COOPERATIVE FORESTRY RESEARCH UNIT

2021 ANNUAL REPORT

COOPERATIVE FORESTRY RESEARCH UNIT
2021 Annual Report

Founded in 1975, the CFRU is one of the oldest industry/university forest research cooperatives in the United States. We are composed of 35 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.

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.

Citation: Smith, R. K., (Ed) 2022. Cooperative Forestry Research Unit: 2021 Annual Report. Center for Research on Sustainable Forestry, University of Maine. Orono, ME. 53 p.

Cover illustration: (from left to right) Laura Kenefic, USFS, presents on climate change affecting spruce-fir forests in Maine. Alex K. George & Anil Kizha in December of 2021 doing time and motion studies on a harvest taking place on a MASN site. Joshua Goldsmith & Autumn Brann, UMO undergraduates, taking measurements on a MASN to study alternatives to controlling beech for their capstone. A leaf affected by beech leaf disease on the PEF. Sierra Croney, a MS Entomology grad student working on HWA (photo credit: Ron Lisnet). Alex K. George & Anil Kizha in December of 2021 doing time and motion studies on a harvest taking place on a MASN site. Bishnu Wagle (UMO PhD student) & Thomas Fennell (MF in SFR) taking measurements on a CTRN site. All photos other than top right by Regina Smith, CFRU.

Cooperative Forestry Research Unit
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on Sustainable Forests
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CFRU YouTube Page

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Chair's Report

I am very pleased to present this year's Annual Report to the CFRU membership. This report is a testament to the CFRU's continued commitment to forestry research in Maine. With all the challenges of 2021 the CFRU remained active and engaged and credit should be given to those involved.

I would like to thank Dr. Aaron Wesikittel who continued as the CFRU Interim Program Leader until October, his leadership and belief in the CFRU's mission was unfaltering. A huge thank-you to Leslee Canty-Noyes and Meg Fergusson who ensured the CFRU's continued success. Their efforts have not gone unnoticed in the light of our staffing challenges.

Dr. Neil Thompson, Irving Woodlands Forestry Professor at Fort Kent officially became the CFRU Program Leader in October 2021. Even before his official start date Dr. Thompson was enthusiastically engaged and thinking about what he could bring to the CFRU. His teaching experience, research, and being based in Fort Kent bring a unique perspective to the CFRU. His passion in forestry is obvious and I look forward to seeing where his leadership will bring the CFRU.

In March 2021 Regina Smith started as the CFRU Research and Outreach Coordinator and has been very active. Some highlights include the Fall Advisory Meeting and Field Tour in October that was in-person, something we have not been able to do in recent years. Her communications efforts have involved numerous e-mail updates, newsletters, field tours, webinars, and several informational videos. Her efforts have been instrumental in engaging with you, the CFRU membership.

I would also like to thank all the scientists for their continued interest in the CFRU and their research. This annual report lists four research projects as completed. In addition, the CFRU funded a Spruce Budworm L2 Monitoring Program that established the University of Maine Spruce Budworm Lab. This lab has been up and running for several months and is processing L2 samples from across Maine and publishing results. There are also six ongoing research projects, covering a wide array of topics, described in this annual report.

I wish Eugene Maher every success as he assumes the CFRU Chair position in January 2022. His work experience in Maine and past service with the CFRU Executive Committee will ensure the continued success and relevance of the CFRU.

I would also like to welcome our newest members: The Conservation Fund, Fresh Timber, Hancock Forest Management, and Tree-Star Timberlands to the CFRU family.

I encourage all CFRU members to remain engaged, it is your input that helps guide the CFRU and the research it supports.

Sincerely,

Ian Prior
Chair, Cooperative Forestry Research Unit

Director's Report

FY 2020-21 continued be another unique one in the long history of the Cooperative Forestry Research Unit's due to the ongoing global pandemic, which continues to shift our plans and regular activities. However, we have learned to adopt and continue to move forward. I believe many positive outcomes resulted from our efforts in FY2020-21.

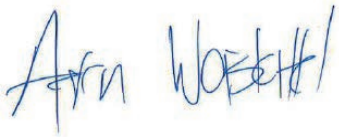
First, we approved several new research projects including the establishment of a spruce budworm L2 processing facility led by Dr. **Angela Mech**. Given the ongoing spruce budworm outbreak in Canada and the closure of the US-Canada border, having the capacity to quickly process L2 sample will help us to be ready for spruce budworm here. Also, there was support for a new spruce-fir silvicultural guide led by Dr. **Laura Kenefic** and a state of the art statewide land cover map being developed by Dr. **Kasey Legaard**.

In this year's Annual Report, the results of eleven CFRU projects addressing our member's needs in the areas of silviculture & productivity, forest inventory, remote sensing and wildlife habitat are presented. Some important highlights include Dr. **Anil Kizha** presenting a new model for estimating potential harvesting costs for small-diameter trees, Dr. **Amber Roth** indicating some possible habitat preferences for Rusty Blackbird, and Dr. **Colby Brungard** showcasing some preliminary high-resolution digital soil maps of three key attributes for 1.5 million acres in central Maine.

Many thanks go to all of our CFRU members, staff, Project Scientists, as well as the graduate and undergraduate students who made FY 2020-21 another successful year. Special thanks go to our CFRU Executive Committee **Ian Prior** (Chair), **Eugene Mahar** (Vice Chair), **Gordon Gamble** (Financial Officer), and **Elizabeth Farrell** (Member-at-Large). In particular, I am highly grateful for Gordon's extended years of service on the CFRU Executive Committee and much appreciation to Ian for his highly successful term as Chair. I look forward to working more closely with Eugene as the incoming Chair. This year we welcomed our new Research Communications & Coordinator, **Regina Smith**, and our incoming interim Program Leader, Dr. **Neil Thompson**.

With the close of FY 2020-21, my role as Interim Program Leader comes to an end and I was more than delighted to be able to serve in this capacity, particularly as we managed numerous transitions within and external to the organization. I strongly believe we turned an important corner and we are back to doing what the CFRU does best, relevant and applied forest research for Maine's diverse landowners. I look forward to seeing what the next year will bring.

Sincerely,



Aaron Weiskittel
Interim CFRU Program Leader
CRSF Director

Incoming Program Leader's Report

This is my first annual report as leader of the CFRU, and I would like to thank the membership for their warm welcome and the trust they have placed in me. This is a new model of leadership for the CFRU, as I continue to work from UMFK and Regina Smith and Leslee Canty-Noyes work from UMaine. I give a heartfelt thanks to both of them for their work as we establish this new model. Regina's background in forest entomology and media production are the foundation of a successful launch of the CFRU YouTube channel, which will provide brief reports of completed work in addition to traditional results papers and field presentations.

Many thanks go to the CFRU membership, staff, Project Scientists, and undergraduate students who made this year's work possible. Special thanks go to Ian Prior for his service as Chair of the Executive Committee, Eugene Mahar (Vice Chair and incoming Chair), Gordon Gamble (Financial Officer), and Elizabeth Farrell (Member at Large).

My goals for the coming years are A) to enhance communication of CFRU-funded research, especially in video format in collaboration with our Research and Outreach Coordinator Regina Smith, B) consolidate existing and new CFRU data into an easily navigated system accessible within the organization, C) meet regularly with CFRU landowners in the field, D) facilitate collaborative research opportunities, and E) build on existing and expanding long-term research such as CTRN and MASN. This FY 2020-2021 Annual Report details the results of 11 CFRU projects addressing our members' needs in the areas of silviculture & productivity, growth & yield modeling, and wildlife habitat.

Sincerely,

Dr. Neil Thompson

Dr. Neil Thompson takes a L2 sample for spruce budworm. He is a co-principle investigator for the new budworm lab that was funded this year by the CFRU.

CFRU Communications

R. Smith filming a CFRU hosted field tour. Photo - A. Kanoti

Greetings! I hope you enjoy the 2021 annual CFRU report that speaks to the diversity of research that our scientists, staff, and students make possible each year. I joined the CFRU in the spring of 2021 as the new research and outreach coordinator. This year, our communication efforts expanded to video format. Our new YouTube page features CFRU research highlights and findings, as well as how-to guides for detecting forest disturbances and pests, be it the emerging beech leaf disease or Spruce budworm. We have nearly 1,000 views since we established the page and are focused on expanding our content and following in the coming year. We look forward to working with researchers and cooperators alike in 2022 to enhance CFRU messaging about the depth and breadth of projects we support. Have an idea related to the CFRU that you would like to see in video format? Email me at regina.smith@maine.edu.

Best,

Regina Smith

Regina Smith
Research and Outreach Coordinator
Cooperative Forestry Research Unit

Photos L to R: Kelly French (Maine Tree). Christian Salas (Universidad Mayor, Chile). Neil Thompson and Maxwell McCormack (UMFK/CFRU). Alessio Mortelliti (UMO). Bishnu Wagle (UMO). Clint Demusz and Shawn Bugbee (SILC).

MEMBERSHIP

FOREST LANDOWNERS / MANAGERS

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

WOOD PROCESSORS

Sappi North America

CORPORATE/INDIVIDUAL MEMBERS

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

ADVISORY COMMITTEE - 2021

CHAIR:
Ian Prior, Seven Islands Land Company

VICE CHAIR:
Eugene Mahar, Landvest

FINANCIAL OFFICER:
Gordon Gamble, Wagner Forest Management Ltd.

MEMBER-AT-LARGE:
Elizabeth Farrell, American Forest Management

RESEARCH TEAM

STAFF

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

Neil Thompson (PhD), CFRU Program Leader

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

Meg Fergusson (BA), CRSF Outreach and Communications Specialist

Regina Smith (BA), CFRU Research and Outreach Coordinator

PROJECT SCIENTISTS

Scott Bailey (PhD), Northeastern Soil Monitoring Cooperative

Aaron Bergdahl (MS), Maine Forest Service

Nicholas Butler (BS), USDA, NRCS

Colby Brungard (PhD), Environmental Soil Consulting/New Mexico State University

Mindy Crandall (PhD), Oregon State University

Adam Daigneault (PhD), School of Forest Resources, University of Maine, Orono

Bethany Muñoz Delgado (PhD), U.S. Forest Service, Northern Research Station

David Evanoff (PhD), CORE, University of Maine Orono

Ivan Fernandez (PhD) School of Forest Resources, Climate Change Institute, University of Maine Orono

Carol Foss (PhD), Senior Advisor for Science and Policy, New Hampshire Audubon

Shawn Fraver (PhD), University of Maine Orono

Hamish Greig (PhD), University of Maine Orono

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

Anthony Guay (PhD), Wheatland Geospatial Laboratory, University of Maine Orono

John Gunn (PhD), Spatial Informatics Group - Natural Assets Lab

John Hagan (PhD), Our Common Climate

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

Chris Hennigar (PhD), FORUS Research, University of New Brunswick

Dave Houston (PhD), U.S. Forest Service, Northern Research Station

Allison Kanoti (PhD), Maine Forest Service

Keith Kanoti (MS), University of Maine

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

Amanda Klemmer (PhD), University of Maine Orono

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

Greg Lawrence (PhD), Northeastern Soil Monitoring Cooperative

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

Kasey Legaard (PhD), School of Forest Resources, University of Maine Orono

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

William Livingston (PhD), University of Maine, School of Forest Resources

Libin Thiakkatil Louis (PhD), Applied Forest Management, University of Maine Fort Kent

Angela Mech (PhD), School of Biology & Ecology, University of Maine

Eric Miller (MS & MA), University of Maine Orono

Peter McKinley (PhD), The Wilderness Society

Stacy McNulty (PhD), State University of New York, College of Environmental Science and Forestry, Adirondack Ecological Center

Robert Northington (PhD), Husson University

Shane O'Neill (MS), School of Forest Resources, University of Maine, Orono

Joshua Puhlick (PhD), The Jones Center at Ichauway

Michael Reed (PhD), Tufts University

Amber Roth (PhD), School of Forest Resources & Dept. of Wildlife, University of Maine, Orono

Brian Roth (PhD), SeedTree Organization

David Sandilands (PhD), Wheatland Geospatial Laboratory, University of Maine Orono

Charles (Tat) Smith (PhD), University of Toronto

Neil Thompson (PhD), University of Maine at Fort Kent

Aaron Weiskittel (PhD), Center for Research on Sustainable Forests, University of Maine

Ethel Wilkerson (MSES/MPA), Manomet Inc.

Patricia Wohner (PhD), New Hampshire Audubon

PARTNERS/STAKEHOLDERS/COLLABORATORS

Adirondack Ecological Center
American Forest Management
Cooperative Forestry Research Unit
Canadian Wood Fibre Centre
Garden Club of America
Huber Resources
J.D. Irving Limited
Landvest
Maine Agricultural and Forest Experiment Station
Maine Bureau of Parks and Land
Maine Department of Inland Fisheries and Wildlife
Maine Forest Service
Maine Outdoor Heritage Fund
Maine Research Reinvestment Fund
Maine Timberlands Charitable Trust
Manomet Inc.
National Council for Air and Stream Improvement
Northeastern Soil Monitoring Cooperative
NASA Goddard
Oregon State University
Penobscot Valley Chapter of Maine Audubon
Rangeley Lakes Heritage Trust
Seven Islands Land Company
Stephen Phillips Memorial Preserve Trust
Umbagog National Wildlife Refuge
University of Maine at Fort Kent
University of Maine Presque Isle
University of Maine:

- Center for Research on Sustainable Forests
- Dept. of Wildlife, Fisheries, & Conservation Biology
- Ecology and Environmental Sciences
- School of Forest Resources
- Wheatland Geospatial Lab

University of Toronto
USDA, NRCS
USFS, Northern Research Station
Wagner Forest Management
Weyerhaeuser Company
William P. Wharton Trust

GRADUATE STUDENTS

Kelsi Anderson (BA), Colorado College

Bishnu Wagle (PhD), School of Forest Resources, University of Maine Orono

Luke Douglas (MS), School of Forest Resources, University of Maine Orono

Thomas Fennell (MS), School of Forest Resources, University of Maine Orono

Alex Kunnathu George (PhD), School of Forest Resources, University of Maine Orono

Jamin Johanson (PhD), School of Forest Resources, University of Maine Orono & USDA, NRCS

Jonah Levy (PhD), Tufts

Stephanie Willsey (MS), School of Forest Resources, University of Maine Orono

Jenna Zukswert (PhD), SUNY College of Environmental Sciences and Forestry

UNDERGRADUATE STUDENTS

Jackson Ashby (BS), Applied Forest Management, University of Maine at Fort Kent

Autumn Brann (BS), School of Forest Resources, University of Maine Orono

Liam Daniels (BS), EES, University of Maine Orono

Jack Ferrara (BS), EES, University of Maine Orono

Joshua Goldsmith (BS), School of Forest Resources, University of Maine Orono

Hateva Levesque (BS), Applied Forest Management, University of Maine at Fort Kent

Shane Peterson (BS), Parks and Recreation, University of Maine Orono

Emily Roth (BS), School of Forest Resources, University of Maine Orono

Kyle Smelter (BS), Wildlife Biology, University of Maine Orono

Emily Tomak (BS), EES, University of Maine Orono

Financial Report

The CFRU engaged 35 members representing 8.21 million acres of Maine's forestland this year. CFRU members contributed $496,852 to support research activities during Fiscal Year 2020-21. We thank all of our members for their financial and in-kind contributes, as well as the trust in the CFRU and UMaine that these contributions represent.

CFRU Member Contributions Received FY 2020-21

CFRU Projected Income Status Report for FY 2020-21	
CFRU Member	**Contributions for FY20-21**
FOREST LANDOWNERS / MANAGERS:	
Irving Woodlands, LLC	$69,312.00
BBC Land, LLC	$54,259.00
Wagner Forest Management	$50,295.00
Weyerhaeuser	$47,059.00
Clayton Lake Woodlands Holding, LLC	$44,363.00
Prentiss and Carlisle Company, Inc.	$42,990.00
Seven Islands Land Company	$42,354.00
Maine Bureau of Parks & Public Lands	$25,229.00
Katahdin Forest Management, LLC	$17,517.00
The Nature Conservancy	$9,269.00
Fallen Timber, LLC	$13,028.00
Solifor Timberland Inc.	$9,287.00
Baskahegan Company	$8,323.00
Sandy Gray Forest, LLC	$5,840.00
Sylvan Timberlands, LLC	$5,524.00
Appalachian Mountain Club	$4,315.00
Frontier Forest, LLC	$3,115.00
Downeast Lakes Land Trust	$3,266.00
EMC Holdings, LLC	$2,363.00
Baxter State Park, SFMA	$1,725.00
Robbins Lumber Company	$1,564.00
Presley Woods, LLC	$1,379.00
Mosquito, LLC	$1,000.00
New England Forestry Foundation	$259.00
TOTAL	**$463,635.00**
WOOD PROCESSORS:	
SAPPI Fine Paper	$28,317.00
TOTAL	$28,317.00
CORPORATE and INDIVIDUAL MEMBERS:	
Huber Engineered Woods, LLC	
The Forestland Group	$3,000.00
Forest Society of Maine	$1,000.00
Si Balch	$500.00
LandVest	$200.00
David B. Field	$100.00
Acadia Forestry, LLC	$100.00
TOTAL	**$4,900.00**
GRAND TOTAL (members):	**$496,852.00**

CFRU Expenses Incurred FY 2020-21

Based on total funding awarded for projects in FY 2020-21, expenses by category this year included 39% for Silviculture & Management, 53% for Inventory & Growth Modeling, and 8% allocated to Wildlife Habitat & Biodiversity.

Final expenses as of October 1, 2021			
PROJECT	**Principal Investigator**	**Approved Amount**	**Amount Spent To-Date**
Total Administration		**$205,287.00**	$108,907.00
Administration	Weiskittel	$205,287.00	$108,907.00
Research Projects			
Silviculture and Productivity:		$146,629.92	$54,350.76
Maine's Adaptive Silviculture Experimental Network (MASN)	Weiskittel	$103,976.50	$22,709.15
Quantifying the ecological and economic outcomes of alternative riparian management strategies	Greig	$18,434.83	$12,461.00
Beech bark disease 40-year results	Kenefic/Livingston	$1,650.00	$0.00
Small Diameter Tree Harvest	Kizha	$22,568.59	$19,180.61
Spruce Budworm Lab	Mech	$93,781.00	$30,041.66
Growth & Yield Modeling		$200,915.09	$74,203.41
Cartographic Depth to water mapping	Arp/Weiskittel	$16,000.00	$0.00
Assessing and monitoring soil productivity, carbon storage and conservations on MASN	Puhlick	$31,167.40	$26,253.76
Interdisciplinary spatial modeling-new tools for forest management	Johanson	$52,500.00	$16,240.00
Mapping Forest Products	Hayes	$101,247.69	$31,709.65
Wildlife Habitat		$32,159.46	$449.90
Rusty Blackbird Use of Commnercially-managed Spruce-fir forests	A. Roth	$494.89	$449.90
Watershed-scale drivers of temperature and flow of headwater streams in Northern Maine	N. Thompson	$6,664.57	$0.00
Changes in Forest Practices and Bird Populations in Maine's Commercial Forest:1992-2022	J. Hagan	$25,000.00	$0.00
Total		$584,991.47	$237,911.07
Control Account	**Weiskittel**		
		Begin Balance	**Revenue - Expenses**
Fleet Account	Weiskittel	$48,304.19	$9,011.44
CAFS 3 @ 23%	Weiskittel	$200,000.00	$40,579.60

New Members and Updates

We're thrilled to say the CFRU gained four new cooperators this year. We welcome their organizations and representatives to the advisory committee.

