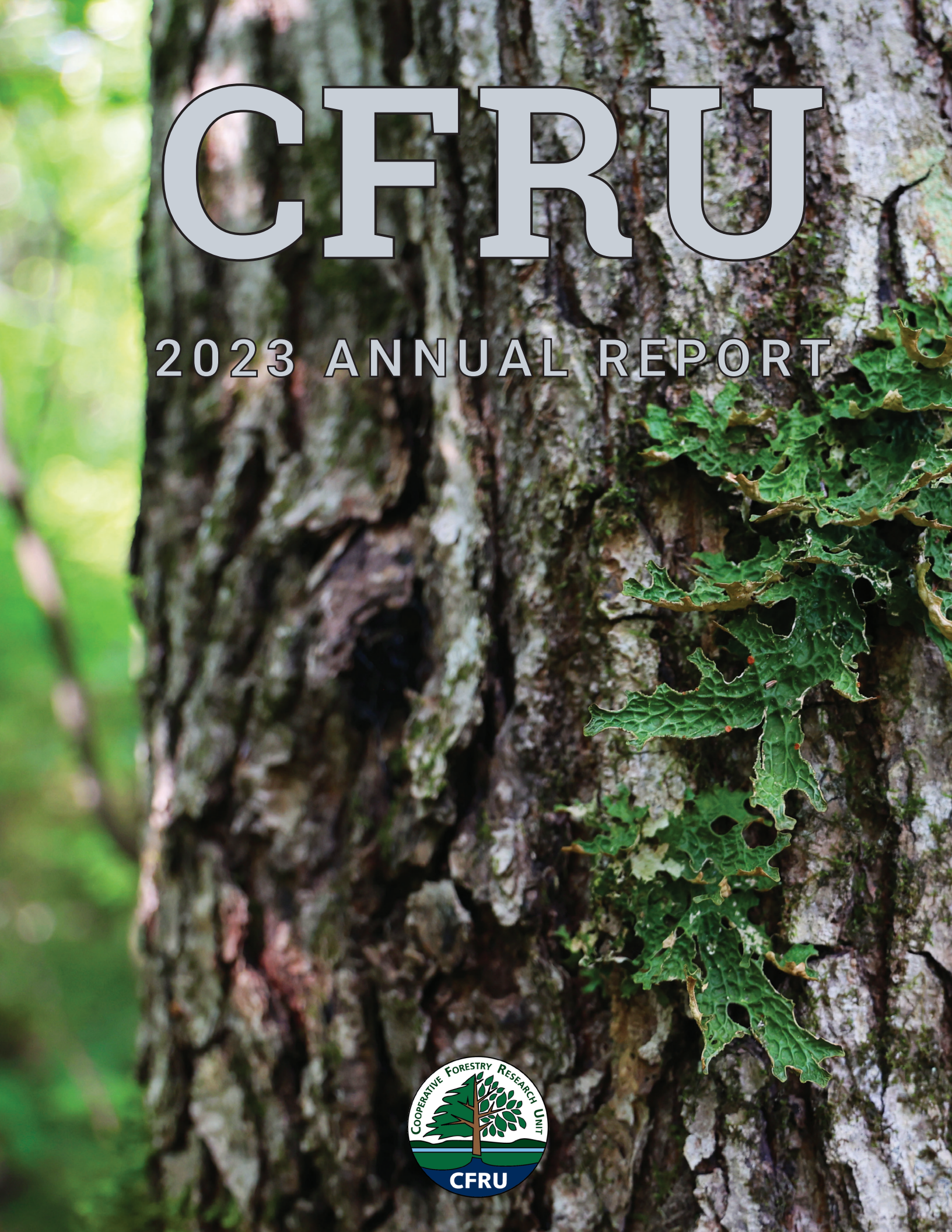

CFRU

2023 ANNUAL REPORT

COOPERATIVE FORESTRY RESEARCH UNIT

CFRU

CFRU & REPORT BACKGROUND

Founded in 1975, the Cooperative Forestry Research Unit (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) 2024. Cooperative Forestry Research Unit: 2023 Annual Report. Center for Research on Sustainable Forestry, University of Maine. Orono, ME. 56 p.

COOPERATIVE FORESTRY RESEARCH UNIT

A Core Program of the Center for Research on Sustainable Forests

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ORONO, MAINE 04469-5755

207.581.2893

CFRU YOUTUBE PAGE

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CONTENTS

WEYMOUTH POINT STUDY AREA, 2023

PROGRAM MANAGER'S LETTER

While some may see annual reporting as a mandatory drag, I appreciate the time it affords me to reflect on the yearly achievements of the CFRU scientists, staff, and of course, our members. When some weeks are filled with Zoom calls, committee meetings, and administrative tasks, one can lose track of the numerous research objectives that are being worked on bit by bit, every day. Spending time with the CFRU annual report provides me the space to appreciate the immense amount of work that we accomplish in a year, all in one place. In a true testament to the diverse research portfolio that we as an organization are committed to maintaining, this year's report covers 13 ongoing projects. While I wish I could take the credit for the good taste in research projects, I defer, with gratitude, to our advisory committee who have a knack for investing in top notch researchers.

I want to thank our advisory committee for investing an equal amount of time and faith in my abilities to lead the CFRU. The best work days are ones spent meeting with you to better understand your challenges and achievements in forest management. Through these field meetings, I've come to know foresters as more than their titles. Full of their own questions and ideas, our members are researchers, ecologists, silviculturists, and remote sensing specialists, too. I learn just as much from my interactions with you as I do from our CFRU scientists. When all of us are in the field together, that's when the applied science really shines.

The biggest investment we make in research is not simply in the ideas themselves, but the individuals who steer the ship, or maybe the forwarder is a better analogy. We are incredibly fortunate to have the class of researchers we do leading us into the future of forestry related research. A warm welcome to our newly funded researchers, and a sincere thanks to those who have been around (and to their fair share of CFRU meetings). Perhaps the biggest investment we made in people this year, was with Eric McPherson. Eric started as an intern with us in the summer of 2022, helping to run and organize the MASN field crews. He stayed on during the school year while he worked on his MF degree, utilizing and cleaning MASN data while estimating carbon pools and futures for his thesis. Eric was offered the new position of Research and Internship Coordinator in spring 2023, a shared position between the CFRU and School of Forest Resources. Welcoming Eric from day one as an intern, to working with him nearly full time now, has always come naturally. While work is work, who you're working with makes a difference in how the day goes. I am grateful for the team I'm on. Many thanks to the rest of our staff, Leslee, Meg, and Aaron.

I hope you enjoy the read.

Regina Smith

Regina Smith (she/her)
Program Manager, Cooperative Forestry Research Unit

DIRECTOR'S LETTER

The Cooperative Forestry Research Unit (CFRU) continues to quickly march to a key milestone, our 50th anniversary, which I am anxious to celebrate and collectively contemplate the next 50 years. Like any complex organization, the CFRU has continued to evolve over time and looks rather different than its original inception. Over the last few years, I have done what I could to help transition the CFRU through a variety of key personnel and organizational changes. Now, there feels like the CFRU has renewed and growing momentum to propel us far along into a productive future together.

High praise and appreciation goes to current CFRU Program Manager, Regina Smith, who has now fully embraced the strong leadership role and responsibilities required for this unique position. Regina has now overseen the annual functions of the CFRU more than once and is starting make strategic changes where she sees fit, which is very exciting to see. Regina is also overseeing a much larger and diverse portfolio of research projects than usual for the CFRU. The details and numerous accomplishments of these research projects are outlined in this annual report. To maintain this level of research productivity and engagement, Regina must often serve as an ambassador and interpreter for both researchers and CFRU members, which she has done most effectively. I am also very excited to see the strong engagement and involvement of several new faces in the CFRU, particularly University of Maine's early-career faculty members.

This past year also represented a positive new development for the CFRU and School of Forest Resources (SFR) with the addition of a full-time Research and Internship Coordinator, Eric McPherson. Eric has done a tremendous job balancing the demands of his position, which includes maintaining the CFRU's diverse long-term field sites throughout the state and working directly with SFR students to prepare them for summer internships. Eric has jumped right in with keeping our CFRU field crews busy, developing better spatial databases, and finalizing plot measurements at one of the CFRU's oldest field site, Weymouth Point. The results of this work are highlighted in this annual report and showcase the importance of long-term research.

In particular, I am very excited to see the growing interest and expansion of the CFRU's Maine Adaptive Silviculture Network (MASN). With Regina's leadership and Eric's dedication, the first ever MASN Advisory Board meeting was organized and conducted. The meeting involved a diverse team of researchers and CFRU members to discuss current opportunities and future challenges for MASN, which will help refine our efforts with this research going forward. As outlined in our annual report, several new MASN installations are in the works and will help to strengthen the existing network, which will help to initiate and support long-term research on forest growth, management, carbon dynamics, and wildlife habitat. The new MASN installations are strategically targeted in areas or forest types where we currently lack installations, which is an important long-term benefit for this network.

As always, I remain honored and appreciative to be part of this collaborative effort that highlights the importance of well-managed working forests. The issues and challenges that the CFRU is trying to address feel even more important than ever given the increasing threats that climate change and emerging policy may place on forests. Of course, the CFRU could not happen without the dedicated efforts of our membership, staff, and students. I would be remiss if I did not acknowledge and appreciate the efforts of Leslee Canty-Noyes and Meg Fergusson who help keep the CFRU functioning.

With gratitude,

Aaron Weiskittel
Director, Center for Research on Sustainable Forests

CHAIR'S LETTER

I am pleased to present this year's Annual Report to the CFRU membership. As the program approaches its 50-year anniversary, this past fiscal year was likely one of the busiest for the CFRU, with 21 different projects underway with some coming to a finish. This wouldn't have been possible without all the support from the CFRU members and the efforts of the staff!

I would like to welcome Eric McPherson, our new Research & Internship Coordinator. This is a newly formed shared position between the CFRU and the School of Forest Resources (SFR) (80% CFRU, 20% SFR) in which Eric is helping students prepare for industry internships and assisting CFRU members in advertising and finding students for internships and job placement.

