affect the bulk density and total porosity of the soil (Solgi et al., 2017)
- Moisture content of the soil plays an important role in aiding soil disturbance. Higher the moisture content, higher will be the susceptibility to soil disturbance (Han et al., 2006)
- The Hybrid Cut-to-length treatment had fewer wounds per ha and lower damage severity compared to whole-tree harvest.

***Table 1**. The average time taken to implement Best Management Practices (BMPs) in different silvicultural treatments*

Treatment[a]	**BMP Time**[b]	**Average DFC (mins. /turn)**	**BMP as % of average DFC**	**BMP Implementation Cost**	
				($/PMH)[c]	**($ m^{-3})** [d]
PH I	3.8	11.8	32	49.8	3.7
PH II	2.4	7.2	34	51.6	2.0
CC I	1.2	5.1	23	35.7	1.2
CC II	1.1	16.4	7	10.0	1.0

[a]PH is partial harvest and CC is clear-cut
[b]Time (in minutes) for implementing BMP was determined by summing picking up slash time, and handling slash from the skidders' Delay Free Cycle (DFC) time.
[c] Implementation cost calculated as a percentage of the skidders' productive machine hour (PMH) devoted for BMP implementation. The operational cost per PMH was calculated to be $153.87.
[d] BMP Implementation cost calculated in $ m^{-3} based on machine rate calculation.

***Table 2**. Cost (US$ m^{-3}) and productivity (m^3 PMH^{-1}) of the different phases of the operation for wood handled in the partial harvest (PH) and clear-cutting (CC) treatments*

Operational Phase			Cost				Productivity	
	PH I	PH II	Combined PH	CC I	CC II	Combined CC	Combine d PH	Combined CC
Felling	1.76	2.65	1.74	1.53	0.74	1.38	101.88	128.72
Skidding[a]	39.76	25.38	15.98	29.58	10.24	7.72	19.07	39.55
Processing	5.96	2.97	3.63	3.69	4.46	3.71	67.41	39.63
Sorting	0.60	0.49	0.63	0.74	0.74	1.11	258.71	146.33
Loading[b]	0.96	0.96	0.96	0.96	0.96	0.96	168.93	168.93
Total	49.04	32.45	22.94	36.50	17.14	14.88		

[a] Cost of skidding includes values for both the skidders used.
[b]Loading cost was same for both treatments as the piles were combined during sorting to facilitate loading of similar market products.

__Table 3.__ Results from the soil compaction and rut depth study

Observations	Rut Depth		Compaction (Average Penetration Depth)	
	Mean (cm)	**SD**	**Mean (cm)**	**SD**
Rut vs	17.3	6.3	16.5	5.4
Crown	10.9*	5.6	21.8*	8.3
Slash vs	16.5	6.2	16.5	5.7
Without slash	19.3*	6.1	16.3	5.7
No turning vs	17.3	6.2	16.0	5.4
Turning	22.6*	8.2	17.0	5.7
Waterlogged vs	18.5	5.8	16.3	5.7
Non waterlogged	12.9*	5.0	18.0	6.9
No slope vs	12.9	5.0	15.7	5.7
Slope	14.0	3.0	19.6*	5.0
First five passes vs	14.5	5.6	16.8	5.7
5-10 passes	11.9*	4.3	14.7*	5.7

***** Shows a significant difference (p=0.05)

__Table 4.__ Tree damages normalized for stand-level for the various treatment blocks on a per ha basis

	Study Site I			Study Site II	
	DLC I	**CTR I**	**OSR I**	**DLCII**	**CTR II**
Total number of tree damaged	47	65	131	52	95
Total number of wound	80	102	186	152	240
Average wound. tree^{-1}	1.70	1.57	1.42	2.92	2.53
Inventory area (ha)	2.03	1.87	2.01	5.06	9.58
Wound. ha^{-1}	39.41	54.55	92.54	30.04	25.05
Tree damaged. ha^{-1}	23.15	34.76	65.17	10.28	9.92

Where, DLC: Diameter Limit Cut; CTR- Crop Tree Release; OSR- Overstory Removal.

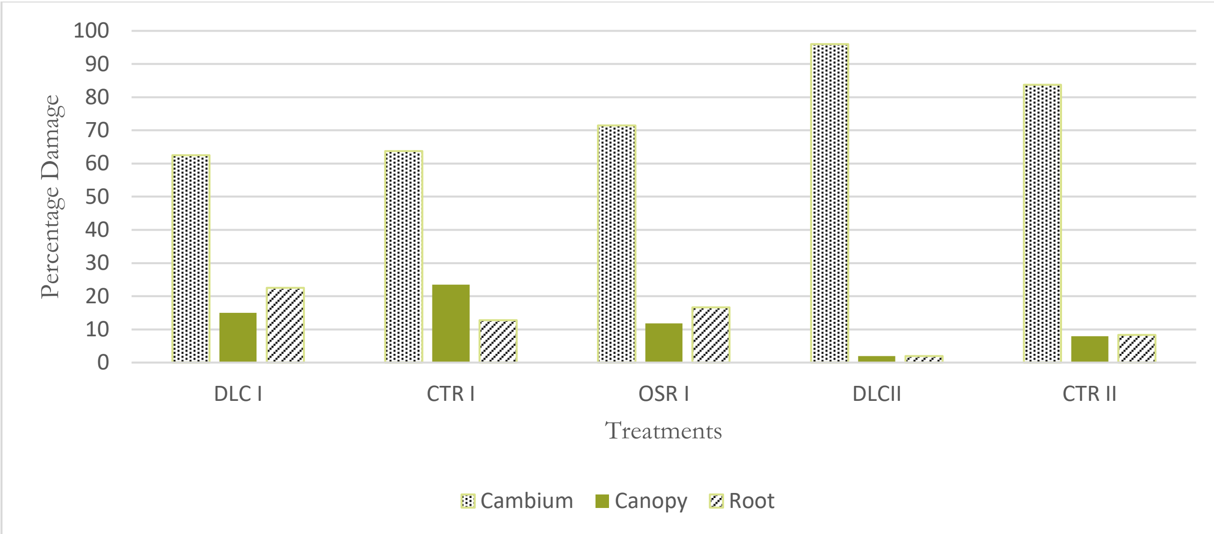

Figure 2. *Types of residual stand damage recorded from treatment blocks using transect sampling method. Where DLC: Diameter Limit Cut; CTR- Crop Tree Release; OSR- Overstory Removal; "I" and "II" refers to study site classification.*

Photo 2. *Slasher loading log trucks at the Grand Falls Operation.*

Photo 3. *Stroke-boom delimber processing at the landing in Grand Falls Operation.*

References

Soman H., Kizha A.R., Roth B.E. 2019. Impacts of Silvicultural Prescriptions and Implementation of Best Management Practices on Timber Harvesting Costs. International Journal of Forest Engineering 30(1): 14-25. doi.org/10.1080/14942119.2019.156269

Kizha AR, Nahor ER, Coogen N, George AK, Louis LT. Residual Stand Damage across Varying Silvicultural Prescriptions. *In preparation for* Forest Ecology and Management.

Han, H.-S., Page-Dumroese, D., Han, S.-K., & Tirocke, J. (2006). Effects of Slash, Machine Passes, and Soil Moisture on Penetration Resistance in a Cut-to-length Harvesting. International Journal of Forest Engineering, 17(2), 11–24. https://doi.org/10.1080/14942119.2006.10702532

Solgi, A., Naghdi, R., Marchi, E., Laschi, A., Behjou, F. K., Hemmati, V., & Masumian, A. (2019). Impact Assessment of Skidding Extraction: Effects on Physical and Chemical Properties of Forest Soils and on Maple Seedling Growing along the Skid Trail. Forests, 10(2), 134. https://doi.org/10.3390/f10020134

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Our appreciation goes to Matt Stedman (Irving LLC), and Allen Lebrun (American Forest Management) for their cooperation on the operational aspect of study. Ashish Alex and Jenna Zukswert (CFRU) for assisting in various aspects of editing and data processing.

Quantifying the Ecological and Economic Outcomes of Alternative Riparian Management Strategies

Hamish Greig[1], Amanda Klemmer[1], Robert Northington[2], Shawn Fraver[1], Mindy Crandall[1], and Ethel Wilkerson[3]

[1]University of Maine
[2]Husson University
[3]Manomet Inc.

Photo 1. *Our team conducting water chemistry in the field.*

Status: Year 1 of 2

Project Objectives

Our overall goal is to measure the long-term costs and ecological benefits of alternative riparian buffer designs and provide data that can be used to guide riparian management decisions. We will achieve this goal by completing the following objectives:

1. *Write a white paper summarizing the current state of knowledge of the investment cost and effectiveness of riparian buffers in the Northeast.*

2. *Resample an existing CFRU-funded experiment to quantify the long-term (17-year) ecological outcomes and economic investment in alternative riparian buffer designs for forested freshwater resources*.

Approach

- We partnered with a senior Ecology and Environmental Science capstone class (EES 489) in Fall 2019 semester to conduct the literature search and synthesis underlying Objective 1. The students were split into groups tasked with completing a meta-analysis on the effectiveness of alternative riparian buffer strategies on physical and chemical properties of streams, stream ecological communities, forest ecosystems, and the economic value of riparian timber resources.

- Each student group was guided by a collaborator or graduate student from our research team. Students searched for literature, extracted qualitative and quantitative information from published studies, and produced written and oral reports on their findings. In addition to these products, we collated literature into a database with the goal of producing a searchable resource of relevant research articles for CFRU members.

- We completed two summers of field data collection to complete with Objective 2. Data collection included riparian forest and timber inventories; stream habitat quality, invertebrates and fish; riparian insects; and ecosystem processes (litter decomposition rates).
- Study sites included 14 western Maine streams subject to alternative riparian management treatments during the 2001 - 2007 CRFU-funded Manomet headwater stream study. These study sizes encompassed three replicates of each of four alternative riparian management approaches: clearcut harvest with i) no buffer, ii) 11m, or iii) 24 m buffers, and iv) a partial harvest without a buffer. We also included two replicate streams that were unharvested controls.
- Our forest and stream field team of undergraduate students Kathleen Brown and Ethan Cantin, working with EES MS student, Mitch Paisker, and faculty Hamish Greig and Amanda Klemmer (SBE), Shawn Fraver (SFR) and Robert Northington (Husson) has completed laboratory analyses and is currently finalizing data analysis on the diversity and abundance of freshwater and riparian biota, and the breakdown of forest leaves in streams. These data will enable us to quantify the ecological outcomes of alternative riparian management approaches. Using the field data, Eric Miller, a Master's student in the School of Economics, has been working with faculty members Mindy Crandall (SFR) and Kathleen Bell (SOE) to model the value differences between the riparian buffer treatments using forest growth and yield programs. These value differences will help inform landowners of the potential economic and ecological trade-offs that result from the different buffer widths.

Photo 2. *Our team sampling stream habitat in headwater streams in western Maine.*

Photo 3. *Emerging stream insects in headwater streams in western Maine.*

: 1

Key Findings / Accomplishments

- Literature searches and synthesis conducted by our undergraduate collaborators for Objective 1 will form the basis of our white paper, to be completed in the next funding year. In addition to generating products that contribute to specific research objectives, the partnership enhanced workforce development by training 16 undergraduate students in the economic and ecological aspects of riparian forest management. Students also practiced skills associated with the scientific process, from forming hypotheses and questions, to collecting and analyzing data, and written/oral communication of results.

- Data analyses of our fieldwork for Objective 2 is being finalized, but initial results indicate that ecological communities reflect a legacy of riparian management approaches 17 years after initial harvest occurred. For example, invertebrate communities differed among riparian management treatments in the relative abundance of different insect species. Communities in control streams were distinct from those in harvested streams, and streams subject to partial harvest and clear cuts with no riparian buffers were the most different from unharvested controls. Streams with 11m and 23m buffers typically supported communities that were intermediate between control streams and those with 0m buffers.

- Although ecological communities differed among riparian management treatments, the total diversity (number of species per stream) and total abundance of insects in streams and adjacent riparian forests appeared robust to riparian harvest. Moreover, we observed consistent rates of

***Photo 4**. Liter breakdown with submerged leaf bags in headwater streams in western Maine.*

leaf breakdown across different riparian management treatments, suggesting differences in ecological communities did not translate to impaired stream ecosystem function.

Future Plans

- Data analysis will continue using field data generated by the previous two summers of sampling in our 14 western Maine headwaters streams. These analyses include ecological responses in the stream and riparian zones, as well as economic analyses of timber resources associated with alternative riparian management approaches.

- Our team will collate data extracted from undergraduate literature syntheses on knowledge of the investment cost and effectiveness of riparian buffers in the Northeast and augment datasets with additional searches as necessary. These data will form the basis of the white paper to be completed over the next funding year.

- We aim to complete one more field season in our western Maine headwater streams focusing on quantifying fluxes of materials and nutrients between the forest and stream ecosystems. Sampling will include measuring inputs of litter and insects from forests into streams, and the export of winged adult aquatic insects from streams into the forest. These fluxes represent forest-freshwater connections that are central to the integrity of forested watersheds and their ecosystems services.

Maine's Adaptive Silviculture Network (MASN)

Brian Roth[1], Aaron Weiskittel[2], Anil Raj Kizha.[2], Amber Roth[2]

[1]Cooperative Forestry Research Unit [2]University of Maine

Status: Progress Report (Year 3)

Summary

This is the second year of a five-year project to establish a new region-wide study series: Maine's Adaptive Silviculture Network (MASN). The MASN study will be the backbone for new research in the areas of growth and yield, wildlife habitat, harvest productivity, regeneration dynamics, remote sensing of inventory, forest health, and others. There has been much interest from researchers wishing to take advantage of these study sites on research problems of interest to CFRU membership. In addition to the American Forest Management (AFM) installation established at Grand Falls township (TWP) in the summer of 2017, there have been two additional installations established in 2018: T16 R8 on Irving Woodlands, LLC and T13 R15 on Seven Islands Land Company. Three more installations are laid out and harvests planned for 2019: Stetsontown TWP on Wagner Forest Management, Thorndike TWP on Weyerhaeuser Company, and the Massabesic Experimental Forest of the U.S. Forest Service (USFS) Northern Research Station.

Project Objectives

- Establish a network of operational research installations across Maine representing low, medium, and high site productivities across hardwood, mixedwood, and softwood stand types.
- Encourage researchers to make use of these outdoor field laboratories for researching problems applicable to CFRU members.

Approach

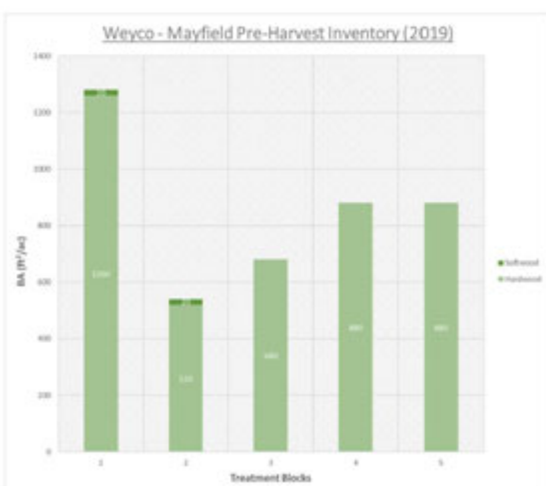
- Working with regional forest managers, identify potential areas with uniform soils, drainage class, topography, stand type, and recent harvest history.

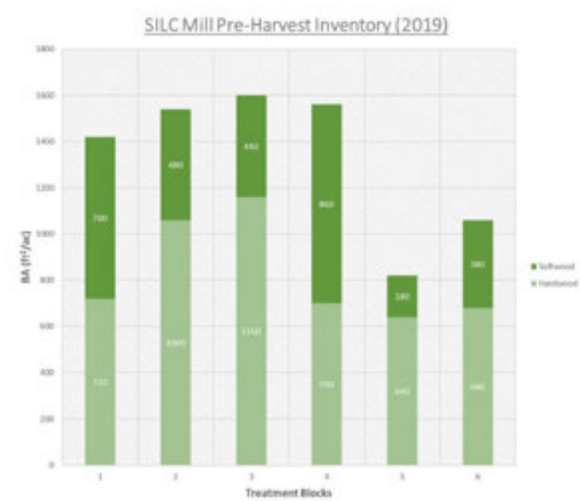
2019 MASN Site Locations

- For each installation, delineate four to seven treatment blocks and randomly assign and implement various operational silvicultural treatments representing the full range of operational harvest conditions found in Maine (e.g., clearcut, overstory removal, crop tree release, first and second entry thinning). A delayed harvest control block will be included.
- Across a grid of permanent sample points on each installation, collect baseline pre- and post-harvest data, including overstory and understory vegetation inventories, forest bird surveys, tree damage assessments, 360-degree photography, high-resolution aerial imagery, and more.

Key Findings/Accomplishments

- Baseline protocols have been documented and preliminary data collected on forest birds, inventory, understory vegetation, harvest damage, and 360-degree photo documentation.
- 8 basal area summaries for the sites that had been inventoried in 2019.
- The files for Stetsontown, T13R15 and Thorndike have good comparisons for pre/post basal area summaries around a harvest.
- The files for SILC Mill, Mayfield, CLWH and Baskahegan were the 2019 installations and so no post-harvest data is available yet.
- The following figures depict basal area summaries are for the sites that were inventoried during the 2019 summer field season. Note that the JDI T16R8 file has two post-harvest inventories summarized in it (one from 2018, one from 2019) because we could not find a pre-harvest inventory dataset in between those chronologically. The files for Stetsontown, T13R15 and Thorndike have good comparisons for pre/post basal area summaries around a harvest. The files for SILC Mill, Mayfield, CLWH and Baskahegan were the 2019 installations and so no post-harvest data is available yet.

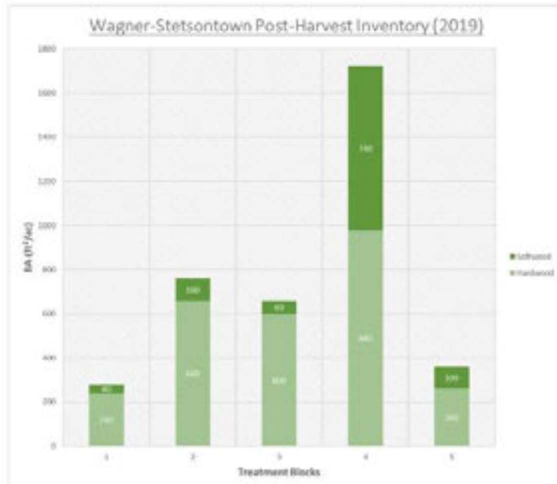


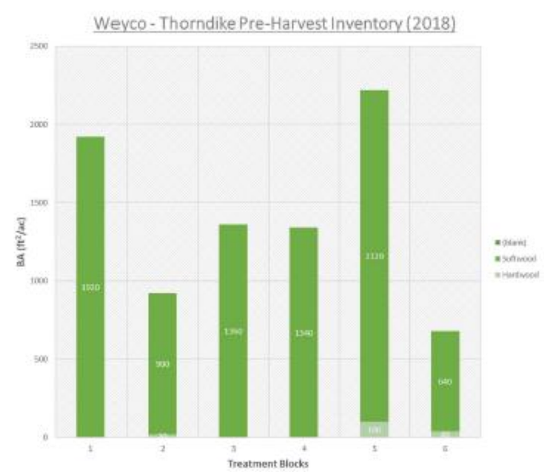


Note. These sites were laid out in 2019 and prescriptions for the treatment blocks have yet to be defined.

- *The silvicultural prescriptions that have been applied to the treatment blocks are as follows:*
  - *1 – Overstory Removal*
  - *2 – High Grade*
  - *3 – Crop Tree Selection*
  - *4 – Control*
  - *5 – Clearcut*

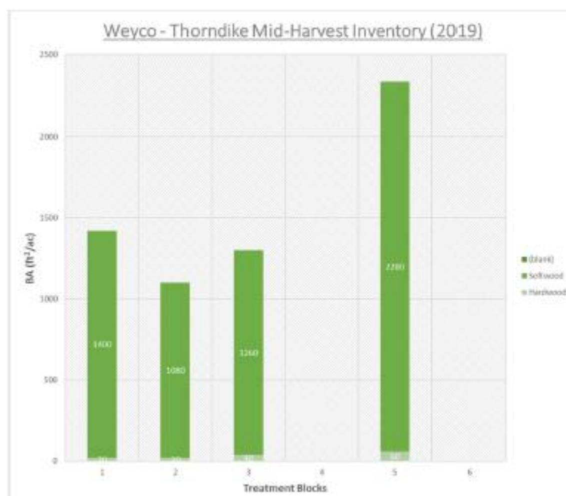
- This site was laid out in 2018 and has been a part of MASN since that time.