- The Conversation Fund - Brian Schneider
- Tree-Star Timberlands INC.- John McNulty
- Hancock Forest Management - Al Lyons
- Fresh Timber, LLC - Eugene Mahar

In the fall of 2021, CFRU members voted to include the Maine Forest Service and Maine Inland Fisheries and Wildlife on our advisory committee. For years we have worked closely with both organizations on a variety of research and monitoring projects. We look forward to continuing innovative collaborations with MFS and MEIF&W.

Interested in joining the CFRU? Send an email to cfru@maine.edu for information on how your organization could benefit from becoming part of our membership.

Fall Field Tour 2021

The CFRU hosted a field tour to visit a MASN site in Nashville Plantation (SILC) and a CTRN site in T7 R6 (JDI) in October 2021. CFRU scientists traveled from Alaska (J. Johanson), New Mexico (C. Brungard), and their partners from USDA-NRCS hailed from various parts of the country to present their work so far on digital soil mapping results in Maine. Libin T. Louis, Alex K. George, and Anil Kizha presented on the challenges and possibilities of small diameter harvests. The 2020 annual report includes their final findings on *Identifying Opportunities for Improving Small-Diameter Tree Harvesting Strategies, Logistics, and Market Diversification.* Seven Island Land Company (SILC) forester Shawn Bugbee presented on what the the layout, plans, and aspirations for Nashville Plantation. Clint Demusz of SILC talked about hopes of using prescribed burning in the future on a MASN installation and was accompanied by Robbie Gross, a ranger with the Maine Forest Service, who spoke to the logistics and planning of prescribed fire. Neil Thompson (UMFK/CFRU) gave a demonstration on surveying for earthworms following Joshua Puhlick's detection of non-native earthworms at two MASN sites in 2020. Assesing and monitoring the extent of non-native earthworms is essential in determining potential effects on the forest ecosystem. Bishnu Wagle, PhD student in Forest Resources at UMaine, is researching CTRN and presented his results thus far on the effect of commercial thinning on structure and growth of spruce fir stands. We look forward to 2022's field tour and reconnecting with our members.

CFRU members and UMFK students listen to Shawn Bugbee's overview of the MASN installation.

Bishnu Wagle presents his findings at a CTRN site.

Neil Thompson explains to the group how to survey for earthworms.

L to R. Libin T. Louis (Applied Forest Management Assistant Professor, UMFK), Alex K. George (PhD student, SFR, UMO), Anil R. Kizha (Associate Professor of Forest Operations, SFR, UMO)

L to R. Shawn Bugbee (SILC forester), Neil Thompson (CFRU Program Leader), Aaron Weiskittel (CRSF Director).

Photos - Regina Smith (CFRU)

SILVICULTURE & MANAGEMENT

Identifying Opportunities for Improving Small-Diameter Tree Harvesting Strategies, Logistics, and Market Diversification

Anil Raj Kizha, Associate Professor of Forest Operations, School of Forest Resources, University of Maine, Orono

Adam Daigneault, Associate Professor of Forest Conservation and Recreation Policy, School of Forest Resources, University of Maine, Orono

Shane O'Neill, Forest Industry Business Development Manager, School of Forest Resources, University of Maine, Orono

Libin Thiakkatil Louis, Assistant Professor, Applied Forest Management, University of Maine Fort Kent

Alex Kunnathu George, PhD student, School of Forest Resources, University of Maine, Orono

FINAL REPORT

Abstract

The information generated from the project will be critical for stakeholders within the forest industry to evaluate the financial viability of harvesting stands having large proportions of small-diameter trees. A new model has been developed to estimate the cost of small-diameter trees, which applies to the New England region. The meta-analysis results provide essential decision-making tools for forest managers across the country for optimizing timber harvesting cost and productivity across a wide range of stand, site, operational, and silvicultural situations. The results are also an essential managerial tool for effectively comparing cost and productivity across different continents. The producers' survey shows the major constraints in harvesting SDT and biomass in the Northeastern United States region. The results also provide policy recommendations and implications of biomass harvesting in the region. CFRU members can use the results generated to explore alternative harvesting strategies and potential markets for managing SDT stands.

Project Objectives

- Optimize efficiency and evaluate operational productivity for harvesting low-grade small diameter tree stands in various silvicultural prescriptions in commercial thinning and clear-cut harvest treatment.
- Investigate supply chain logistics and economic constraints for low-grade SDT products.
- Exploring potential markets, economic impacts, and future demands for SDT products based on market diversification and business attraction activities developed by the FOR/Maine group.

Approach

- The field study was conducted during July and August of 2018 on an industrial timberland property in northern Maine.
- An additional chipping operation was conducted in Western Maine.
- The PI has included an additional objective, i.e., to evaluate the stand damage due to harvesting operation. Two field studies have been completed as a part of this new objective.

- Review of articles for quantitative analysis of the effect of stand and terrain conditions on the cost and productivity of harvesting operations.
- Survey for understanding the perspective of landowners towards the harvest of SDT.

Key Findings/Accomplishments

- Calculated the cost and productivity of the whole tree (WT) and hybrid cut-to-length (Hyb-CTL) operations in Northern Maine and presented an e-poster.
- Calculated the cost of integrated harvesting of small-diameter trees dominated stand using two apportioning methods has been published as conference proceedings.
- Developed a novel method for estimating the cost of producing wood chips solely from SDT, which is applicable for a similar situation in Maine where there are no markets for biomass products.
- Global meta-analysis was conducted to understand the influence of major factors (such as stand conditions and machine attributes) on the harvesting cost and productivity. A detailed review of timber harvesting studies from the past 25 years across the globe was made for the same.
- A survey for understanding the key incentives and constraints for landowners to harvest SDT has been completed.

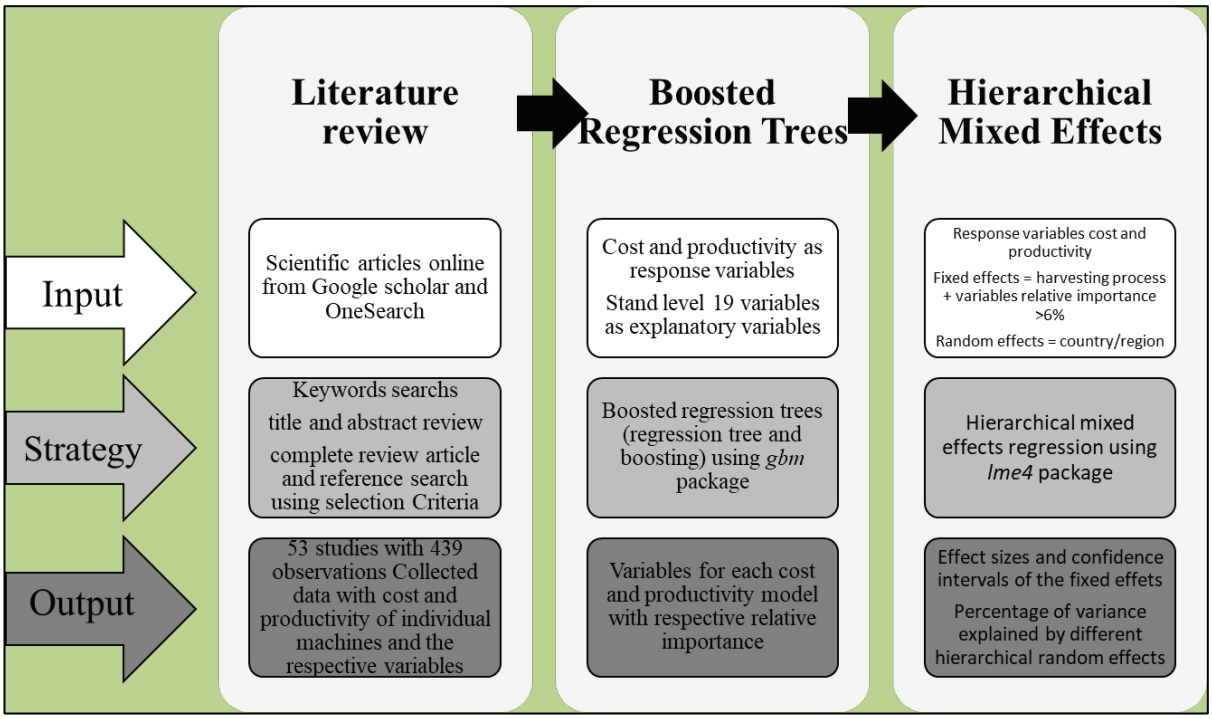


Figure 1. Flowchart showing the input, strategy, and output used in each of the study methods including literature review, boosted regression trees, and hierarchical mixed effects.

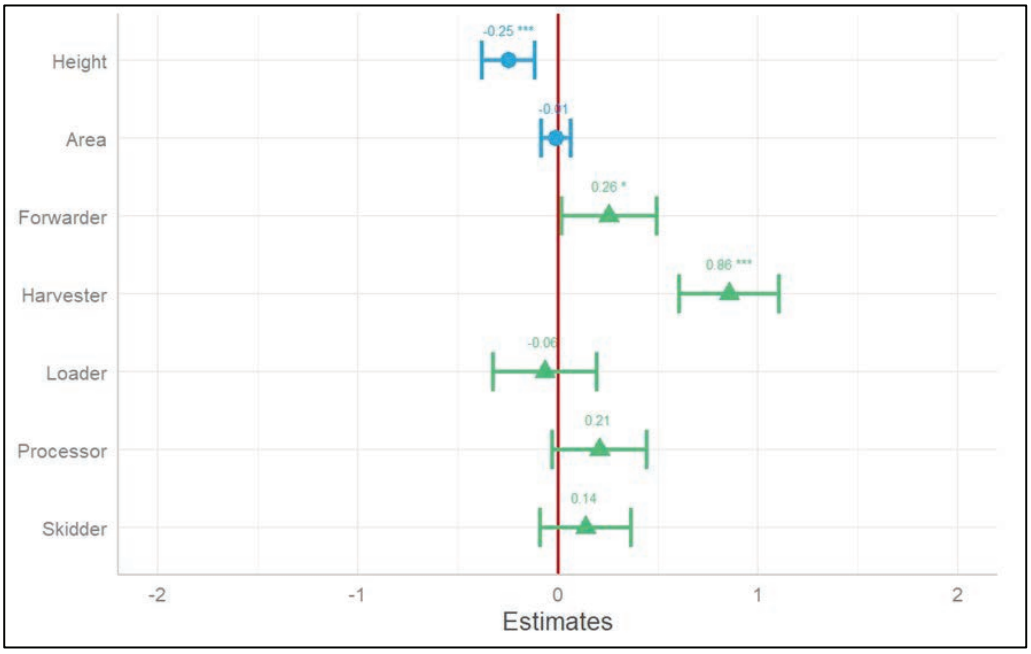


Figure 2. Harvesting cost regression model estimates for regression coefficient (circle) and intercepts (triangle) of predictor variables. The whisker of the estimate shows 95% confidence intervals. The estimates for the intercepts are compared to that of the feller-buncher, which was used for comparing the differences between different harvesting processes. Significant codes are: *<0.05; **<0.01; ***<0.001. (Note: Processor refers to machines working in the landing such as stroke-boom delimber, pull-through delimber, delimber/harvester only performing processing at the landing. Harvester refers to machine working in-woods performing felling and processing which was mostly a Cut-to-Length operation.)

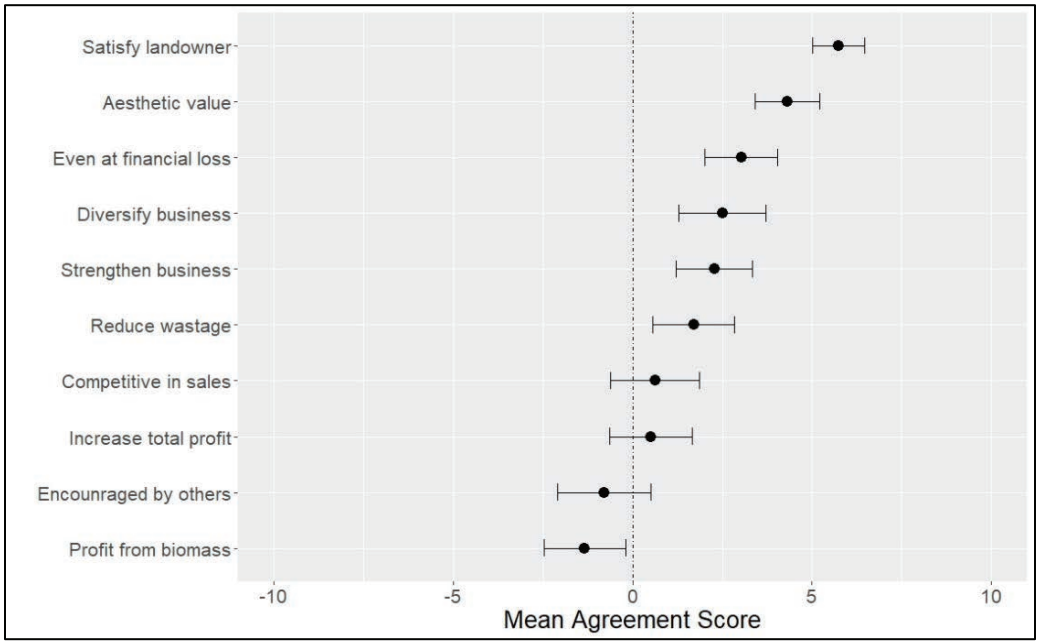


Figure 3. The respondent's agreement (greater than zero) and disagreement (less than zero) towards the provided reasons for biomass harvesting showing the mean with 99% confidence intervals. The scale ranged from -10 (strongly disagree) to 10 (strongly agree).

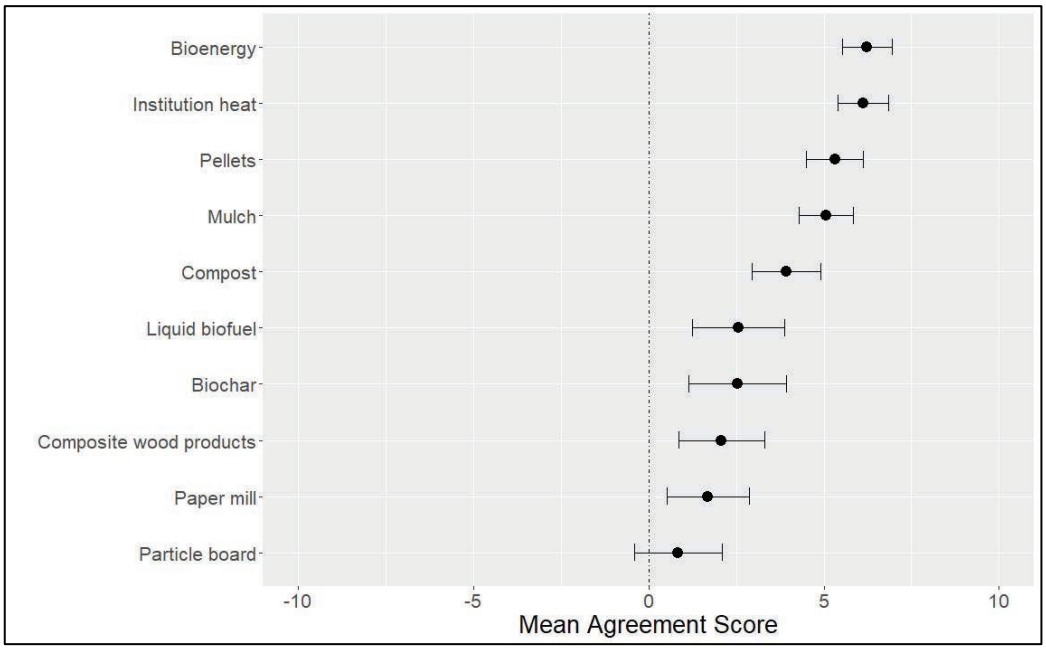


Figure 4. Comparing the mean and confidence intervals for the provided applicability of biomass with a scale ranging from -10 (strongly disagree) to 10 (strongly agree).

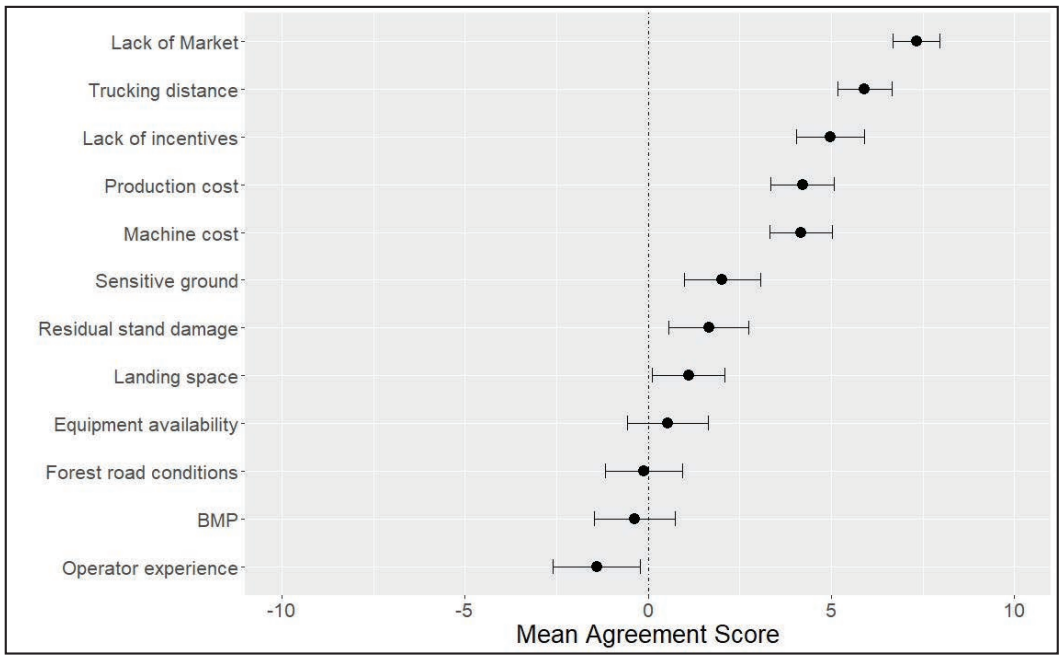


Figure 5. Mean and 99% confidence intervals for major constraints in biomass harvesting. The scale ranged from -10 (very low constraint) to 10 (very high constraint).