Regina Smith continues to grow and succeed as the CFRU Program Manager. Whether it's the close contact with individual members to running the Advisory Meetings and Field Tours, her drive, passion, and effort are instrumental in keeping the CFRU membership engaged and informed on multiple levels. I applaud her efforts to expand communications through e-mail updates, newsletters, field tours, webinars, and by bringing the CFRU message and research to new audiences through social media platforms.

I want to recognize and thank Leslee Canty-Noyes and Meg Fergusson for their efforts over the past year. Much of their work goes unseen by the membership but without question, their commitment and dedication ensure CFRU's continued success.

I would like to thank Dr. Aaron Weiskittel who continues to wear many hats on multiple levels in championing the CFRU as a core research component of the University of Maine's Center for Research on Sustainable Forests, and the importance of the research being conducted by our scientists and cooperators.

I would also like to thank all the scientists, research assistants, and students for their research and continued engagement with the CFRU membership and staff. The listening sessions that have been initiated by Regina have been a great conduit for the membership and the scientists alike to express and explore research opportunities that utilize emerging technologies such as eDNA or builds off/enhances our long-term projects critical to the CFRU members such as the MASN and CTRN sites. This annual report contains 13 research reports that speak to the range of research that has been carried out over the last year and may have resulted from one of the sessions. Not included in this report are 8 projects that started after our new fiscal year, look for updates on these in the coming months.

Lastly, thank you to the membership for allowing me to serve as your Chair, and I encourage you to remain engaged as it is your involvement that makes the CFRU and the research it supports meaningful to us all.

Sincerely,

Eugene R. Mahar

Eugene Mahar
Chair, Cooperative Forestry Research Unit

STAFF

WELCOME, ERIC!

Regina Smith, Program Manager, Cooperative Forestry Research Unit
Aaron Weiskittel, Director, Center for Research on Sustainable Forests
Leslee Canty-Noyes, CFRU/CRSF Administrative and Financial Coordinator
Eric McPherson, CFRU/SFR, Research and Internship Coordinator
Meg Fergusson, CRSF Outreach and Communications Specialist

FOREST LANDOWNERS & MANAGERS

Acadian Timber
Appalachian Mountain Club
Baskahegan Company
Baxter State Park, SFMA
BBC Land, LLC
Clayton Lake Woodlands Holdings, LLC
Downeast Lakes Land Trust
EMC Holdings, LLC
Fallen Timber, LLC
Fresh Timber, LLC
Frontier Forest, LLC
Irving Woodlands, LLC
Maine Bureau of Parks & Public Lands
Maine Forest Service
Maine Inland Fisheries & Wildlife
Manulife Investment Management
Mosquito, LLC
New England Forestry Foundation (NEFF)
Pleasant River Lumber Co.
Prentiss and Carlisle Company, Inc.
Presley Woods, LLC
Robbins Lumber Company
Sandy Gray Forest, LLC
Seven Islands Land Company
Solifor Timberland Inc.
Sylvan Timberlands, LLC
The Conservation Fund
The Nature Conservancy
Tree-Star Timberlands
Wagner Forest Management
Weyerhaeuser

WOOD PROCESSORS

SAPPI North America

CORPORATE & INDIVIDUALS

David B. Field
Forest Society of Maine
Huber Engineered Woods, LLC
LandVest

EXECUTIVE COMMITTEE

Chair: Eugene Mahar, LandVest (*Clayton Lake Woodlands Holding LLC, EMC Holdings, LLC, Falcon Lodge LLC*)
Vice Chair, Steve Tatko, Appalachian Mountain Club
Financial Officer, Ian Prior, Seven Islands Land Company
Member-at-large, Jeremy Miller, American Forest Management (*BBC Land, LLC*)

ADVISORY COMMITTEE

John Ackley, Weyerhaeuser
Kyle Burdick, Baskahegan Company
Thomas Cochran, Downeast Lakes Land Trust
Ked Coffin, Irving Woodlands, LLC
Kenny Fergusson, Maine Forest Service
Alec Giffen, New England Forestry Foundation
Zach Grover, Manulife Investment Management
Mike Jurgiewich, Wagner Forest Management
Laura Kenefic, U.S. Forest Service
Jake Metzler, Forest Society of Maine
Mike Pounch, Maine Bureau of Parks & Public Lands
Gaetan Pelletier, Northern Hardwoods Research Institute
Dan Pelletier, Huber Engineered Woods, LLC
Stephen Pollis, Tree-Star Timberlands
Ian Prior, Seven Islands Land Company
James Robbins, Robbins Lumber Company
Brian Schneider, The Conservation Fund
Dan Smith, Pleasant River Lumber Co.
Chris Stone, The Nature Conservancy
Nava Tabak, Baxter State Park, SFMA
Kevin Topolniski, Acadian Timber Corp.
Mike Treat, Prentiss and Carlisle Company, Inc.
Nate Vir, Sappi North America
Nate Webb, Maine Dept. of Inland Fisheries & Wildlife

RESEARCH SCIENTISTS

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Erik Blomberg (PhD), University of Maine
Kenneth Bundy, University of Maine
Noah Charney (PhD), University of Maine
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Ivan J. Fernandez (PhD), University of Maine
Jereme Frank, Maine Forest Service
Erin Grey (PhD), University of Maine
Anthony Guay (MSc), University of Maine
John Gunn (PhD), The Nature Conservancy

John Hagan (PhD), Our Climate Common
Daniel Hayes (PhD), University of Maine
Alex K. George (PhD), Paul Smith
Keith Kanoti (MSc), University of Maine
Laura Kenefic (PhD), U.S. Forest Service
Claire Kiedroski (PhD), Maine GeoLibrary
Anil Raj Kizha (PhD), University of Maine
Kasey Legaard (PhD), University of Maine
Libin T.Louis (PhD), University of Maine Fort Kent
Peter McKinley (PhD), The Wilderness Society
Eric McPherson (MF), University of Maine
Angela Mech (PhD), University of Maine
Michael Reed (PhD), Tufts University
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Ben Rice, Midgard Natural Resources, LLC
Nicole Rogers (PhD), University of Maine
David Sandilands (MSc), University of Maine
Erin Simons-Legaard, University of Maine
Regina Smith (BA), University of Maine
James Stewart (MSc), University of Maine
Neil Thompson (PhD), University of Maine Fort Kent
Aaron Weiskittel (PhD), University of Maine
Jianheng Zhao (PhD), University of Maine
Carolyn Ziegra (BS), Appalachian Mountain Club

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Jude Dickerson
Josh Kolasch
Jonah Levy
Molly Lynch
Hannah Mirando
Ben Shamogochian
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Elyeah Schweikert (BS), UMaine
Emma Winiarski (BS), UMaine
Logan Woodyard (MSc), UMaine
Nasheeda Yasmin (MSc), UMaine

PROJECT PARTNERS, COLLABORATORS, & STAKEHOLDERS

Acadian Timber
Appalachian Mountain Club
Baskahegan Company
Baxter State Park
Essex Timber
Forest Society of Maine
FORSight Resources, LLC
Horizon Foundation
Huber Resources Corporation
J.D. Irving Limited
LandVest
Maine Bureau of Parks and Lands
Maine Department of Environmental Protection
Maine Department of Inland Fisheries and Wildlife
Maine Department of Transportation
Maine Forest Service
Maine Library of Geographic Information
Maine Natural Areas Program
NASA Goddard Spaceflight Center
Natural Heritage & Endangered Species Program, Massachusetts Division of Fisheries & Wildlife
New England Forestry Foundation
New Hampshire Division of Forests and Lands
NOAA Office for Coastal Management
Northern Forest Conservation Services, LLC
Our Climate Common
Passamaquoddy Forestry Department
Penobscot Nation, Department of Natural Resources
Program for the Human Environment, The Rockefeller University
Rangeley Lakes Heritage Trust
Seven Islands Land Company
Spatial Informatics Group
Stephen Phillips Memorial Preserve Trust
The Nature Conservancy
U.S. Fish and Wildlife Service, Umbagog National Wildlife Refuge
U.S. Forest Service, Forest Management Service Center
U.S. Forest Service, Green Mountain National Forest
U.S. Forest Service, National Forest System, Enterprise
U.S. Forest Service, Northern Research Station FIA Program
U.S. Forest Service, White Mountain National Forest
University Forests
University of Maine Advanced Computing Group
Vermont Department of Forests, Parks, and Recreation
Vermont Land Trust
Wagner Forest Management
Weyerhaeuser
Wildlife Health Lab, Cornell University
Woodwell Climate Research Center

INCOME REPORT FY2023

FOREST LANDOWNERS/MANAGERS	CONTRIBUTIONS
Irving Woodlands, LLC	$69,312
BBC Land, LLC	$57,050
Weyerhaeuser	$46,967
Wagner Forest Management	$44,395
Clayton Lake Woodlands Holdings, LLC	$44,363
Seven Islands Land Company	$41,934
Prentiss and Carlisle Company, Inc.	$41,955
Maine Bureau of Parks & Public Lands	$25,299
Acadian Timber Corp.	$17,520
Fallen Timber, LLC	$13,028
Fresh Timber, LLC	$12,443
Solifor Timberland Inc.	$9,990
The Nature Conservancy	$9,641
Baskahegan Company	$8,299
Sandy Gray Forest, LLC	$5,841
Tree-Star Timberlands	$5,372
Manulife Investment Management	$5,247
Appalachian Mountain Club	$4,315
Sylvan Timberlands, LLC	$3,428
Downeast Lakes Land Trust	$3,383
The Conservation Fund	$2,701
EMC Holdings, LLC	$2,363
Pleasant River Lumber Co.	$2,336
Baxter State Park, SFMA	$1,724
Robbins Lumber Company	$1,564
Presley Woods, LLC	$1,379
Mosquito, LLC	$1,000
New England Forestry Foundation	$1,000
WOOD PROCESSORS	
SAPPI	$27,660
CORPORATE AND INDIVIDUAL MEMBERS	
Huber Engineered Woods, LLC	$1,000
Forest Society of Maine	$1,000
LandVest	$200
David B. Field	$100
TOTAL INCOME IN FY2023:	$513,536.76