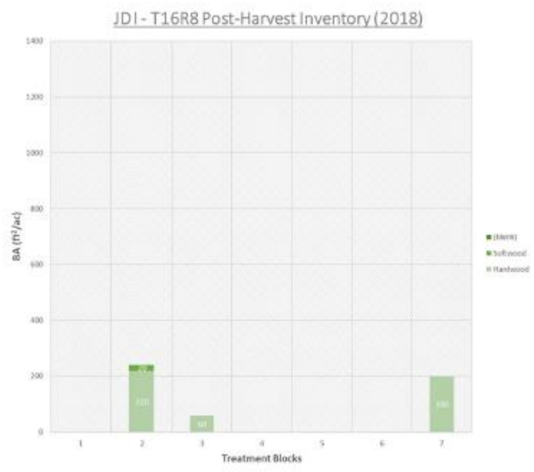




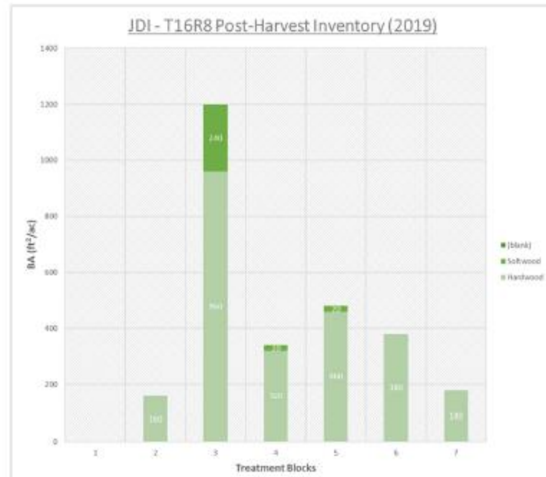
- *The silvicultural prescriptions that have been applied to the treatment blocks are as follows:*
  - *1 – CC, Spray and PCT for Dominance*
  - *2 – Control*
  - *3 – CC, Site Prep, Spray and Plant*
  - *4 – CC, Spray and PCT for Species*
  - *5 – CC, No Spray or PCT*
  - *6 – Commercial Thinning*

- This site was laid out in 2018 and has been a part of MASN since that time.

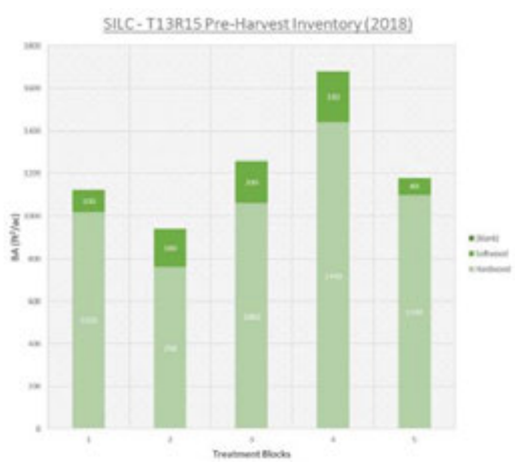




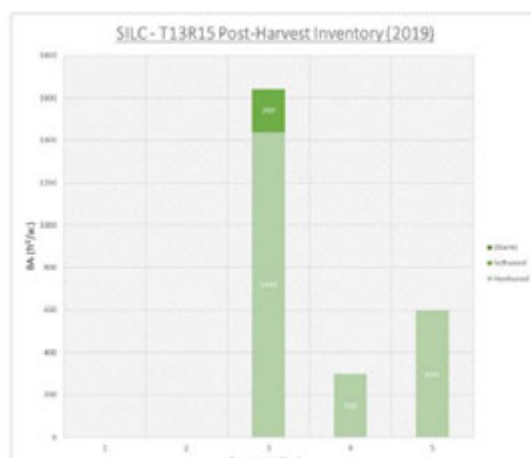
- This site was laid out in 2017 and has been a part of MASN since that time.



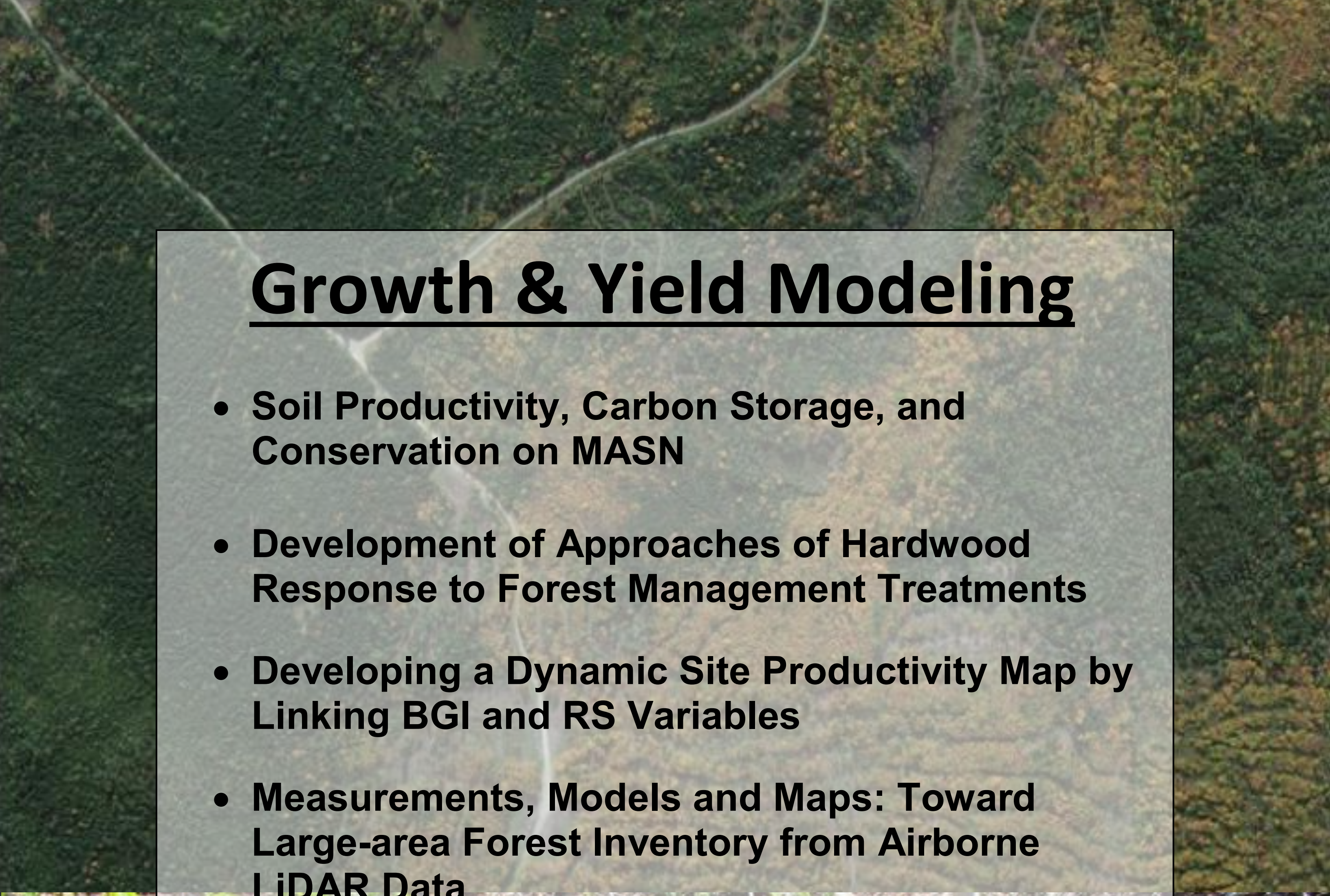
- *The silvicultural prescriptions that have been applied to the treatment blocks are as follows:*
  - *1 – CTR with spray*
  - *2 – CTR with mechanical site prep*
  - *3 – Delayed Harvest*
  - *4 – Clearcut with SW planting*
  - *5 – Overstory Removal*
  - *6 – High Grade*
  - *7 – Clearcut with HW Release*



- This site was laid out in 2017 and has been a part of MASN since that time.



- *The silvicultural prescriptions that have been applied to the treatment blocks are as follows:*
  - *1 – Clearcut*
  - *2 – Overstory Removal*
  - *3 – Delayed Harvest*
  - *4 – High Grade*
  - *5 – Crop Tree Release*



Growth & Yield Modeling

- **Soil Productivity, Carbon Storage, and Conservation on MASN**
- **Development of Approaches of Hardwood Response to Forest Management Treatments**
- **Developing a Dynamic Site Productivity Map by Linking BGI and RS Variables**
- **Measurements, Models and Maps: Toward Large-area Forest Inventory from Airborne LiDAR Data**
- **Cartographic Depth-to-Water Mapping for Maine**
- **SBW Population Monitoring: L2 Surveys**

Assessing and Monitoring Soil Productivity, Carbon Storage, and Conservation on the Maine Adaptive Silviculture Experimental Network (MASN)

Joshua Puhlick[1], Marie-Cécile Gruselle[1], Ivan Fernandez[1], Brian Roth[1]

[1]School of Forest Resources, University of Maine

Status: Year 1 of 3

Abstract
The main objective of this project is to evaluate the influence of different forest management practices on soil productivity, carbon (C) storage, and conservation across operational-scale research installations in Maine. We will identify forest management practices and soil properties that: (1) promote adequate nutrient availability that supports forest sustainability, (2) maintain or enhance soil C stocks, and (3) minimize compaction and erosion. This will provide CFRU members with information related to soils during third-party audits of compliance to SFI, Outcome Based Forestry, and similar programs.

Background

- In December 2017, Puhlick, Gruselle, and Fernandez were awarded a Sustainable Forestry Initiative (SFI) Conservation grant for assessing and monitoring the influence of forest management practices on soil productivity, C storage, and conservation in the Acadian Forest Region. As part of the SFI grant agreement, soils were sampled on two of the Maine Adaptive Silviculture Experimental Network (MASEN) installations. The influence of three forest management treatments on soils will be investigated. These efforts will inform SFI Forest Management Principles and Standards.

Photo 1. *Emily Roth and Joshua Goldsmith measuring downed woody materials after timber harvesting at one of the MASN installations (photo credit: Joshua Puhlick).*

Project Objectives

1. Evaluate the influence of different forest management practices on soil productivity, C storage, and conservation across operational-scale research installations in Maine.
2. Develop a database of forest management effects on aboveground and belowground C pools and soil physical and chemical properties in the Acadian Forest Region.
3. Conduct analyses of archived data to inform the SFI Forest Management Standard and forest management practices promoting the sustainability of soil resources.

Key Findings / Accomplishments

- In 2018 and 2019 (before and after timber harvesting), soils were collected in northern hardwood stands managed by J.D. Irving and Seven Islands Land Company. The soils series of the study areas fall within the Chesuncook (the Maine state soil) catena. The study areas support a diverse range of species including sugar maple, red maple, yellow birch, American beech, spruces, and balsam fir. The forest management practices that will evaluated for their influence on soils include irregular shelterwood cutting, crop tree release, partial harvesting, and control (no cutting in 2018).

***Photo 2**. Emily Roth and Joshua Goldsmith collecting an organic horizon at one of the MASN installations (photo credit: Joshua Puhlick).*

- Soil samples from 52 quantitative soil pits and 150 organic horizons were collected over both years. 550 soil samples were collected to determine mineral soil bulk density for evaluating soil compaction after harvesting. The installations were harvested from mid to late summer of 2018. Live and standing dead trees as well as downed woody debris were measured in association with quantitative soil pit locations.

Future Plans

- In 2020, sample an additional MASN installation in northern Maine that will be established between Ashland and Portage Lake on Seven Islands Land Company timberlands.

Acknowledgements

We especially thank the foresters and leaders of J.D. Irving and Seven Islands Land Company for meeting with us and discussing the details of the project as well as providing the land area to conduct the MASN project.

Development of Individual-Tree and Stand-Level Approaches for Predicting Hardwood Mortality and Growth Response to Forest Management Treatments in Mixed-Species Forests of Northeastern North America

Joshua J. Puhlick[1], Christian Kuehne[1]

[1]*School of Forest Resources, University of Maine*

Status: Final Report

Abstract

In year two of this two-year project, we used repeat measurements of crop trees on the Penobscot Experimental Forest Rehabilitation Study and the Silvicultural Intensity and Species Composition (SIComp) experiment to evaluate hardwood growth response to forest management treatments. These data will also be used to develop growth and mortality response functions for common hardwood species of the northeast North America to account for treatment effects after various forest management activities.

Project Objectives

- Compile and standardize data from existing tree-ring chronologies and forest inventories with repeat measurements of tree attributes in the Northeast.
- Develop growth and mortality response functions for common hardwood species of the Northeast to account for treatment effects after various forest management activities.
- Compare performance of derived sub-models of growth and mortality after forest management treatments to current predictions in the Northeast and Acadian variants of the Forest Vegetation Simulator (FVS-NE and FVS-ACD, respectively).
- Incorporate potential growth and mortality treatment response functions into FVS-ACD.

Key Findings / Accomplishments

We analyzed data from repeat measurements of crop trees on the Penobscot Experimental Forest Rehabilitation Study and the SIComp experiment. The Rehabilitation Study measurements were used in analysis of crop tree growth and quality in cutover mixed-wood stands after rehabilitation treatments. A manuscript with the results of this analysis were published in a peer-reviewed journal. Analysis of the SIComp experiment data were divided into two parts: (1) the evaluation of common softwood and hardwood species response to precommercial management activities, and (2) assessing improved white spruce and hybrid poplar crop tree growth over time as well as individual crop tree and stand metrics 14 years after planting. The results of the SIComp analyses were presented in a Center for Advanced Forestry Systems report. The measurements and findings from both studies will be used to develop tree growth and yield models for early successional hardwood and mixed-wood stands.

Future Plans

- Plans include developing growth and mortality response functions for common hardwood species, which will improve the prediction of stand and tree-level growth and mortality in FVS-ACD.

- We will also work with the US Forest Service to incorporate the hardwood growth and mortality modifiers into the online version of FVS-ACD.

- Additional findings will be provided to CFRU in a future report.

Acknowledgements

We thank the Gaetan Pelletier (Northern Hardwoods Research Institute) and Chris Hennigar (University of New Brunswick) for meeting with us and discussing the details of the project.

Developing a Refined Forest Site Productivity Map for Maine and New Brunswick by Linking Biomass Growth Index to Remotely Sensed Variables

Parinaz Rahimzadeh-Bajgiran[1], Aaron Weiskittel[1], Chris Hennigar[2]

[1]*University of Maine*
[2]*University of New Brunswick*

Status: Final Report

Abstract

Due to the essential need for a fine-resolution region-wide map of forest productivity for effective large-scale forestry planning and management, a novel productivity model, biomass growth index (BGI), was suggested by Hennigar et al., (2016) for the Acadian region. Given the strong potential for the improvement of this model by incorporating remote sensing (RS) data, several newly-launched Sentinel-2 satellite derived variables were selected for the analysis. 21 variables including 9 single spectral bands and 12 spectral vegetation indices (SVIs)) with combination of other variables were used to predict tree volume/ha (GTV) and tree height. The results showed a 10–12 % increase in out of bag (OOB) r^2 when Sentinel-2 variables were included in the prediction of total volume in combination with BGI. Four Sentinel-2 variables were finally selected for biomass growth prediction in Maine and New Brunswick using 7738 provincial permanent sample plots. Among four best variables, S2REP was selected to produce BGI. v2 for Maine and New Brunswick due to its highly significant performance in predicting BGI. S2REP was identified as the most important variable over others to have known influence on site productivity.

Project Objectives

The overall goal of this project was incorporating remote sensing data into the BGI model (Hennigar et al., 2016) and present a more accurate BGI model for Maine and New Brunswick. Specific objectives are:

1. *Estimating various spectral vegetation indices (SVIs) from Sentinel-2 satellite imagery.*
2. *Evaluating the performance of SVIs using plot inventory data.*

3. *Normalizing SVI data layers by land cover/land use, history of previous and current forest disturbances and forest composition data.*

4. *Developing a model based on the combination of Sentinel-2 derived SVIs and site factors, improving the existing BGI model for the regions with higher uncertainty and provide a more accurate, high-resolution BGI map (BGI v.2) for Maine and New Brunswick.*

Approach

- Sentinel-2 imagery has spectral bands in red-edge (RE) regions that were not available in previous multi-spectral satellites like Landsat. These spectral bands are more efficient to detect forest biophysical attributes such as leaf chlorophyll content, LAI and fractional vegetation cover (Delegido et al. 2011, Rahimzadeh-Bajgiran et al., 2012). In this project based on previous research, 21 Sentinel-2 satellite derived variables were selected for the analysis. In Year 1, Sentinel-2 derived variables in combination with other variables were used to predict LiDAR-derived tree volume/ha (GTV) and height. Total volume/ha and height were modeled by Random Forest (Breiman, 2001) using species composition, age, and management type (Mgmt), BGI and Sentinel-2 spectral bands and indices. The details of this part and the results were presented in Year 1 report.

- Based on the results obtained in Year 1, four best Sentinel-2 variables were selected including green and near infrared (NIR) bands, Red edge position index (S2REP) and Normalized Difference Vegetation Index 45 (NDVI45). Seamless mosaics of Sentinel-2 best indices and bands were created for summer time (late July to early September) in 2018 and 2019 for Maine and New Brunswick using over 50 Sentinel-2 images. All variables were normalized. Normalization process includes removing non-forested regions and recent harvests from the layers. Also a new geographically weighted regression model was developed to smooth and fill missing pixels in the mosaics by incorporating DEM, depth to water table and slope data (Figure 1).

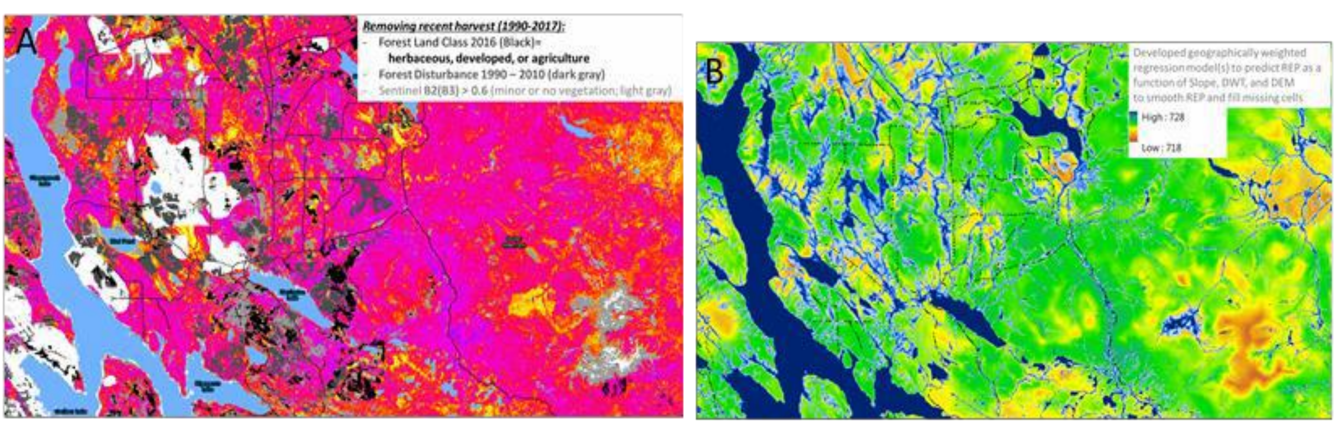


Figure 1. *Examples of A) normalization using land cover/land use and recent harvest data, B) applying geographically weighted regression model on S2REP map.*

- The selected Sentinel-2 variables were used for biomass growth prediction in Maine and New Brunswick using over 5000 provincial permanent sample plots (PSPs) using Random Forest method. Later the best variables were used to produce BGI v.2 for Maine and New Brunswick.