Acknowlegdments

We would like to express our gratitude to Matt Stedman, Brian Holland, Frank Cuff, Keith Kanoti, Brian Roth, Aaron Weiskittel, Jenna Zukswert, and Regina Smith for the support and help in various stages of the study. Our appreciation goes to all the foresters, contractors, and machine operators associated with Irving Woodland LLC and Weyerhaeuser for their involvement in the operational aspect of the study. Sincere gratitude towards the SDT producers who participated in the survey.

Long-Term Outcomes of Beech Bark Disease on the Penobscot Experimental Forest

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Dave Houston, U.S. Forest Service, Northern Research Station

Bethany Muñoz Delgado, U.S. Forest Service, Northern Research Station

Stacy McNulty, State University of New York, College of Environmental Science and Forestry, Adirondack Ecological Center

William Livingston, University of Maine, School of Forest Resources

With cooperation from:

Allison Kanoti, Maine Forest Service

Aaron Bergdahl, Maine Forest Service

Keith Kanoti, University of Maine

Photo 1: Dave Houston stands with a relocated resistant beech tree in the Penobscot Experimental Forest (PEF)

RESEARCH ONGOING

Abstract

Beech bark disease (BBD) is detrimental to the health and quality of American beech (Fagus grandifolia) in Maine and elsewhere. This disease is caused by the combined effects of the beech scale insect Cryptococcus fagisuga and Neonectria fungi. Though the general stages of the disease spread are well understood, local tree and site factors are also believed to influence disease progression and mortality of individual stems (Houston et al 1979). This project utilizes historical plot locations and existing data to further investigate factors influencing BBD progression, decline in tree condition, and mortality of individual stems over time. Characteristics and management potential of American beech trees with tolerance to the disease are also being considered. Preliminary findings suggest positive relationships between some indicators of tolerance (i.e., lesions where infection has been restricted to the bark by the periderm) and tree vigor and growth.

Project Objectives

- Generate and communicate new findings from a long-term study of beech bark disease (BBD) on the Penobscot Experimental Forest (PEF) to better inform management priorities regarding diseased beech.
- Quantify BBD progression, decline in tree condition, and mortality probabilities in relation to a range of tree-level factors, including but not limited to tree size, severity of infestation, and BBD tolerance.
- Provide expert training to CFRU members and partners regarding BBD, including characteristics and commodity production or wildlife habitat potential of disease-tolerant trees.

Approach

- Re-establish and re-measure two historical BBD monitoring plots on the PEF (approximately 0.5-acre beech-dominated plots established in 1979 by Forest Service scientist Dave Houston as part of a regional study (Houston et al. 2005)).

- Digitally record and archive historical data, stem maps and preliminary data summaries.
- Reinitiate data collection. Data were collected annually from 1979-1992, and annual data collection was resumed in 2019. Data include:
  - Tree attributes – diameter at breast height (DBH), crown class, and crown condition (categories describing crown vigor and chlorosis [yellowing]).
  - Evidence of BBD within two 2-meter height zones – wax amount and cover as evidence of C. fagisuga (none to very heavy), tarry spots as evidence of Neonectria infestation, dead bark (strip canker, necrosis, or callusing), and Neonectria fruiting.
  - Potential disease tolerance – evidence of raised lesions are recorded as a potential indicator of disease-tolerant trees.

Photos 2 & 3. Cankers (left): fungal infection has reached the vascular cambium. Lesions (right): fungal infection has been walled off by the periderm and restricted to the bark. Source: capstone presentation by Lauren Keefe, June 2nd 2020, University of Maine, Orono

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- Develop infestation and infection indices in accordance with methods of Houston et al. (2005) for comparison of current findings to historical research.
- Model mortality probabilities in accordance with methods of Cale and McNulty (2018) to determine effect of BBD severity and DBH on tree time-until-death.
- Use historical and newly collected data to evaluate relationships between presence/abundance of lesions (as an indicator of BBD tolerance) and historical and current growth and vigor of survivor trees.
- Develop management recommendations with consideration of commodity production and biodiversity/wildlife values of trees with BBD, focusing on preservation of trees displaying tolerant indicators.

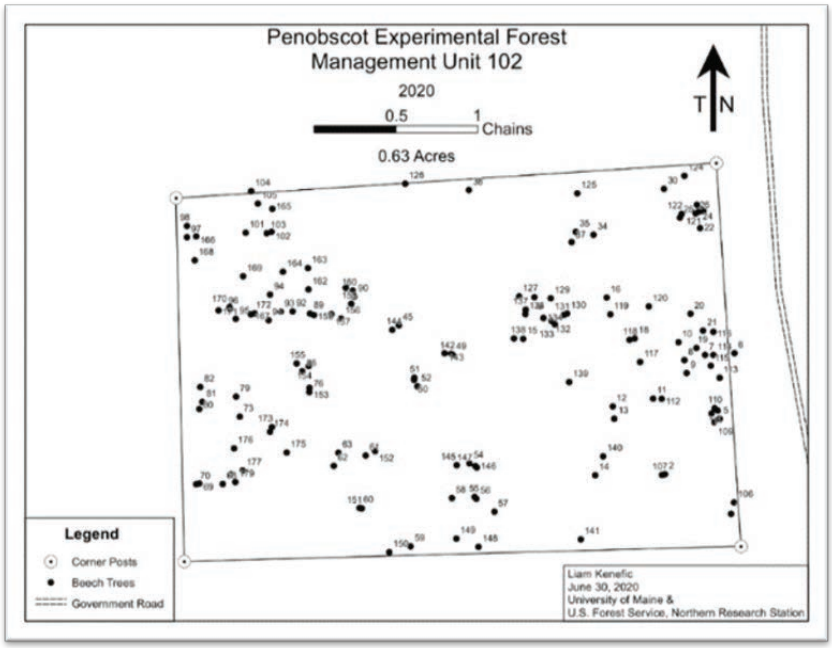


Figure 1 (left). MU102 (one of two BBD monitoring plots) stem location map of all beech stems within the plot. GPS data were updated to sub-meter accuracy in June 2020.

Key Findings/Accomplishments

- Using the information provided by Dave Houston – PEF staff were successfully able to locate plot (management unit, MU) 102 and the historical stems that had been mapped.Three annual inventories have been conducted in this plot since that time (2019 - 2021). In 2020, new GPS locations were recorded for the stems in this plot and synthesized into Figure 1 (p. 17). 141 historical and ingrowth beech trees were mapped.
- Using the same information, plot 103 and its mapped trees could not be located in the field. It was concluded that the representative beech trees in this plot had apparently experienced 100% mortality.
- Following this realization, the location for a new replication plot (MU102A) was determined on the PEF in collaboration with the University of Maine and added to the study for future continued measurement starting in July, 2019.Three annual inventories have been conducted in this plot since that time. In 2020, initial GPS locations for the stems in this plot were recorded and a stem location map was created.185 beech trees were mapped in this plot.
- In 2019, a special session on beech bark disease was organized by PI Laura Kenefic at the New England Society of American Foresters Annual Winter Meeting. Presentations were later reprised and made available as webinars by Ralph Nyland through ForestConnect and by Stacy McNulty through the Center for Research on Sustainable Forests.
- In 2020, University of Maine School of Forest Resources undergraduate student Lauren Keefe completed her senior capstone project using historical and new data from this study under the guidance of co-principal investigator William Livingston: Quantification of Tolerance to Beech Bark Disease. Though preliminary, Lauren's findings show that trees with greater area of necrophylactic periderm (lesions) have higher growth rates, less crown dieback, and reduced infection and infestation rates. These results provide substantial evidence suggesting necrophylactic lesions are a quantifiable symptom of tolerance correlated with healthier trees afflicted by beech bark disease.

Photos 4 & 5. A raised necrophylatic lesion before (left) and after (right) being "popped off" of a diseased beech tree in MU102A. Removal of the outermost layer of the raised lesion shows that the tree has walled off the cambium at this location to protect itself from the BBD by preventing penetration of the fungus farther into the cambium. Raised lesions are thought to be a good indicator of a tolerant beech tree.

- In June 2021, PI Laura Kenefic presented the background and preliminary findings of the BBD research to researchers and land managers at the Northern Hardwood Conference. The presentation, titled "Beech Bark Disease Tolerance: An Emerging Concept in American Beech Management", highlighted the potential for using indicators of BBD tolerance to inform management decisions and retain more beech trees in affected forests. Figures 3 and 4 show the relationship between (3) crown dieback and (4) diameter growth with canker and lesion cover using data from the 2019 field inventory on the PEF. These results show that increased canker cover has a significantly negative association with crown vigor and diameter growth, while increased lesion cover is associated with greater diameter growth. Dr. Kenefic stresses that in badly affected stands in which most trees have high total coverage of cankers and lesions, high lesion cover is likely not beneficial to diameter growth, per se. Rather, it is the lower canker:lesion ratio that is responsible for the observed results. An extended abstract based on this presentation will be included in the forthcoming conference proceeding.
- In August 2021, Cameron McIntire (USDA Forest Service), Aaron Bergdahl (Maine Forest Service) and members of their crews installed a 0.1-ac beech leaf disease (BLD) monitoring plot within plot MU102A. BLD was first detected in Maine in 2021, though had not yet been detected in Penobscot county at the time of the installation of this plot.This crew found evidence of early infection of BLD at the newly established plot on the PEF, making it the first official detection of BLD in Penobscot county. Photo 6 below shows an example of a leaf with BLD.

• This BLD plot is a part of a larger long-term monitoring network for BLD that spans many states in the eastern region of the United States and Canada. The goal of this network is to monitor the relatively new disease over time as it spreads and to relate infection severity and tree mortality with varying site factors across the region. The pre-existing long-term BBD monitoring plots at the PEF provided a unique opportunity for the potential to combine understanding of the two diseases by locating the new BLD plot within the existing BBD plot. Figure 2 below shows the layout of the BLD plot.

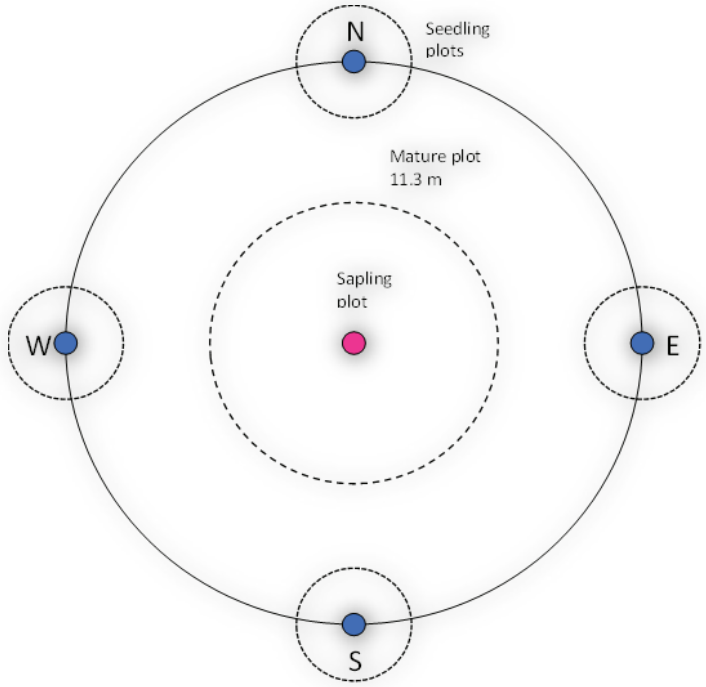
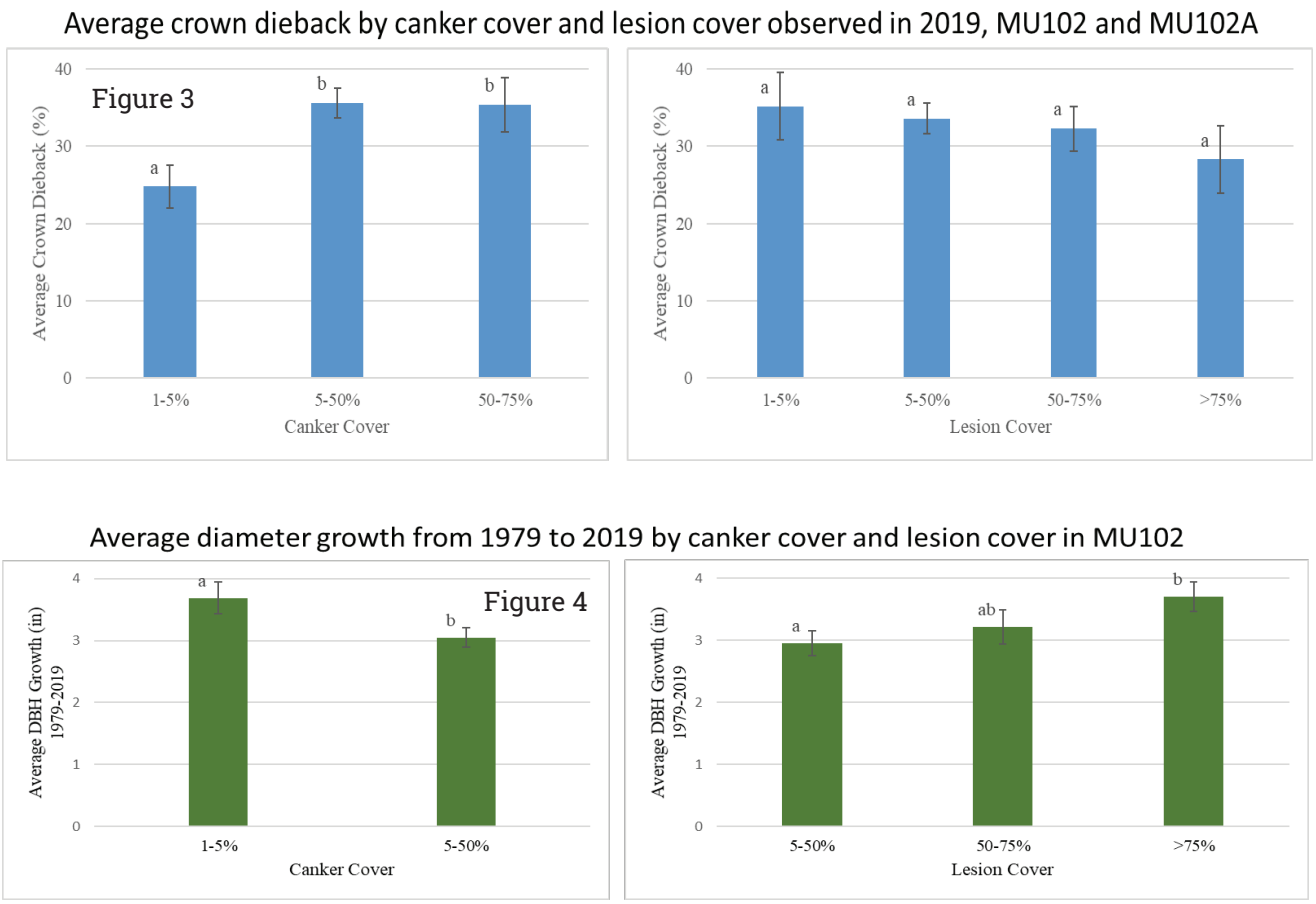


Figure 2. Beech leaf disease plot diagram. One plot was established within the BBD monitoring plot MU102A in August 2021 at the PEF. Diagram provided by Cameron McIntire.

• In October 2021, a field tour/workshop entitled ***"Beech Bark and Leaf Diseases & The Many Values of Beech"*** was hosted at the PEF with support from the CFRU. PI Laura Kenefic, PI Stacy McNulty, PI Dave Houston, PI William Livingston, Allison Kanoti (MFS) and Cameron McIntire (USFS) were among those presenting at this event. The tour focused on the causes, signs and effects of both beech bark and beech leaf disease, as well as the wildlife and other ecological values of American beech as a key part of the larger forest ecosystem. Increased emphasis was placed on identification and management of trees with BBD tolerance and resistance.

Photo 6. A leaf taken from an American beech tree in MU102A that is showing the banding symptom of beech leaf disease. Discovered in August 2021. **Photo -** Cameron McIntire.

Photo 7. A leaf taken from an American beech tree in MU102A that is showing the banding symptom of beech leaf disease well into the fall. October 2021. **Photo -** Regina Smith



Figures 3 & 4. Data synthesis of preliminary canker/lesion cover vs. crown class/condition (3) and DBH growth (4). Results from the 2019 annual inventory at the PEF, with letters above bars indicating statistical significance (p <0.1). Source: Presentation by PI Laura Kenefic at the Northern Hardwoods Conference 2021 titled "Beech Bark Disease Tolerance: An Emerging Concept in American Beech Management".

Future Plans

- Complete audio restoration of Dave Houston's presentation from the New England SAF session on American beech and publish it on the CRSF YouTube channel
- Continued data collection, analysis, and presentation of results
- Publication in a journal – targeting Forest Science
- Publication by Forest Service or Maine Agricultural and Forest Experiment Station

Acknowlegdements

We thank the Cooperative Forestry Research Unit; U.S. Forest Service, Northern Research Station; Maine Forest Service; State University of New York College of Environmental Science and Forestry, Adirondack Ecological Center; and the University of Maine, School of Forest Re-sources for funding or in-kind support of this project.

Dave Houston and Laura Kenefic stand next to a newly erected memorial sign for Dave's resistant beech tree. Photo - Regina Smith

Strategies for Altering Species Composition in Stands with American Beech and Beech Bark Disease on the Maine Adaptive Silviculture Network

Autumn Brann, University of Maine Orono

Joshua Goldsmith, University of Maine Orono

RESEARCH ONGOING

Abstract

Long-term management goals are to maintain northern hardwood composition and increase stand productivity while maintaining early to mid successional habitat. In addition, Weyerhaeuser and the Cooperative Forestry Research Unit (CFRU) are using this site to conduct long-term research by installing 5 different research prescriptions to see what treatments reduce American beech composition most effectively. After plots have been established and data has been collected, Autumn and Josh will summarize the current stand conditions in Mayfield, do an in depth literature review of beech management and herbicide use, and make alternative treatment recommendations.