EXPENSES REPORT FY2023

PROJECTS BY CATEGORY	APPROVED AMOUNT FOR FY2023	AMOUNT SPENT IN FY2023
SILVICULTURE		
Maine Adaptive Silviculture Network (MASN)	$59,716.00	$37,794.64
Northern Conifer Silvicultural Guide	$14,856.00	$1,711.33
Weymouth Point Remeasurement	$5,007.00	0.00*
Total silviculture funds awarded:	$79,579.00	
GROWTH AND YIELD MODELING		
Measurements, Models and Maps: toward a reliable and cost-effective workflow for large-area forest inventory from airborne LiDAR data	$27,179.00	$24,708.18
Spruce budworm L2 monitoring program in Maine	$77,069.00	$41,042.00
High Resolution Land Cover and Forest Type Data for the State of Maine	$41,220.00	$23,308.42
Refining the Acadian model	$21,000.00	$6,000.00
Total G&Y modeling funds awarded:	$166,468.00	
CARBON		
Forest Carbon and Timber Potential for Northern Maine's Working Forests	$25,523.66	$1,160.30
Soil carbon sequestration dynamics post-harvesting: effect of stand characteristics and site factors	$13,414.00	$11,603.28
Carbon footprint of the predominant mechanized timber harvesting methods in the Northeastern US	$10,450.00	$2,250.00
Total carbon research funds awarded:	$49,387.66	
HABITAT & BIODIVERSITY		
American marten: refining the umbrella species concept in Maine	$24,187.00	$2,207.75
Thirty years of change in commercial forest management and implications for bird conservation in Maine (1992-2022)	$25,000.00	$25,000.00
Using eDNA for biodiversity and rare species monitoring	$21,603.00	$21,603.00
Total habitat & biodiversity research funds awarded:	$70,790.00	
ADMINISTRATION		
Administrative budget	$278,070.27	$240,996.58

FIELD TOURS IN 2023

MIXEDWOOD MANAGEMENT IN MAINE - SEPTEMBER 2023

While you'll have to wait until next year to get a full annual report from this newly funded CFRU project (lousy reporting cycles!), we've got a field tour debriefing from Laura Kenefic's *Mixedwood Management: Silviculture for Hardwood–Softwood Mixtures in Maine.* Similar to seeing the need for an update to the Northern Conifer Silviculture Guide, Kenefic pitched this research proposal to the CFRU in spring of 2023 and received overwhelming support for creating a guide for mixedwood management in Maine. And with good reason - over 51% of our forests are mixedwoods, that is where neither component of hardwood or softwood is greater than 75-80% of the basal area in a stand. Mixedwood forests have a range of benefits (market flexibility, reduced susceptibility to pests and diseases, wildlife habitats, etc.) but can be difficult to maintain as such over time. Mixedwood types in Maine tend to move to a hardwood-dominated composition following repeated or heavy harvesting. Kenefic's recent work has been in collaboration with a group of researchers from across the eastern United States and Canada who call themselves the Mixedwooders, specializing in mixedwood management and ecology. As a starting point for her new CFRU project, she wanted to bring The Mixedwooders to Maine to meet the landowners and stewards who would benefit the most from a new management guide. CFRU members and beyond spent the morning reviewing the facts, benefits, and limitations of mixedwood ecology in the northeast. They were given a draft table of contents and asked for input and edits on what would be needed most in the design of such a guide. Working with stakeholders as the guide is conceived ensures that the challenges managers are facing today, be it climate change or volatile markets, are considered with operational context. The afternoon was spent in the various mixedwood forests and guided by Appalachian Mountain Club staff, Steve Tatko and Carolyn Ziegra.

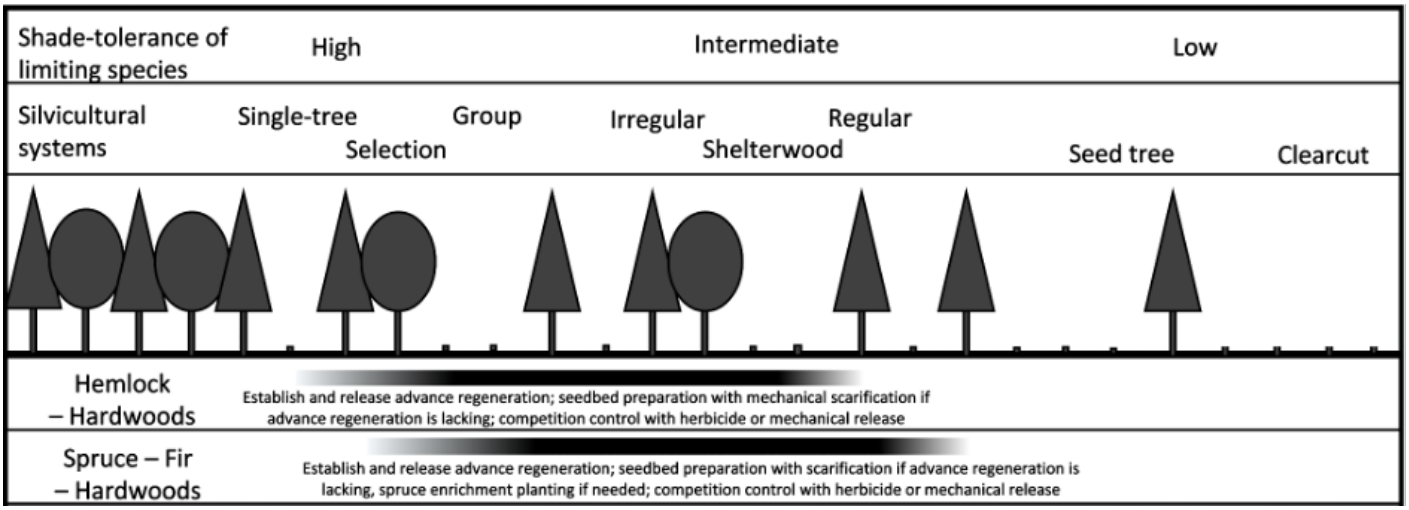


FIGURE 1. A table of limiting species and their shade-tolerances and potential silvicultural solutions from Strategies for Managing Compositionally Degraded Mixedwood Stands.

THE CEDAR CLUB - OCTOBER 2023

In October 2023, The Cedar Club gathered in Danforth, Maine with Baskahegan Company and CFRU members to present their latest research projects on cedar ecology and management including managing cedar in high deer browsing scenarios, with a focus on material in the soon-to-be-published second edition of the USFS cedar silviculture guide. Attendees spent an afternoon in the field for an operational overview of irregular shelterwood in lowland cedar stands and cedar silviculture in mixed and cedar-dominated stands. Speakers included Laura Kenefic (USFS), Robin Clark (Michigan Tech), Jean-Claude Ruel, Olivier Villemaire-Cote, and Jean-Pierre Tremblay (Laval University), and Charles Tardif (Maibec). The morning featured talks from the presenters listed above and you can find their slide decks here.

CFRU FALL FIELD TOUR, RANGELEY LAKES REGION OCTOBER 2023

This year's CFRU tour was spent in the Rangeley Lakes area, with a handful of updates provided in the field by our funded research scientists. The first stop was on Rangeley Lake Heritage Trust (RLHT) lands to set the scene for an update on Wheatland Geospatial Lab's ongoing project, Measurements, Models and Maps: toward a reliable and cost-effective workflow for large-area forest inventory from airborne LiDAR data. This project has several case studies across the state, and RLHT was one of them. In the field, Tony Guay, Remote Sensing Specialist with WGL, outlined what they have found most important for any EFI, from plot design to high-precision plot locations for calibration. The final synthesis for this project is expected in Spring 2024.

Cooperator Mike Pounch discussing follow-up silvicultural treatments for a PCT spruce-fir stand.

The Northern Conifer Silviculture Guide team was represented by Nicole Rogers and Laura Kenefic. The team coordinated with CFRU and SILC ahead of time to find softwood sites that would provide a backdrop for a useful discussion with forest practitioners. The stops included a mature, unmanaged post-budworm stand, a SILC contrast thinning study to create and enhance stand structure, and stands where SILC was looking to favor pine in a slow shelterwood release for future climatic conditions. Sites provided talking points about various softwood stands that we all have and how to go about managing them.

We stopped at Sarah's Road, SILC's Commercial Thinning Research Network site, for Mike Premer's newly funded project: Causal Factors of Thinning Response and Transfer to Adaptive Management Regimes in Maine Spruce-Fir Forests (check back next year for the first year report!). Lila Beck, Premer's master student in the School of Forest Resources, is using CTRN sites for quantifying the mechanisms of stem growth response to variations in thinning through coring and analyzing tree ring stable isotopes, linking productivity with thresholds of thinning response across the hydrologic gradient of the CTRN network, testing the accuracy and compatibility of stand reconstruction through increment cores, and developing silvicultural guidelines and geospatial tools for decision support systems.

Our last stop featured Harrison Goldspiel, a PhD student in the Department of Wildlife, Fisheries, and Conservation Biology at UMaine who is leading the field work for the CFRU funded project Using eDNA for biodiversity and rare species monitoring (check back next year for this report, too!). Goldspiel went over the various methods and products that are currently available for eDNA sampling. Key considerations covered price, the ease of filtering, quality of DNA preservation (getting a sample from the woods to the lab), and general portability.

Harrison Goldspeil giving a demonstration on the different types of equipment and filtration systems that can be used for eDNA sampling.

You can find project updates for all of the newly funded projects listed above in our Summer 2023 Newsletter. Interested in learning more about what was presented on the field tour? A link to the field tour booklet can be found here. A warm thanks to the SILC & RLHT for hosting us.

RESEARCH HIGHLIGHTS & ACCOMPLISHMENTS

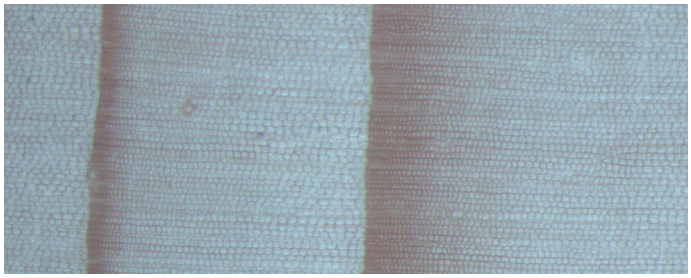
Silviculture

Maine Adaptive Silviculture Network

- The MASN Advisory Panel Meeting with stakeholders & researchers was established in August 2023 to guide current and future priorities related to study site implementation, long-term data retention and usability, and future goals for landowners and researchers alike
- CFRU summer crews remeasured 4 MASN sites and 3 new sites are slated to be installed over the next 2 years

Weymouth Point Study Area

- A full remeasurement of 61 plots at WPSA has been completed
- Over 100 trees were cored across the study site to better understand stand history and dynamics. Cores are being processed now by Eric McPherson and Shawn Fraver for use in CFRU studies and Fraver's dendrochronology class



WPSA tree core sample under the microscope. PHOTO Eric McPherson.