Key Findings / Accomplishments

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

- Results showed a 10-12 % increase in out of bag (OOB) r^2 when Sentinel-2 data were included in the prediction of total volume. Prediction of stand-level volume based on age, species composition, management type, and BGI yielded an OOB r^2 of 68%, whereas the addition of the Sentinel-2 data increased the OOB r^2 to 80.5%. Additionally, dropping species composition as a predictor variable did not significantly affect the OOB r^2 (80% vs. 78%).

- Removing age and management variables and running the model on only BGI and three Sentinel-2 derived variables (green band, NIR band and S2REP) yielded an OOB r^2 of 62%.

- After reviewing the correlation matrix of the bands and indices, green and NIR bands, S2REP and NDVI45 were selected as the best bands and indices.

- Results for height prediction incorporating Sentinal-2 data were similar to those obtained for GTV.

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

- Prediction of total volume (GTV), with spectral bands and indices performed the best when two single bands (green and NIR) and two SVIs (S2REP and NDVI45) were used.

- Prediction of GTV using only the best bands and indices and BGI resulted in an out of bag r^2 of 62.5%. Removing BGI reduced the out of bag r^2 to 59.3%. BGI does not seem to have considerable effects on predicting GTV. Results for height prediction incorporating Sentinal-2 data were similar to those obtained for GTV (only the best bands and indices resulted in an out of bag r^2 of 59.9%)

Prediction of biomass growth rate in Maine and New Brunswick using Sentinel-2 best bands and indices:

- S2REP was identified as the most important variable over others (including site variables and Sentinel-2 variable) to have known influence on site productivity.
- Green band and NDVI45 were not well correlated with plot growth rate.

Table 1. *BGI base model and new model performance for Maine and New Brunswick (mean absolute bias (MAB), mean square error (MSE) and mean bias (MB)).*

Base BGI Model							
Predictions	**Subset**	**Plot#**	**Mean**	**MSE**	**R^2**	**MB**	**MAB**
OOB	Model	7738	2804.821	744109.9	46.61137	1.079514	673.616
OOB	Maine	3856	2901.483	880325	44.31148	80.19982	731.4799
OOB	New Brunswick	3882	2708.793	608807.2	48.82085	-79.43052	616.1398
Base BGI Model +S2REP							
Predictions	**Subset**	**Plot#**	**Mean**	**MSE**	**R^2**	**MB**	**MAB**
OOB	Model	7738	2804.821	726068.6	47.90581	3.948975	663.0142
OOB	Maine	3856	2901.483	859243.1	45.6451	91.9703	719.3875
OOB	New Brunswick	3882	2708.793	593785.9	50.0836	-88.37067	607.0184

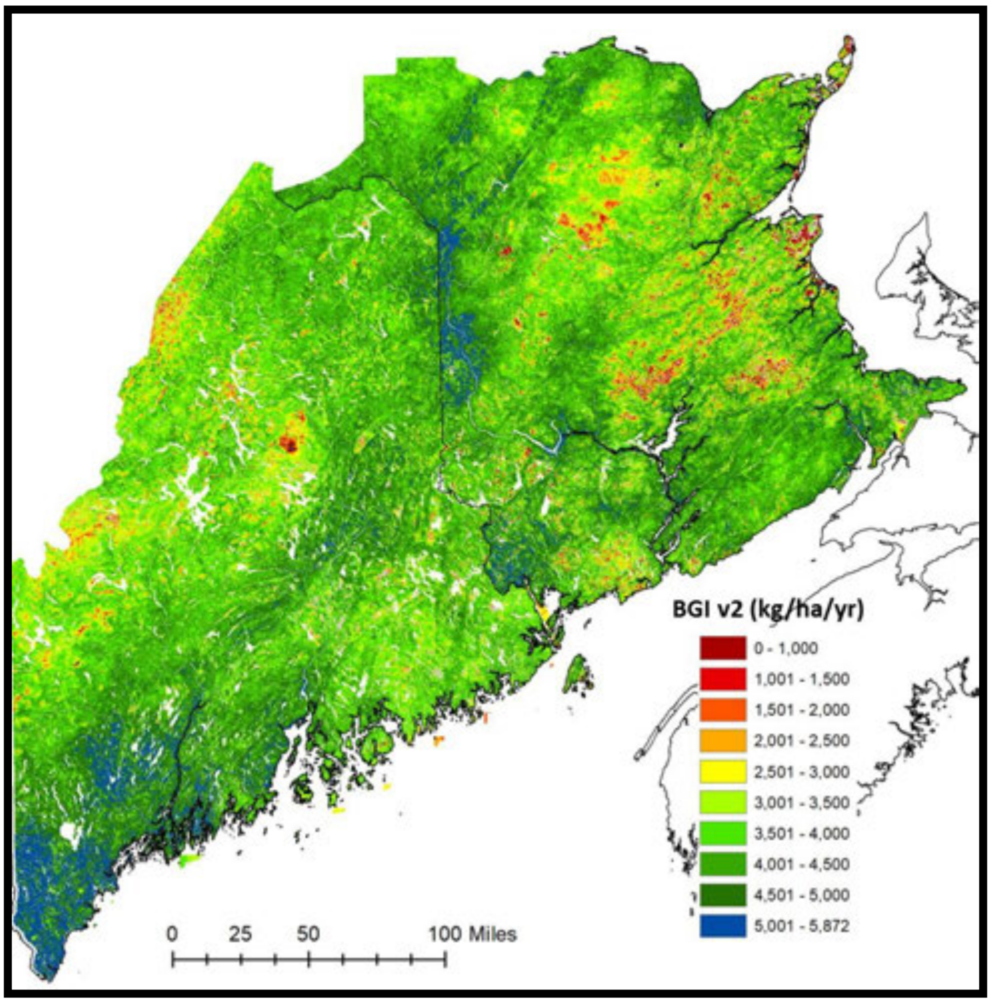


Figure 2. *New Biomass Growth Index map for Maine and New Brunswick.*

- NIR and S2REP were found to be correlated with plot biomass growth rate but NIR band had correlation with hardwoods and was not used in the final model.
- Using early summer imagery and possible haze issues in 5 out of 26 tiles in each mosaic, relatively low positional accuracy of PSP coordinates and removing PSPs from New Scotia and Prince Edward Island from the model lowered the performance of the model. Addressing the above issues will improve the model performance.
- While only a slight improvement in accuracy of the model occurred (around 2%), **substantial changes to coefficients of other variables were evident; i.e., some site variables became less important when S2REP was included** (Table 1).
- When BGI v2 was mapped for all of Maine and New Brunswick (Figure 2), some regional difference was evident, but locally there were more visually striking changes in good vs poor sites. The S2REP incorporated BGI maps clearly predict poorer site productivity in areas of exposed rock in the NB highlands, compared to the previous BGI map.

Future Plans

- Replacing above mentioned Sentinel-2 tiles with mid-summer imagery and releasing BGI v.2 map.

References

Breiman, L., 2001. Random forests. Machine learning, 45(1), pp.5-32.

Delegido, J., Verrelst, J., Alonso, L. and Moreno, J., 2011. Evaluation of sentinel-2 red-edge bands for empirical estimation of green LAI and chlorophyll content. Sensors, 11(7), pp.7063-7081.

Hennigar, C., Weiskittel, A.R., Allen, H.L., MacLean, D.A., 2016. Development and evaluation of a biomass increment-based index for site productivity. Canadian Journal of Forest Research, 10.1139/cjfr-2016-0330.

Pfeifer, M., Gonsamo, A., Disney, M., Pellikka, P. and Marchant, R., 2012. Leaf area index for biomes of the Eastern Arc Mountains: Landsat and SPOT observations along precipitation and altitude gradients. Remote Sensing of Environment, 118, pp.103-115.

Rahimzadeh-Bajgiran, P., Munehiro, M. and Omasa, K., 2012. Relationships between the photochemical reflectance index (PRI) and chlorophyll fluorescence parameters and plant pigment indices at different leaf growth stages. Photosynthesis Research, 113(1-3), pp.261-271.

Measurements, Models and Maps: Toward a Reliable and Cost-Effective Workflow for Large-Area Forest Inventory from Airborne LiDAR Data

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Status: Year 1 of 3

Abstract

In its first year, this project has organized and carried out initial investigations into the use of LiDAR remote sensing analysis to enhance the design and operation of inventory programs for Maine's forest industry stakeholders. The research conducted here is evaluating ground-based inventory plot designs together with existing, publicly-available Airborne Laser Scanning (ALS) data sets processed in a high-performance computing environment for workflow efficacy in generating geospatial data products useful for forest management. For these initial investigations, we have partnered with the Seven Islands Land Company in using their Ashland West property (~150,000 acres) to evaluate the impact of plot type, size and location accuracy on model prediction of forest inventory attributes derived from relating field data sampling with wall-to-wall LiDAR measurements across the study area. Our initial results have highlighted some of the challenges in linking plot data with the LiDAR models – particularly with variable radius plots with large locational error – but also suggest opportunities to improve results with alternative plot designs and ALS data sets that will be the focus of investigations over the second year of this project.

Project Objectives

- To develop LiDAR metrics and models for accurately and consistently mapping enhanced forest inventory (EFI) attributes over large managed forest areas in Maine.
- To evaluate the various plot layout and measurement requirements for calibrating ALS-based EFI models for large-area, mixed-species and structurally-complex forests.
- To produce, disseminate and train stakeholders in the use of high quality EFI maps and analytics deliverables designed to inform the management of large forest areas.

Approach

- Overall, we are building a set of workflows for generating gridded maps of forest inventory attributes from ALS data sets using an area-based modeling approach calibrated on ground-based plot data.
- The first step in the workflow is to acquire and organize the plot data locations and measurements from the ground-based inventory that are used to 'clip out' the associated locations and metrics generated from the LiDAR point clouds.
- Next, a statistical model is developed that relates the LiDAR metrics to the plot-based inventory measurements for each concurrent location. The model is evaluated in terms of its explanatory power, average error and bias in matching the predictions to the observations.
- Once the model is calibrated (and verified) at the plot locations, it is then applied over a wall-to-wall, gridded raster of LiDAR metrics to "predict" the inventory attributes for each grid cell in the study area. The results of the model application are evaluated against a held-out subset of plots, stand-level information and/ or parcel-level summaries.
- A designated set of alternative models are then developed, applied and evaluated to investigate applied research questions on the impacts of plot design, location accuracy, stratification and sampling intensity, along with ALS density and other acquisition specifications.
- Finally, findings from these applied research investigations will be vetted within the community through scientific publications and conference presentations and disseminated to stakeholders through annual hands-on workshops and a "best practices guidelines" report to be delivered at the end of the project.

Key Findings / Accomplishments

- A comprehensive, flexible and efficient workflow was developed for building, applying and evaluating EFI prediction maps using an area-based approach. The LidR package (Romain 2018) in R is used to calculate the LiDAR metrics, Microsoft Excel is used to prepare the variable-radius calibration plot data, and randomForest (Breiman 2001) is used to perform the EFI variable prediction modeling.

- In testing several alternative calibration data sets, model performance showed significant improvement when built on a newer set of plot data located with high-accuracy (survey-grade) GPS as compared to older data collected with a lower-accuracy (navigation-grade) system. The modeling also demonstrated the importance of consistency with scaling and summary calculations in the plot data for reducing error in the LiDAR-based models (Table 1).

- Volume predictions were also compared to an advanced artificial intelligence-based method by species composition, which showed our randomForest-based method performed better (Figure 1).

- Wall-to-wall EFI maps of percent softwood, stem density, quadratic mean diameter, basal area and volume were generated for the entire Ashland West study area.

- Visual evaluation of the EFI maps suggest broad agreement in spatial patterns with basemap imagery (Figures 2 and 3) as well as a regional-scale LiDAR data product developed using artificial intelligence. The predictions from the locally-calibrated models generally showed better agreement with observations in this study area than the regionally-developed products.

- In collaboration with CFRU members, the WGL organized and carried out several outreach events and technical workshops related to project research involving the use of LiDAR in forest inventory and management, including terrain and hydrologic modeling and wet areas mapping workshops (at UMaine campuses in Orono and Presque Isle) and a joint CFRU/WGL exhibit at the 2019 New England Society of American Foresters meeting in Burlington, VT.

Table 1. *Measures of model performance in predicting each EFI variable among calibration plots located using the low-, high- and combined- accuracy plots.*

Metric	Combined Plots	Low-accuracy Plots	High-accuracy Plots	Variable Importance
PSW				Mean int, Zpcumx*, TC
Rsq	60	60	60	
RMSE	26	26	25	
Mean Bias	0.33	0.3	0.24	
CV (%)	46.5	46.3	47.8	
TPA				Mean int, Lower HT pct, NDVI
Rsq	10	10	6	
RMSE	209	206	243	

Table 1. Continued

Metric	Combined Plots	Low-accuracy Plots	High-accuracy Plots	Variable Importance
Mean Bias	-9.6	-9.4	-14.3	
CV (%)	69.2	69.8	82.4	
QMD				Max HT, Upper HT pct, Zpcumx*
Rsq	42	42	33	
RMSE	2.74	2.8	2.44	
Mean Bias	-0.11	-0.12	-0.09	
CV (%)	33.2	33.7	28.6	
BApAc				Mean int, Upper HT pct
Rsq	25	25	18	
RMSE	47	47	57	
Mean Bias	-1.73	-1.81	-2.02	
CV (%)	57.4	58.5	60.1	
CUFTpAc				Upper HT Pct, Max HT, Mean int
Rsq	20	19	29	
RMSE	613	638	393	
Mean Bias	-35	-39	-5.6	
CV (%)	95.8	100	63.2	
AGB				Upper HT Percentiles
Rsq	17	32	32	
RMSE	1.69	1.17	1.17	
Mean Bias	-0.09	-0.01	0	
CV (%)	84.9	59.1	60.6	

**Cumulative percentage of returns in the x^{th} layer*

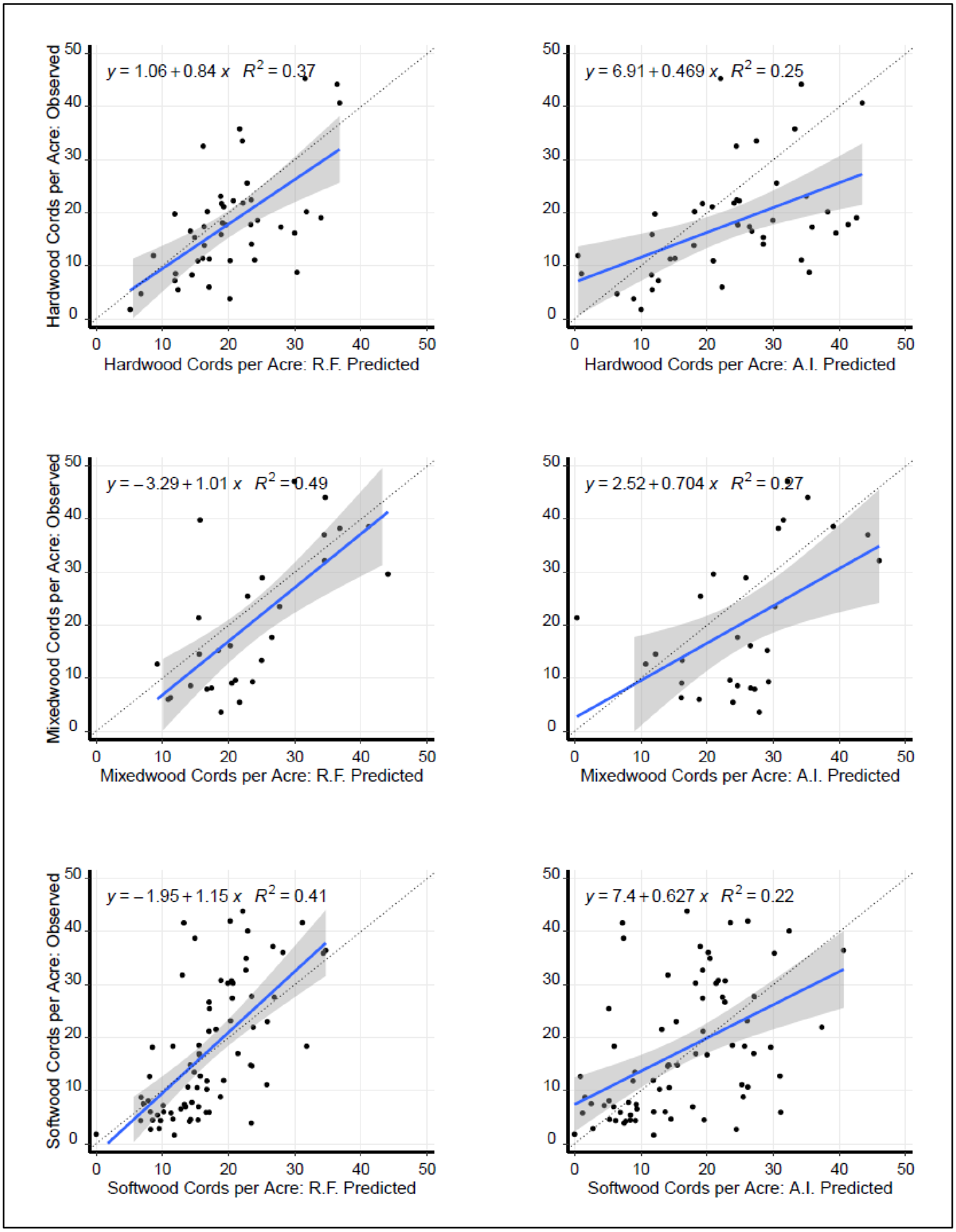


Figure 1. *randomForest vs. artificial intelligence-based comparisons of predicted volume by species composition.*

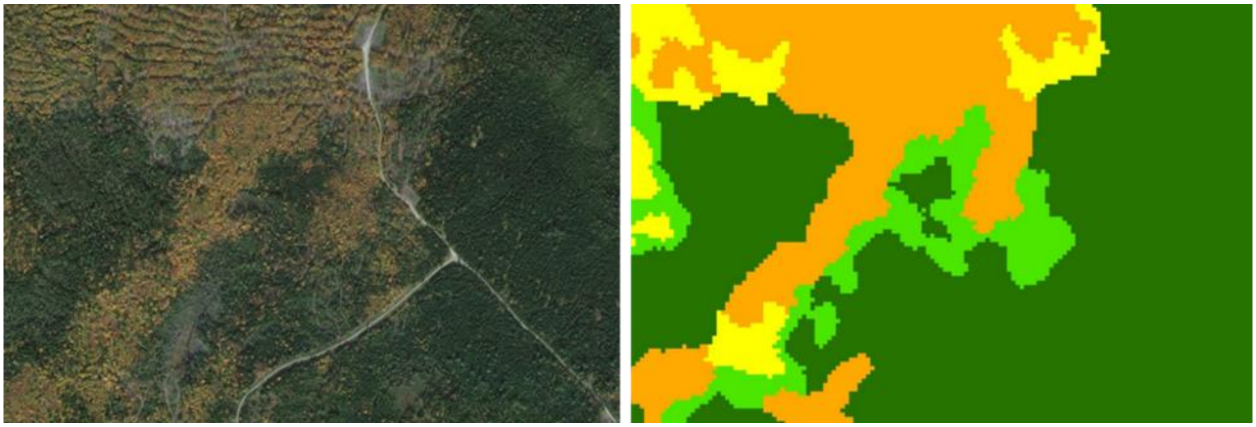


Figure 2. *Comparison of PSW predictions (right) with true color (fall) basemap imagery (left).*