Example of understory conditions at the Mayfield MASN Installation. **Photo -** Joshua Goldsmith

Approach

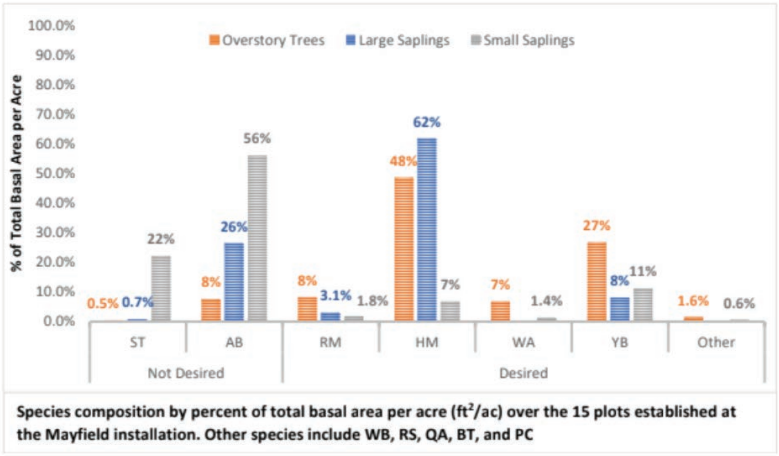
- Operability: This stand can be operated on in the summer or winter months. It lacks water bodies that need to be avoided, has well drained soils, and is relatively flat.
- General property description and history: This is a 163 acre stand in central western Maine near the town of Mayfield that is 99% forested.
- Topography: The site is relatively flat with some slight slopes that is a mid-range in elevation.
- General hydrology: There are no significant streams, there is a moderately wet spot in the control unit, so it will not be disturbed.
- Primary past land uses: This land has always been forested and used for lumber production.
- Term of ownership: This has been owned by Weyerhaeuser since 2016 with prior ownership by Plum Creek for the last two decades.
- Recent harvests and/or natural disturbances: Based on available imagery, there are no detectable recent harvests or natural disturbance, which was supported by on the ground observations.

- Soils: There are four primary soil types present with Mondara-Telos being the dominant soil type (77%; Figure 2 & Table 1). All soils are relatively well drained with moderate to high stoniness.

Figure 2. NRCS soils map highlighting the primary soil types present.

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
EMC	Elliottsville-Monson complex, 3 to 15 percent slopes, very stony	0.5	0.3%
MOB	Monarda-Burnham complex, 0 to 3 percent slopes, very stony	1.6	1.0%
MTB	Monarda-Telos complex, 0 to 8 percent slopes, very stony	125.9	77.3%
TEC	Telos-Chesuncook-Elliottsville association, 3 to 15 percent slopes, very stony	34.8	21.4%
Totals for Area of Interest		**162.8**	**100.0%**

Table 1. Description of soils present within the stand. Provided in NRCS soils report.



Species composition by percent of total basal area per acre (ft²/ac) over the 15 plots established at the Mayfield installation. Other species include WB, RS, QA, BT, and PC

Stand composition by species and size classes where overstory trees are >=4.5in, large saplings >=2.5in - <4.5in, and small saplings >=0.5in - <2.5in DBH

Key Findings/Accomplishments

- For trees ≥ 4.5 inches DBH across 15 permanent plots at Mayfield, there were 207 ± 71 trees/ac (mean ± SD), basal area was 75.1 ± 21.9 ft2/ac, and QMD was 8.3 ± 1.2 inches. For this size class, 12.9% of the basal area was composed of American beech and striped maple. Other tree species included sugar maple, yellow birch, red maple, paper birch, white ash, red spruce, quaking and bigtooth aspen, and pin cherry.

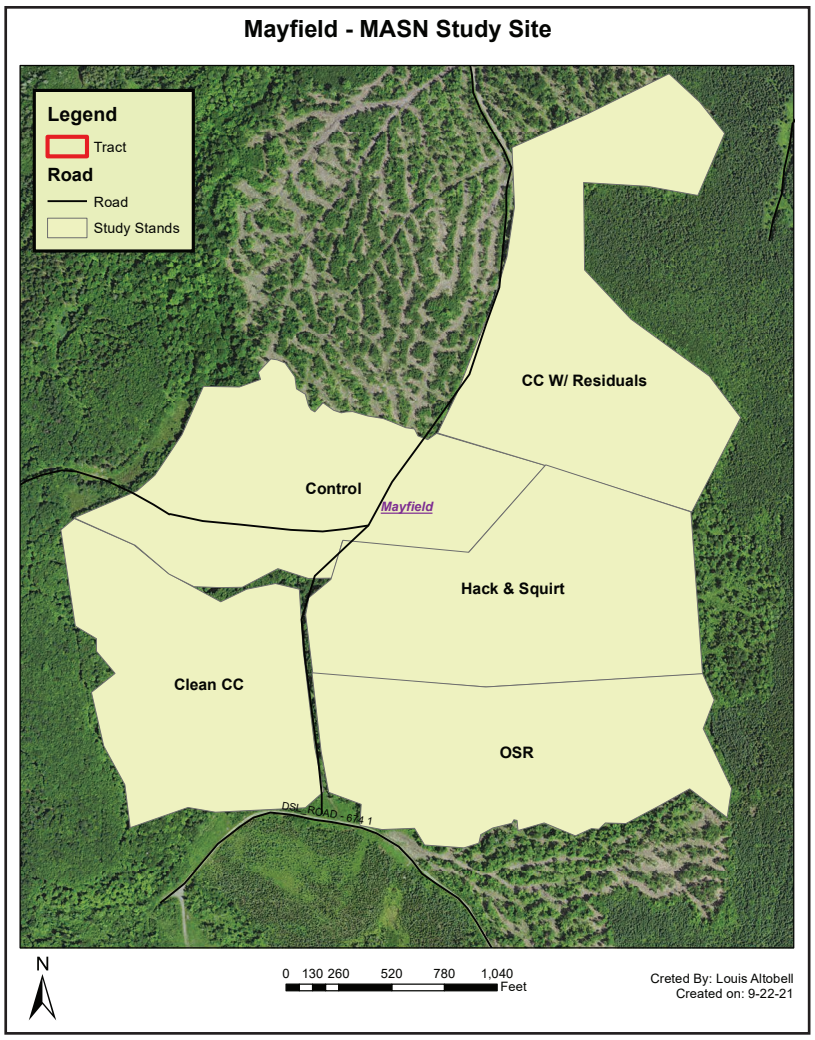
- For large saplings ≥ 2.5 and < 4.5 inches DBH, there were 103 ± 71 trees/ac, and QMD was 2.9 ± 1.2 inches. For this size class, 27.2% of the basal area was composed of American beech and striped maple.

- For small saplings ≥ 0.5 and < 2.5 inches DBH, there were 2790 ± 1323 trees/ac, and QMD was 0.9 ± 0.1 inches. For this size class, 78.2% of the basal area was composed of American beech and striped maple.

- Timber inventory information: Fifteen permanent, fixed radius, nested plots were established across the installation. A nested plot design was used including 1/5th acre, 1/20th acre, and 1/50th acre sizes based on stem sizes. The species composition was primarily American beech and striped maple in the overstory, while hemlock and yellow birch were present in understory (Table 2).

Soil Series	Common Tree Species Present
EMC	American beech, yellow birch, red spruce, white spruce, balsam fir, red maple and sugar maple.
MOB	red spruce, balsam fir, black spruce, northern white cedar, red maple, eastern white pine, eastern hemlock, and paper birch
MTB	red spruce, balsam fir, black spruce, northern white cedar, red maple, eastern white pine, eastern hemlock, and paper birch
TEC	red spruce, white spruce, balsam fir, yellow birch, paper birch, and red maple.

Table 2. Suitability of each soil series for growing particular tree species or species groups.



Stand map for Mayfield describing planned prescriptions for each block
Map - Louis Altobell, Weyerhaeuser

Future Plans

Undergraduates Autumn Brann and Joshua Goldsmith are in the process of summarizing collected data and plan to do an in depth literature review of beech management and herbicide use, and make alternative treatment recommendations for their senior capstone.

In November 2021, Weyerhaeuser began harvest operations on the MASN installation in Mayfield. Post harvest measurements will be conducted in the summer field season of 2022 for further summary of silvicultural presriptions to manage American beech in the stand.

Due to the COVID-19 pandemic and staffing shortages, MASN sites were not measured in 2021. Regular measurements and installation of new sites will resume in 2022.

Acknowlegdements

The CFRU would like to thank Joshua Goldsmith and Autumn Brann for their exemplary committment to working with the CFRU on their senior capstone. Josh and Autumn presented their initial findings on beech at a SAF field tour in Nashville Plantation (MASN, SILC) in August of 2021 as well as some of Joshua Puhlick's findings on invasive earthworms that had been observed at the site.

We would also like to thank the CFRU membership for their continued support on MASN.

Joshua Goldsmith and Autumn Brann present at SAF field tour, August 2021. **Photo** - Regina Smith

HABITAT & BIODIVERSITY

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

Amber Roth, School of Forest Resources & Dept. of Wildlife, University of Maine, Orono

Luke Douglas, M.S. student in School of Forest Resources, University of Maine, Orono

Carol Foss, Senior Advisor for Science and Policy, New Hampshire Audubon

Adrienne Leppold, Maine Department of Inland Fisheries and Wildlife

FINAL REPORT

Abstract

The Rusty Blackbird (Euphagus carolinus) is a spruce-fir obligate that has experienced a steep population decline since the 1970s. The species' response to intensive commercial forestry practices within its breeding range has 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 precommercial 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 working forest landscapes. Blackbirds were confirmed nesting in wetlands, naturally regenerating stands, and stands that had undergone precommercial thinning. Analysis is ongoing, though preliminary results suggest that Rusty Blackbirds select stands for nesting with approximately 30% canopy cover and 50% wetland cover, and select for within-stand microsites with relatively higher basal area of small-diameter softwoods. Additionally, results suggest that fledglings select sites based on percent cover of boreal wetlands and distance to streams/rivers (as in dictated by NHD flowlines); both are quadratic relationships. Preliminary nest survival analysis results suggest that the daily survival rate increased with increasing canopy cover around the nest and decreased in stands that had undergone precommercial thinning.

An adult female Rusty Blackbird that has been banded with a USGS aluminum band and metal color bands.
Photo - Shane Peterson

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

Approach

- Located Rusty Blackbird nests at two sites: 1) land owned by Wagner Forest Management and Umbagog National Wildlife Refuge in New Hampshire, and 2) more intensively managed land owned by Weyerhaeuser Company and Seven Islands in Maine.
- Tagged and tracked fledglings via radio telemetry.
- Measured vegetation characteristics using field methods at nests and paired random points.
- Measured LiDAR-based vegetation characteristics and described other habitat features using a GIS at nest, fledgling, and paired random points.
- Used resource selection functions to identify habitat characteristics that are preferentially selected by Rusty Blackbirds for nests and fledgling rearing and promote their survival.

Photo left: A Rusty Blackbird fledgling that has received a USGS aluminum band and a VHF transmitter. **Photo - Kyle Smelter**

Shane Peterson tracks tagged Rusty Blackbird fledglings using a 5-element Yagi antenna. **Photo - Kyle Smelter**

Key Findings/Accomplishments

- Analysis (sans forestry inventory information, which is still pending from our landowner cooperators) is complete for nest site selection and survival. Analysis (sans forestry inventory information) for fledgling site selection is complete. Fledgling survival analysis is pending.
- High ranking preliminary models for nest site selection included canopy cover and percent wetland cover along a quadratic curve at the landscape scale, with site selection peaking ~30% canopy cover and ~50% wetland cover. (Figure 1). High ranking models at the within-stand scale suggest that selection increases with increasing basal area of small (DBH ≤ 10cm) softwood trees and decreases with increasing percent ground cover of herbs (Figure 2).
- High ranking nest survival models suggest that daily survival rate increased with decreasing canopy height at the stand scale and increased with increasing canopy cover at the within-stand scale. Additionally, preliminary results suggested that stands that underwent precommercial thinning within the past twenty years saw reduced survival of nests.
- High ranking preliminary models for fledgling site selection include distance to streams and rivers (based on National Hydrography Dataset flowlines) and percent cover of wetlands; both covariates have quadratic relationships with selection.

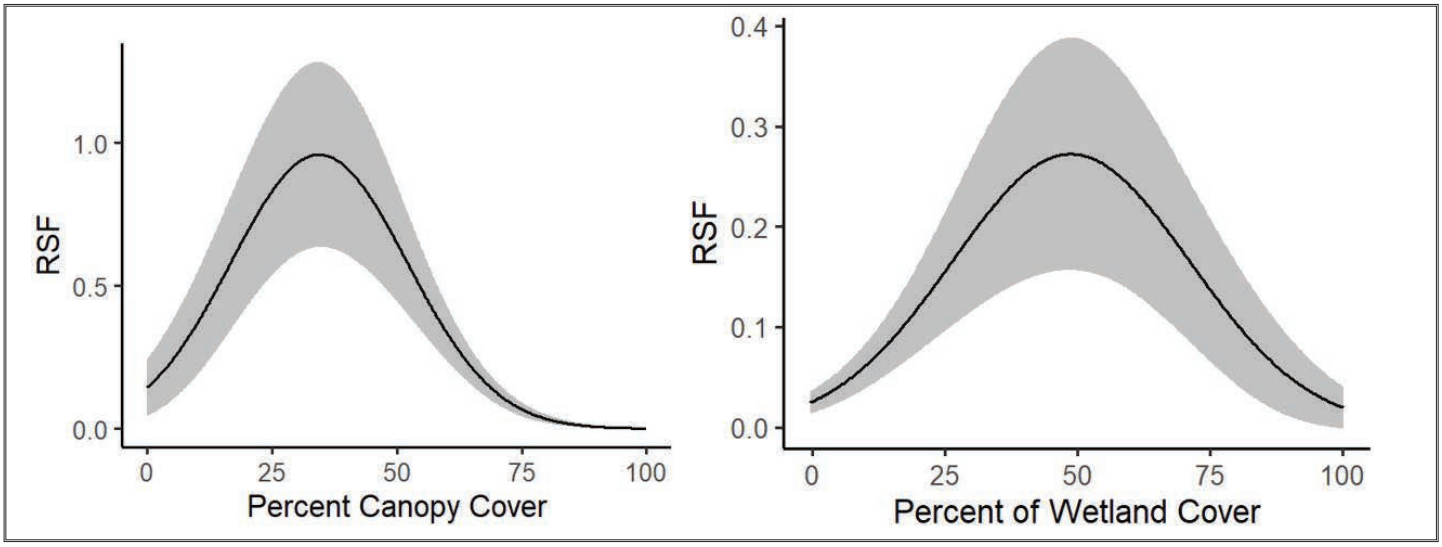


Figure 1. Resource Selection Function (RSF) estimates for canopy cover and percent cover of boreal wetlands from the top ranked Rusty Blackbird nest site selection model at the stand scale in Maine and New Hampshire.

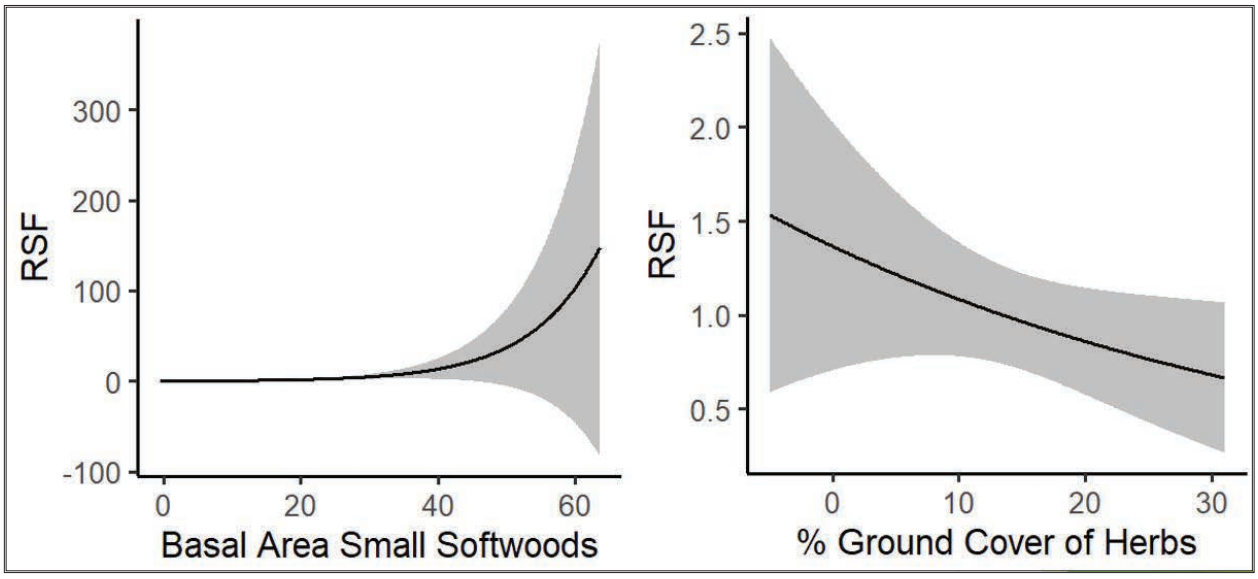


Figure 2. Resource Selection Function (RSF) estimates for basal area of small softwoods (m2/ha) and percent ground cover of herbaceous vegetation from the top ranked Rusty Blackbird nest site selection models at the within-stand scale in Maine and New Hampshire.

Future Plans

- We plan to incorporate forest inventory data, once we obtain them from cooperators, into our nest and fledgling habitat selection and survival models.
- We plan to refine our fledgling habitat selection and survival analyses by subdividing the time when fledglings are dependent on their parents into two time periods: 1) the first two weeks out of the nest, and 2) weeks 3 and 4 out of the nest until independence from parents (~28 days since fledge).
- We will perform survival analyses for fledglings using nest survival models in RMark.

Acknowledgements

We would like to thank Wagner Forest Company, Seven Islands Land Company, Weyerhaeuser Company, and American Forest Management for access to their land and/or forest inventory data. We are grateful for assistance from Henning Stabins of Weyerhaeuser since the project's inception and the contributions from CFRU staff 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 Maine Agricultural and Forest Experiment Station, UMaine Research Reinvestment Fund, National Council for Air and Stream Improvement, Maine Outdoor Heritage Fund, the William P. Wharton Trust, New Hampshire Audubon, the Penobscot Valley Chapter of Maine Audubon, the Garden Club of America, and our generous donors at experiment.com.

Partners/Stakeholders/Collaborators

American Forest Management
Cooperative Forestry Research Unit
Garden Club of America
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
National Council for Air and Stream Improvement
Penobscot Valley Chapter of Maine Audubon
Seven Islands Land Company
Umbagog National Wildlife Refuge
University of Maine at Fort Kent
University of Maine Presque Isle
Wagner Forest Management
Weyerhaeuser Company
William P. Wharton Trust

An adult male Rusty Blackbird captured near Kibby Mountain, Maine.
Photo: Luke Douglas

Geographic Location of Project:

Kibby Township, Maine. Errol, New Hampshire.

We will use these data to provide a web-based map of where CFRU is doing research in state.

Thirty Years of Change in Commercial Forest Management and Implications for Bird Conservation in Maine (1992-2022)

John Hagan Ph.D., Our Common Climate

John Gunn Ph.D, Spatial Informatics Group - Natural Assets Lab

Peter McKinley Ph.D., The Wilderness Society

Michael Reed Ph.D., Tufts University

RESEARCH ONGOING - YEAR 1

Abstract

In 2021 we began the replication of a major study of birds and commercial forestry conducted in the early 1990s in the greater Moosehead Lake region. The replication of this study is relevant because of national-scaled declines in bird populations, and because forestry practices (and therefore bird habitat) have changed significantly since the early 1990s.