Patricia Raymond, Quebec Ministry of Forestry, has joined the NCSG team. She brings silviculture specialties to the team including her research on shelterwoods and group selection.

Northern Conifer Silviculture Guide

- Density management guides for spruce-fir stands have been developed and released by David Ray, UMaine, member of the NCSG writing team
- Science writer and former CFRU employee Jenna Zukswert, U.S. Forest Service, has joined the team to help ensure the guide is written in a way that will be clear and useful for forest practitioners. Additional co-authors have been recruited

Growth & Yield

Spruce Budworm L2 Monitoring Program in Maine

- The lab processed 906 branches for the 2022 monitoring season, with a 25% decrease in the overall average # of L2's per site compared to 2021 values
- Dr. Mech used CFRU funding as leverage to secure a USDA grant for the SBW lab amounting to $165,000 over 3 years

Refining the Acadian Model

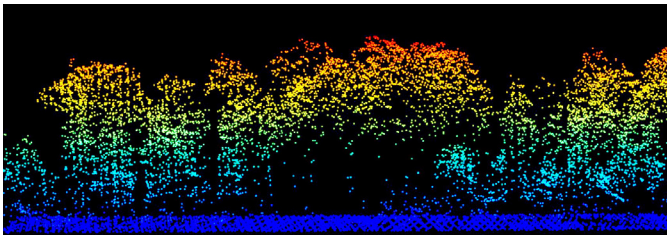
- Improvements to the Acadian model this past year include mortality approaches, a new stand basal area increment equation, and more
- Outreach, training, and reference material for how to use FVS and the Acadian Model is being developed in the final year of this project

High Resolution Land Cover and Forest Type Data for the State of Maine

- Production workflows have been tested over 5 million acres in northern Maine, with cross-validation estimates of mean prediction error around 5-10% for each species/group
- Final production and distribution of statewide 1-meter and 10-meter land cover/forest type data is expected to be released in fall 2024

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

- The final analysis in this project is underway with the compiled and synthesized case studies expected by spring 2024



Carbon

Forest Carbon and Timber Potential for Northern Maine's Working Forests

- Forest Carbon for Commercial Landowners was released in March 2023 and details various scenarios for increasing net carbon sequestration while continuing to support the forest products sector and rural communities
- Created Maine Integrated Forest System Model for evaluating opportunities and tradeoffs when considering silvicultural options at a large landscape scale to achieve carbon goals

Soil Carbon Sequestration Dynamics Post-Harvesting: Effect of Stand Characteristics and Site Factors

- Meta-analysis approach has been completed to acquire data on stand and site level factors that influence forest soil carbon post-harvest

Carbon Footprint of the Predominant Mechanized Timber Harvesting Methods in the Northeastern US

- This project focused on completing a life cycle analysis, or LCA, on various harvesting methods to quantify the total carbon footprint from stump to mill
- The study quantifies the average global warming potential (kg C02 equivalent) by method and season and can be used for future LCAs for various wood products harvested in the Northeast

Habitat & Biodiversity

American Marten: Refining the Umbrella Species Concept in Maine

- Researchers analyzed field recordings using BirdNet, developed by Cornell, to ID songbirds. This identification data is being screened to find species with high co-occurance with marten
- Spatial patterns and species richness is being compared to available maps of forest composition and structure from Sentintel satellite imagery and LiDAR data

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

- Fieldwork has been completed. Analyses show about two-thirds of the 47 species showed increases in abundances since the 1990s, while one-third of species decreased in abundance
- A self-guided birding trail near Greenville is being developed along with public outreach material demonstrating the conservation values of working forests

Using eDNA for Biodiversity and Rare Species Monitoring

- Researchers surveyed CFRU members regarding their interests in eDNA for monitoring specific species
- Submitted hundreds of eDNA samples for metabarcoding
- Began sampling locally to test methodologies and materials, and recorded 5,000+ images of wildlife for two-factor verification of species presence

MAINE ADAPTIVE SILVICULTURE NETWORK (MASN)

REGINA SMITH, COOPERATIVE FORESTRY RESEARCH UNIT
ERIC MCPHERSON, COOPERATIVE FORESTRY RESEARCH UNIT & SCHOOL OF FOREST RESOURCES

PROGRESS REPORT

ABSTRACT

The goal of this long-term CFRU managed study is to examine alternative silvicultural approaches for improving rotation length productivity and value of mid-rotation stands in Maine. The main objective of this project is to establish a network of operational scale study installations distributed across the state in all combinations of mid-rotation softwood, mixedwood, and hardwood stands of good, medium, and low site quality.

PROJECT OBJECTIVES

Once established, this network will serve as a field laboratory, where on an operational scale silvicultural treatments can be compared, productivity and costs of multiple harvest methods can be quantified, data will inform and improve growth and yield models, predictions of remotely sensed forest inventory attributes and habitat quality can be validated, and the effects of forest management on wildlife habitat can be quantified.

KEY FINDINGS/ACCOMPLISHMENTS

In August of 2023, the CFRU held the first MASN Advisory Panel Meeting with stakeholder and researchers in attendance. The purpose of this meeting was to address priorities and challenges for landowners and researchers alike as we move forward in our goal to install 18 MASN sites across northern and central Maine. As we are currently half way to our goal for total sites, with 8 currently installed, a bulk of the discussion was centered around defining and striving to achieve silvicultural replicates for existing sites. Realizing an adequate number of silvicultural prescription replicates, ideally 3 or more of each Rx, is key for researchers looking to form questions and reach conclusions based on MASN data. Other replicate variables that were discussed in the MASN Advisory Panel Meeting include equipment used and the year/season of installation. Other accomplishments include:

- CFRU summer field technicians and staff measured a total of 4 MASN sites. Three of the sites (AMC Mooresville, Baskahegan Brookton and Manulife Blueback) are new and will be installed in the next 2 years. The other site (CLWH Oxbow) received the first postharvest measurement.
- In an effort to create more replications across the network, the CFRU has worked closely with Appalachian Mountain Club (AMC) and Baskahegan Company to develop prescriptions that will be duplicated at each site.

PHOTO 1. CFRU staff & cooperators use NHRI Prescription system to assess options for MASN prescriptions on the Manulife Blueback site.

- CFRU staff met with members from Manulife and Huber on the Manulife Blueback site to discuss possible prescriptions using the NHRI Silvicultural Prescription System as a guide. Treatments will be finalized this summer with installation planned for the winter of 2024/2025
- Approximately 75% of CLWH Oxbow was remeasured this summer. Following the harvest in 2019 there was a large wind event which caused significant blowdown on the site. A sal-vage logging operation occurred on the group selection and early commercial thinning blocks but blowdowns were left in the shelterwood with reserves block. A protocol was developed to quantify the blowdown and measurements will be completed in the summer of 2024.
- Cleaning and organization of data has continued with a focus on GIS files and making data available to the cooperators as well as the public. An ArcOnline map has been created with all site data included and the MASN ArcStory map is being updated.
- Eric McPherson used data from 6 installations to complete his Master of Forestry project. Pre- and postharvest data was entered into the Northeast variant of the U.S. Forest Service (USFS) Forest Vegetation Simulator (FVS) and projected out 50 years with fol-low-up treatments such as plantings and thinnings simulated. Above and below ground carbon was calculated and total storage and annual sequestration were modeled. Findings showed higher storage rates for less intensive harvests (Figure 1) and higher sequestration rates related to more intensive harvests (Figure 2).