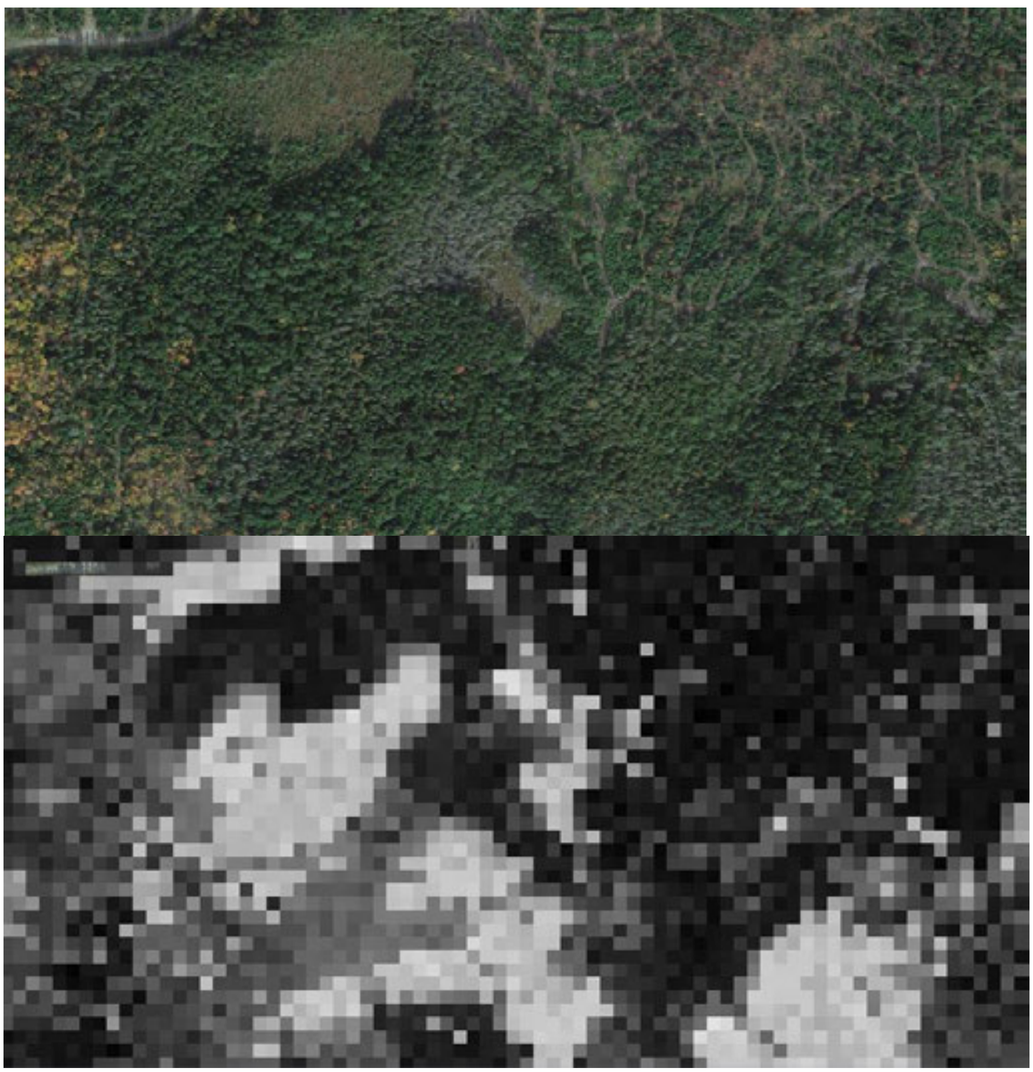


Figure 3. *Comparison of Basal Area predictions (bottom) with true color basemap imagery (top).*

Cartographic Depth-to-Water Mapping for Maine, Using Existing and Forthcoming LiDAR-DEM Coverage

Paul A. Arp[1]

[1]*Faculty of Forestry & Env. Management, UNB*

Status: Year 1 of 2

Abstract

The project involved presenting the current state of UNB's LiDAR-based flow-channel, depression and wet-areas mapping initiative through presentations and rollout workshops, by focusing on select proof-of-concept sites. The purpose of these presentations and workshops was to inform how geomorphic features such as flow channels, depressions, cartographic depth-to-water and related seasonal variations can be emulated based on digital elevation models (1 m resolution). The information so generated can be provided using (e.g.) ArcMap packages for quick display of:

- The digital elevation model (DEM)
- Its hill-shaded version
- DEM-derived depression areas, with volumes up to the depression pour points
- Flow networks including stream attributes with hydro-technical attributes by segment, with 0.25-ha (snow melt season), 1-ha (wet summer/fall season) and 4-ha (end of summer) upslope flow initiation areas;
- Cartographic depth-to-water maps, based on, e.g., 0.25-, 1- and 4-ha upslope flow initiation areas to emulate soil wetness by season;
- Data layers for depressions, wetlands, lakes, shorelines, roads, and other transportation corridors
- Road-stream crossings, with upslope flow accumulation specifications
- Extending the above information using UAV surveys at 5 to 10 cm resolution for location specific projects, e.g. MASN sites.

Project Objectives

1. To conduct two rollout workshops at the following locations:
    - University of Maine, at Orono, with field excursion to the Penobscot Experimental Forest

- University of Maine, at Presque Isle, with field excursion to JDI's forest management area.

2. Some of this material was also presented to foresters and officials working for:
    - Prentiss & Carlisle (Bangor), about 15 foresters plus senior staff members attending
    - Weyerhaeuser (Bingham), with field excursion, with foresters attending and with communications to headquarters
    - Government of Maine, Department of Agriculture, Conservation and Forestry (Augusta).

Approach

The workshops and presentations centered on the following topics:

- delineating flow channels, depressions, wet areas, wetlands and lakes using LiDAR DEMs
- mapping vegetation distribution by moisture regimes
- soil trafficability
- optimizing and analyzing alternative road and trail layouts
- forest plantation site selection and productivity
- UAV surveying

Key Findings / Accomplishments

- LiDAR- and UAV-based flow-channel, depression and depth-to-water in Orono, Bangor, Presque Isle, Augusta and Bingham presentations and workshops.
- Field excursions (Univ. of Maine Forest, JDI forest management area (north east of Stockholm, Northern Maine), Weyerhaeuser Forest Management area (Bingham).
- Mapping results generally coincide with GPS-tracked streams, wetland borders, depressions, and road-stream crossing locations, within meters.
- Soil trafficability depends on topographic location, weather and soil substrate. LiDAR-generated trafficability maps can be produced when soils are saturated, at field capacity, and when the soils are at, say, one third of field capacity.
- Methods are being developed to map species-related site suitability's.
- We are linked with the CFRU-approved project on digital soil mapping (c/o J. Johanson) entitled: "Methods and tools for interdisciplinary modeling of hydrology, soils and forest productivity throughout Maine and the surrounding region."

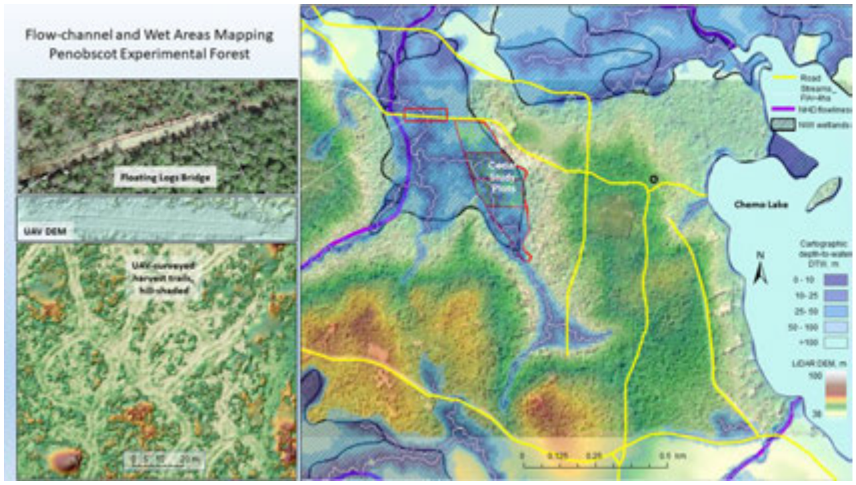


Figure 1. *Field excursion, Penobscot Experimental Forest, Cedar Study Area. Details generated with currently available LiDAR-DEM generated flow-lines and water-body delineations. Also shown: NWI-wetlands delineations, and NHD flowlines. LiDAR DEM source: Maine GeoLibrary. LiDAR-DEM and UAV-DEM derived flow channels and associated wet areas: FWRC, UNB. On the left: details of the UAV DEM survey (c/o Wheatland Lab, U. of Maine).*

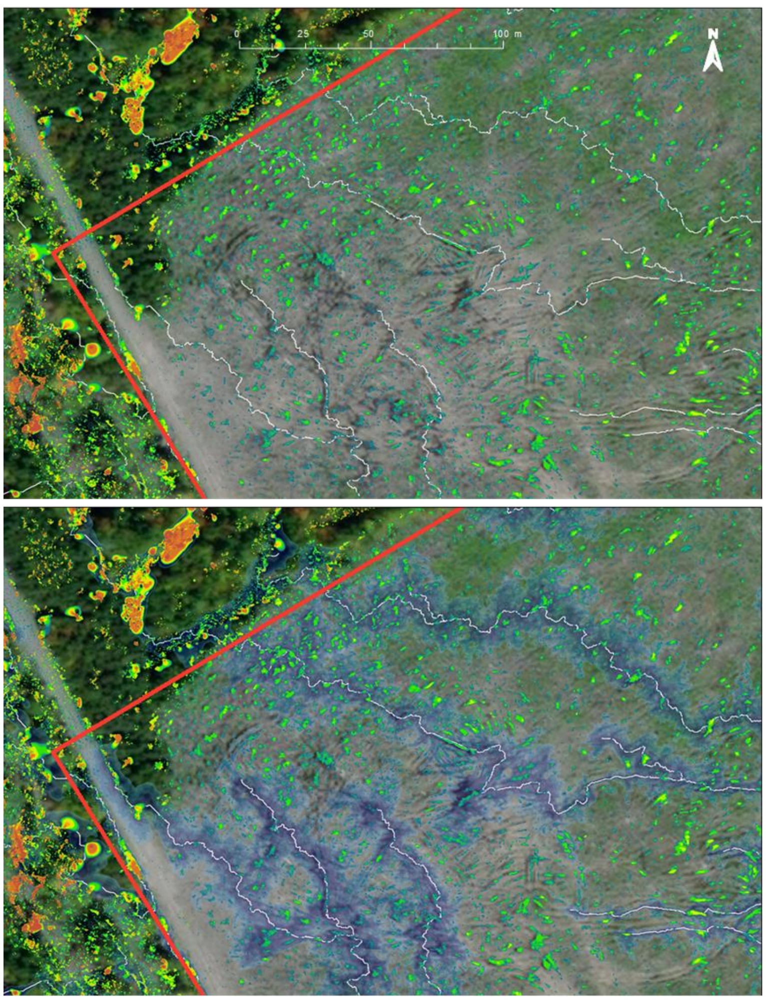


Figure 2. *Field excursion, northern Maine, 12. June, 2019. Ascertaining soil trafficability on an upland drainage-challenged portion of a cutblock. Surface image reveals extent of soil rutting. LiDAR- and UAV-generated DEMs reveal (i) flow channels with > 0.1 ha upslope flow accumulation area (top), (ii) associated extent of soil wetness based on DTW mapping (0 to 40 cm shaded blue; bottom) and (iii) depressions (colored green to light green). Brown spots outside the red cutblock border refer to canopy gaps within the uncut area.*

Spruce Budworm Population Monitoring: L2 Surveys

Brian Roth[1], Erin Simons-Legaard[2], Kasey Legaard[2]

[1]Cooperative Forestry Research Unit, [2]University of Maine

Status: Progress Report (Year 3)

Summary

Sampling the second instar (L2) larval population of spruce budworm can identify areas of local population growth (versus immigration) and help managers anticipate the degree of defoliation to be expected during the next growing season. Although there is generally thought to be a positive relationship between pheromone trap catch and larval abundance, the strength of that relationship is likely to vary in space and time. In Maine and New Brunswick, L2 counts have so far been highly variable in areas with high moth trap catch and overall rates of L2 occurrence across plots have been relatively low. This project aims to collect data on pheromone trap catch and larval abundance in northern Maine ahead of the next outbreak.

Project Objectives

- The main objective for this project is to support repeat sampling of spruce budworm larval (L2) densities from 2017 to 2019 across northern Maine.
- In combination with ongoing pheromone trapping, the information gained through this project would allow assembly of a long-term time series of budworm population monitoring data for more than 250 locations broadly distributed across northern Maine.

Approach

- Collect one branch sample per each of three trees co-located with pheromone traps during the fall and winter. Locations are selected in areas where pheromone trap catches had been high, modeling predicted at-risk stands, or previous samples had been collected.
- The Fettes Method is used to quantify defoliation on current-year growth. This method provides a systematic approach to measuring defoliation. It was employed during the last budworm outbreak in Maine, and is currently in use in Quebec. The Fettes Method captures defoliation from all causes and can be used to estimate both current-year defoliation and cumulative defoliation.
- Collected branch samples continue to be transported to the Canadian Forest Service Insect Laboratory in Fredericton, NB for processing, with data and maps shared annually on the Maine SBW Task Force website: https://www.sprucebudwormmaine.org/map/l2-survey-maps/

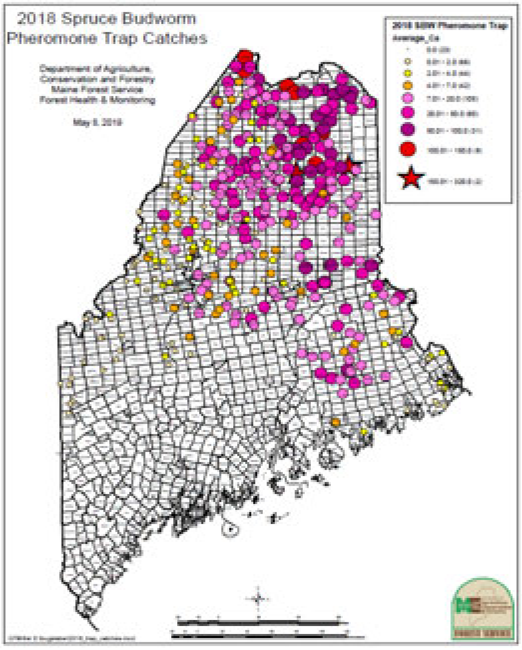


Figure 1. *2018 distribution of spruce budworm pheromone traps and trap catches across Maine (Source: Maine Forest Service).*

Key Findings/Accomplishments

- Spruce budworm populations in Maine have left the "stable" phase and appear to be building. Pheromone and light trap catches have been up above zero for a number of years, defoliation in Quebec has increased year after year, and defoliation has been mapped in New Brunswick. The expanded 2018 spruce budworm pheromone survey shows spruce budworm is widespread but still at low numbers across the trapping range. Average county-wide catches in 2018 were at least double in Aroostook, Hancock, Penobscot and Piscataquis Counties and as a whole vs. 2017 (Kanoti, 2019).
- Both ground and aerial surveys were conducted in 2018, looking specifically for spruce budworm in northern Maine where damage would first appear. This year defoliation was assessed by CFRU student employees on all L2 sites.
- No defoliation was detected during aerial survey. Feeding needs to be approaching a moderate level of damage before it is visible from the air. All population measures indicate that numbers are too low everywhere in Maine to expect that level of feeding yet (Kanoti, 2019).
- CFRU cooperators continue to facilitate the study by placing pheromone traps and collecting branches for the L2 study.

Future Plans

- Continue branch collection and L2 surveys.
- Students at UM and UMFK will quantify current-year defoliation on branch samples using the Fettes method at the end of 2019.

References

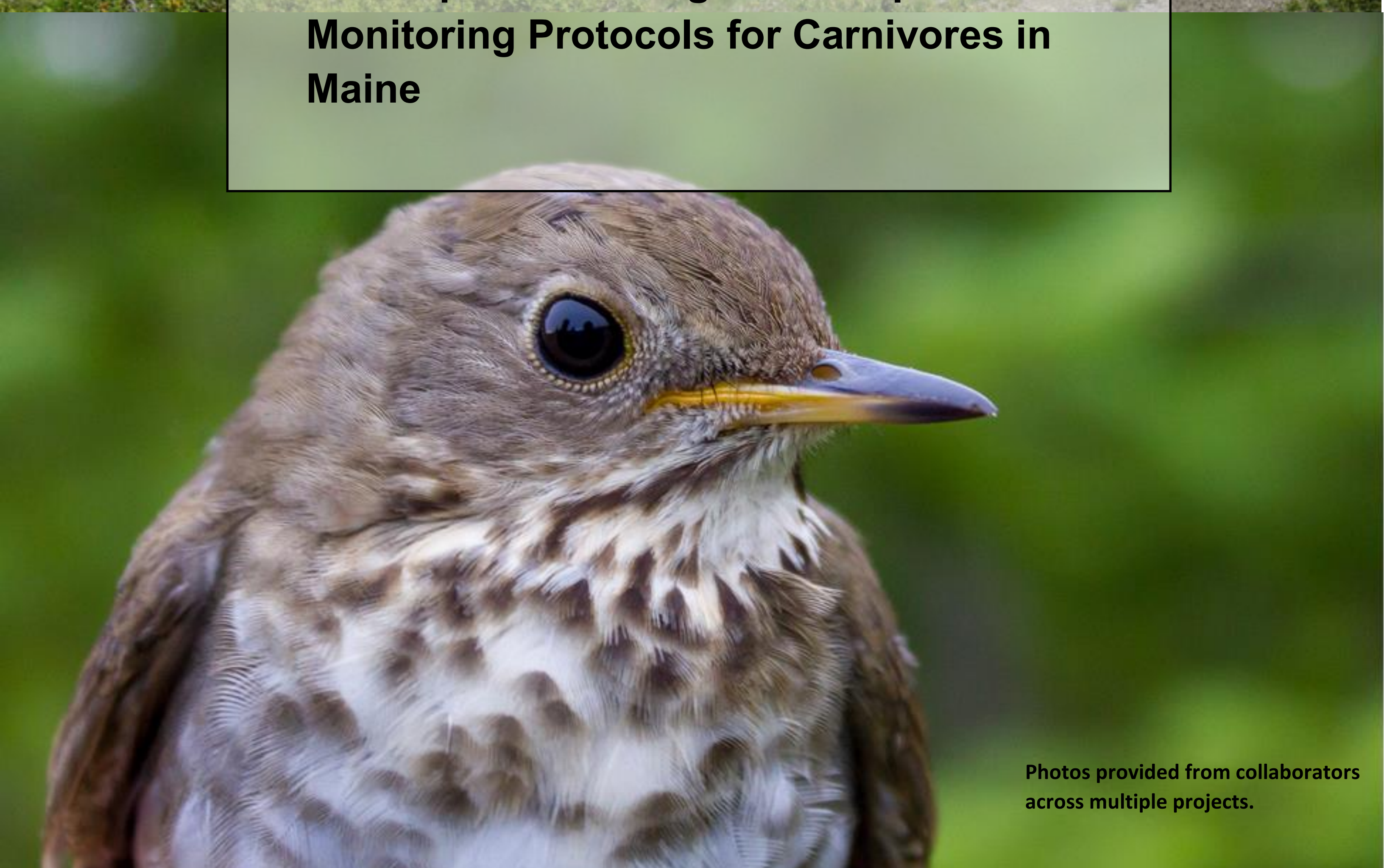
Kanoti, A. 2019. Spruce Budworm in Maine: Conditions Update. Maine Forest Service, May 2019.

Acknowledgements

We would like to thank American Forest Management, Maine Bureau of Public Lands, Appalachian Mountain Club, Maine Forest Service, Baskahegan Company, Passamaquoddy Tribal Forestry Department, Baxter State Park, Penobscot Indian Nation Forest Society of Maine, Prentiss & Carlisle, Hilton Timberlands, LLC Rangeley Lakes Heritage Trust, Houlton Band of Maliseet Indians, Seven Islands Land Company, J.M. Huber Corporation, The Nature Conservancy, J. D. Irving Ltd., USDA Forest Service, Katahdin Forest Management, LLC Wagner Forest Management, Ltd., LandVest, and Weyerhaeuser for their willingness to collect samples and place traps.

Wildlife Habitat

- Responses of Marten Populations to 30 Years of Habitat Change in Commercially Managed Landscapes of Northern Maine
- Rusty Blackbird Use of Commercial Spruce-Fir Forests in Northern New England
- Bicknell's Thrush Distribution and Habitat Use on Commercial Forests in Maine
- Development of Large-scale Optimal Monitoring Protocols for Carnivores in Maine



Photos provided from collaborators across multiple projects.