In 2021 we conducted the first of two field seasons of data collection. We exceeded our sample set goal of 100 points (we sampled 120 points) toward our study goal of 387 points. In 2022, a 6-person crew will work further south, nearer to Moosehead Lake. With only about one-third of the project data having been collected, it is too early to draw quantitative conclusions. Qualitatively, all of the same bird species are present today, albeit in different abundances in accord with habitat availability. So far, our hypothesis that the commercial forests of Maine contribute in a major way to national-scale bird conservation is supported.

A photo comparison of a portion of the 1M-acre study area. Top: The Great Ragmuff Clearcut (T4R14) in 1993, spanning some 15,000 acres. Bottom: The Ragmuff Clearcut from roughly the same perspective in 2021, 28 years later. Today, the dominant canopy is 45-60 feet tall, primary red spruce and balsam fir. Scattered white pines that were retained during in the 1980s harvest now make up a supercanopy 100-150 feet tall. **Photos - J. Hagan**

Project Objectives

Goal 1: Determine how changes in forest management in Maine's commercial forest over the last 30 years have affected bird populations, in relation to national-scaled bird conservation goals.

- **Objective 1a:** using the same bird survey and vegetation sampling methods we used 30 years ago, quantify changes in density and abundance of landbird populations in a one-million-acre (400K ha) section of Maine's commercial forest.
- **Objective 1b:** compare habitat availability (i.e., forest types) today with availability in the study area from 30 years ago.
- **Objective 1c:** compare and contrast changes in landbird abundance and diversity in Maine's commercial forest to regional and national bird population trends.

Goal 2: Identify silvicultural practices that could enhance national-scaled bird conservation goals going forward.

- **Objective 2a:** describe changes in habitat structure as a result of changes in silvicultural practices in the one-million-acre (.4-million-ha) study area.
- **Objective 2b:** as warranted by changes in bird abundance and diversity, identify silvicultural strategies that would "rebalance" bird habitat to achieve both regional and national bird conservation goals as well as future harvest goals of the landowners.
- **Objective 2c:** bring together all the "birds and forestry" researchers from the Acadian region (Maine, New Brunswick, Nova Scotia) in a day-long virtual symposium to consolidate lessons learned from regional bird research.

Goal 3: Create new opportunities for the birding public to experience the bird conservation benefits of Maine's commercial forest.

- **Objective 3a:** create a web-based "story map" about the contributions of commercial forests to bird conservation.
- **Objective 3b:** create a self-guided, roadside birding trail to enhance eco-tourism in Maine's commercial forest.
- **Objective 3c:** create a short video of both conservation biologists and commercial landowners/managers explaining how forestry contributes to bird conservation at the national scale.

Approach

- Replicate the bird survey sampling intensity of the 1990s study using point count methods.
- Extrapolate species current-day bird species abundances from point count data and stand maps.
- Determine which species have increased and which species have decreased in 30 years.
- Compare species changes in Maine's commercial forest with national-scaled changes.
- Work with landowners to identify forest practice changes that might increase nationally declining species while maintaining or increasing wood supply.
- Create innovative public outreach mechanisms to demonstrate the conservation value of commercial forests, such as a self-guided birding trail out of Greenville, and various short videos to be distributed through social media.

Kelsi Anderson conducting a bird point count in the former Great Ragmuff Clearcut. **Photo - J. Hagan**

Key Findings/Accomplishments

- Completed first of two field seasons of field data collection
    - 120 bird point counts in all forest types and age classes (ultimate goal is 387 points)
    - 120 detailed vegetation surveys at each point count station
- Resurrected stand maps and data from 1990s study
- Assesses Breeding Bird Survey trend data for Maine, region, and U.S.
- Front-page featured article in Maine Sunday Telegram (Aug. 8, 2021)
- 2-min popular video on the project

Commercial forestry bad for the birds? Things aren't so clear-cut

A feller buncher clears fir and spruce trees in Maine's North Woods in July. The clearcut is adjacent to forest where warblers, like the one below, may fatten up on raspberries and blueberries that will emerge ahead of fall migration.

Logging operations in northern Maine can in fact offer migrating songbirds an ideal habitat. Now a team of researchers returns after 30 years to expand its study of this 'shifting mosaic' – how forestry can play a role in biodiversity.

By TUX TURKEL
Staff Writer

TOWNSHIP 4, RANGE 14 — After flying from Central America this spring, a small, yellowish songbird called a mourning warbler homed in on a patch of forest northeast of Moosehead Lake and determined it was the right place to find a mate and raise a family.

This patch is no wildlife refuge. Five or so years ago, loggers harvested most of the trees, leaving a tangle of branches and trunks. Now waist-high maples and alders, raspberry bushes and ferns are emerging amid the slash. It's the perfect habitat for this warbler, a secretive bird that likes to nest near the ground, eat insects and spiders and is more frequently heard than seen.

Nearly 30 years ago, a team of bird researchers came to this land to conduct the first large-scale study of the impact of commercial forestry on bird populations in the United States. At the time, a big paper company was in the process of clearcutting 19,000 acres. That's an area the size of Manhattan.

The Ragmuff Clearcut, named for a stream and road bearing the name, was unsightly and disturbing to many humans. But

Please see BIRDS, Page A6

Front page of Maine Sunday Telegram featuring the "30-year Bird study" from August 8, 2021. Many of the CFRU members are included in the article.

Future Plans

2022

- Complete Year 2 field season (a much bigger field operation than 2021)
- Organize and host a virtual Spring 2022 mini-symposium of bird researchers in the Acadian Forest Region.

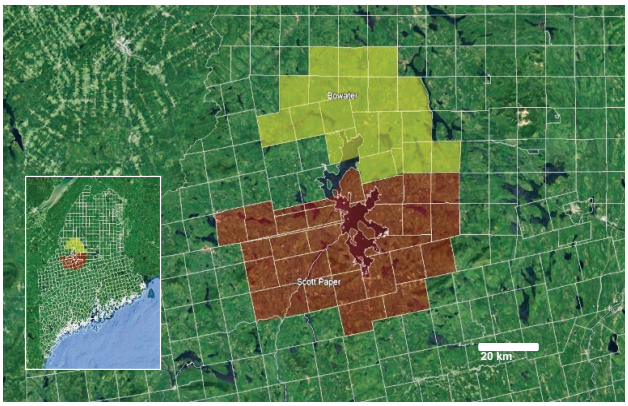
2023

- Finish all scientific deliverables
- Focus on outreach to the public, including a birding trail through the commercial forest.

Acknowledgements

We are very grateful to Eugene Mahar and Jim O'Malley at Landvest for stand maps and for providing free housing at the Ragmuff Camps for Year 1 of this study. We had a phenomenally successful first field season, in part because of the support from Eugene and Jim. Trevor London also helped us understand the Huber landbase and participated in the Portland Press Herald visit. Henning Stabins has been a key promoter of the project, and connected us to NCASI as a potential funder. Ben Dow and Chris Fife from Weyerhaeuser also helped lead the Portland Press Herald field trip. Jan Santerre helped us gain access to BPL lands for some of our survey points. Amy Meehan helped up resurrect the electronic stand maps from the 1990s study.

Geographic Location of Project



The study area includes some 40 townships in the Moosehead Lake region, the same region used in the 1992/1993, which at the time was owned by Scott Paper Co. (red) and Bowater (yellow).

Partners / Stakeholders / Collaborators

Henning Stabins, Weyerhaeuser
Eugene Mahar, LandVest
Jim O'Malley , LandVest
Trevor London, Huber Resources
Tim Post, Bureau of Parks and Lands
Jan Santerre, Maine Forest Service
Amy Meehan, MEIFW

Watershed Scale Drivers of Temperature and Flow of Headwater Streams in Northern Maine

Neil Thompson, University of Maine Fort Kent

Hamish Greig, University of Maine Orono

A tributary to Lane Brook located in T7 R6 is one of the streams that was randomly selected for monitoring. **Photo - Neil Thompson**

FINAL REPORT

Abstract

Stream temperature loggers (n=85 2019, n=180 2020 & 2021) have been placed in randomly selected first and second order streams in Northern Maine for the purpose of building a model predicting stream temperature regimes region-wide. Pressure sensors (n=11) were similarly placed to provide insights on flow regimes. Severe drought affected data collection in 2020 as some streams were dry by late summer, but the majority of data from that year will be usable. Final retrieval of approximately 50% of the temperature loggers has been delayed by high waters in Fall 2021; retrieval will be completed in the 2022 field season. Analysis will include the now-available 2018/2019 Crown of Maine LiDAR collection, especially the canopy height model across the entire watershed and in the riparian area. Operations in the Smith Brook watershed, where two tributary watersheds will be harvested at the higher and lower ends of the normal range of management intensity and compared to a third with no harvesting, has been delayed to 2023 as roads are completed. A doctoral student funded by a WRRI grant has been accepted to UMaine, co-supervised by Dr. Sean Smith of UMaine, planned to start in January. This student will focus on the stream geomorphology questions at the intersection of climate change and forest management for the next 3-5 years.

Project Objectives

- Establish a network of stream temperature loggers in Aroostook and northern Penobscot, Piscataquis, and Somerset counties to predict temperature regimes of 1st and 2nd order streams within the study area.
- Investigate the influence of forest management on stream temperature and flow utilizing a triplet of watersheds (~1,600 acres each), holding one in reserve and operating on the other two at the higher and lower intensity ends of the range of normal management activities.

Approach

- Temperature loggers (n=85 2019, n=180 2020 & 2021) have been placed in randomly selected 1st and 2nd order streams within in the study area. Metrics, such as average daily maximum stream temperature, will be used as dependent variables in models with predictors such as stream gradient, watershed size, elevation, harvest level, area in lakes and ponds, beaver dams, etc. LiDAR data are now available for the full study area and will be used to calculate metrics representing canopy cover within the watershed and within the riparian area.

- Temperature loggers have been placed at intervals in each of the three Smith Brook tributaries. The initial 2019 layout has been replaced and enhanced with a greater number of strongly anchored, higher-capacity loggers that will remain in place and record data through the winter.

Key Findings/Accomplishments

- Three years of temperature data collection have been completed, though final retrieval of 50% of the sensors has been delayed until the 2022 field season. The sample size in 2020/2021 is twice what was originally planned, growing from 85 to 180 as I replaced temperature loggers in Smith Brook with higher capacity models and redeployed the original set to the landscape wide study.

- Preliminary analyses suggest that stream gradient is strongly correlated to temperature, with higher-gradient (steeper) streams tending to be cooler. This result is based on the 10m resolution elevation model; further analysis using metrics from LiDAR are ongoing and will be completed when the last sensors are retrieved in the 2022 season.

Left Fork Twentymile Brook in T12 R9. **Photo - Neil Thompson**

Future Plans

Collection and readout of the last temperature loggers will be completed in spring 2022, analysis in summer/fall 2022, and results submitted for publication fall/winter 2022.

A road was built into the control watershed at Smith Brook; Maine IF&W considers this fatal to the experiment and has withdrawn as a collaborator on all aspects of this work. They have indicated that they remain interested in the results but will have no further involvement in study design, data collection, or analysis. We plan to continue the study at Smith Brook with the incoming doctoral student, who will also consider other sites across the landscape.

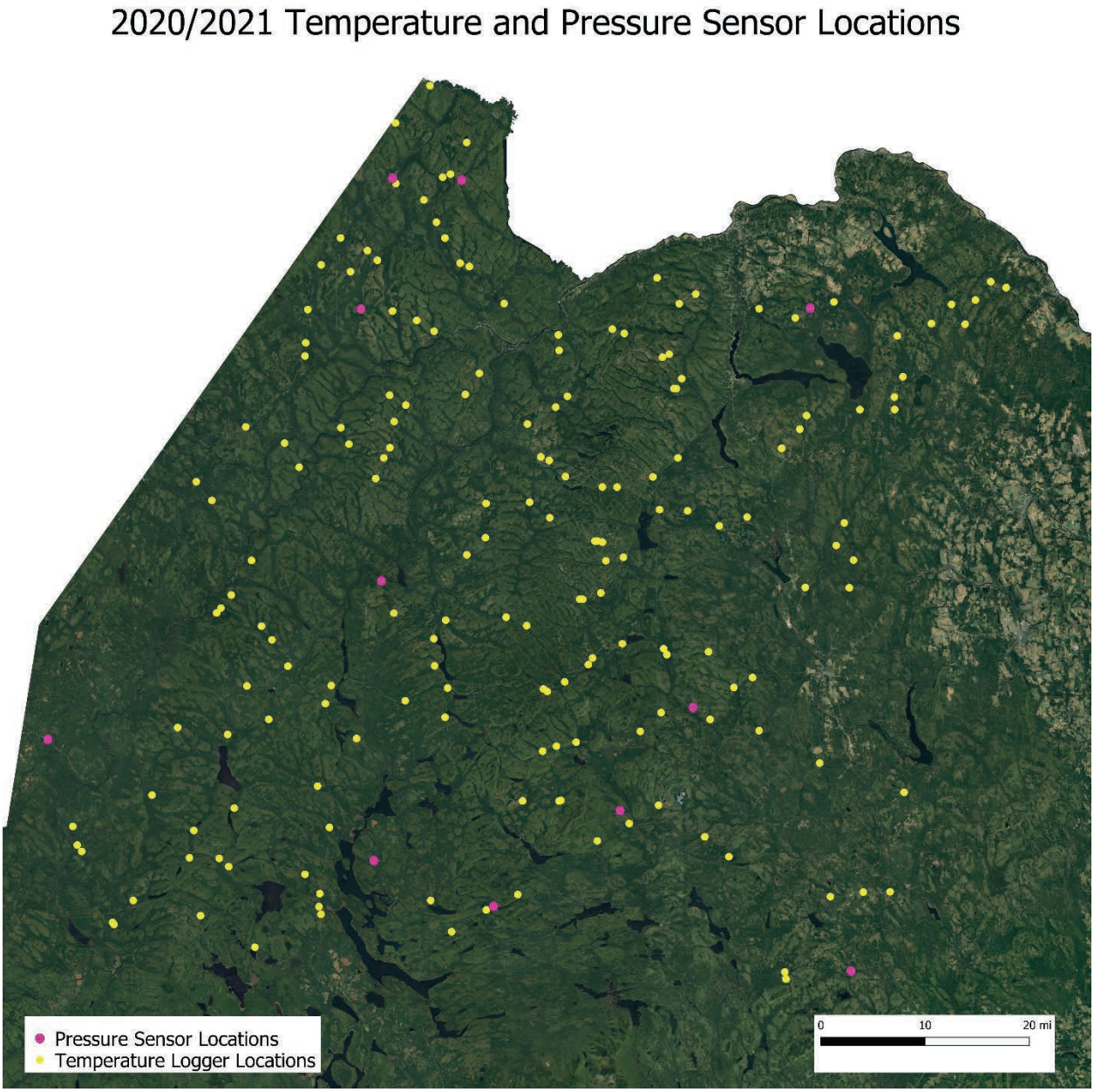
Amin Reza Meghdadi has been accepted to the doctoral program at UMaine, co-supervised by myself and Dr. Sean Smith, a geomorphology expert at UMaine. Amin earned his Master of Science in Water Resources Engineering in 2011 and has established a publication record on stream geomorphology. He is anticipated to start in January 2022, and will develop his research proposal in 2022-2023. His first year is funded by the WRRI grant, and subsequent years will be covered by Dr. Smith's MAFES funding.

Partners / Stakeholders / Collaborators

JD Irving Woodlands

Geographic Location of Project

See map below for pressure sensor and temperature logger locations.



Quantifying the Ecological and Economic Outcomes of Alternative Riparian Management Strategies

Hamish Greig, University of Maine Orono

Amanda Klemmer, University of Maine Orono

Robert Northington, Husson University

Shawn Fraver, University of Maine Orono

Eric Miller, University of Maine Orono

Mindy Crandall, Oregon State University

Ethel Wilkerson, Manomet Inc.

RESEARCH ONGOING

Abstract

Maximizing the economic productivity of timberlands while safeguarding freshwater and riparian ecosystems and their resources requires effective riparian management. These management decisions are improved by access to region-specific information on which buffer approaches optimize long-term investment-to-outcome ratios for forgone harvest vs. freshwater ecosystem health. Our goal is to provide this information by 1) conducting a literature review of the current state of knowledge of the investment cost and effectiveness of riparian buffers in the Northeast; and 2) resample a 2001 riparian buffer experiment in 15 western Maine streams to quantify the long-term (17-year) ecological outcomes and economic investment in alternative riparian buffer designs for forested freshwater resources. These objectives will provide information that CFRU members can use to develop regionally-specific best management practices for riparian buffer designs. We will communicate our results in 2-page summaries, webinars, and searchable databases aimed at foresters and forest managers, as well as in traditional scientific reports and publications.

Project Objectives

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

- Objective 1: Summarize the current state of knowledge of the investment cost and effectiveness of riparian buffers in the Northeast.
- Objective 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

- Our fieldwork focused 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: clear cut 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 control blocks.
- Over two summers, our team collected and analyzed data on riparian forest composition and timber value; stream habitat quality; aquatic invertebrate communities; fish abundance and condition; riparian insects; and litter decomposition rate as a measurement of ecosystem processes.
- These data enable us to quantify the ecological outcomes of alternative riparian management approaches and model the timber value differences between the riparian buffer treatments using forest growth and yield programs.

Key Findings/Accomplishments

• All streams we sampled held diverse insect communities but there were no significant differences in the abundance and diversity of mayflies, stoneflies, and caddisflies among the alternative riparian management treatments.

• We did see a legacy of riparian harvest in the relative abundance of different insect species: communities in unharvested control treatments were significantly different from treatments in which harvest occurred in the immediate riparian zone (i.e., blocks with 0m buffers and partial harvest).

• Streams in harvested blocks were dominated by insects that feed in a collector-gatherer mode, whereas streams in unharvested control blocks had a higher proportion of algal scrapers and a more even distribution of feeding guilds.

• The breakdown rate of forest litter in streams (Figure 1) did not significantly differ among harvest treatments although there was a trend towards higher breakdown rates in streams with partial harvest (Figure 2). These results suggest the modest differences in stream insect communities among riparian management treatments did not translate to impaired stream ecosystem function in terms of litter breakdown.

• Brook trout were present in 9 of the 14 streams with a mean abundance of 20 fish per 40m stream reach fished. Trout abundance and biomass did not differ between harvest types, but individuals were in higher condition (mass per unit length) in streams with harvested riparian zones (0m buffer and partial harvest streams).

• The riparian forest of each stream supported a diverse community of winged adult insects with 10 different orders captured on our sticky traps (Figure 3). We observed no significant differences in the total abundance of adult insects, or the abundance of adult mayflies, stoneflies or caddisflies among the five harvest types.

Figure 1. Leaf bags consisting of 5 g of dried, senesced red maple leaves were added to each of the 14 streams to measure the instream breakdown rate of forest litter. Stream insects (especially shredders) play an important role in this key ecosystem process that transfers forest nutrients and energy into stream food webs. Leaf bags were retrieved 3 times over the 90 day period they were inundated within each stream. **Photo -** Kathleen Brown

• The opportunity cost of alternative riparian management approaches was highest for unharvested control blocks and lowest for clear cut blocks (Figure 4). The opportunity cost of partial harvest trended higher than blocks in which unharvested 11m and 23m buffers were retained.