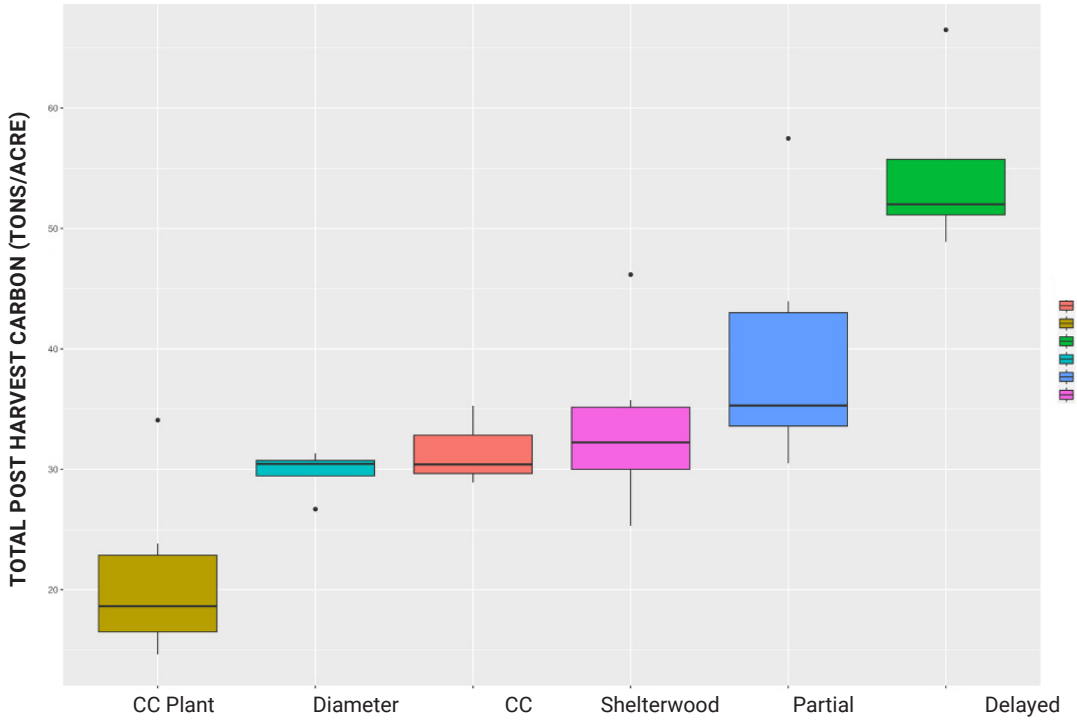


FIGURE 1. Total Post Harvest Carbon by Standardized Treatment

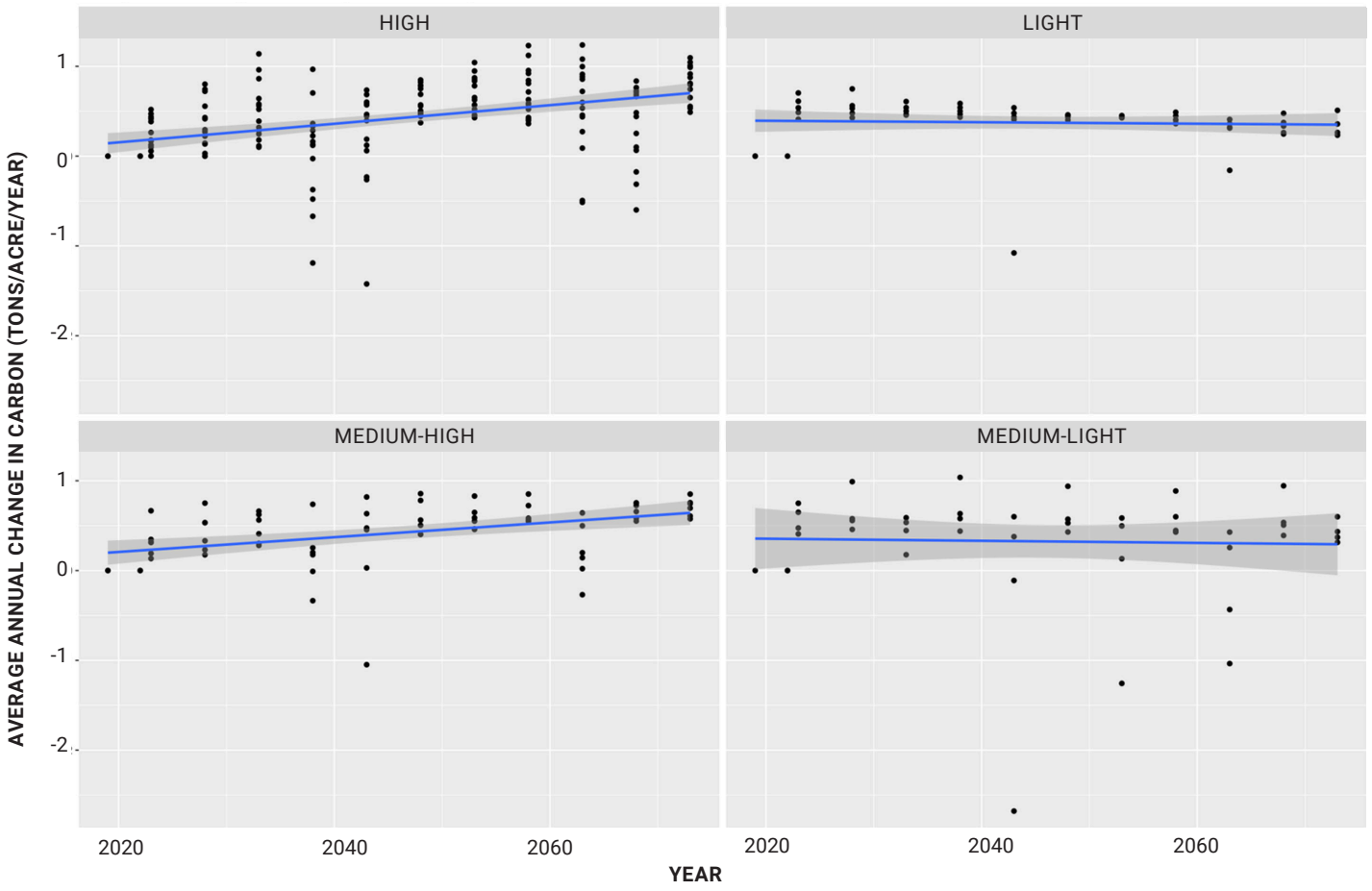


FIGURE 2. Average Annual Change in Carbon by Harvest Intensity

FUTURE PLANS

- Baskahegan Brookton and AMC Mooresville are slated to be installed this summer. Field season plans for the 2024 CFRU summer crew include visiting MASN sites that are up for remeasurement and completing full inventories.
- We are currently working with two landowners to identify similar sites and a suite of treatments that are ideal for both the landowners and the replicate matrix we are looking to fill in.
- Cooperator and public facing data will continue to be updated and made available for better communications and visibility of the project.

ACKNOWLEDGEMENTS

We would like to thank the CFRU membership for their continued support of this long-term research network, especially those who provided critical landowner perspectives during our first MASN Advisory Panel meeting. We would also like to thank the researchers who have utilized our data for current/future projects and who frequently make themselves available to discuss and provide critical input on research design. Lastly, this project would not be possible without the hard work of our summer field crews. They worked long, especially wet days in the summer of 2023 with an exceptional eye to collecting research grade measurements. Thanks to Ashley Carter, MS student with the School of Forest Resources, Ethan “Mac” MacKenzie, BS student with the Department of Wildlife, Conservation, Fisheries, & Biology, and Eddie Nachamie, BS student in Ecology and Environmental Sciences.

GEOGRAPHIC LOCATION OF PROJECT

Current MASN sites can be found here.

PARTNERS, STAKEHOLDERS, & COLLABORATORS

The CFRU membership and the researchers who utilize our data for collaborative research.

EXTERNAL/MATCHED FUNDING SOURCES

None.

REVISITING WEYMOUTH POINT

ERIC MCPHERSON, COOPERATIVE FORESTRY RESEARCH UNIT & SCHOOL OF FOREST RESOURCES
REGINA SMITH, COOPERATIVE FORESTRY RESEARCH UNIT

PROGRESS REPORT

ABSTRACT

The Weymouth Point Study Area (WPSA) was established in 1979 to quantify nutrient removals through whole tree and stem-only logging (1981), nutrient mobilization after herbicide treatment (1985), and the growth of trees with and without precommercial thinning and fertilization (1991). WPSA has been one of CFRU's flagship long-term study areas, and was last measured in 2016. A 42-year measurement in 2023 will provide additional insight on 35-year growth patterns discussed by Smith et al. (2022) and inform a discussion on the next steps for the site in the context of other ongoing spruce/fir silviculture research.

PROJECT OBJECTIVES

- Repeat diameter and height measurements at all permanent plots in the WPSA
- Analyze growth response for each treatment, following up on the 35-year measurement conducted in 2016
- Assess growth model behavior (Acadian FVS variant)
- Calculate site index on harvested watershed for red spruce (Picea rubens Sarg.) and balsam fir (Abies balsamea L. Mill) across Natural Resources Conservation Service (NRCS) soil drainage classes.
- Better understand stand history and dynamics of reference watershed.

APPROACH

Weymouth Point is a long-term biomass removal study of unique value to the CFRU and beyond. Dr. Tat Smith and colleagues completed an array of detailed measurements in 2016 to capture the trends 35 years after the initial set of treatments, which have been published in a variety of formats (Preece 2017, Smith et al. 2022a,b). As Weymouth Point is beginning to approach rotation age, questions about its status, value, and future need to be addressed. In 2023 the CFRU summer crew repeated the measurements completed by Smith et al. in 2016 on 61 permanent plots across the study area. The data was then cleaned and projected out 50 years using the Acadian variant of FVS and trends were assessed for statistical significance between treatments and NRCS drainage classes. In the fall of 2023, approximately 150 red spruce and balsam fir were cored throughout the study area to better understand how site productivity played a role in growth on the harvested watershed and stand dynamics in the reference watershed. Cores are being processed and analyzed by CFRU staff in the Fraver Dendrochronology Lab at the University of Maine.

FIGURE 1. Mean Basal Area Per Acre (BAPA, ft2/acre) for each treatment.

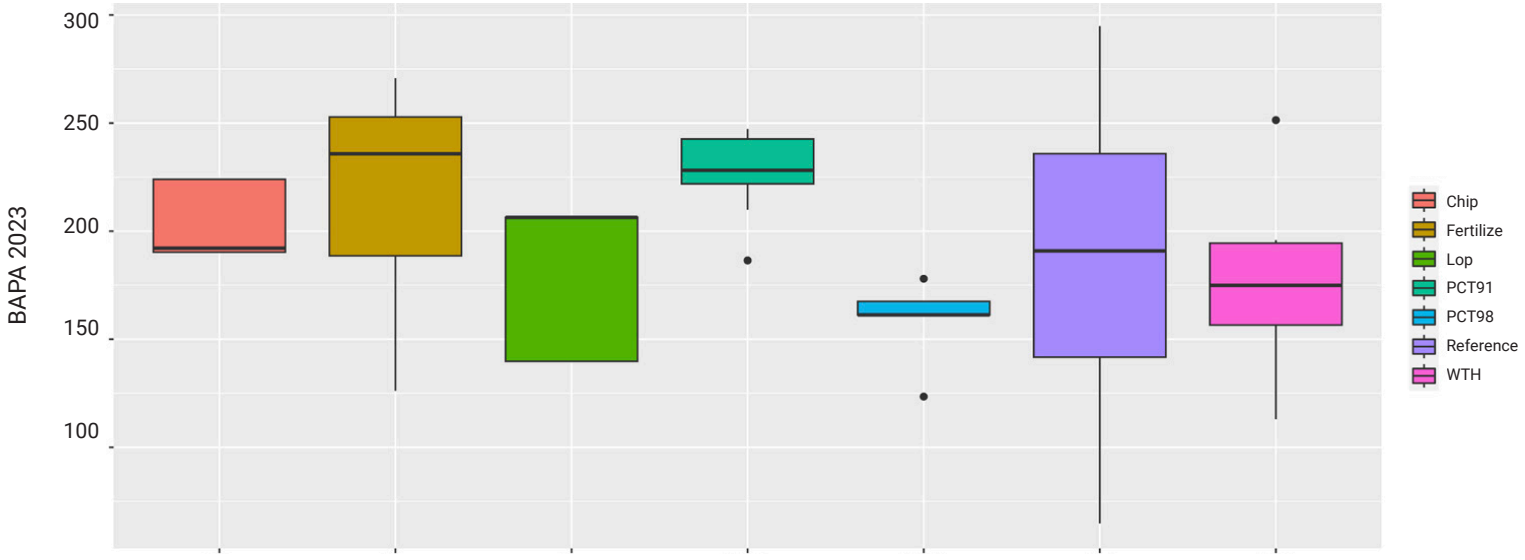


PHOTO 1. Weymouth point study area. Photo by Neil Thompson.