Responses of Marten Populations to 30 Years of Habitat Change in Commercially Managed Landscapes of Northern Maine

Daniel Harrison[1], Erin Simons-Legaard[2]

[1]Department of Wildlife, Fisheries, and Conservation Biology, University of Maine CFRU
[2]School of Forest Resources, University of Maine CFRU

Progress: Year 2 of 3

***Photo 1**. Kirstin Fagan (PhD Student, WLE) and Jon Rheinhardt (BS Student, EES) taking final measurements on a resident male marten captured in T5 R11 WELS, May 2019. Credit: Tyler Woollard.*

Abstract

We resurveyed commercially managed timberlands bordering the western boundary of Baxter State Park for American marten in 2018 and 2019 by replicating leaf-on season trapping and radio-tracking protocols established from 1989–1997. Despite consistent spatial and temporal trapping effort over time, capture rates of resident marten varied among and within distinct study eras. During the current study period, we documented the lowest capture rate of annual residents and most male-biased sex ratio of any year of study. Male martens typically reach breeding age (≥ 1yr) a year prior to females (≥ 2 yrs). Ground telemetry efforts in 2018 and 2019 yielded 964 locations, contributing to an overall dataset of 7,009 telemetry locations on 153 resident marten. Future work will integrate these data with a time series of habitat data developed from satellite and aerial imagery to investigate marten responses to three decades of habitat change.

Project Objectives

Our goal is to contribute to management planning for viable wildlife populations in the commercial timberlands of Maine by providing reliable models characterizing the responses of American marten to 30 years of cumulative habitat change. To achieve this goal, our objectives include the following:

- Resurvey commercially managed timberlands bordering the western boundary of Baxter State Park for marten by replicating leaf-on season trapping protocols established from 1989–1997 (Katnik 1992, Payer 1999).

- Radio-collar and -track marten captured during May–July of 2018 and 2019 to estimate home range boundaries and determine habitat use and selection within resident territories.

- Develop a time series of forest characteristics derived from aerial photography and satellite imagery to document patch composition, harvest histories, and harvest intensities across the landscape.

- Evaluate the effects of changes in forest patch structure, composition, and spatial configuration on the habitat selection patterns of resident marten within their home ranges from 1989–2019.

- Investigate the effects of cumulative landscape change on patterns of spatial occurrence, home range characteristics, survival, and population density for resident marten monitored in our study area from 1989–2019.

Photo 2*. Tyler Woollard (MS Student, WLE) and Jon Rheinhardt (BS Student, EES) coax a captured female marten into the handling cone in T4 R11 WELS, June 2019. Credit: Kirstin Fagan.*

Approach

- We established trap lines, which we surveyed from mid-May to early July in 2018 and 2019, with the intent to capture resident, nonjuvenile ($\geq$ 1 yr) marten on commercially managed lands in T4 R11 and T5 R11 WELS. We checked and baited live traps for 10 trap nights at each location. In 2019, we simultaneously conducted a companion study to assess the efficacy of systematic live-trapping for resident marten using motion-triggered trail cameras. Cameras were active at trap sites both during and after the live-trapping period for a total of three weeks per site.

- Captured martens were sexed, weighed, evaluated for evidence of lactation; we also extracted a first premolar for age estimation. Marten equipped with VHF transmitters were relocated via ground telemetry (i.e., triangulation) May through October in both 2018 and 2019.

Photo 3. *View to the southeast from a telemetry receiving station in T5 R11 WELS. Credit: Tyler Woollard.*

- For landscape-scale analyses, we are developing a time series of binary maps of habitat and non-habitat from satellite imagery based on published thresholds for structural characteristics found to strongly influence habitat selection by marten (Payer and Harrison 2003, 2004; Fuller and Harrison 2011). For patch-scale analyses, we are mapping the same landscape using aerial imagery, supplemented with field measurements, according to patch structure, composition, and harvest history.

- Tyler Woollard's MS thesis focuses on the patch-scale objectives of the study. Patch-scale analyses will use location data for martens collected on our study area during three time periods: 1989–1990, 1994–1997, and 2018–2019. Those analyses will use generalized linear mixed models to compare the structure, composition, and spatial configuration of used and unused patches within established home ranges through time.

- Kirstin Fagan's PhD dissertation focuses on the landscape-scale objectives of the study. Landscape-scale analyses will utilize data collected across the 3 study periods for martens in T4 R11 and T5 R11 WELS (1989–2019) and for field studies of martens in a neighboring forest reserve (Baxter State Park) conducted during 1994-1997. Those analyses will use a variety of statistical models to evaluate potential changes in marten spatial occurrence, population density, home range area and spatial overlap, survival and cause-specific mortality, and landscape resistance associated with landscape change.

Key Findings / Accomplishments

- Despite consistent spatial and temporal trapping effort over time (Table 1), capture rates varied considerably among and within the three study periods (Figure 1).

- We observed higher interannual variability in resident marten captures during the 2018–2019 interval than during previous years of study. In 2019 we captured 3.5-fold more resident marten than in 2018, whereas trapping results were more consistent across consecutive years during the earlier phases of the study (1989–1997).

- Our live-trapping results suggest lower representation of non-resident martens (i.e., martens that did not establish home ranges within our study area) relative to resident martens in 2018 and 2019 than in previous years of study (Figure 1). On average, our 2018–2019 live-trapping resulted in the lowest ratio of total individuals captured relative to captures of individuals subsequently documented as residents (1.2 total individuals captured per resident, compared with 1.5 individuals captured per resident during 1994–1997 and 1.7 individuals captured per resident during 1989–1990). Fewer non-resident captures during the current study period compared with prior years of study may simply reflect changes in local habitat availability and density. Alternatively, fewer non-resident captures could be indicative of a broader-scale population decline since the 1990s.

- The sex ratios (M:F) of resident martens we observed in 2018 and 2019 were heavily skewed towards males, as compared to sex ratios that did not differ significantly from 1:1 during the 1989–1990 or 1994–1997 study periods. Male martens typically reach breeding age (≥ 1yr) a year prior to females (≥ 2 yrs). Male-biased sex ratios in the current study period may indicate broader demographic changes since the 1990s, including changes in effective population sizes.

- Our ground telemetry efforts in 2019 yielded 753 locations (mean error ellipse = 0.9 ± 1.1 hectares) on 20 resident martens in T4 R11 and T5 R11 WELS (Table 2). Pooled with prior years, our working dataset is comprised of 7,009 individual locations on 153 resident marten, with a mean of 45 ± 7 locations per animal (Figure 2).

Future Plans

- By January 2020, we anticipate the age estimates via cementum analysis (Matson's Laboratory) of premolars extracted from martens captured during the current study period. Age estimates will be validated by radiographs of canines extracted from marten harvested during the 2018 and 2019 furbearer trapping season, if available. These data will be incorporated into subsequent patch- and landscape-scale analyses.

- During winter of 2019–2020, we will finalize classification of photos from motion-triggered cameras placed at trap sites, focusing on detections of collared and uncollared marten. These data will be used to make inferences about the efficacy of live-trapping as a survey method for resident marten.

Table 1*. Overview of effort for spring trapping sessions (approximately 15 May – 4 July) targeting resident American martens in T4 R11 and T5 R11 WELS during eight field seasons from 1989–2019. We present the total number of trap sites, total number of trap nights, and sex-specific estimated surveyed areas. Estimated surveyed areas are not available for 1989 and 1990.*

Year	Total Trap Sites	Total Trap Nights	Estimated Surveyed Area (km^2)	
			Males	Females
1989	409	3995	NA	NA
1990	460	4560	NA	NA
1994	265	2490	155.5	133.7
1995	267	2593	167.2	142.2
1996	272	2550	166.9	143.0
1997	270	2945	157.4	136.2
2018	292	2954	179.4	153.7
2019	293	2927	176.5	151.1

Table 2*. Overview of effort for leaf-on season telemetry (approximately 15 May – 31 October) locations obtained for American martens equipped with VHF collars in T4 R11 and T5 R11 WELS during eight field seasons from 1989–2019. We present the total number of resident marten, sex ratio, total number of ground and aerial telemetry locations, and number of locations per animal ($\bar{x}$ ± SD). Aerial telemetry was not conducted during the contemporary study period (2018–2019).*

Year	Resident Marten		Telemetry Locations		Locations per Animal ($\bar{x}$ ± SD)
	Total	Sex Ratio	Ground	Aerial	
1989	10	1.0	384	44	36 ± 5
1990	17	1.1	711	319	57 ± 7
1994	16	1.0	464	273	47 ± 5
1995	26	1.0	547	545	43 ± 4
1996	34	1.3	725	830	47 ± 7
1997	23	1.3	714	489	53 ± 8
2018	7	2.5	211	NA	42 ± 1
2019	20	1.9	753	NA	38 ± 2
Grand Total	153	-	4509	2500	-

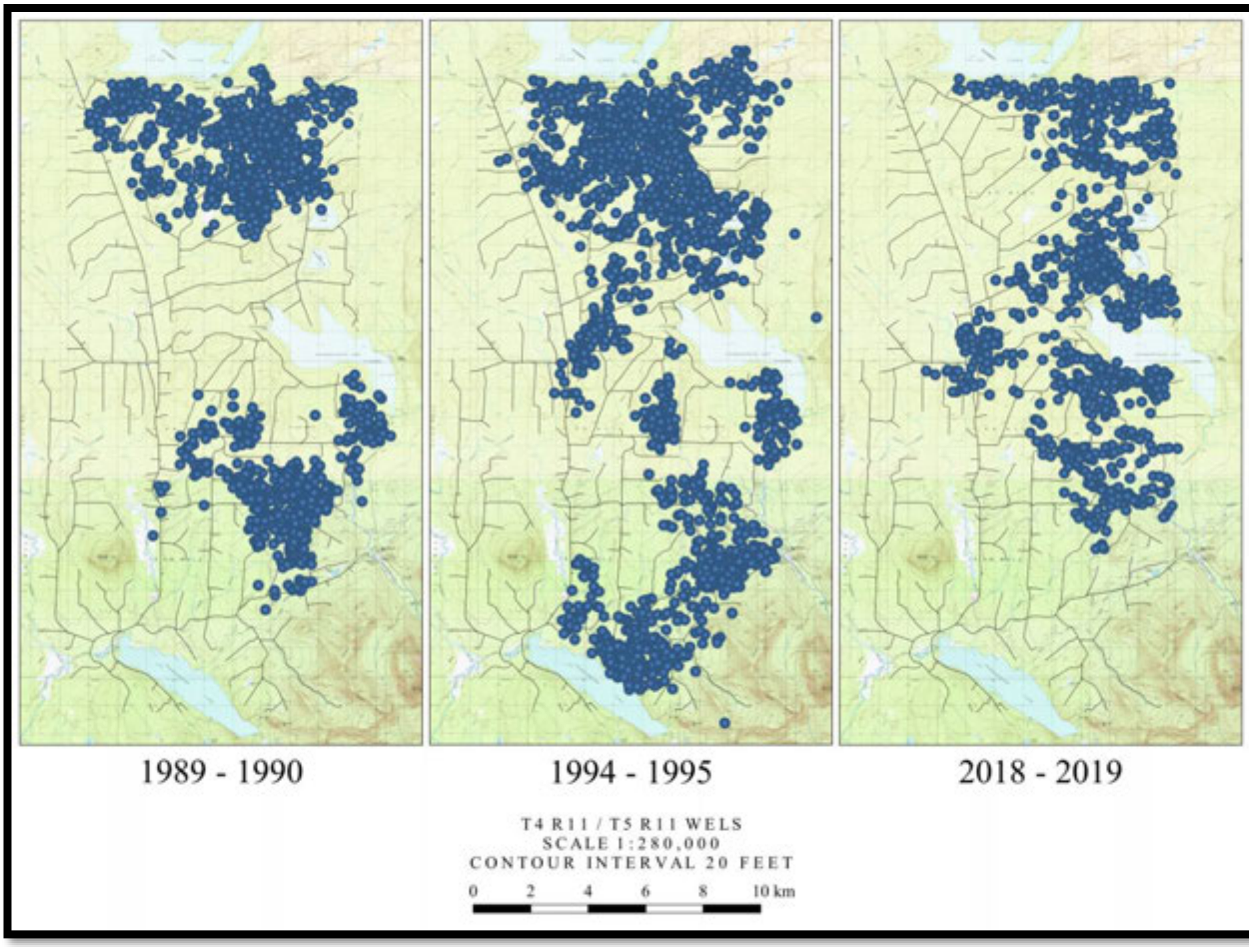


Figure 1. *Distribution of initial captures and telemetry locations for resident, nonjuvenile (≥ 1 yr) American marten monitored during the leaf-on season (approximately 15 May – 31 October) in T4 R11 and T5 R11 WELS during 1989–2019. We pooled locations across consecutive two-year intervals to depict three distinct eras of study: 1989–1990, 1994–1995, and 2018–2019. Basemap: USGS Topographic Maps (Caltopo), 2018. Additional data are available for 1996–1997, but were very similar to location distributions obtained in 1994–1995 and were not presented for clarity.*

- During spring 2020, we will focus on cataloging and organizing data from marten studies conducted in Baxter State Park from 1994–1997, an area with no furbearer trapping or forest harvesting. These data will be used in subsequent analysis of spatial occurrence, demographics, survival, and landscape resistance.
- From summer to fall of 2020, we will develop predictive models of marten occurrence based on field data collected from 2018 and 2019 and compare performance and reliability with previous models developed from data collected from 1989–1997.

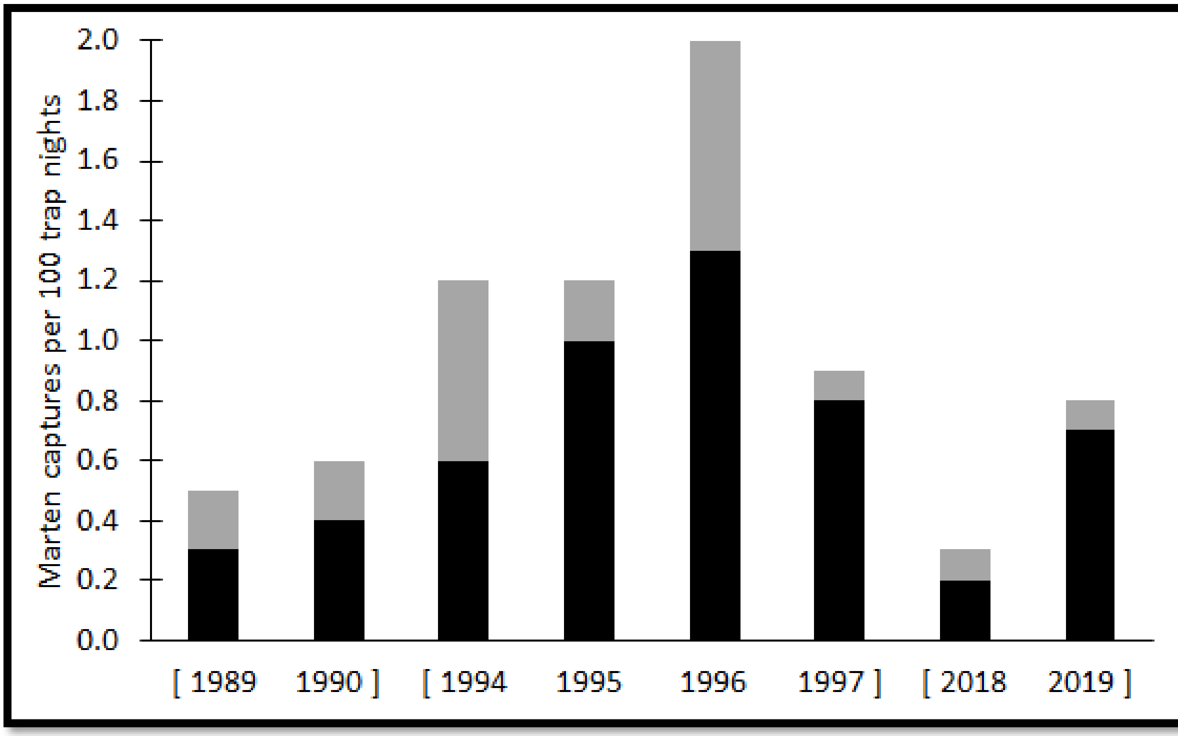


***Figure 2**. Capture success (initial captures per 100 trap nights) for spring trapping sessions (approximately 15 May – 4 July) targeting American marten in T4 R11 and T5 R11 WELS during eight field seasons from 1989–2019. Distinct study eras are indicated with brackets ([ ]). We present capture success partitioned by marten subsequently determined to be resident animals (black) and non-residents (gray).*

- During winter of 2019–2020, efforts will focus on quantifying differences in the availability and spatial configuration of habitat types within marten home ranges across all years of study. During this time we will model functional responses of martens to changes in habitat availability within home ranges through time. During spring 2020 we will model the relationship between marten patch use and within-home range patch configuration, as quantified by metrics of patch isolation, area, and edge density.

- The patch-scale component of the project is anticipated for completion during 2020, whereas the landscape modeling aspects of our work are scheduled for completion in 2021.

References

Fuller, A. K., and D. J. Harrison. 2011. A landscape planning initiative for northern Maine using area-sensitive umbrella species: Evaluating baseline conditions and effects of alternative management scenarios and silvicultural portfolios on future timber harvest volumes, standing forest inventory, and marten and lynx habitat supply on The Nature Conservancy's St. John Lands in northern Maine. Report to the Maine Chapter of the Nature Conservancy.

Katnik, D. D. 1992. Spatial use, territoriality, and summer-autumn selection of habitat in an intensively harvested population of martens on commercial forestland in Maine. Thesis, University of Maine, Orono, USA.

Payer, D. C. 1999. Influences of timber harvesting and trapping on habitat selection and demographic characteristics of marten. Dissertation, University of Maine, Orono, USA.

Payer, D. C., and D. J. Harrison. 2003. Influence of forest structure on habitat use by American marten in an industrial forest. Forest Ecology and Management 179:145–156.

Payer, D. C., and D. J. Harrison. 2004. Relationships between forest structure and habitat use by American martens in Maine, USA. Pages 173–186 *in* D. J. Harrison, A. K. Fuller, and G. Proulx, eds. Martens and Fishers (*Martes*) in Human-Altered Environments: An International Perspective. Springer, New York, USA.

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Rusty Blackbird Use of Commercial Spruce-Fir Forests in Northern New England

Amber Roth[1], Carol Foss[2], Adrienne Leppold[3]

[1]University of Maine
[2]New Hampshire Audubon
[3]Maine Department of Inland Fisheries and Wildlife

Photo 1. *Rusty Blackbird nestlings that have been affixed with VHF radio transmitters. Photo: Amber Roth.*

Status: Year 1 of 2.

Abstract

The Rusty Blackbird (*Euphagus carolinus*) is a spruce-fir obligate that has experienced a steep population decline since the 1970s. How the species reacts to intensive commercial forestry practices within their breeding range have yet to be assessed. Our research seeks to evaluate Rusty Blackbird nesting and fledgling habitat selection and survival in intensively managed forests in Maine and New Hampshire that contain practices such as pre-commercial thinning and regenerating clearcuts. Through the use of radio telemetry, GIS, and habitat measurements, we have begun to describe how the species is using these commercial landscapes. Birds during the 2019 field season were confirmed nesting in wetlands, naturally regenerating stands, and stands that had undergone pre-commercial thinning. A second field season is planned for summer 2020 which will incorporate state LIDAR data to describe habitat characteristics. This research will be used to revise management guidelines for the species.

Project Objectives

- Describe Rusty Blackbird nest and fledgling site selection at both stand and within-stand scales in commercially managed forest in New Hampshire and Maine.

- Describe habitat and vegetation characteristics associated with Rusty Blackbird nest and fledgling survival.

- Propose recommendations to forest owners to manage their lands for successful Rusty Blackbird breeding.

Photo 2. Luke Douglas with an adult male Rusty Blackbird. Photo: Patricia Wohner.

Approach

- Locate Rusty Blackbird nests at two sites (land owned by Wagner Forest Management and Umbagog National Wildlife Refuge in New Hampshire, and more intensively managed land owned by Weyerhaeuser Company in Maine) and tag and track fledglings via radio telemetry.
- Collect vegetation measurements at nest, fledgling and paired random points.
- Use resource selection functions to identify habitat characteristic that are preferentially selected by Rusty Blackbirds and promote their survival.

Key Findings / Accomplishments

- We found 23 nests in New Hampshire and 9 in Maine.
- Rusty Blackbirds were confirmed nesting in naturally regenerating clearcut stands, stands that underwent pre-commercial thinning, and wetlands.
- VHF-radio transmitters were deployed on 10 nestlings from six nests in Maine, and on 10 nestlings from six nests in New Hampshire.

Future Plans

- Complete habitat selection and survival analysis of 2019 field data.
- Work with landowners on expanding the study area with the goal of finding more nests in 2020.
- Locate nests and tag and track fledglings during the summer of 2020.
- Incorporate available LIDAR data to describe vegetation at study sites.