Figure 3: Sticky traps (left) consisting of transparent plastic sheets with a sticky coating were installed in the riparian zone of each stream to quantify the abundance of flying terrestrial insects and the winged adults of aquatic insects. Traps captured very high abundances of smaller winged species (right), especially in summer. **Photos -** Kathleen Brown.

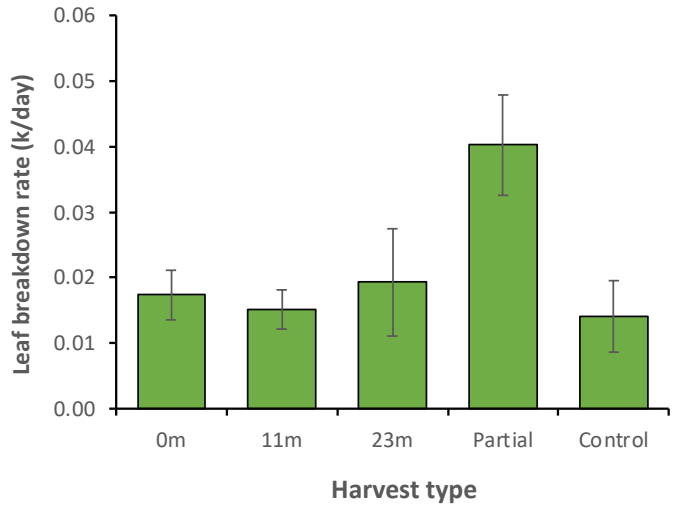


Figure 2. Mean (±1 SE) breakdown rate of leaf bags (5g red maple) added to 14 streams that differed in riparian harvest treatment. Breakdown rate (k) is calculated as the slope of the relationship between mass of leaf lost vs time.

Future directions:

- Finalizing data analysis on the ecological and economic outcomes of alternative riparian management approaches, developing manuscripts for peer-review, and producing written summaries and datasets of our results for managers (Objective 2).
- Summarizing the outcome of an extensive literature search on the the effectiveness of alternative riparian management strategies in the northeast and identify knowledge gaps that could inform future research directions. (Objective 1).
- Our progress on completing objectives this past 12 months has been limited. Unfortunately, our graduate student focusing on Objective 1 suspended their degree because of health challenges, and other project members had ongoing issues associated with impacts of the COVID pandemic on research time. We endeavor to complete the deliverables for both objectives over the next 6 months.

Photo - Neil Thompson

INVENTORY & GROWTH MODELING

Assessing and monitoring soil productivity, carbon storage, and conservation on the Maine Adaptive Silviculture Network

Joshua Puhlick, The Jones Center at Ichauway

Marie-Cécile Gruselle, Friedrich-Schiller University, Jena, Germany

Ivan Fernandez, School of Forest Resources, Climate Change Institute, University of Maine Orono

Brian Roth, SeedTree Organization

FINAL REPORT

Abstract

For this project, soil sampling was done at four Maine Adaptive Silviculture Network (MASN) installations. Changes in soil C and nutrient stocks were evaluated using soils collected from quantitative soil pits. At two of the installations, preliminary analyses indicate that pre-harvest soil P stocks were greater than post-harvest soil P stocks. To a depth of 30 cm below the surface of the mineral soil B horizon, total soil C, N, and K stocks were influenced by depth to bedrock. Soil compaction was also evaluated by comparing the bulk density of soils within and adjacent to side trails used by logging machinery. Our findings indicate that some slash could be dispersed outside of trails during dry weather conditions. Finally, discoveries of non-native earthworms were reported at two of the MASN installations. It is critical that we identify the extent of these invasions and the potential impacts they may have on ecosystem function.

Earthworms in the genera Aporrectodea or Octolasion (top left) and Lumbricus (bottom left). Black A horizon overlying a brown B horizon at the portion of the Seven Islands installation with earthworms (top right). Forest floor characteristics (mostly fresh leaf litter overlying mineral soil) in an earthworm invaded area at Nashville Plantation (bottom right). **Photos -** Joshua Puhlick

Background

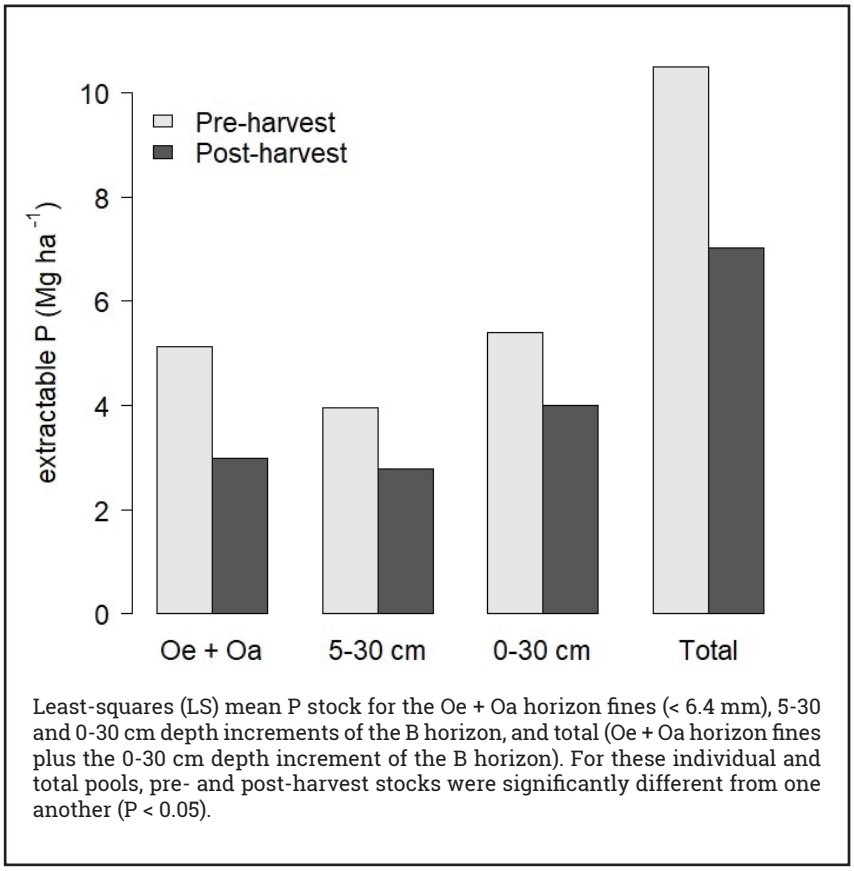
In 2017, Puhlick, Gruselle, and Fernandez were awarded a SFI Conservation grant for assessing and monitoring the influence of forest management practices on soil productivity, C storage, and conservation in the Acadian Forest Region. As part of the SFI grant agreement, soils were sampled on two of the MASN installations. CFRU funding was used to sample soils at additional installations.

Project Objectives

The main objective of this project was to evaluate the influence of different forest management practices on soil productivity, C storage, and conservation across operational-scale research installations in Maine. Key findings about pre-harvest soil attributes, soil compaction, and non-native earthworms were documented in previous CFRU annual reports. During 2020-2021, we also began to test for changes in soil C and nutrient stocks after timber harvesting.

Changes in soil C and nutrients one year after timber harvesting:

Preliminary analyses indicate there was a significant change in soil P stocks ($P < 0.05$), with less P one year after harvesting (see the included figure). For the 5-30 and 0-30 cm depth increments of the mineral soil B horizon and the Oe + Oa horizon fines plus the 0-30 cm depth increment of the B horizon, we did not detect a statistically significant change in C, N, and K stocks. These stocks were influenced by the depth to bedrock, with shallower depths to bedrock tending to have less C, N, and K. For the 0-5 cm depth increment of the B horizon, a greater percentage of coarse fragments in the mineral soil was associated with less C and N.



Least-squares (LS) mean P stock for the Oe + Oa horizon fines (< 6.4 mm), 5-30 and 0-30 cm depth increments of the B horizon, and total (Oe + Oa horizon fines plus the 0-30 cm depth increment of the B horizon). For these individual and total pools, pre- and post-harvest stocks were significantly different from one another ($P < 0.05$).

Future Plans

- Make revisions to the manuscript on projected carbon accumulation after implementing different forest management treatments on the MASN (see appendix).
- Draft and submit a manuscript on changes in soil C and nutrient stocks one year after timber harvesting at the Sauls Brook and Seven Islands MASN installations.

Acknowledgements

We especially thank the foresters and leadership of J.D. Irving, Seven Islands Land Company, and Weyerhaeuser for their discussions about our research, and for providing the land area to conduct the MASN project.

Partners/Stakeholders/Collaborators

Greg Adams, Irving Woodlands, LLC

Ian Prior, Seven Islands

Eugene Mahar, LandVest Timberland Division

Gordon Gamble, Wagner Forest Management

Kenny Fergusson, Maine Forest Service (formerly with Huber Resources Corporation)

Jenna Zukswert, SUNY-ESF (formerly with 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

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

Daniel Hayes, School of Forest Resources, University of Maine Orono

David Sandilands, Wheatland Geospatial Laboratory, University of Maine Orono

Anthony Guay, Wheatland Geospatial Laboratory, University of Maine Orono

Aaron Weiskittel, Center for Research on Sustainable Forests, University of Maine

RESEARCH ONGOING - YEAR 3

Abstract

In its third year, this project is carrying out ongoing 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 efficiency and accuracy in generating geospatial data products useful for forest management. Our investigations have relied on partnerships with landowners in Maine where we are using their inventories as demonstration projects to evaluate the impact of LiDAR and calibration plot quality on model predictions of forest inventory attributes mapped over previous and new ALS data acquisitions.

Our initial investigations year 1 and 2 highlighted many of the key challenges in linking plot data with the LiDAR models. More recently, we have developed and streamlined an operational methodology that has markedly improved both the process and the outcomes. We have applied and evaluated this end-to-end workflow for new projects including with Katahdin Forest Management, Rangeley Lakes Heritage Trust (RLHT), and Stephen Phillips Memorial Preserve Trust (SPMPT). The results notably point to the potential value in the pre-placement of ground plots, strategically located to capture the variation in the LiDAR data (as well as optimizing time- and cost- effectiveness in the field). The results also confirm the importance of high-quality calibration data inputs to ALS-based EFI models, including the use of large, fixed-radius plots located with high-precision GPS. The initial, "qualitative" feedback from our partners is encouraging with respect to the quality and usability of the EFI products.

All of these statistical results from the various comparisons – along with more general "lessons learned" on the process and products – are being compiled within a "Best Practices Guide" for Maine EFI. This project is now supporting a new graduate student, Stephanie Willsey (M.S.), who will focus her thesis work on investigating these research questions, particularly as related to the design and layout of the calibration plot data. Expanding on this research, we are working with several new LiDAR data sources collected with NASA airborne and spaceborne assets. In light of the latest and coming advancements in EFI data and methodology, we will continue to work closely and collaboratively in the coming year (and beyond) with CFRU members, including holding collaborative workshops on project design and future research priorities.

Project Objectives

1. To develop LiDAR metrics and models for accurately and consistently mapping enhanced forest inventory (EFI) attributes over large managed forest areas in Maine.

2. To evaluate the various plot layout and measurement requirements for calibrating ALS based EFI models for large-area, mixed-species and structurally-complex forests.

Approach

In general, we are building our EFI workflow using the area-based approach, which involves the collection of ground measurements that are then linked, via spatial statistical models, with remotely-sensed data to enable area-wide, wall-to-wall estimation and mapping of forest inventory attributes (Næsset, 2002; White et al., 2013). This approach requires high-quality, ground-based measurements co-located with ALS data in order to calibrate the EFI prediction models. In this study, we have set up a series of "experiments" in a factorial design where certain specifications of the calibration plots (i.e., number, size, type, location, and layout) are tested in combination with ALS data sets from various sources. Individual EFI models are being developed for each experiment, taking advantage of coincident plot and ALS data sets for several different study areas in Maine and similar forests in New England and eastern Canada. We are comparing the results of all models based on fit, error, and bias – and these statistics can be used to identify the impact of different data specifications and methodological choices on the quality of the EFI products. All of these statistical results from the various experimental comparisons – along with more general "lessons learned" on the overall process and deliverables – are being compiled and synthesized within a "Best Practices Guide" for Maine EFI.

Key Findings/Accomplishments

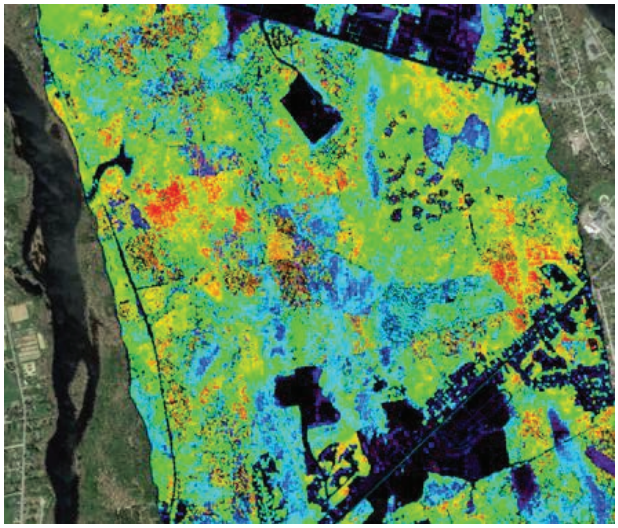
- A comprehensive, flexible and efficient workflow has been developed for building, applying and evaluating EFI prediction maps using an area-based approach. The lidR package (Romain 2018) in R is used to calculate the LiDAR metrics, the variable-radius calibration plot data are prepared and organized in spreadsheets, and randomForest (Breiman 2001) is used to perform the EFI variable prediction modeling.

- Wall-to-wall maps of a list of EFI variables including softwood percent and merchantable volume were generated for the RLHT and SPMPT project areas. We have evaluated the model performance and using these results for case studies in compiling the "Best Practices Guide".

- Compared to models built from variable-radius plots (Ashland West), models consistently performed better and returned lower measures of root mean squared error (RMSE) when fixed radius plots were used for calibration in the RLHT and SPMPT projects.

- The RLHT and SPMPT projects used a modified workflow wherein principal components analysis of the ALS data metrics was used to stratify the study for plot placement. This allowed for efficient field data collection by targeting plots within representative areas across the full range of variability in forest types and structures, and for easily accessible locations.

- New, high-resolution research grade ALS data from NASA Goddard's Lidar-Hyperspectral-Thermal (G-LiHT) instrument were acquired in summer 2021 for several areas of interest in Maine. These new acquisitions, and accompanying field measurements, are being incorporated into our experimental design for testing plot and data quality on model performance.



Canopy Height Model (CHM) of the Demeritt (University) Forest, Old Town, Maine, derived from G-LiHT lidar acquisition in August 2021.

Future Plans

- We are continuing to investigate several research questions on plot design, placement, and LiDAR data density for their impacts on EFI model performance and applicability across various project objectives. Specifically, we have expanded these analyses by acquiring plot data from the Canadian Forest Service and high-density airborne LiDAR from NASA to analyze a larger set of comparisons designed to address key parts of the workflow to be reported in the "Best Practices" guidelines deliverable.
- EFI model performance comparisons include (1) calibration plot stratification by LiDAR metrics and existing stand type vs. grid and random sampling designs, (2) calibration plot type (fixed- vs. variable-radius) and location accuracy, and (3) LiDAR point density and type (leaf-on vs. leaf-off).

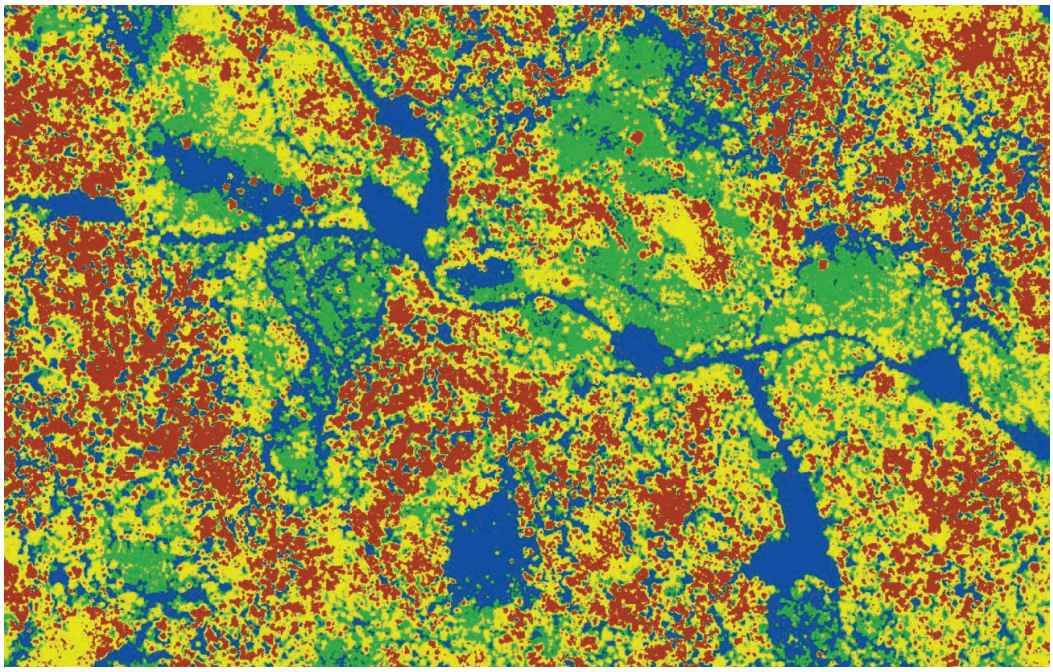
- We have recently brought on a new graduate student, Stephanie Willsey (M.S.), who will focus her thesis work over the next year on investigating these research questions.
- Expanding on this research, we are also now bringing several new LiDAR data sources to bear on these questions, including a recent (summer 2021) airborne campaign in Maine flown by NASA's Goddard Space Flight Center (G-LiHT) as well as from satellite (ICESat-2) and even the International Space Station (GEDI).
- We are expanding our stakeholder collaborations to include a greater number of CFRU members in model development, data analysis and technology transfer. Future in-person workshops include custom EFI workflow development, specifically with Baskahegan Co. (delayed by the pandemic). We will also plan 1-2 virtual / hybrid workshops on EFI for the coming year, to include CFRU members and other interested stakeholders.
- We will continue to adhere to our timeline of project deliverables and associated communications plan, including holding technical workshops for CFRU members, disseminating our current findings in presentations to the stakeholder and science communities, and delivering an annual report to the CFRU members on this project's progress, results-to-date and future plans.

Acknowledgements

We thank the CFRU members for their support of this project through a financial contribution, data sharing and general interest in this project's research and objectives. Special thanks goes to Seven Islands Land Company and the Maine Timberlands Charitable Trust for their active participation and strong support. It is very much appreciated and is critical to the WGL's mission of supporting geospatial education, research, and innovation needs of students, forest industry, and natural resource partners in Maine.