KEY FINDINGS/ACCOMPLISHMENTS

- The CFRU summer crew re-established and measured 61 permanent plots across the study area. Measurements for overstory trees included: diameter, height, height to crown base, tree status, Northern Hardwoods Research Institute (NHRI) form and risk. Saplings and regeneration were also measured on fixed area plots at the four corners of each overstory plot.
- Analysis of growth at 42 years post harvest showed no statistical significance in mean basal area per acre or volume per acre between treatments (Figure 1).
- Plots receiving a pre-commercial thinning in 1991 showed a higher quadratic mean diameter, holding consistent with findings from the 2016 measurements.
- Volume and basal area is projected to increase linearly for all treatments, including the reference watershed, for the next 50 years (Figure 2).
- Periodic annual increment for basal area is projected to peak around 2028 for most treatments and will intersect with mean annual increment around 2033, indicating that all treatments will likely be nearing the economic rotation age in the next 10-20 years (Figure 3).
- 100 red spruce were cored across all diameter and soil drainage classes on the reference watershed to better understand stand history and dynamics. Preliminary results show a multi-aged stand with at least 3 cohorts, the oldest dating back to the 1840s. Cohorts were likely due to spruce budworm events. (Photo 2 and 3).
- 27 codominant red spruce and 23 codominant balsam fir were cored across all treatments and soil drainage classes to better understand site productivity. The cores are currently being processed by Dr. Shawn Fraver's dendrochronology class.

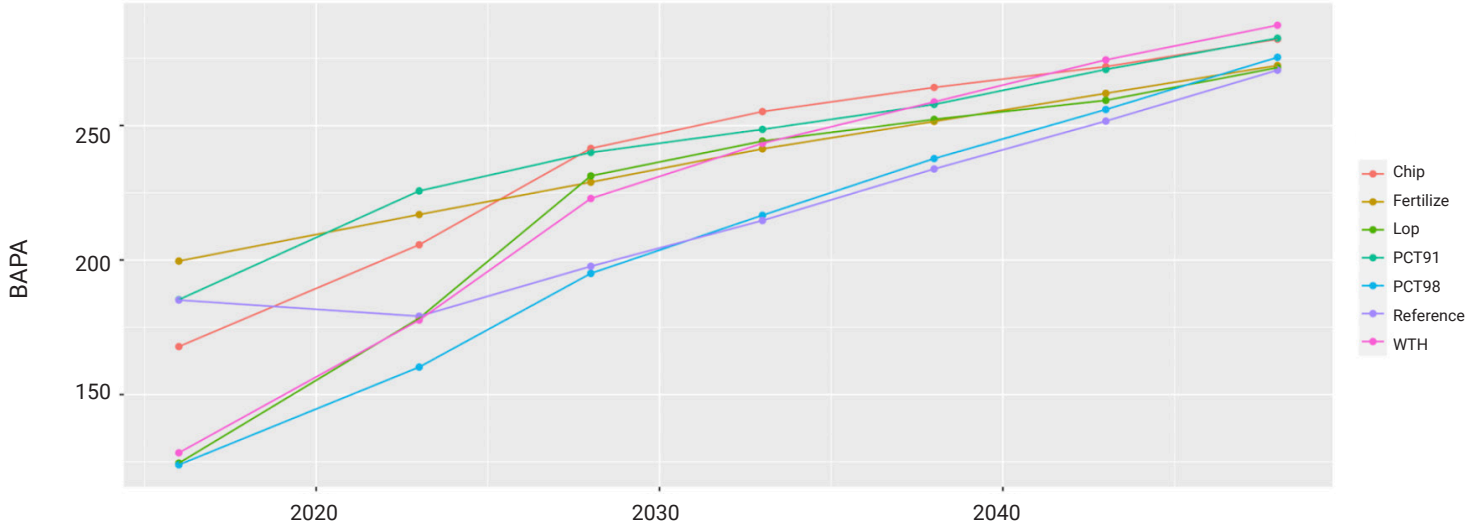
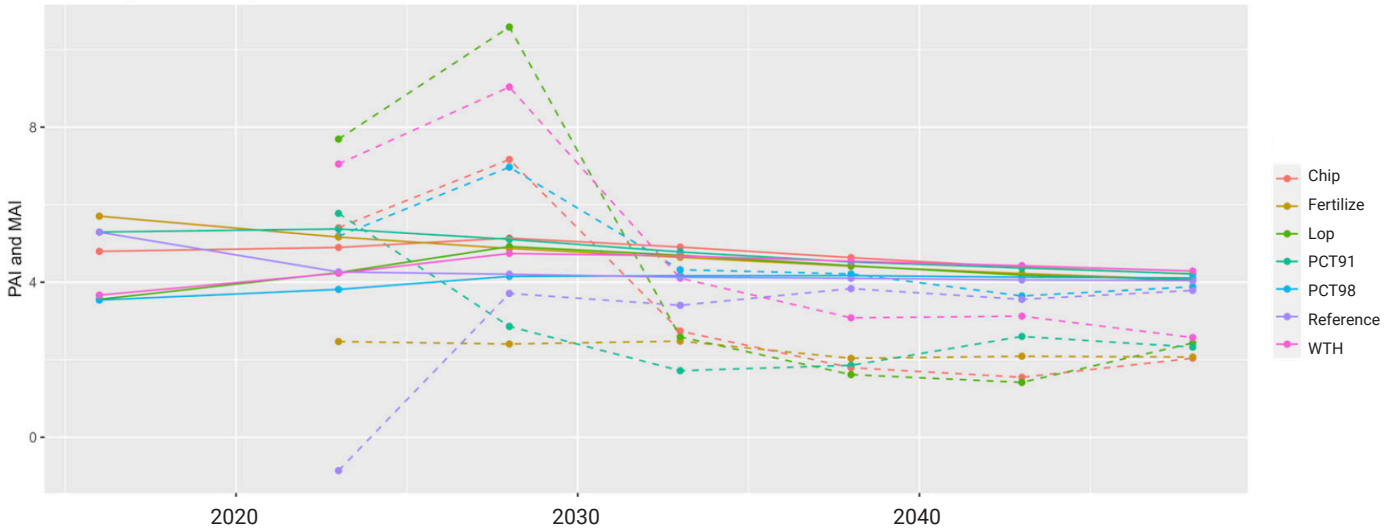


FIGURE 2. Basal Area Per Acre by Treatment and Year (ft^2/ac)

FIGURE 3. Projected Periodic (dashed lines) and Mean Annual Increment for BAPA (ft2/acre) for each treatment



FUTURE PLANS

- Cleaned data from inventory has been shared with Drs. Tat Smith and Inge Stupak to conduct further analysis of growth trends.
- Finish processing and analyzing tree cores from harvested and reference watersheds.

PHOTO 1. Rachel Poppe, MSc student in the School of Forest Resources, assists with the tree coring effort on WPSA in September 2023.

ACKNOWLEDGEMENTS

The CFRU thanks Dr. Tat Smith and Dr. Inge Stupak for their continued involvement in WPSA through member engagement, presentations, and insights for future harvest plans and considerations. We also thank Acadian Timber Corp. for their continued commitment to the research conducted at WPSA. Thanks to our CFRU summer field crew: Ashley Carter, MS student with the School of Forest Resources, Ethan "Mac" MacKenzie, BS student with the Department of Wildlife, Conservation, Fisheries, & Biology, and Eddie Nachamie, BS student in Ecology and Environmental Sciences.

GEOGRAPHIC LOCATION OF PROJECT

T4R12 WELS, Weymouth Point on Chesuncook Lake, 45°57'05.2"N 69°18'35.2"W

PARTNERS/STAKEHOLDERS/ COLLABORATORS

Acadian Timber Corp.

EXTERNAL/MATCHED FUNDING SOURCES

None.

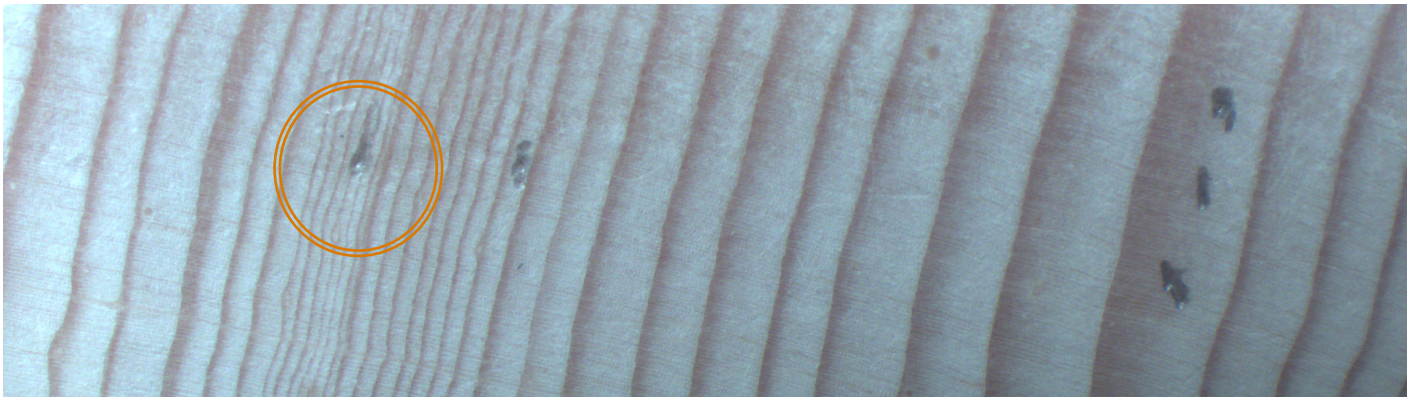


PHOTO 2. Tree core sample from WPSA sanded and ready for analysis. The thin rings circled above are signals of the SBW outbreak in the 1910s.