***Figure 1.**.Maps displaying the locations of a single Rusty Blackbird fledgling between days 0-7 (above) and days 0-10 (below). Numbers denote days since fledging.*

References

Douglas, L. and A. Roth. 2019. "Rusty Blackbird (Euphagus carolinus) use of commercial spruce-fir forests of northern New England." Poster for the USGS Maine Cooperative Fish and Wildlife Research Unit Annual meeting, Orono, ME. March 26.

Roth, A, Wilson, K., and L. Douglas. 2019. Woods, Wildlife, and Wind Power. Cooperative Forestry Research Unit Fall Field Tour, Weyerhaeuser, Kibby Township, September 19.

Acknowledgements

We would like to thank Wagner Forest Company and Weyerhaeuser Company, for access to their land. We would like to acknowledge Henning Stabins of Weyerhaeuser for his continued assistance. We are very grateful for CFRU members at the University of Maine, including Dr. Brian Roth, Leslee Canty-Noyes and Steve Dunham for their invaluable help in making this project possible. We thank Douglas' advisory committee and our collaborators, Dr. Cynthia Loftin, Dr. Aaron Weiskittel, and Dr. Patricia Wohner. We thank our funding sources, including MAFES, the UMaine Research Reinvestment Fund, the William P. Wharton Trust, New Hampshire Audubon, the Penobscot Valley Chapter of Maine Audubon, and our generous donors at experiment.com.

Bicknell's Thrush Distribution and Habitat Use on Commercial Forests in Maine

Kaitlyn Wilson[1], Amber Roth[1], Hateya Levesque[1]

[1]*University of Maine*

Status: Final Report

***Photo 1**. Male Bicknell's thrush. Photo by Kaitlyn Wilson.*

Abstract
Bicknell's thrush (BITH) is a range-restricted habitat specialist occurring in balsam fir-dominated montane forests that have been recently disturbed and are undergoing successional growth or regeneration. The species historically occurs at elevations above 800 m in the U.S., but if suitable habitat is available, BITH can occur at lower elevations. The potential for suitable habitat at lower elevations exists in Maine because of the state's unique distribution of tree communities and due to changes in forest structure and composition brought about by forestry practices. By means of telemetry, resource selection functions, and LiDAR, we aim to understand the use of breeding habitat for BITH in commercial forestlands in Maine. To accomplish this, we successfully tracked 24 individuals to obtain 27 home

ranges among the 2018 and 2019 breeding seasons at two study sites: Kibby Mountain (harvested landscape; 15 home ranges) and Mt. Redington (non-harvested landscape; 12 home ranges). Habitat selection analysis is underway.

Project Objectives

1. Understand the extent of Bicknell's thrush occurrence on commercial forest lands in Maine, both above and below the traditional elevation threshold for the species.
2. Describe Bicknell's thrush breeding habitat characteristics and forest management history at the home range and landscape level on commercial forests in Maine.
    a. *Identify forest structure characteristics as quantified by LiDAR associated with multi-scale breeding habitat selection by Bicknell's thrush.*
    b. *Obtain or re-create forest management records to describe the management history that has resulted in the occupied breeding habitat.*
3. Obtain occurrence and breeding data for Bicknell's thrush and associated bird species for use by Mountain Bird Watch and the 2nd Maine Breeding Bird Atlas.

Approach

Project Objective 1 and 2:

- Bicknell's thrushes were tagged and tracked using two methods in Western Maine at Kibby Mountain (harvested landscape), and Mt. Redington (non-harvested landscape).
- Habitat was quantified using LiDAR-derived estimates of forest structure.
- LiDAR-derived estimates of forest structure at used locations will be compared to those at available locations using resource selection functions in a mixed conditional logistic regression framework to identify multi-level and multi-scale habitat selection.

Project Objective 3:

- Bicknell's thrush survey data for Maine was obtained from multiple sources and standardized. A complete dataset and map will be produced as final products.
- Observations of breeding evidence for Bicknell's thrush and associated bird species were reported to the 2nd Maine Breeding Bird Atlas.

Key Findings / Accomplishments

Project Objective 1 and 2:

- In 2018 we tagged 20 individuals with VHF-radio tags and successfully tracked 11 across both sites (8 male, 3 female). In 2019 we tagged 13 individuals with VHF-radio tags at Kibby Mountain, and successfully tracked 9 (all male). Additionally, we tagged 9 individuals with archival GPS tags at Mt. Redington and obtained data for 7 birds (all male). In summary, we successfully collected sufficient relocation data on 24birds for home range analysis (3 individuals tracked in both 2018 and 2019 for 27 total home ranges).

Photo 2. *Bicknell's thrush habitat. TOP LEFT and TOP RIGHT: Traditional high elevation habitat (above 800 m) at Mt. Redington (left) and Kibby Mountain (right). BOTTOM: Commercially managed spruce/fir stand at Kibby Mountain (below 800 m).*

- The use of archival GPS tags in 2019 allowed us to obtain less biased and data rich estimates of individual home ranges compared to those obtained using VHF-radio tags.
- Home ranges averaged 21 ± 25 ha with a range of 2.5 ha – 129 ha. The largest home range was that of a second-year male who made multiple long trips outside of his core home range area. On average, home ranges were approximately twice as large at Mt. Redington (29 ha) compared to those at Kibby Mountain (14 ha). Home range estimates may be larger at Mt. Redington due to two possible reasons: 1) using archival GPS tags in 2019 that were unconstrained by accessibility limitations which are problematic when using VHF-radio tracking methods, or 2) greater habitat availability.
- Habitat was quantified using LiDAR data and includes estimates of canopy cover at multiple height cut-offs (1.5m, 2.0m, 2.5m, and 3.0m), tree counts for small (<10cm diameter) and large (>10cm diameter) trees, biomass estimates for small and large trees, canopy height, canopy roughness, and disturbance metrics (year of last, magnitude, and duration). Additionally, forest composition was categorized using a combination of datasets including NLCD, inventory data, LiDAR, and Google Earth.

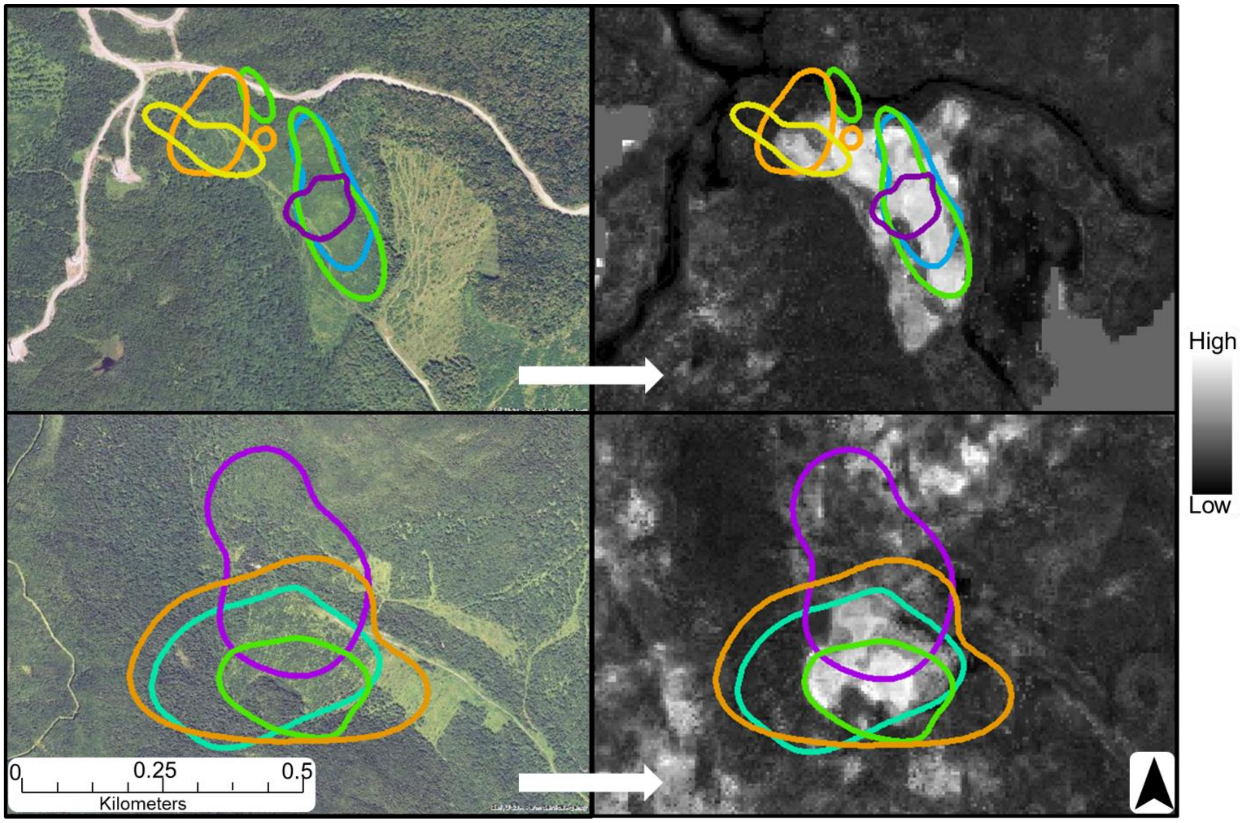

Figure 1. *LEFT (top and bottom): Bicknell's thrush home ranges from two separate stands at Kibby mountain displayed over 2017 NAIP imagery. RIGHT (top and bottom): The same home ranges displayed over small (<10 cm diameter) tree count map modeled using LiDAR. Lower stem densities are represented by darker colors, and higher stem densities are indicated by lighter colors as illustrated by the legend.*

Project Objective 3:

- Bicknell's thrush survey data was acquired from Mountain Bird Watch, Maine IF&W, TransCanada, NAVFAC Atlantic Biological Resource Services, and TRC. These data have been standardized and combined into one dataset summarizing the species' occurrence in Maine. Map products are in progress.
- Sixteen checklists reporting 63 individual Bicknell's thrush were submitted to the 2nd Maine Breeding Bird Atlas. These checklists also included reports of associated species.

- A Mountain Bird Watch survey route was established on TNC property at No. 5 Mountain, however due to current project protocol, this route could not be officially adopted.

Future Plans

- We are currently optimizing the scale of each habitat variable at both the home range and landscape level.

- Following scale optimization, we will investigate habitat selection within the home range and/or social group (second order selection), and within the landscape (third order selection). We will also investigate habitat selection within forest stands as delineated by forest inventory.

- Future analysis will include general comparisons between VHF-radio and archival GPS tag data, including comparisons of habitat use by the same individual as inferred by two different tag types.

- A dataset of Bicknell's thrush occurrence data in Maine and associated map products will be completed.

- Final thesis will be complete in 2020.

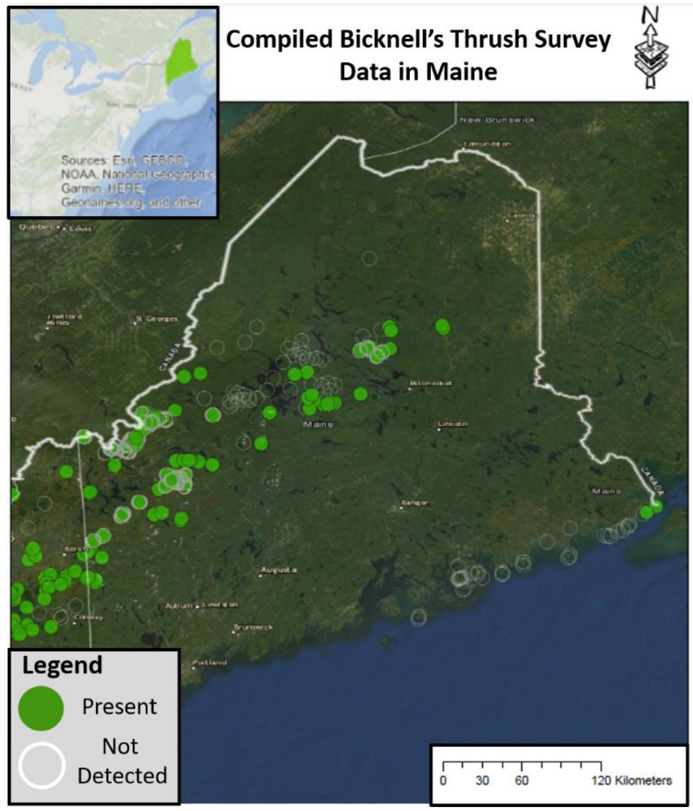

***Figure 2**. Preliminary map of Bicknell's thrush detections compiled from multiple survey datasets. Map developed by Hateya Levesque.*

References

Lambert, J. D., McFarland, K. P., Rimmer, C. C., Faccio, S. D., & Atwood, J. L. (2005). A Practical Model of Bicknell's Thrush Distribution in the Northeastern United States. The Wilson Bulletin, 117(1), 1–11. doi: 10.1676/04-013

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Development of Large-scale Optimal Monitoring Protocols for Carnivores in Maine

Dr. Alessio Mortelliti[1], Bryn Evans[1]

[1]*Department of Wildlife, Fisheries and Conservation Biology, University of Maine*

Status: Year 2 of 3

Photo 1. *Trail camera image from Bryn Evans (Graduate Research Assistant, University of Maine - Wildlife, Fisheries, and Conservation Biology)*

Abstract

Our project began in early 2017 with a pilot season (three study areas) and has since expanded to full-scale surveys (31 study areas to date) in summer and winter seasons from 2017 to 2021. We conduct trail camera surveys for carnivore species in areas across the state selected to assess the variation in occupancy probabilities between different forest stand types and ages, harvest histories, landscape configuration, latitudes, and other anthropogenic influences. During the second year of CFRU funding (October 2018 to September 2019) we a) completed our second year of full scale surveys (88 points during winter months), b) initiated our third year of surveys (59 revisited sites and 38 new sites), and c) published the first peer-reviewed article from this project (the findings of our pilot season are available here: https://doi.org/10.1371/journal.pone.0217543). Our three primary objectives and our methodology are detailed below.

Project Objectives

- Understand current occupancy patterns for carnivores in Maine, especially species of management and conservation interest (American marten, fisher, lynx, coyote and black bear).
- Investigate how landscape configuration and timber harvest may influence carnivore distributions.
- Look at co-occurrence patterns for potentially interacting carnivores.
- Assess the efficacy of camera traps as a long-term monitoring tool and provide user-friendly, hands-on tools for managers and researchers to design optimal surveys for different species

under different conditions. These protocols will be developed in collaboration with the Maine Department of Inland Fisheries and Wildlife (MDIFW) and tailored to meet the agencies statewide monitoring needs, as well as made available to stakeholders and to the broader research community.

Approach

- We are using motion triggered trail cameras, an increasingly popular and cost-effective tool to research cryptic wildlife species (Burton et al. 2015).

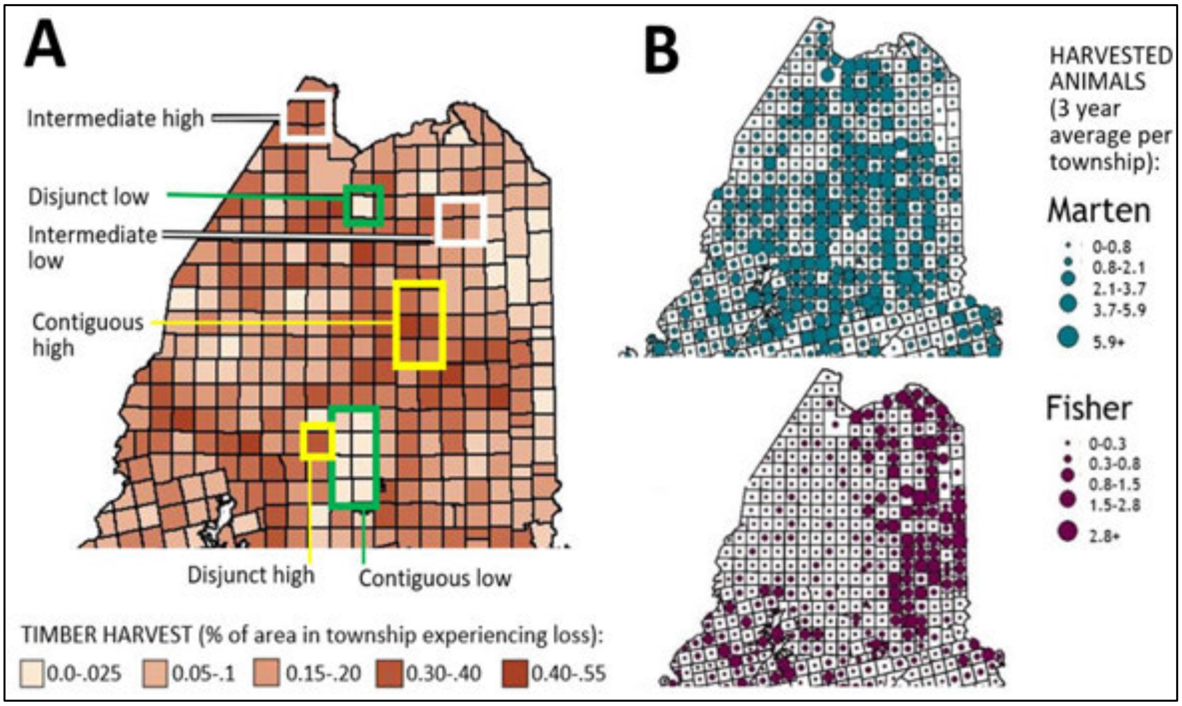

Figure 1. *Characteristics of Maine townships used to select study areas. (A) Categories of timber harvest from Hansen et al (2015), latitude, and neighboring townships used to determine highest priority townships for the first two years. (B) Fur harvest records from MDIFW from 2014-2017 for marten and fisher used to ensure sampling effort in areas of both high and low trapping pressure in year three.*

- Our survey locations were selected to optimize our ability to a) detect carnivores throughout northern Maine and b) make useful inference on the variables influencing their occupancy patterns using a *natural experiment* study design. By incorporating several remotely sensed landscape datasets and MDIFW fur harvest information, we located study areas to represent contrasting characteristics, thus enablingrdeft5 the widest inference possible, including the effects of
    - *Geographic location*
    - *Timber harvest activity*
    - *Forest cover types and habitat features*
    - *Size and configuration of "patches" of similar habitat features*
    - *Recorded trapping activity for furs (marten and fisher)*

(Figure 1 demonstrates our study area selection process, and Figure 2 is a map of the survey locations incorporated up to this year of our research.)

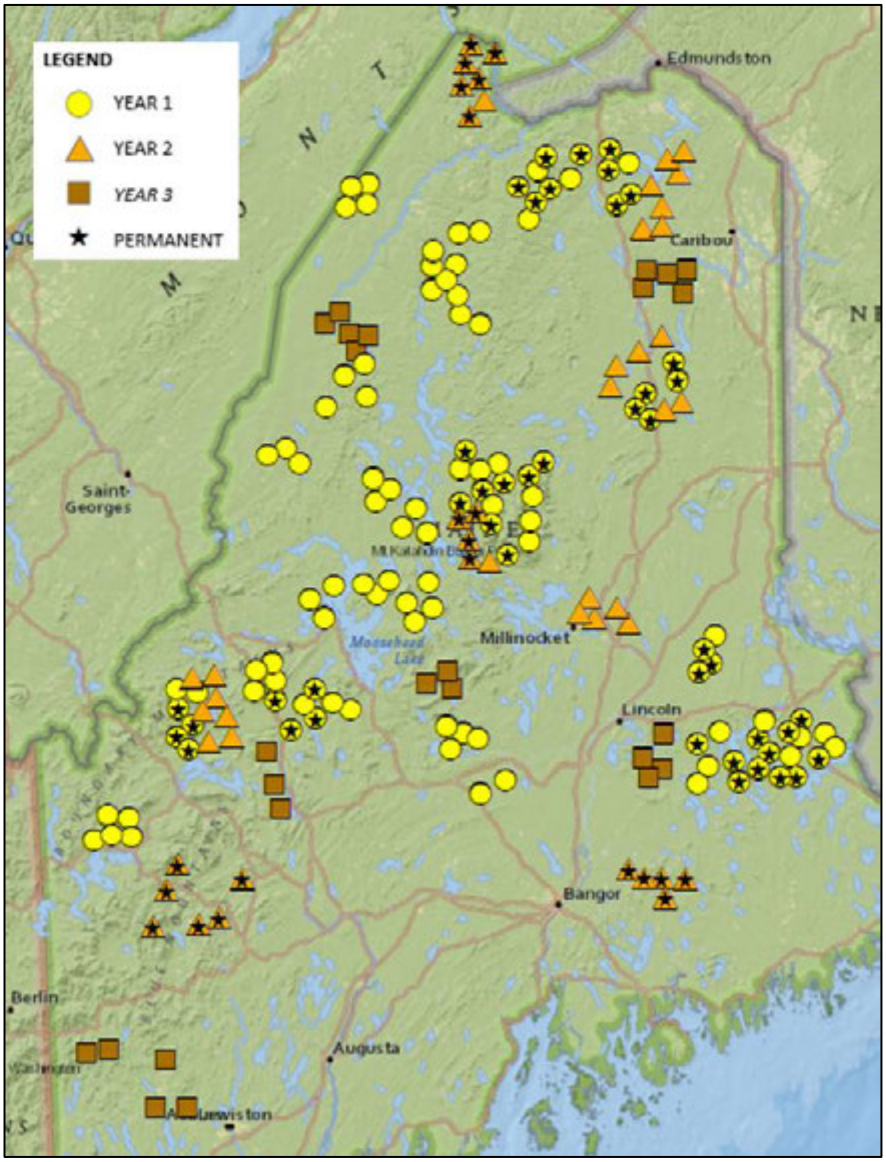

Figure 2. *Map of Maine indicating the survey locations to date (fall 2019)*

- At each of our survey sites, we place three trail cameras, each baited with beaver meat and skunk-based scent lure (Figure 3). We chose this design based on the results of our pilot season, which tested between the detection probabilities for six different species using multiple different camera configurations.