Partners/Stakeholders/Collaborators

Seven Islands Land Company, Baskahegan Company, Rangeley Lakes Heritage Trust, Stephen Phillips Memorial Preserve Trust, Katahdin Forest Management, NASA Goddard, US Forest Service, Canadian Forest Service / Wood Fibre Centre.



Example of a size class raster product (seedling, sapling, pole, log) developed from synthesizing multiple raster EFI maps.

References

- Næsset, E., 2002. Predicting forest stand characteristics with airborne scanning laser using a practical two-stage procedure and field data. Remote sensing of environment, 80(1), pp.88-99.
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Spruce Budworm L2 Monitoring Program in Maine

Angela Mech, Assistant Professor of Forest Entomology, School of Biology & Ecology

Neil Thompson, University of Maine Fort Kent

RESEARCH ONGOING - YEAR 1

Abstract

In 2008, spruce budworm (SBW) initiated its current outbreak. With the previous outbreak having caused extensive ecological and economic losses, the ability to identify areas where SBW populations are growing exponentially had become of the utmost importance. The goal of this project was to establish a SBW processing lab in the state to allow land managers in Maine to make time-sensitive decisions about SBW control. This project was initiated mid-July 2021 with the hiring of the spruce budworm processing lab manager, James Stewart. Since then, James has helped clean up the space that would become the processing lab, ordered all of the necessary supplies, and set up the lab according to all safety protocols. We also worked with the Department of Industrial Cooperation at the University of Maine and set up the SBW storefront for processing jobs outside of those associated with the monitoring program, and on October 6th, 2021, the lab officially opened. All landowners/managers were supplied with collection bags for the 307 monitoring sites in Maine. As of December 1st, 2021, 67 monitoring sites (201 branches), comprising 22% of the total monitoring program, and 8 contract sites have been processed. So far, 22 sites had L2 counts of one or greater (max = 6.33 L2's) in 2021 compared to 19 sites in 2020.

James Stewart, SBW Lab Manager & Sierra Croney, MS Entomology graduate student at the University of Maine Orono process branch samples
Photo - Ron Lisnet

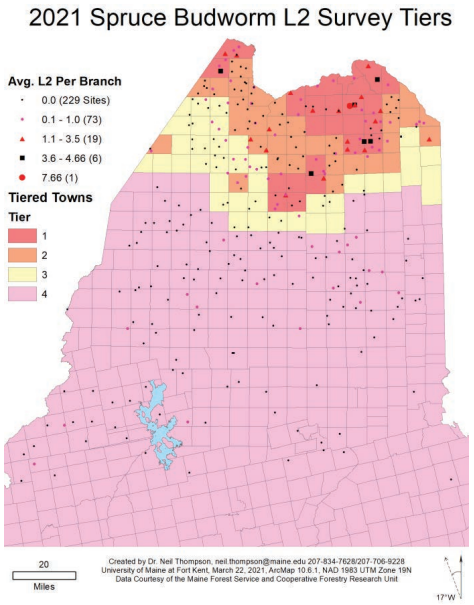


Figure 1. All 307 SBW monitoring sites broken down into priority tiers for the 2021 sampling season. Avg. L2 counts are from 2020 results.

Project Objectives

- To establish a SBW processing lab at the University of Maine that would be responsible for determining the L2 counts for 307 monitoring sites across the state.
- To provide a fee-for-service option for landowners to have additional sites processed.
- To provide rapid results for areas that need to make management decisions quickly.

Key Findings/Accomplishments

- As of 12/1/2021, 75% of the Tier 1 sites and 44% of Tier 2 sites (total of 201 branches) have been processed. Of those, there has been a 50% increase in the number of sites with L2 > 2.0, but the overall average L2's for Tier 1 sites has remained about the same (avg. 1.26 L2's in 2020 vs. 1.30 L2's in 2021).

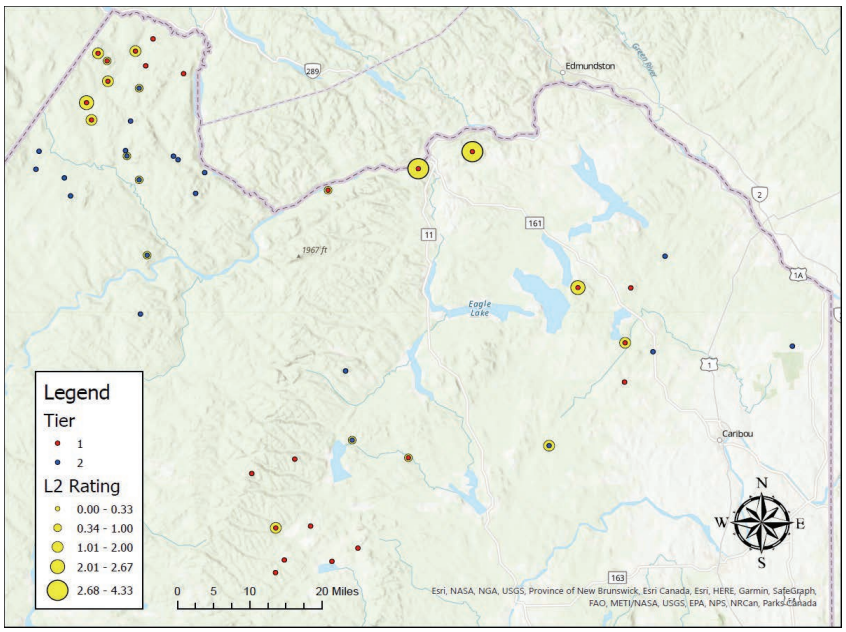


Figure 2. Partial L2 monitoring results as of 12/1/2021. *Note – sites with missing 2021 latitude and longitude were not included in this map.

Key Findings/ Accomplishments

- As of 12/1/2021, 75% of the Tier 1 sites and 44% of Tier 2 sites (total of 201 branches) have been processed. Of those, there has been a 50% increase in the number of sites with L2 > 2.0, but the overall average L2's for Tier 1 sites has remained about the same (avg. 1.26 L2's in 2020 vs. 1.30 L2's in 2021).
- Tier 2 sites have increased from an average of 0.18 L2's in 2020 to 0.45 L2's in 2021.
- The same number of sites increased as did decreased in L2 counts since 2020.

Future Plans

- Complete processing for remaining 2021 monitoring sites and any additional contract sites that come in.
- Create final map of 2021 L2 counts and share results
- Prepare for 2022 branch processing

Partners/Stakeholders/Collaborators

Frank Cuff, Weyerhaeuser

Ked Coffin, J.D. Irving

Jim O'Malley, LandVest

Eugene Mahar, LandVest

Ian Prior, Seven Islands Land Co.

Allison Kanoti, Maine Forest Service

Mike Parisio, Maine Forest Service

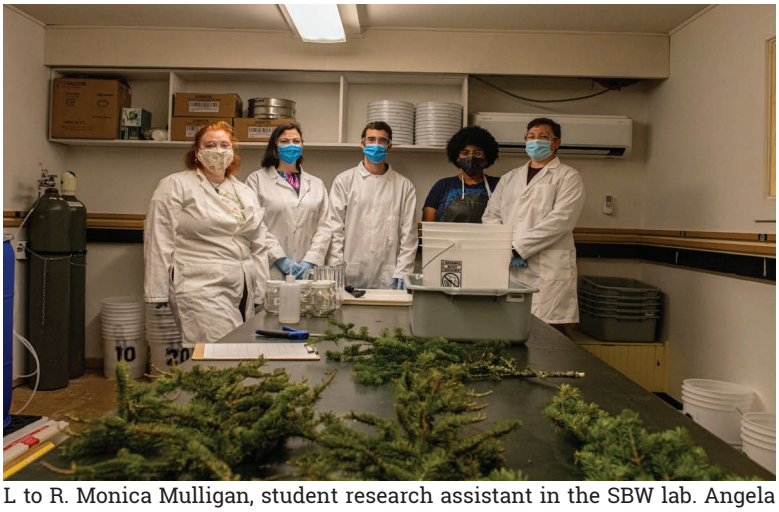
Joe Birther, Maine Forest Service

Erin Simons-Legaard, University of Maine Orono

Kasey Legaard, University of Maine Orono

David Evanoff, University of Maine Orono

1865 THE UNIVERSITY OF MAINE
Spruce Budworm Lab



L to R. Monica Mulligan, student research assistant in the SBW lab. Angela Mech, Assistant Professor of Forest Entomology, University of Maine. James Stewart, SBW lab manager, Sierra Croney, M.S. in Entomology working on HWA. Sadia Crosby, M.S. in Entomology working on browntail moth. **Photo** - Ron Lisnet

Interdisciplinary Spatial Modeling of Terrain, Wetness, Soils and Productivity: New Tools for Forest Management

Colby Brungard, Environmental Soil Consulting

Chris Hennigar, FORUS Research

RESEARCH ONGOING - YEAR 2

Abstract

Forest planning and management considerations rely on accurate terrain, soil, wetness, and productivity information. This digital soil mapping (DSM) project combines thousands of georeferenced soil observations with hi-resolution LiDAR and satellite imagery to create raster maps of soil properties and wetness at 5m spatial resolution. In addition to DSM, this project combines LiDAR-derived forest stand height with existing stand age data (clearcut harvest data contributed by CFRU members) to produce a 20m resolution forest productivity layer. The first two years of this project focused on DSM model development in a 1.5 million acre pilot area in central Maine. We integrated 2,666 soil observations with 141 terrain derivatives to produce quantitative spatial models for three soil properties using seven statistical and machine learning techniques. Model performance was compared for each property, and an ensemble model approach resulted in RMSE of plus or minus 15.4 cm for depth to seasonal wetness, 24.3 cm for depth to bedrock, and 6.7 cm for depth to dense root restricting layer. Initial efforts to integrate DSM and terrain layers into a harvest suitability class layer were promising but require further refinement. Forest productivity modeling was halted in the central Maine pilot area because of the limited availability of reliable clear-cut harvest data in the area. As a remedy, we are working with CFRU members to gather stand age data from the 4.5 million acre study area in northern Maine for model development this coming year. These hi-resolution raster data layers promise to help users anticipate site accessibility and productivity in pursuit of sustainable forest management.

Colby Brungard presents with his team at the CFRU fall field tour.
Photo -Regina Smith

Project Objectives

- Combine soil point data with terrain and landform layers (and LiDAR-derived Wet Areas Mappin, WAM, where possible) to produce a suite of soil property layers using digital soil mapping techniques.
- Incorporate relevant soil property layers with LiDAR-derived WAM to produce a soil-adjusted wetness layer (depth to water table) where possible.
- Produce three custom forest management layers derived from soils, wetness, and terrain layers: harvest operability, general harvest season, and soil rutting hazard.
- Produce layer of forest productivity estimates using remotely sensed data (LiDAR-based biomass and satellite-based stand age)
- Correlate productivity with soils, wetness, terrain, and climate factors to predict site index for hardwood,

softwood, and mixedwood forest types.

- Assess accuracy of soils, wetness, and productivity layers and create raster layers that express model accuracy (e.g. in terms of RMSE) and bias spatially.

Approach

- Gather and pre-process new and existing soil description data (texture, parent material, depth to water table/bedrock, etc.), along with LiDAR and other relevant remotely-sensed data for spatial analysis in the 1.5 million acre pilot area in Somerset and Penobscot counties.
- Use well-established terrain analysis, digital soil mapping, and hydrology modeling techniques to generate environmental spatial layers that are useful for modeling site productivity, harvest operability, general harvest season, and soil rutting hazard.
- Use machine learning techniques to spatially predict soil properties by combining thousands of field observations from NRCS soil survey with environmental spatial layers as model covariates. Validate soil property models with an independent dataset. Generate uncertainty layers that show the spatial variability of soil model performance.
- Develop a calibration for WAM according to soil properties, such that areas with deep or coarse-grained soils reflect deeper water tables and areas with shallow fine-grained soils reflect shallower water tables. Compare the differences between calibrated and uncalibrated WAM, and validate model performance with independent dataset or cross-validation.
- Create logic-based algorithms that generate forest management interpretation layers for harvest operability, harvest season, and soil rutting hazard comparable to existing NRCS soil survey interpretations.
- Use LiDAR point cloud data to calculate canopy height, and estimate site productivity based on growth per year. This approach relies on quality stand age data contributions from CFRU members. Fit non-linear models of LiDAR-derived biomass estimates and age across hardwood, softwood, and mixedwood types and assess model performance.
- Relationships and interactions between modeled biomass and site layers (soils, WAM, climate, terrain) will be explored with machine learning techniques to produce an estimated forest productivity layer.

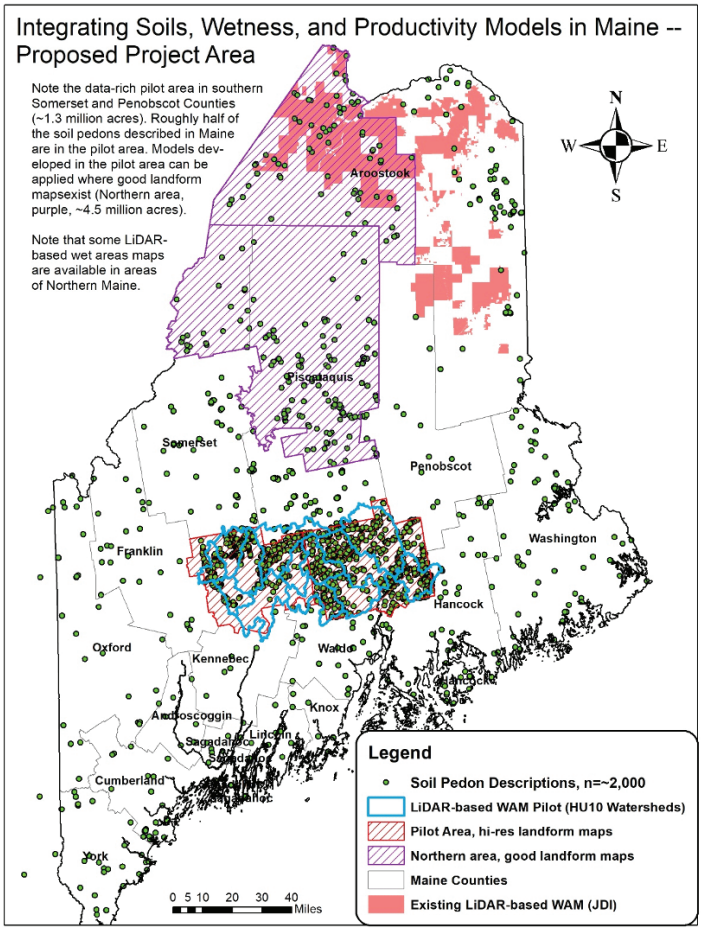


Figure 1. Map of georeferenced soil observations (green) in the central Maine pilot area (red stripes) and the northern Maine study area (purple). Areas with existing LiDAR-derived Wet Areas Mapping (red) have been expanded to new areas not shown on this map.

Key Findings/Accomplishments

- 2,666 soil observations and 141 environmental layers were used to train models in pilot area (Fig. 1).
    - 7 statistical and machine learning models run and compared (Gradient Boosting Machines, Random Forests, Cubist, Multivariate Adaptive Regression Splines, Elastic Net, Regression Tree, Linear Regression).

- Accurate models were ensembled to produce a single, best spatial model for each soil property.

- An independent validation dataset of 46 observations was collected to assess model performance.
  - Random sample, stratified by soil parent material

- 3 soil properties modeled in pilot area with high vertical precision.
  - Depth to seasonal wetness – RMSE ± 15.4 cm (Fig 2).

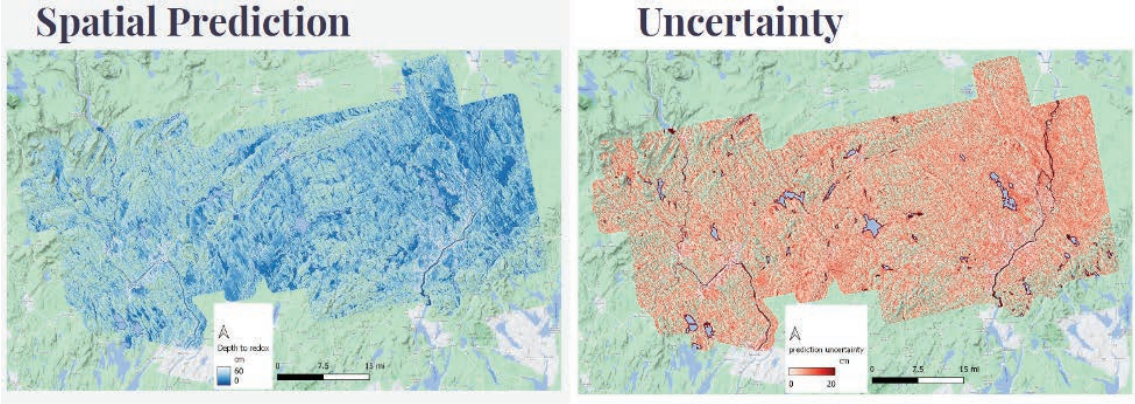


Figure 2. Spatial prediction of depth to seasonal wetness (left) and spatial prediction of uncertainty in depth estimates (right). RMSE ± 15.4 cm.

  - Depth to bedrock – RMSE ± 24.3 cm (Fig 3).

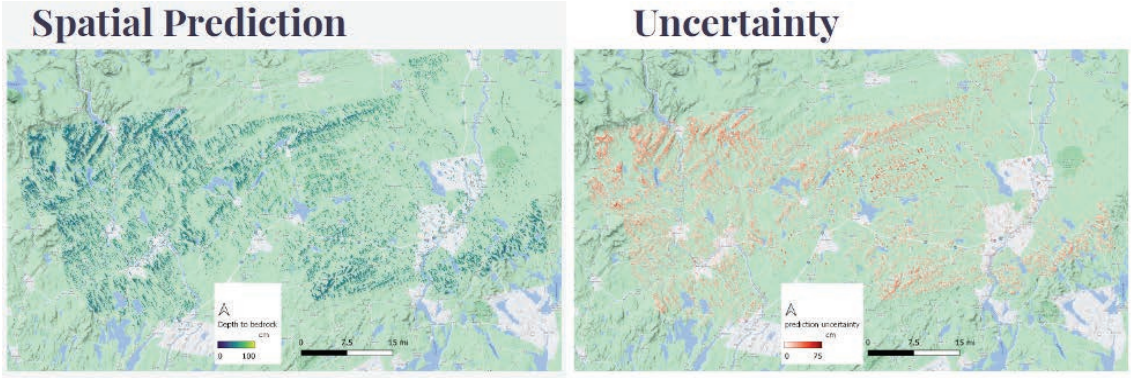


Figure 3. Spatial prediction of depth to bedrock (left) and spatial prediction of uncertainty in depth estimates (right). RMSE ± 24.3 cm.

  - Depth to dense root restricting layer – RMSE ± 6.7 cm (Fig 4).