A NEW NORTHERN CONIFER SILVICULTURE GUIDE

LAURA KENEFIC, RESEARCH FORESTER, U.S. FOREST SERVICE
NICOLE ROGERS, ASSISTANT PROFESSOR OF SILVICULTURE, UNIVERSITY OF MAINE
KEITH KANOTI, UNIVERSITY FOREST MANAGER, UNIVERSITY OF MAINE

PROGRESS REPORT

ABSTRACT

A new silviculture guide for northern conifers (spruce – fir and associated species) is in preparation and will be published by the U.S. Forest Service with support from the Cooperative Forestry Research Unit and Northeastern States Research Cooperative. Using a model of co-production, the writing team (Kenefic, Rogers, Kanoti, and Carolyn Ziegra of the Appalachian Mountain Club) continued their work in 2022-2023 with periodic presentations and requests for feedback from practitioners. Additional co-authors were added to the team, including experts in forest soils (Russ Briggs, SUNY-ESF), spruce budworm (Dave MacLean, University of New Brunswick), and ecological forestry (Patricia Raymond, Quebec Ministry of Forests, Wildlife, and Parks). Contributed sections are in preparation by cooperators and include silvicultural highlights from Baskahegan (Kyle Burdick) and Umbagog National Wildlife Refuge (Thomas LaPointe and Sean Flint) among others. A framework to guide decision making and density management guidance for submerchantable stands are among the important developments this year.

PROJECT OBJECTIVES

- Produce a new Silviculture Guide for Northern Conifers using a process of co-production wherein stakeholders including CFRU members and other public and private forestland owners and managers are engaged in content development.
- Collaborate with partners to disseminate the guide (online and in print) and a professionally produced companion video.
- Host an in-field workshop for CFRU members and others.

APPROACH

- Complete literature review and draft table of contents.
- Invite cooperators to advisory panel. Convene advisory panel to review and make recommendations for revision of the contents of the guide and video at key steps in the development process.
- Gather unpublished data or research results from cooperators and/or extract data from long-term experiments to fill information gaps. Use these to update supporting materials such as density management guides.
- Write the draft guide and draft the content of the companion video. Undertake workshop planning and logistics.
- Finalize the guide and video based on feedback from advisory panel with assistance from a science writer. Submit these to the U.S. Forest Service and Center for Research on Sustainable Forests, respectively, for review, approval, and publication/posting.
- Host workshop for practitioners, and work with communications and public affairs staffs and partners to widely disseminate products.

KEY FINDINGS AND ACCOMPLISHMENTS

- Writing team spent two days at Umbagog National Wildlife Refuge in July 2022 to review management strategies for wildlife habitat in spruce – fir – hardwood forests.
- Further developed density management guides (stocking guide and density management diagram) for spruce – fir dominated stands (David Ray, University of Maine). Published a paper on density management guides highlighting spruce – fir (Ray et al. 2023).
- Presented an update on the guide in a technical session at the New England Society of American Foresters annual winter meeting in March 2023, with feedback from practitioners.
- Expanded the co-author team to include Russ Briggs, Dave MacLean, and Patricia Raymond. Invited expert contributors to draft sections on nonnative invasive plants (Nancy Olmstead, The Nature Conservancy), insect pests (Angela Mech, University of Maine), wildlife habitat (Thomas LaPointe and Sean Flint, U.S. Fish and Wildlife Service), deer wintering areas (Sarah Spencer, Maine Department of Inland Fisheries and Wildlife).
- Solicited data from the U.S. Forest Service to evaluate the state of the spruce – fir resource.
- Contracted with Matthew Russell of Arbor Analytics to complete new assessment of PCT and CT outcomes from long-term U.S. Forest Service experiments in spruce – fir.
- Drafted sections on silviculture (regeneration, density management, and rehabilitation), operations, wildlife considerations, and others. Incorporated science writer Jenna Zukswert into the team to ensure clarity and consistency.

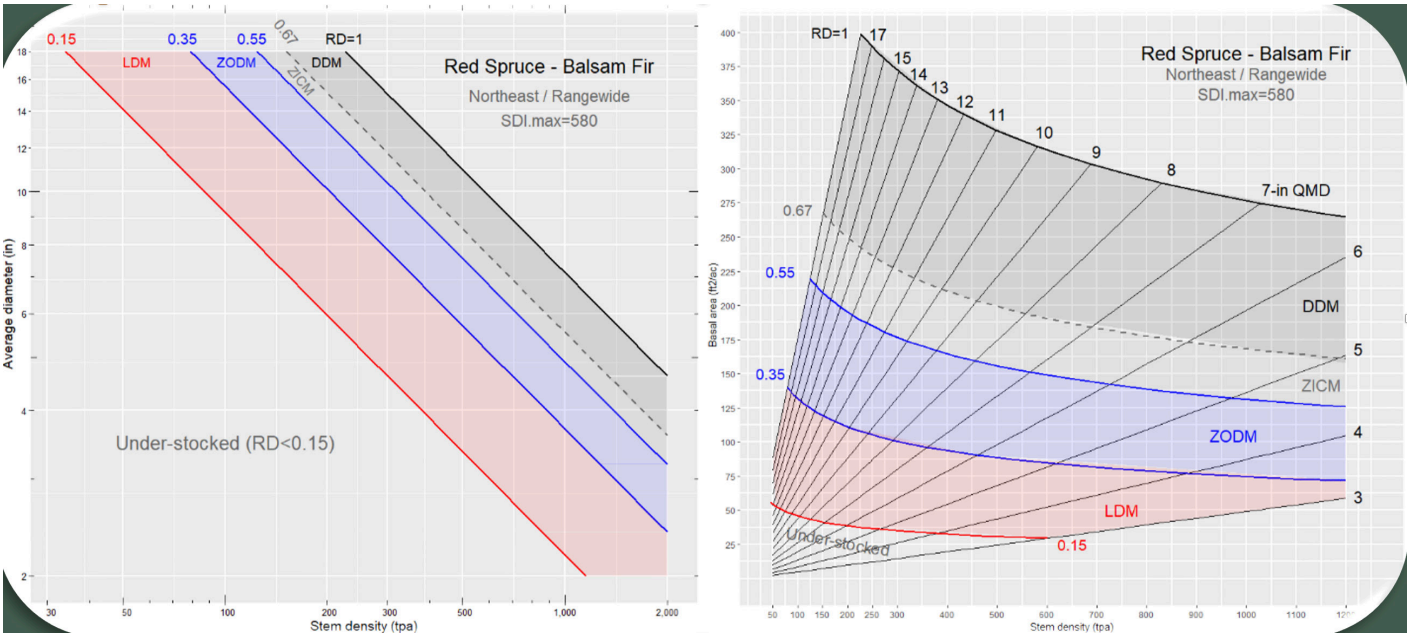


Figure 1. Updated quantitative silviculture tools for the spruce – fir forest type in the Northeast include a stocking guide based on stand density index (SDI). This guide shows basal area (ft2/acre) on the y-axis and average stand diameter (QMD) isolines (3-17 inches). It uses relative density (RD), a function of maximum and observed SDI, to define upper and lower bounds of five management zones: zone of high density-dependent mortality (DDM) (RD 1.0 - 0.67), zone of imminent competition mortality corresponding to the average self thinning trajectory (ZICM) (RD 0.67 - 0.55); zone of optimal density management where net stand level production is expected to be highest (ZODM) (RD 0.55 - 0.35), and zone of low density management where growth rates of individual trees are optimized (LDM) (RD 0.35 - 0.15). RD < 0.15 is considered understocked relative to wood production objectives. This figure compares the updated guide (black lines) to previous spruce – fir stocking guides published by the U.S. Forest Service (Solomon et al. 1987 in orange, and Frank and Bjorkbom 1973 in green). The data points shown are from the U.S. Forest Service, FIA (colored dots) and the CFRU Commercial Thinning Research Network (black solid dots = unthinned, black hollow dots = thinned). As you can see, many of the data points fall outside the bounds of previously published stocking guides; the new guide more accurately reflects spruce – fir forest dynamics. The choice of SDI.max=580 corresponds to average values for red spruce and balsam fir used to predict density-dependent mortality in the Northeast Variant of the Forest Vegetation Simulator; other values can be used. Credit: David Ray. Graph is available with additional explanation in the Supplementary Materials of Ray et al. 2023.

FUTURE PLANS

Writing and editing, video production, and planning of the practitioner workshop will continue until all deliverables are finalized. Target completion date is mid to late 2024.

ACKNOWLEDGEMENTS

We would like to thank project manager Jeanette Allogio. Thank you to the many practitioners, including those from CFRU member organizations, who have participated in our advisory panel and continue to provide critical feedback.