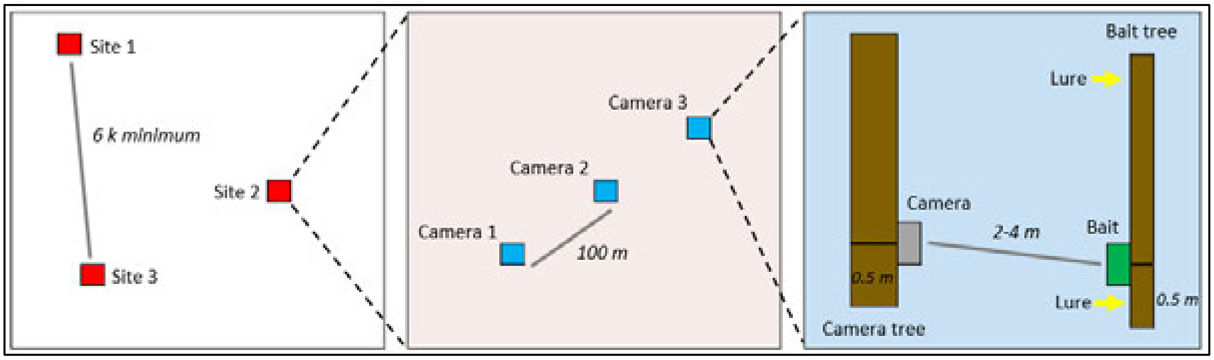

Figure 3. *Diagram of survey location design. (A) Independent survey sites within each study area are located a minimum of 6 k apart. (B) Each survey site is comprised of three camera locations, spaced 100 m, and at each location a camera tree and bait tree are selected and set as shown in (C).*

Figure 4. *Images of wildlife detected on trail cameras during the past year. Clockwise from top a marten wearing a collar as part of the UWM Harrison lab research project observed at a camera site, a raccoon eating bait at a far south winter location, a pale colored coyote, and a bear sow with two inquisitive cubs.*

- Our analytical approaches use the robust and flexible framework of occupancy models (MacKenzie et al. 2017) to explore relationships between both detection probability and occupancy patterns for carnivore species individually, in relations to other species, and over time and space. Detection probability (p) explicitly incorporates the fact that wildlife species are not "perfectly" detected using any survey approach – sometimes a species may be present without ever being observed. By using repeated surveys and tracking variables that might influence this probability of observing an animal that is present in the area, we can model the actual probability of occupancy with greater accuracy (MacKenzie et al. 2002)

Key Findings / Accomplishments

- A notable accomplishment within the time frame of CFRU research year two was the publication of our first peer reviewed article from this project. We conducted multi-method occupancy analyses (Nichols et al. 2008) on the data from our pilot season to compare the detection success of 1, 2 or 3 trail camera units spaced either 100 m or 150 m apart in linear transects. We used the results from analyzing detection histories of six species (marten, fisher, coyote, white-tailed deer, snowshoe hare and American red squirrel) to finalize our study design. The article detailing our findings has 176 reads on ResearchGate and 1,020 views on PlosONE as of 10-29-2019 (https://doi.org/10.1371/journal.pone.0217543).
- In the past year we surveyed at 59 "permanent" survey location in both winter (January – April 2019) and summer (June – September 2019) as well as completing winter surveys for 24 new sites representing intermediate harvest and adding 28 new locations for fur harvest in summer.
- To date, we have "tagged" to species and cleaned data from roughly 130,000 trail camera images with the assistance of undergraduate research assistants and volunteers.
- One of our undergraduate students completed independent field work to collect data to complete his Honors thesis, and another won a CUGR research grant and presented a poster in Spring 2019.

Future Plans

- During Year 3 of this CFRU project we will continue broad-scale field surveys, revising sites in the coming winter and summer seasons.
- Data analysis of images will continue, and preparation for our next publications will begin.
- We anticipate further collaborative meetings with MDFIW (following our annual meeting held this November) to detail protocol key objectives and cost-benefit trade-offs.

References

Burton, A.C., E. Neilson, D. Moreira, A. Ladle, R. Steenweg, J.T. Fisher, E. Bayne and S. Boutin. 2015. Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. Journal of Applied Ecology 52: 675–685

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. Estimating site occupancy rates when detection probabilities are less than one. Ecology. 2002; 83(8): 2248–2255.

MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. 2017. Occupancy estimation and modeling. Second edition. Elsevier Academic Press, Burlington, MA.

Nichols, J.D., L.L. Bailey, A.F. O'Connell Jr., N.W. Talancy, E.H. Campbell Grant, A.T. Gilbert, E.M. Annand, T.P. Husband and J.E. Hines. 2008. Multi-scale occupancy estimation and modelling using multiple detection methods. Journal of Applied Ecology 45:1321–1327

Acknowledgements

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Center for Undergraduate Research (CUGR) Students

Three students were awarded funding grants from CUGR to work on CFRU projects this year.

- **Relative Risk of Soil Nutrient Depletions Among Different Intensities of Tree Biomass Removal During Timber Harvesting in Maine**
- **Comparing Passive Acoustic Monitoring to Radio Telemetry**
- **Climate Change and Nest Parasitism of Rusty Blackbirds by Bird Blow Flies**

Relative Risk of Soil Nutrient Depletions Among Different Intensities of Tree Biomass Removal During Timber Harvesting in Maine, USA

Emily Roth[1], Joshua J. Puhlick[1], Ivan J. Fernandez[1]

[1]*School of Forest Resources, University of Maine*

Abstract

This project addresses questions about soil productivity following forest management activities that include the utilization of trees for bioenergy and low-grade products. We will calculate a Nutrient Stress Index for estimating the relative risk of forest stands to reduced productivity after tree biomass removal for product utilization. This research will take advantage of soil and other forest attribute data from operational-scale research installations in Maine. Nutrient Stress Indices will be calculated with data collected in stands before timber harvest. Tree biomass removals will be simulated under different forest management treatments and intensities of tree utilization. These scenarios will be ranked in terms of relative nutrient impact using the pre-treatment Nutrient Stress Indices as benchmarks. In addition to these scenarios, actual biomass removals will be assessed for potential impacts on soils.

Background

The proposed research would complement an existing CFRU project to evaluate the influence of different forest management practices on soil health and conservation across operational-scale research installations in Maine. The installations are part of the Maine Adaptive Silviculture Network (MASN) initiated by the CFRU. The MASN project provides a unique opportunity to evaluate how different forest management practices and soil properties influence soil nutrient availability that supports forest sustainability. The undergraduate student involved in the project, Emily Roth, will be working under the supervision of Dr. Joshua Puhlick and Dr. Ivan Fernandez.

Objectives

- To use the soils data to calculate a Nutrient Stress Index for estimating the relative risk of the sampled installations and units within installations to reduced stand productivity through different intensities of tree biomass removal for product utilization. This metric may be useful in determining which soil types and geographic locations are most at risk to soil nutrient depletions that would negatively influence stand productivity following the removal of aboveground biomass.

Approach

Soils and forest attribute data from MASN installations that were sampled in 2018 will be used in the analysis. For each plot within unit and installation, a Nutrient Stress Index will be derived for each nutrient (e.g., soil available Ca and P) by dividing the aboveground nutrient stock by the available stock of the nutrient in the soil. Aboveground nutrient stocks will be calculated using species-specific biomass equations and nutrient concentration estimates by tree component. The soils (based on soil type and soil properties) most at risk of nutrient depletions following tree biomass removal will be identified. The Nutrient Stress Indices will be calculated with pre-treatment data. Emily will simulate tree biomass removals under different forest management treatments and intensities of tree utilization. Harvest scenarios will include forest management treatments using whole-tree harvesting and stem-only harvesting (i.e., tops and branches of trees left on-site). The pre-treatment Nutrient Stress Indices will be used as benchmarks to rank the scenarios in terms of relative nutrient impact after tree biomass removals from plots within units.

Key Findings / Accomplishments

- During the summer of 2019, Emily measured post-harvest conditions on the installations, which will be used to compare and contrast the relative risk of nutrient depletions among different forest management treatments that took place in 2018.

Future Plans

- Calculate the Nutrient Stress Indices when soil chemical results are received by the University of Maine Analytical Laboratory.
- Emily Roth will present the results at a Student Symposium in 2020.

Comparing Passive Acoustic Monitoring to Radio Telemetry to Understand How Detection Relates to the Elevational Distribution of Bicknell's Thrush in a Non-Commercial Forest in Maine's Western Mountains

Michael Turso[1], Amber Roth[1], Kaitlyn Wilson[1]

[1]*University of Maine*

Status: Final report

Bicknell's thrush. Photo: Kaitlyn Wilson

Summary

Bicknell's thrush has long been considered one of the highest conservation priority species internationally (Rosenberg et al. 2016) due to the increasing threat from global climate change and winter habitat loss (Lambert et al. 2008). Because of this, effective monitoring methods are important for tracking populations and understanding habitat occupancy. Much of the previously obtained information on distribution and habitat use was obtained using the point-count method. Because of the highly challenging terrain associated with Bicknell's thrush breeding habitat, alternative methods may provide more representative data of habitat use. Relative to radio telemetry using VHF-radio tags and archival GPS tags, the primary methods employed by our parent project, acoustic recording using Song Meters (SM) allows for passive and less resource-intensive data collection that may be both a more accurate and cost-effective method of monitoring this rare, highly-specialized species.

Three Song Meters were deployed in a non-commercially managed forest on a false peak of Mount Redington in western Maine to record sound for three hours around dusk and three hours around dawn. Each Song Meter was moved to a different elevation several times throughout the two-month field season that began in June 2019 and ended in July. Two software programs were used to identify Bicknell's thrush vocalizations in the sound files. By comparing the detections obtained by the Song

Meters to those obtained via five-minute point-counts and to those obtained by the parent project's two telemetry methods, we intend to determine if acoustic monitoring can be used as an equally effective method to determine Bicknell's thrush occupancy at lower elevations.

Our preliminary results may suggest that acoustic monitoring can be used as a satisfactory substitute for radio telemetry using VHF-radio tags. However, when archival GPS tags were deployed, they detected Bicknell's thrush at elevations far lower than the threshold used in the aforementioned methods. Therefore, for the purpose of determining Bicknell's thrush occupancy at lower elevations, acoustic monitoring is an acceptable option for lower budget studies relative to VHF telemetry. In contrast, if the project can afford to deploy archival GPS tags, these are certainly the best option due to their more passive protocol, their higher data yield, and their overall better representation of Bicknell's thrush occupancy.

Project Objectives

- To investigate whether Bicknell's thrush is present at elevations lower than 900 meters in a non-commercially managed forest.
- To investigate whether the species vocalizes at elevations lower than 900 meters when it is present.
- To explore if acoustic monitoring can effectively be used as a substitute for radio telemetry or GPS technology to monitor this threatened species in the interest of improving monitoring efficiency and accuracy.

Approach

- Three SM3BAT Song Meters were deployed on the slopes of one of Mount Redington's false peaks in Franklin County, Maine. We began by placing the Song Meters at the lowest elevational points in the interest of having the highest chance of Bicknell's thrush detection earlier in the season (Chisholm and Leonard 2008) and progressively moved them higher towards traditional habitat. Each Song Meter was programmed to record all sounds for one three-hour period between 4:00 and 7:00 and another between 18:00 and 21:00. Additionally, we conducted a five-minute point-count with one minute of playback at each Song Meter placement location as an initial determination of detection. Each Song Meter was then moved to a different point in the forest at a different elevation. The sampling period was June 1st, 2019 to July 31st, 2019 which is the general time frame this species sings (Chisholm and Leonard 2008).

- This project was conducted simultaneously to a radio telemetry study of Bicknell's thrush in the interest of mapping individual home ranges using VHF-radio tags and PinPoint archival GPS tags. The results of this project will be used to show us where Bicknell's thrush should be present according to individual home ranges relative to where the Song Meters were placed (change).

- Using these four methods, we sought to determine which would be most appropriate for determining Bicknell's thrush occupancy at lower elevations.

- To analyze the raw acoustic data, we ran the files through two bioacoustics software programs. The first was Wildlife Acoustics Kaleidoscope, a program designed to broadly identify the songs and calls of many different species based on specified frequency parameters. The second was CallSeeker, a relatively new tool used to specifically identify the calls of Bicknell's thrush and its close relative, gray-cheeked thrush. We used both programs for two reasons. The first was to maximize our chance of identifying a Bicknell's thrush on a recording given that it was present. The second was to compare the two programs to see which tool more effectively identified Bicknell's thrush vocalizations.

Key Findings

- Although our results are still preliminary, Bicknell's thrush were detected as low as 888 meters using archival GPS tags only. Therefore, we can conclude that this species is actively present below 900 meters on Mount Redington's false peak. VHF-radio tags detected them as low as 980 meters, and Song Meters detected them at 984 meters. Using active point-counts, we only found Bicknell's thrush as low as 1032 meters.

- Because our Song Meters failed to detect any Bicknell's thrush vocalizing below 900 meters, we have no evidence to suggest that they do so even though they are actively present there according to the GPS archival tag data. Although this is likely due in part to the relatively small dataset, it is also likely that they only forage at these elevations and thus may avoid vocalizations. This is supported by the fact that most of the high-quality nesting habitat ends well above 900 meters.

- Our data suggest that acoustic monitoring of Bicknell's thrush to determine occupancy at lower elevations is likely as effective as using VHF radio telemetry for this purpose because the extreme low points of each of their positive detections are almost the same. In contrast, our data suggest that the use of archival GPS tags to determine occupancy at lower elevations is far more effective than the use of both Song Meters and VHF-radio tags. This method tracked Bicknell's thrush at elevations much lower than Song Meters or VHF tags. Additionally, archival GPS tags are far more passive than the use of VHF-radio tags and can collect much more data. Point-counts were found to be the least effective method, not even finding the species below 1000 meters.

Future Plans

- We will statistically determine the relative effectiveness of each of the four monitoring methods using GIS and a contingency table analysis.
- We will determine which software program, Wildlife Acoustics Kaleidoscope or CallSeeker, more effectively detects Bicknell's thrush. Additionally, we will manually listen to all recordings to rule out any false negatives.
- We will investigate whether Bicknell's thrush vocalizations are more effectively detected around dawn or dusk.

Photo 2. *Michael Turso with a Song Meter setup. (Photo credit: Kaitlyn Wilson)*

Acknowledgments

We would like to thank the U.S. Navy for providing access to their lands and funding in support of this study. Specifically, thank you to Ian Trefry for access assistance, equipment, and other logistical assistance. We also gratefully acknowledge the Cooperative Forestry Research Unit for funding this project. Finally, we give a special thanks to Gil A. Paquette with the Eric. C. York ’92 Memorial Travel Fund and Carol L. Polley with the David M. Veverka Memorial Fund for providing funding for Michael Turso to travel to the Society of Canadian Ornithologists Conference and the International Bicknell’s Thrush Conservation Group meeting in Quebec City in August 2019 to share our results and receive very helpful feedback from other Bicknell’s thrush researchers of the IBTCG.

References

Chisholm, S. E., & Leonard, M. L. (2008). Effect of forest management on a rare habitat specialist, the Bicknell's Thrush (Catharus bicknelli). *Canadian Journal of Zoology*, 86(3), 217+.

Lambert, J., King, D., Buonaccorsi, J., & Prout, L. (2008). Decline of a New Hampshire Bicknell's Thrush Population, 1993-2003. *Northeastern Naturalist*, 15(4), 607-618

Rosenberg, K.V., Kennedy, J. A., Dettmers R., Ford, R. P., Reynolds D., Alexander J. D., Will T. (2016). Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. 119 pp.

Climate Change and Nest Parasitism of Rusty Blackbirds (*Euphagus carolinus*) by Bird Blow Flies (*Protocalliphora*)

Emily Tomak[1], Luke Douglas[1], Amber Roth[1]

[1]*University of Maine*

Summary

The Rusty Blackbird (*Euphagus carolinus*) is a songbird that migrates annually from its breeding grounds in North American boreal forests to temperate areas of the United States (McClure et al. 2012). Human alteration of their breeding grounds in the form of timber management and construction has become increasingly more common (Powell et al. 2014). Once common throughout North America, it has experienced severe population declines within the recent decades. As its range retracts due to climate change and other anthropogenic factors, the additional stress puts this species at greater risk from parasites such as blow flies (*Protocalliphora*). Blow fly larvae have been discovered in Rusty Blackbird nests in New England, adding a possible contributing factor to the decline of the once prevalent species. In other songbirds, larval blow fly presence has had detrimental effects on nestlings and breeding success (Puchala 2005). Blow flies are often likely to occur in drier nests, whose numbers are determined by a high moisture content (Puchala 2005). Blow fly oviposition is typically affected by temperature, with peak egg load occurring near 30ºC. (Hans et al. 2018). As average temperature continues to rise, larval blow fly infestation of Rusty Blackbirds nests and other songbird species are likely to increase. Studies have shown that high nest infestation rates have contributed to increased nestling mortality (Puchala 2005). These parasites will not only take blood from their avian hosts but can also serve as a line for the transfer of various other diseases (Thomas and Shutler 2001). Birds have many mechanisms that serve to counter the pressures of parasites like *Protocalliphora,* such as increased nestling feeding and prolonged nestling periods (Puchala 2005). However, these mechanisms are likely to increase brood competition, leading to death of smaller nestlings and smaller broods overall (Puchala 2005). As the temperature of the range of Rusty Blackbirds continues to increase, the number of *Protocalliphora* per nest will likely increase. This is likely to be demonstrated in the species overall health and population trend, which is already vulnerable and decreasing.

Project Objectives

- Through a partnership with New Hampshire Audubon Society, Weyerhaeuser, and Wagner Forest Management, we investigated the relationship between ambient temperature patterns of Rusty Blackbird nests during their egg laying, incubation, and maturation periods of nestlings with the presence of *Protocalliphora* in their nests.

Photo 1: Undergrad Emily Tomak using a telemetry device to track nestlings at a one study site in New Hampshire.

- This will provide important insight about nesting ecology and stresses on Rusty Blackbird populations. We hypothesized that nests with sustained warm temperatures (above 18ºC) will demonstrate greater numbers of *Protocalliphora* within their nests, and that nestlings will show signs of parasitic stress, such as anemia or other blood abnormalities. We expect there to be a positive correlation between these factors.

Approach

- Two study areas were located in Coos County, New Hampshire and in Franklin County, Maine. In early May, we used a homing technique to locate the nests of Rusty Blackbirds at these sites. In New Hampshire, we located 28 nests among 14 study sites. In Maine, 9 nests among 1 study site.

- We used 60 iButton temperature monitors across the New Hampshire and Maine study sites (a monitor used to continually record temperature and/or humidity data) to track the ambient temperature fluctuations of the nests, shown in photo 2.