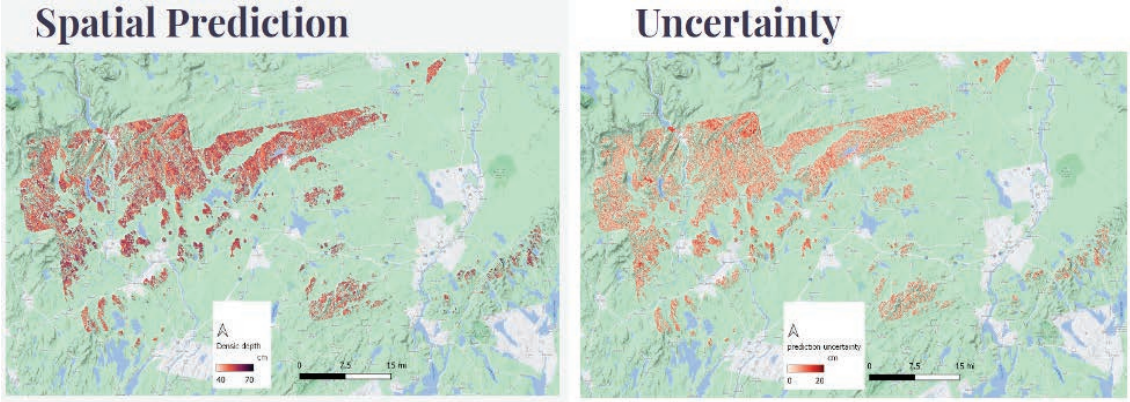


Figure 4. Spatial prediction of depth to dense root restricting layer (left) and spatial prediction of uncertainty in depth estimates (right). RMSE ± 6.7 cm.

- Note: Depth of organic surface horizon was not accurate using this approach.

- Initial interpretive layers were developed for harvest operability and general harvest season, but require further refinements in year 3.

- There is evidence to suggest that the three modeled soil properties may explain a portion of the residual error in the Biomass Growth Index (BGI) produced by past CFRU investments (Fig 5).

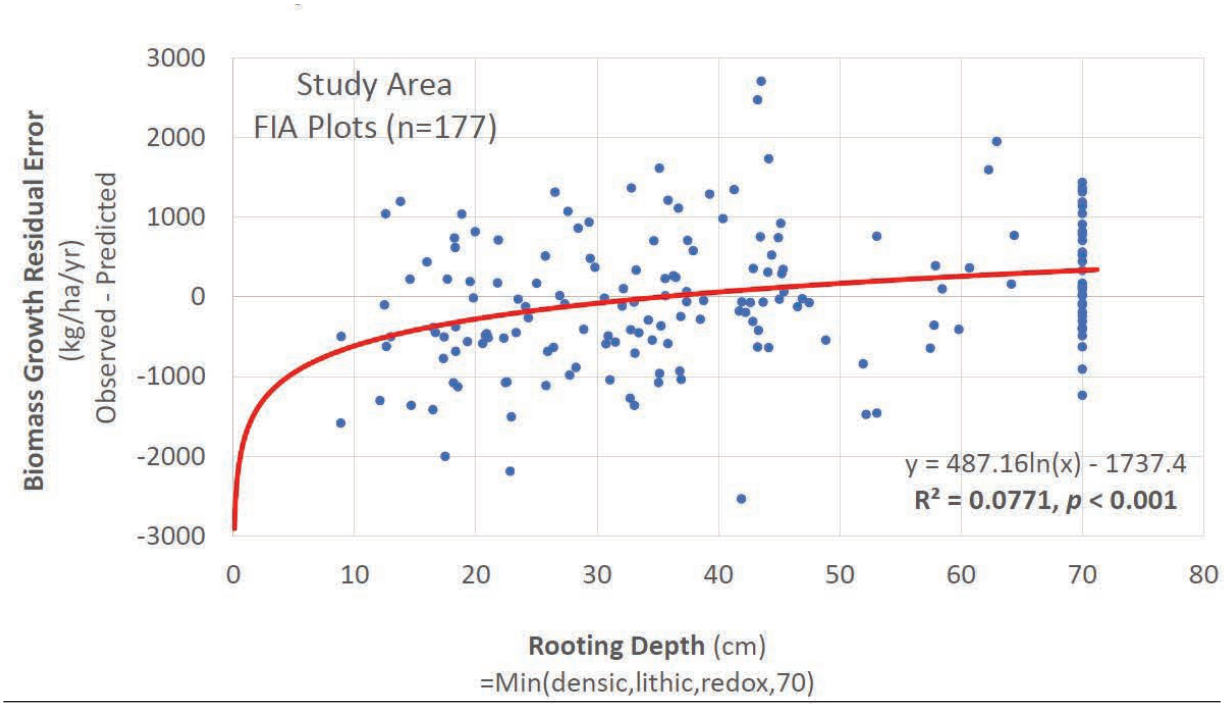


Figure 5. Relationship between minimum tree rooting depth and the residual error of biomass growth of the Biomass Growth Index based on 177 FIA plots.

- Minimum tree rooting depth, as derived from the 3 DSM layers, is correlated to the residual error of biomass growth (kg/ha/yr) of the BGI based on 177 FIA plots in the pilot area.

- There are many more FIA plots in the northern study area, so this and other relationships between soil properties and productivity will be assessed.

- The use of LANDSAT-derived harvest history was not feasible in the pilot area due to the relatively small size and low density of harvests compared to northern Maine (Fig 6).

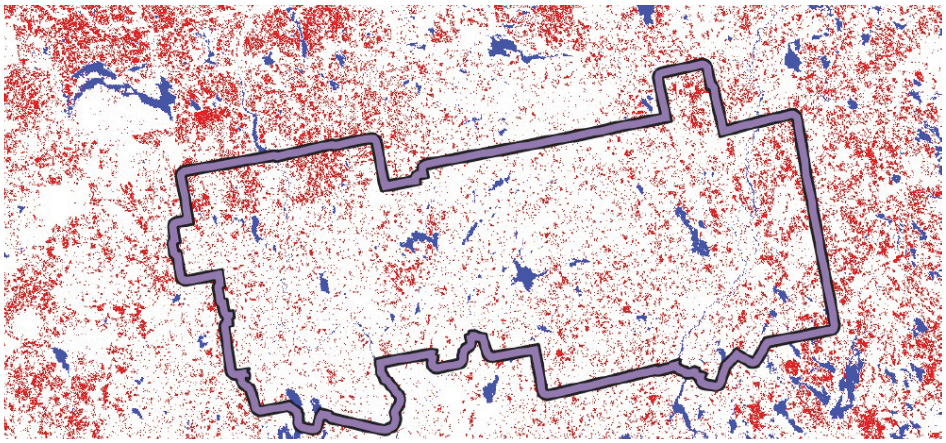


Figure 6. Map of timber harvests from 1986-2010, derived from LANDSAT imagery. Note the size and density of harvest within the pilot area is less than other areas of the state.

- Acquiring harvest history data from CFRU members in the northern study area is necessary to develop a LiDAR-derived productivity layer, including the following:
    - Clear-cut harvest polygons from 1985 to present
    - Year of harvest
    - Additional treatments since year of harvest (description of each treatment code)
    - Cutover regeneration species type, if possible (not required, but helpful)

Future Plans

- Expand DSM project extent to the 4.5 million acre study area in northern Maine (Fig 1).
    - NRCS has found thousands of additional georeferenced soil observations in the northern Maine study area and is currently processing the data for use in this project.
    - An independent validation dataset has been collected for the northern study area.
- A few additional soil properties will be modeled and assessed for both project areas.
    - Soil property models with acceptable levels of uncertainty will be included in the final deliverables.
    - Each soil property model will be delivered as a single raster layer that includes both project areas at 5m resolution.
- Interpretive layers for harvest operability and general harvest season will be refined, and soil rutting hazard will be developed.
    - Creating interpretive layers from DSM products is cutting-edge research.
    - We are actively testing and comparing several approaches to integrate relevant spatial information to create useful interpretive layers.
- Assess the feasibility of incorporating WAM products with DSM and productivity models in areas where LiDAR-derived WAM is available.
    - Staffing changes have prompted a shift away from the use of WAM.
    - We are considering depth to seasonal wetness as a viable alternative if incorporating WAM into this project remains infeasible.
- Work with CFRU members to collect reliable harvest history data for forest productivity modeling in the northern area.

Partners/Stakeholders/Collaborators

Jamin Johanson, USDA, NRCS

Nicholas Butler, USDA, NRCS

Acknowledgements

Special thanks to Alaina Kresovic and Joshua Dera for assisting with soils data entry and field data collection of the validation dataset.

Geographic Location of Project

See Figure 1 (pg. 44)

Pilot Area – 1.5 million acres in southern Somerset and Penobscot Counties, ME.

North Area – 4.5 million acres in northern Maine.

APPENDIX: PROJECT OUTPUTS

Refereed Journal Publications (8)

- Kizha AR, Nahor ER, Coogen N, Louis LT, George AK. 2021. Residual Stand Damage across Varying Silvicultural Prescriptions. Sustainability 13 (14), 7641
- Louis LT, Kizha AR, Daigneault A, Han SH, Weiskittel AR. In press. Factors affecting operational cost and productivity of ground-based timber harvesting machines; A meta-analysis. Current Forestry Reports.
- George AK, Kizha AR, Kenefic L. 2021. Sustainable timber harvesting on fragile ground and impacts of uncertainties in the operational cost. International Journal of Forest Engineering. DOI: 10.1080/14942119.2022.1988432.
- Louis LT, Kizha AR. 2021. Wood biomass recovery costs under different harvesting methods and market conditions. International Journal of Forest Engineering 32 (2), p 164-173. https://doi.org/10.1080/14942119.2021.1874206.
- Puhlick, J. J., A. R. Weiskittel, I. J. Fernandez, K. A. Solarik, D. Sleep. Evaluation of projected carbon accumulation after implementing different forest management treatments in mixed-species stands in northern Maine. In review.
- Puhlick, J. J., I. J. Fernandez, and J. W. Wason. 2021. Non-native earthworms invade forest soils in Northern Maine, USA. Forests. 12, 80. doi: 10.3390/f12010080.
- Puhlick, J. J. and I. J. Fernandez. 2020. Influence of mechanized timber harvesting on soil compaction in northern hardwood forests. Soil Sci. Soc. Am. J. 84(5): 1737-1750. doi: 10.1002/saj2.20127.
- Ayrey, E., D.J. Hayes, J.B. Kilbride, S. Fraver, J.A. Kershaw, B.D. Cook, and A.R. Weiskittel (2021) Synthesizing Disparate LiDAR and Satellite Datasets through Deep Learning to Generate Wall-to-Wall Forest Inventories of New England, submitted to Remote Sensing, in review.

Other Publications (3)

- Puhlick, J. J., and S. Bugbee. 2021. Maine Adaptive Silviculture Network (MASN) Field Tour Booklet. Maine Society of American Foresters and University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit.
- Roth, E., J. J. Puhlick, and I. J. Fernandez. 2020. Relative risk of soil nutrient depletion among different intensities of biomass removal during timber harvesting in Maine, USA. University of Maine, Center for Undergraduate Research Final Report.
- Guay, A,P., D. Sandilands, and D.J. Hayes. 2019. Processing Airborne Laser Scanning data acquisitions for Enhanced Forest Inventory (ALS-EFI) geospatial data products – Baskahegan Company. Final Report, June 14th 2021, Prepared by the Wheatland Geospatial Lab, School of Forest Resources, University of Maine. 9pp.

Presentations, Workshops, Meetings, & Field Tours (24)

- George AK, Louis LT, Alex A, Kizha AR. 2021 Cost of Logging and Residual Stand Damage: Insights from the MASN Study. Cooperative Forestry Research Unit. October 21, 2021. Ashland, ME.
- Louis LT, Daigneault A, Kizha AR. 2021. Biomass harvesting amidst market and policy constraints: perspectives of foresters and loggers in the Northeastern United States. Council on Forest Engineering and International Symposium on Forestry Mechanization (COFE-FORMEC). Sep 27-30. Oregon State University, Corvallis, OR (Accepted).
- Kizha AR, Alex A, George AK, Louis LT. 2020. Cost of Harvesting Small-diameter Trees: Comparing Semi-Mechanized and Mechanized Harvesting Operation. Society of American Foresters National Conference. Providence, RI. Oct 18-Nov 1.
- Louis LT, Kizha AR, Daigneault A. 2020. Uncertainty in Timber Harvesting Cost and Productivity: A Review. Society of American Foresters National Conference. Providence, RI. Oct 18-Nov 1.
- Louis TL, Kizha AR. 2020. Woody Biomass Harvest: Comparing Conventional with Exclusive Cost Apportioning Methods. University of Maine 2020 Student Symposium. Bangor, ME. Oct 2nd.
- Douglas, L. 2021. "Rusty Blackbird use of commercial spruce-fir forests of northern New England." Oral presentation for The Maine Chapter of the Wildlife Society Fall Meeting & Wildlife Research Symposium, December 2, 2021.
- Roth, A, C. Foss, and L. Douglas. 2021. "Rusty Blackbird Nesting Habitat: To PCT or Not To PCT?." Oral Presentation for NCASI Virtual Conference, September 14-16, 2021.
- Roth, A, L. Douglas, and C. Foss. 2021. "New England Rusty Blackbird Project." Oral Presentation for NCASI Eastern Biodiversity Working Group Meeting, March 29, 2021.
- C. Foss, L. Douglas, and A. Roth. "Improving Best Management Practices in Commercial Forests for Rusty Blackbird, a High Conservation Priority Spruce-Fir Obligate." Oral Presentation for the NCASI Northern Sounding Board Meeting, April 5, 2021.
- Douglas, L., A. Roth, and C. Foss. 2020. "Rusty Blackbird use of commercial spruce-fir forests of northern New England." Oral presentation for 27Th Annual Conference of The Wildlife Society, 2020. This presentation was also posted on International Rusty Blackbird Working Group's (IRBWG) website at the following link: http://rustyblackbird.org/2020-symposium-presentations-at-the-wildlife-societys-annual-conference/
- Roth, A. (2020, October 7-9). Rusty Blackbird use of commercial spruce-fir forests of northern New England. Presentation to Rusty Blackbird workshop hosted by the IRBWG.
- Douglas L. 2020. "The Rusty Blackbird Project – 2019 Inez Boyd Environmental Research Award Recipient Presentation." Digital presentation for the Penobscot Valley Chapter of Maine Audubon, sent out to chapter members during May 2020. https://video.maine.edu/media/The+Rusty+Blackbird+Project+-+2019+IBERA+Recipient+Presentation/1_c7hyo2cs.
- Hagan, J., Gunn, J., McKinley, P., Reed, M. (2021, March 3). Thirty years of change in commercial forest management and implications for bird conservation in Maine (1992-2022). Presentation to Maine Forest Products Council Wildlife Committee.
- Hagan, J., Gunn, J., McKinley, P., Reed, M. (2021, May 5). Thirty years of change in commercial forest management and implications for bird conservation in Maine (1992-2022). Presentation to Wagner Forest Management group.

- Hagan, J., Gunn, J., McKinley, P., Reed, M. (2021, August 4). Thirty years of change in commercial forest management and implications for bird conservation in Maine (1992-2022). Presentation to NCASI Northern Research Committee.
- Hagan, J., Gunn, J., McKinley, P., Reed, M. (2021, Dec. 1). Thirty years of change in commercial forest management and implications for bird conservation in Maine (1992-2022). Presentation to SFI SIC.
- Puhlick, J. J. Assessing and monitoring the influence of forest management practices on soil productivity, carbon storage, and conservation on the Maine Adaptive Silviculture Network. Cooperative Forestry Research Unit Advisory Committee Meeting (final reporting, virtual presentation). Orono, ME, October, 20, 2021.
- Bugbee, S. and J. J. Puhlick. 2021. Silvicultural strategies to promote forest resiliency to future change. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18, 2021.
- Weiskittel, A. R. and J. J. Puhlick. 2021. Carbon accumulation after implementation of forest management treatments on the Maine Adaptive Silviculture Network. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18, 2021.
- Puhlick, J. J. and J. Goldsmith. 2021. Non-native earthworm discoveries and implications for forest health. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18, 2021.
- Puhlick, J. J., J. Goldsmith, and A. Brann. 2021. Strategies for altering species composition in stands with American beech and beech bark disease on the Maine Adaptive Silviculture Network. Maine Adaptive Silviculture Network Field Tour. Sponsored by the Maine Society of American Foresters and the University of Maine, Center for Research on Sustainable Forests and Cooperative Forestry Research Unit. Nashville Plantation, ME, August 18, 2021.
- Kenefic, L. S. and J. J. Puhlick. 2020. Carbon outcomes of silvicultural alternatives at the Penobscot Experimental Forest. Maine Climate Table, Forest Carbon Discussion Group (co-presentation, oral presentation), Online Webinar. September 23, 2020. Recording available online: https://crsf.umaine.edu/resources-2/
- Puhlick, J. J. 2020. Strategies for enhancing long-term carbon sequestration in mixed-species, naturally regenerated northern temperate forests. Sustainable Forestry Initiative Inc. Sounding Board (oral presentation), Online Workshop. May 20, 2020. Recording available online: https://www.forests.org/conservation-impact-project/
- Wheatland Geospatial Lab. 2021, May. An introductory seminar and demonstration on the EFI workflow were given to a large group of participants (n=27), including CFRU members.

Newspapers / Periodicals / Television / Webpages (5)

- Turkel, T. (2021, August 8). In northern Maine, forestry practices create shifting habitat for migrating songbirds. Portland Press Herald. https://www.pressherald.com/2021/08/08/in-northern-maine-forestry-practices-create-shifting-habitat-for-migrating-songbirds/
- Our Climate Common. (2021, July 5). 30YR Bird Study CutV2. https://www.youtube.com/

watch?v=6xgLoMVcK28

- Forbes, A. (2021, October 6). New Spruce Budworm Testing Lab at UMaine critical to mitigating impact of destructive insect. University of Maine Press Release.
- Schipani, S. (2021, October 6). The destructive spruce budworm is back. Bangor Daily News.
- Holloway, D. (2021, October 21). New UMaine lab dedicated to spruce budworm research. FOX 22 WFVX Bangor.

Awards (2)

- Charles E. Schomaker Memorial Scholarship, School of Forest Resources, University of Maine, Orono. 2020 – Alex K. George
- Ralph H. Griffin Memorial Scholarship, School of Forest Resources, University of Maine, Orono. 2020 – Libin T. Louis

Theses (2)

- Louis LT. 2021. Economics and operational decision constraints of small-diameter tree harvesting. Ph.D. Theses, University of Maine, Orono.
- Tomak, E. 2020. "Temperature and nest parasitism and Rusty Blackbirds (Euphagus carolinus) by bird blow flies." Undergraduate thesis for the College of Natural Sciences, Forestry, and Agriculture.

Capstone (1)

- Brann, Autumn. Goldsmith, Joshua. 2021, December. Management Plan for Mayfield (MASN). Undergraduate capstone document.