- We also used a variety of blood sampling techniques on the nestlings a few days before fledging to assess their physical condition. After the young have fledged, we collected and sent all nests for analysis to determine the species and quantity of *Protocalliphora* larvae present in the nests.

Future Plans

- These data will then be used to analyze the relationships between the ambient temperature of the nests, the number/species of *Protocalliphora* present, and the overall health of the fledglings between the two study areas.
- With this data, I plan to complete a student thesis in the Spring 2020 semester and submit a poster with my findings to the spring student research symposium.

Photo 2. *The picture above shows an example of an iButton temperature monitor used to track ambient temperature data in and around the nest site.*

Acknowledgements

Thank you to Weyerhaeuser and Wagner Forest Management for access to their lands. I gratefully acknowledge CFRU and the Center for Undergraduate Research for providing funding for this research. Another thank you to the New Hampshire Audubon Society and Carol Foss for their dedicated contributions to the project. I would like to acknowledge my advisor Amber Roth and her graduate assistant Luke Douglas for their support and assistance throughout the entire field process. Finally, thank you to the field assistants Skye Cahoon and Patti Wohner for their support and contributions to the success of the project.

Resources

Hans, K. R., LeBouthillier, R., & VanLaerhoven, S. L. (2018). Effect of Temperature on Oviposition Behavior and Egg Load of Blow Flies (Diptera: Calliphoridae). *Journal of Medical Entomology*, (X), 1–7. https://doi.org/10.1093/jme/tjy173

McClure, C. J. W., Rolek, B. W., McDonald, K., & Hill, G. E. (2012). Climate change and the decline of a once common bird. *Ecology and Evolution*, *2*(2), 370–378. https://doi.org/10.1002/ece3.95

Powell, L. L., Hodgman, T. P., Fiske, I. J., & Glanz, W. E. (2014). Habitat occupancy of Rusty Blackbirds (Euphagus carolinus) breeding in northern New England, USA . *The Condor*, *116*(1), 122–133. https://doi.org/10.1650/condor-13-033-r1.1

Puchala, P. (2005). Detrimental effects of larval blow flies (Protocalliphora azurea) on nestlings and breeding success of Tree Sparrows (Passer montanus) . *Canadian Journal of Zoology*, *82*(8), 1285–1290. https://doi.org/10.1139/z04-111

Thomas, K., & Shutler, D. (2001). Ectoparasites, nestling growth, parental feeding rates, and begging intensity of tree swallows. *Canadian Journal of Zoology*, *79*(2), 346–353. https://doi.org/10.1139/z00-206

Partners / Stakeholders / Collaborators

White Cedar Project

Cooperative Forestry Research Unit; U.S. Forest Service, Northern Research Station; University of Maine, School of Forest Resources; University of Maine, University Forests Office; Maibec; Baskahegan Company; Wagner Forest Management; and Vermont Land Trust.

Evaluating the Effects of Timber Harvesting Operations on Soil Project

Matt Stedman (Irving LLC), and Allen Lebrun (American Forest Management)

Soil Productivity, Carbon Storage, and Conservation MASN Project

Greg Adams	Irving Woodlands, LLC
Ian Prior	Seven Islands
Eugene Mahar	LandVest Timberland Division
Gordon Gamble	Wagner Forest Management
Kenny Fergusson	Huber Resources Corporation
Jenna Zukswert	CFRU
Keith Kanoti	University Forests Office
Pat Sirois	Maine SFI Implementation Committee (Maine SIC)
Aaron Weiskittel	Center for Research on Sustainable Forests
Greg Lawrence	Northeastern Soil Monitoring Cooperative
Scott Bailey	Northeastern Soil Monitoring Cooperative
Charles (Tat) Smith	University of Toronto

Hardwood Mortality and Growth Response Project

Chris Hennigar	University of New Brunswick, Fredericton, NB, Canada
Gaetan Pelletier	Northern Hardwoods Research Institute, Edmundston, NB, Canada
Steve Bédard	Ministère des Forêts, de la Faune et des Parcs, Québec, Canada
Martin Béland	Université de Moncton, Edmundston, NB, Canada
Ian Prior	CFRU member, Seven Islands Land Company
Kenny Fergusson	CFRU member, Huber Resources Corporation

Measurements, Models and Maps

Seven Islands Land Company

Marten Project

University of Maine: Department of Wildlife, Fisheries and Conservation Biology; Cooperative Forestry Research Unit; National Institute of Food and Agriculture, McIntire-Stennis Program, Katahdin Forest Management, LLC; Pelletier Brothers Inc.

Rusty Blackbird Project

Cooperative Forestry Research Unit, J.D. Irving Limited, Maine Agricultural and Forest Experiment Station, Maine Department of Inland Fisheries and Wildlife, Maine Outdoor Heritage Fund, Maine Research Reinvestment Fund, University of Maine at Fort Kent, University of Maine Presque Isle, Wagner Forest Management, Weyerhaeuser Company, William P. Wharton Trust.

Bicknell Thrush Project

U.S. Department of the Navy, Weyerhaeuser, The Nature Conservancy of Maine, Vermont Center for Ecostudies, Maine Department of Inland Fisheries and Wildlife, TRC Companies, Inc.

Large-Scale Carnivore Monitoring Project

American Forest Management, Baxter State Park and Scientific Forestry Management Area, Clayton Lake Woodlands Holdings, Downeast Lakes Land Trust, J. D. Irving, Katahdin Forest Management, LandVest, Maine Bureau of Public Lands, Maine Department of Inland Fisheries and Wildlife, Northwoods Management, Passamaquoddy Tribe of Indian Township, Seven Islands Wheatland, The Nature Conservancy, The North Maine Woods, Wagner Forest Management, and Weyerhaeuser.

Appendix

Peer Reviewed Publications (2)

Large Scale Monitoring Project

Evans, B.E., C.E. Mosby and A. Mortelliti. 2019. Assessing arrays of multiple trail cameras to detect North American mammals. PLoS ONE 14(6): e0217543. https://doi-rg.prxy4.ursus.maine.edu/10.1371/journal.pone.0217543

Hardwood Mortality and Growth Response Project

Puhlick, J. J., C. Kuehne, and L. S. Kenefic. 2018. Crop tree growth response and quality after silvicultural rehabilitation of cutover stands. *Can. J. For. Res.* doi: 10.1139/cjfr-2018-0248

Presentations / Workshops / Meetings / Field Tours (30)

White Cedar Study

Allogio, J., S. Fraver, L. Kenefic. 2019. Requirements for successful regeneration of northern white-cedar in lowland sites in Maine. Presented at the Northern White-Cedar: Linking Research and Management Meeting. 24 Apr. Quebec, QC.

George, A., A. Kizha, L. Kenefic, L. Louis. 2019. Northern white-cedar harvesting cost and productivity. Presented at the Northern White-Cedar: Linking Research and Management Meeting. 24 Apr. Quebec, QC. INVITED

Kenefic, L., S. Fraver, A. Kizha, K. Gerndt, A. Richley. 2018. Operational Considerations for Lowland Northern White-Cedar: Deadwood, Microtopography, and Regeneration. Poster presented at Eastern Canada – USA Forest Science Conference. 19 Oct. Fredericton, NB. INVITED

Kenefic, L., S. Fraver, A. Roth, A. Kizha, J. Wason, K. Kanoti, D. Rocque. 2018. Silviculture and Operations in Northern White-Cedar Lowlands. Project Update presented at CFRU Meeting. 25 Oct. Orono, ME. INVITED

Kenefic, L., S. Fraver, J. Wason, A. Kizha. 2019. Ecology and Management of Lowland Northern White-Cedar. 28 Mar. Presented at New England Society of American Foresters Meeting. Burlington, VT.

Kenefic, L., S. Fraver, J. Wason, A. Kizha. 2019. Lowland White-Cedar Ecology and Operations and White-Cedar Old Growth. Presented at the Northern White-Cedar: Linking Research and Management Meeting. 24 Apr. Quebec, QC. INVITED

Kenefic, L.; A. Kizha; A. George; and R. Avery. 2019. Lowland White-Cedar Management. Field tour for Cooperative Forestry Research Unit, Wet Areas Mapping Workshop. 11 June. Eddington, ME. INVITED

Woodall, C., L. Kenefic, B. Muñoz Delgado, C. Kern. 2019. Status and Trends of Northern White-Cedar in the U.S. 27-28 Mar. Poster presented at New England Society of American Foresters Meeting. Burlington, VT.

Kenefic, L.; Richley, A. 2018-2019. Northern white-cedar lowlands: Operational research. Field tours at the Penobscot Experimental Forest.

- Visiting scientists, U.S. Forest Service and University of Missouri, 22 Oct. 2018
- U.S. Forest Service, Northern Research Station Leadership, 25 Oct. 2018
- American Forest Foundation, 16 Nov. 2018
- U.S. Forest Service, R&D, FIA and State and Private Forestry, 8 Nov. 2018
- Students, University of Maine 14 May 2019
- Visiting foresters, Nova Scotia, 20 May and 28 June 2019

Weymouth Point Study

Rezai-Stevens, A. 2018. Long-Term Effects of Whole-tree Harvesting and Residue Management on Spruce-Fir Soil Quality in Central Maine. MFC program capstone project seminar. Faculty of Forestry, University of Toronto. 11 December 2018.

Smith, C.T. 2018. Conceptual Overview: Adaptive Forest Management. Presentation given at: Cooperative Forestry Research Unit (CFRU) workshop "Long-Term Site Productivity Research: Lessons from Other Regions and Opportunities for Maine". University of Maine, Orono. 7-8 June 2018.

Smith, C.T., M.L. McCormack, Jr., J.W. Hornbeck, C.W. Martin, C.A. Federer, J.W. McLaughlin, B.A. Roth, R.D. Briggs, C. Preece, I.J. Fernandez. 2018. Long-term effects of whole-tree and stem-only harvesting on spruce-fir ecosystem nutrient cycling and site productivity in central Maine. Presentation given at: Cooperative Forestry Research Unit (CFRU) workshop "Long-Term Site Productivity Research: Lessons from Other Regions and Opportunities for Maine". University of Maine, Orono. 7-8 June 2018.

Evaluating the Effects of Timber Harvesting Operations on Soil Project

George, A.K., Kizha, A.R. 2019. Quantifying soil disturbance in a whole-tree operation method. Session: environmental impacts of forest operations. Session: Environmental impacts of forest operations. 42nd Annual Meeting of the Council on Forest Engineering and 52nd International Symposium on Forestry Mechanization (FORMEC), 6-9 October 2019, Sopron, Hungary. http://formec2019.com/down/FORMEC2019_PROCEEDINGS.pdf .

Kizha, A.R., Nahor, E., Coogen, N., Louis, L.T., George, A.K. 2019. Residual stand damage under different silvicultural prescriptions. Session: Environmental impacts of forest operations. 42nd Annual Meeting of the Council on Forest Engineering and 52nd International Symposium on Forestry Mechanization (FORMEC), 6-9 October 2019, Sopron, Hungary. http://formec2019.com/down/FORMEC2019_PROCEEDINGS.pdf

Kizha, A.R. 2019. Cost of timber harvesting operations and BMP execution. Parentsis and Carliesle Forest Resource Management Timberland Services. July 23rd 2019. Bangor, ME.

Kizha, A.R., George, A.K., Louis, L.T. 2019. Comparison of Timber Harvesting Costs across Wet and Sturdy Grounds. High Resolution Wet Areas Mapping Workshop. Cooperative Forestry Research Unit. June 11, 2019. Orono, ME.

Kizha, A.R. 2018. Harvest Productivity, Residual Stand Damage, and Soil Disturbance. Outcome based forestry and long-term research. Cooperative Forestry Research Unit fall field tour 2018. September 14, 2018. Irving Woodlands, LLC, Ashland, Maine (invited; show cased on cover page).

Kizha, A.R. 2018. Impacts of timber harvesting on site and stand quality. Long-Term Site Productivity Research: Lessons from Other Regions and Opportunities for Maine. Cooperative Forestry Research Unit. June 7–8. Orono, Maine. https://umaine.edu/cfru/event/long-term-site-productivity-research-lessons-regions-opportunities-maine/

Hardwood Mortality and Growth Response Project

Puhlick, J. J., A. R. Weiskittel, B. E. Roth, and A. S. Nelson. 2019. Growth and yield of hybrid poplar and white spruce in pure and mixed plantations in eastern Maine. New England SAF Winter Meeting (oral presentation), Burlington, VT, March 27-29, 2019.

Puhlick, J. J., A. R. Weiskittel, B. E. Roth, and A. S. Nelson. 2019. Silvicultural options for increasing productivity of early successional stands: 14-year results of the Silvicultural Intensity and Species Composition Experiment. New England SAF Winter Meeting (poster presentation), Burlington, VT, March 27-29, 2019.

Puhlick, J. J., C. Kuehne, and L. S. Kenefic. 2018. Crop tree growth response and quality after silvicultural rehabilitation of cutover stands. New England SAF Winter Meeting (oral presentation), Nashua, NH, March 28-29, 2018.

Puhlick, J.J. Crop tree growth response and quality after silvicultural rehabilitation of cutover stands. Cooperative Forestry Research Unit Advisory Committee Meeting (invited guest, oral presentation). Orono, ME, January 24, 2018.

Developing a Dynamic Site Productivity Map by Linking BGI and RS Variables Project

Rahimzadeh-Bajgiran P., Hennigar, C. and Weiskittel, Developing a refined forest site productivity map for northeastern forest of Maine and New Brunswick by linking environmental to remotely sensed variables, The joint meeting of the 21st William T. Pecora Memorial Remote Sensing Symposium (Pecora 21) and the 38th International Symposium on Remote Sensing of Environment (ISRSE 38), Baltimore, Maryland, USA from October 6-11, 2019.

Rahimzadeh-Bajgiran, P. Hennigar, C., Weiskittel, A., Developing a refined forest site productivity map by linking biomass growth index to remotely sensed variables at20 m spatial resolution, CFRU Advisory Committee Meeting, October 24, 2018.

Rahimzadeh-Bajgiran, P. Hennigar, C., Weiskittel, A., Developing a refined forest site productivity map by linking biomass growth index to remotely sensed variables, CFRU Advisory Committee Meeting, October 23, 2019.

Bicknell Thrush Project

Wilson, K.W. and A.M. Roth. 2019. Bicknell's Thrush Habitat Use on Commercial Forests in Maine, Invited oral presentation to the Society of Canadian Ornithologists, August 28, Quebec City, Quebec.

Roth, A.M., Wilson, K.W., and L. Douglas. 2019. Woods, Wildlife, and Wind Power, CFRU Fall Field Tour, September 19, Weyerhaeuser Timberlands.

Turso, M., K.W. Wilson, and A.M. Roth. 2019. Invited oral presentation to the International Bicknell's Thrush Conservation Group, August 27, Quebec City, Quebec.

Large Scale Monitoring Project

Evans, B. E. 2019. Camera trapping as a tool for large-scale monitoring of carnivores in Maine. PRESENTATION. CFRU Fall Field Tour. Rangeley area, Maine, September 19, 2019.

Archambault, G, B. E. Evans and A. Mortelliti. 2019. Developing a Novel Approach to Estimate Reproductive Success of Black Bears in Maine. POSTER. University of Maine Center for Undergraduate Research Spring Symposium. Bangor, Maine, April 10, 2019.

Conference Papers (4)

Weymouth Point Study

Barusco, B., Agnė Grigaitė, C.T. (Tat) Smith, I. Stupak, A. Weiskittel, A. Rezai-Stevens, B.E. Roth, C. Preece, I.Fernandez, J.Zukswert, J.L. Campbell, J. Metsaranta, R.D. Briggs, S. Fraver, S. Kull, and W. Kurz. 2019. Forest carbon pool development over 35 years in a balsam fir-red spruce forest in northern Maine after stem-only and whole-tree harvesting. Poster presented at the 2019 Annual Meeting, Amer. Soc. of Agronomy, San Antonio, Texas, 11-13 November 2019.

Preece, C., C. Smith, B. Roth, R. Briggs, I. Fernandez. 2018. Long-Term Effects of Harvest Residues on Spruce-Fir Site Productivity Following Whole-Tree and Stem-Only Harvesting. Poster presented at: International conference: Governing sustainability of bioenergy, biomaterial and bioproduct supply chains from forest and agricultural landscapes. Copenhagen, Denmark, 17-19 April 2018.

Preece, C., C. Smith, B. Roth, R. Briggs, I. Fernandez. 2018. Long-Term Effects of Harvest Residues on Spruce-Fir Site Productivity Following Whole-Tree and Stem-Only Harvesting. Poster presented at: North American Forest Soils Conference – International Symposium on Forest Soils, "Soils-Forests Interactions in Changing Environments", Quebec City, Quebec, Canada, 10-16 June 2018.

Rezai-Stevens, A., C. Smith, B. Roth, R. Briggs, I. Fernandez. 2018. Long-Term Effects of Whole-tree Harvesting and Residue Management on Spruce-Fir Soil Quality in Central Maine. Poster presented at: North American Forest Soils Conference – International Symposium on Forest Soils, "Soils-Forests Interactions in Changing Environments", Quebec City, Quebec, Canada, 10-16 June 2018.

Theses and Capstone Projects (7)

Evaluating the Effects of Timber Harvesting Operations on Soil Project

Soman, H. 2019. Productivity, Costs, and Best Management Practices for Major Timber Harvesting Frameworks in Maine. Masters in Forest Resources, University of Maine, Orono.

Coogen, N. 2019. Analyzing Residual Stand Damage under different Harvesting Methods in the Northern Maine Acadian Forest. BS Forestry, Capstone P

roject University of Maine, Orono.

Nahor, E. 2018. Residual Stand Damage: A Comparison of Silvicultural Prescriptions. BS Forestry, Capstone Project. University of Maine, Orono.

Weymouth Point Study

Barusco, B., Grigaite, A. 2019. Forest carbon pool development over 35 years in a balsam fir - red spruce forest in northern central Maine after stem-only and whole-tree harvesting. Master of Science (M.Sc.) in Forest and Nature Management thesis, University of Copenhagen, edited version, 30 October 2019, 128 pp + appendices.

Preece, C.J. 2018. Long-Term Effects of Harvest Residues on Spruce-Fir Forest Growth Following Whole-Tree and Stem-Only Harvesting in Maine. Master of Forest Conservation thesis. University of Toronto. 43 p. Available at: https://tspace.library.utoronto.ca/handle/1807/81289.

Rezai-Stevens, Adriana. 2019. Long-Term Effects of Whole-tree Harvesting and Residue Management on Spruce-Fir Soil Quality in Central Maine. Master of Forest Conservation thesis. University of Toronto. 43 p.

Large Scale Monitoring Project

Buyaskas, M. 2019. Assessing the Effectiveness of Attractants to Increase Detection Probabilities of Northeastern Mammals. B.S. Honors Thesis, University of Maine, Orono. 38p.

Online Websites (2)

Rusty Blackbird Project

Barker, C. 2019. What's the attraction? Featured in UMaine Today Fall/Winter 2019 and online feature: https://umainetoday.umaine.edu/stories/2019/whats-the-attraction/

The University of Maine. 2019. Elevated concerns. Available online at https://www.youtube.com/watch?v=j7ay1YYtPao

Newspapers / Periodicals / Television / Web Pages (4)

Bicknell Thrush Project

Barker, C. 2019. What's the attraction? Featured in UMaine Today Fall/Winter 2019 and online feature: https://umainetoday.umaine.edu/stories/2019/whats-the-attraction/

The University of Maine. 2019. Elevated concerns. Available online at https://www.youtube.com/watch?v=j7ay1YYtPao

Hardwood Mortality and Growth Response Project

Puhlick, J. J., A. R. Weiskittel, B. E. Roth, and A. S. Nelson. 2019. Evaluation of silvicultural options for increasing productivity of early successional stands in the Acadian Forest Region. Center for Advanced Forestry Systems final report.

Kenefic, L. S., Gerndt, K. M., Puhlick, J. J., and Kuehne C. 2018. Overstory tree and regeneration data from the "Rehabilitation of cutover mixedwood stands" study at Penobscot Experimental Forest. Fort Collins, CO: Forest Service Research Data Archive.

The **Cooperative Forestry Research Unit** (CFRU) connects Maine's forestry community with the University of Maine. The CFRU serves the large, commercial forest landowners of Maine and has more than 30 members representing over 8 million acres of forestland. CFRU scientists conduct applied research that provides Maine's forest landowners, forestry community, and policymakers with the information needed to ensure both sustainable forestry practices and science-based forest policy.

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