PARTNERS, STAKEHOLDERS, AND COLLABORATORS

Acadian Timber
Appalachian Mountain Club
Baskahegan Company
Baxter State Park
Cooperative Forestry Research Unit
Forest Society of Maine
Huber Resources Corporation
J.D. Irving Limited
Landvest
Maine Bureau of Parks and Lands
Maine Forest Service
Maine Department of Inland Fisheries and Wildlife
New England Forestry Foundation
New Hampshire Division of Forests and Lands
Northern Forest Conservation Services, LLC
Passamaquoddy Forestry Department
Penobscot Nation, Department of Natural Resources
Seven Islands Land Company
The Nature Conservancy
U.S. Fish and Wildlife Service, Umbagog National Wildlife Refuge
U.S. Forest Service, Green Mountain National Forest
U.S. Forest Service, National Forest System, Enterprise
U.S. Forest Service, White Mountain National Forest
Vermont Department of Forests, Parks, and Recreation
Vermont Land Trust
Wagner Forest Management

GEOGRAPHIC LOCATION OF PROJECT

Maine, New Hampshire, Vermont, New York

SPRUCE BUDWORM L2 MONITORING PROGRAM IN MAINE

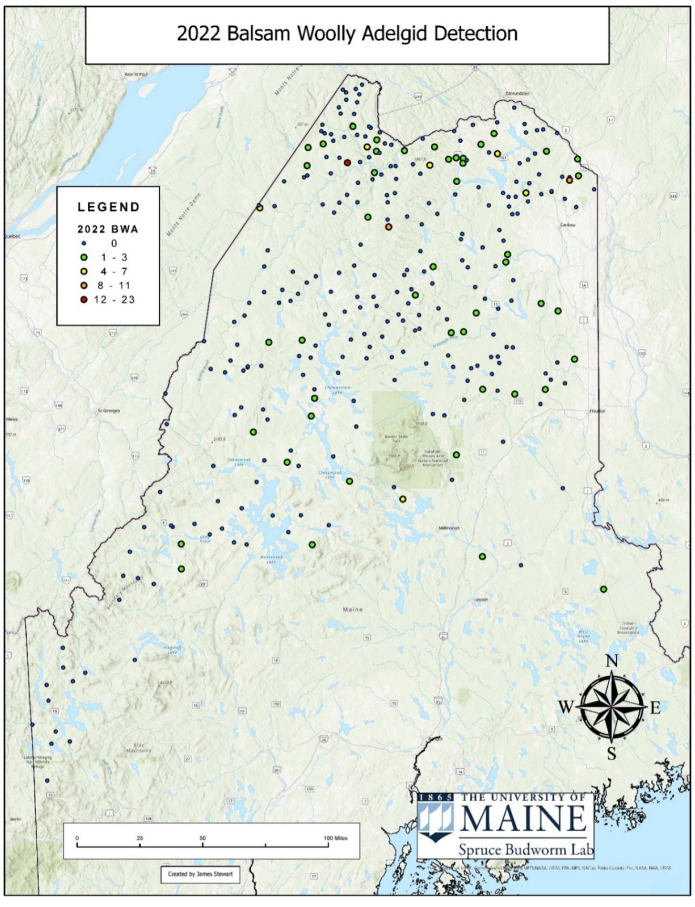
ANGELA MECH, ASSISTANT PROFESSOR OF FOREST ENTOMOLOGY, UMAINE
NEIL THOMPSON, PROFESSOR OF APPLIED FOREST MANAGEMENT, UMAINE FORT KENT

PROGRESS REPORT

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. In August 2022, using CFRU funds as match, the USFS awarded PI Mech with a grant to cover ~50% of the processing costs and allowed the lab to expand monitoring to 350 sites, including those in other states. All landowners/managers were supplied with collection bags for their monitoring sites and all processing was completed in April 2023. Seven new sites were submitted from Vermont based on their flight catches. Overall, 2022 saw a decline in SBW across the region (none were above the seven L2 threshold), and sampling of sites that used early intervention strategies showed promising results. Lastly, processing in 2022 included counts for balsam woolly adelgid, which was detected in 19% of the sites submitted.

PHOTO 2. James Stewart, Spruce Budworm Lab Manager inspects a finished branch sample under a microscope to see whether or not spruce budworm larvae were present on branches. Photo by R. Smith. PHOTO 3. Balsam Wooly Adelgid in the trunk phase. Photo by USFS.



1865 THE UNIVERSITY OF MAINE
Spruce Budworm Lab

PROJECT OBJECTIVES

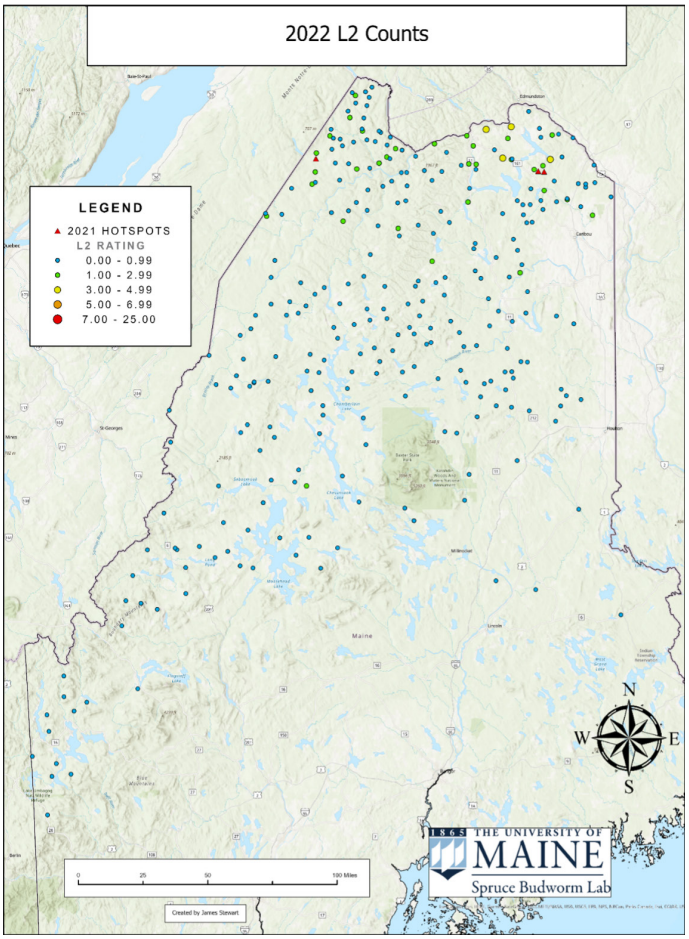
- To establish a SBW processing lab at the University of Maine that would be responsible for determining the L2 counts for 307 monitoring sites across the state.
- To provide a fee-for-service option for landowners to have additional sites processed.
- To provide rapid results for areas that need to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

APPROACH

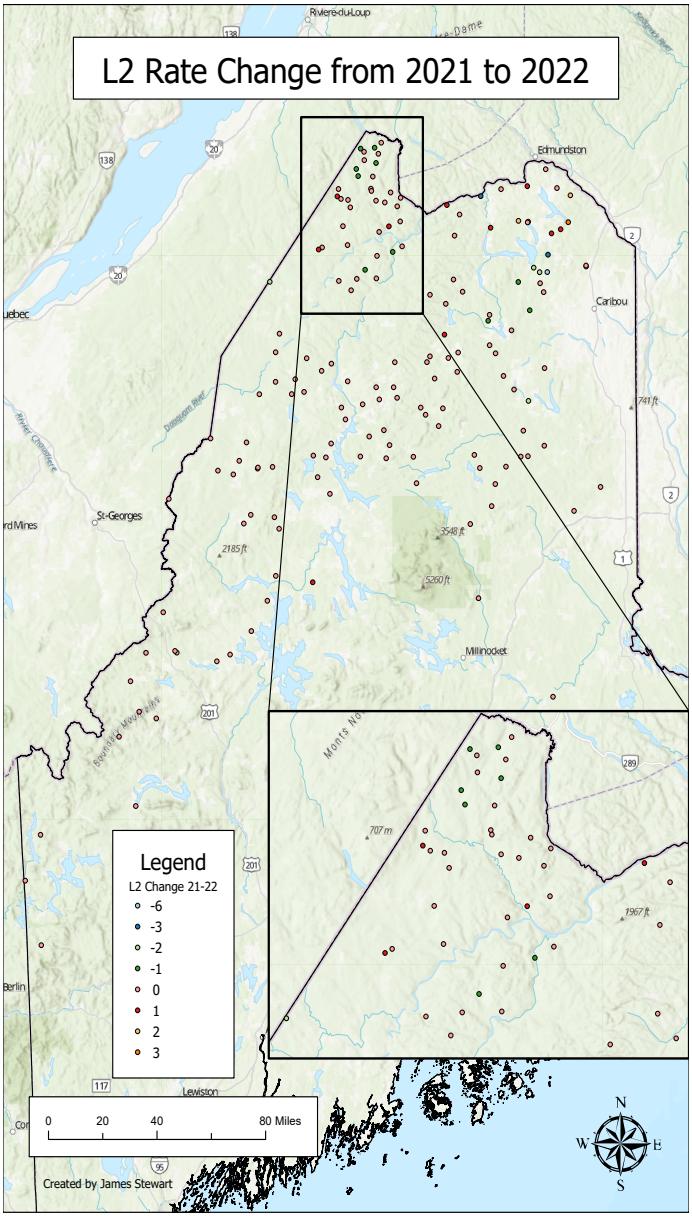
- Designated all sites into 4 ranked tiers based on 2020 average L2 counts (avg. 3 branches per site) and proximity to hot spots. Sites in the northern region of the state are at higher risk and were therefore designated as higher priority.
- As branches arrive to the lab, they are sorted and processed based on tier.
- Landowners/managers are emailed results weekly if any of their sites have been processed.
- Any contract sites are processed as Tier 1's.

KEY FINDINGS/ACCOMPLISHMENTS

- A total of 302 sites (906 branches) were processed for the 2022 SBW monitoring season.
- Monitoring results showed that the 2021 hotspot sites (those with more than 7 L2's) were successfully decreased by management in 2022.
- None of the 302 monitoring sites had > 7 L2's; the highest site average was 4.67 L2's (Fig. 1).



- There has been a 25% decrease in the overall average number of L2's per site compared to 2021 values. Most of the population growth that did occur was concentrated in the northern part of the state (Fig. 2).
- Overall, only 16% of sites had an increase in L2's compared to 2021 values; this trend was similar for the other larvae on the branches as well.
- Due to significant increases in pheromone trap catches, 7 sites (21 branches) were submitted for processing from the Vermont Department of Forests, Parks & Recreation. None of the sites have > 7 L2s, but it is worth noting that the outbreak in Maine was not detected until 1-2 years following the peak in pheromone trap catches.
- 19% of sites detected balsam woolly adelgid (BWA), with higher BWA numbers in the same areas where we're finding more SBW (Fig. 3).
- Once processing for SBW was completed, a similar process was used in the lab to dissolve the silk of browntail moth (BTM) nests. This was done following a brief experiment to determine the winter mortality



experienced. During the winter of 2022, 35% of BTM larvae died, but it is unknown whether this above, below, or an expected amount of mortality. Subsequent years of data will assist in answering this question.

FUTURE PLANS

- Conduct 2023 season SBW branch processing for up to 350 monitoring sites
- Provide fee-for-service option for additional site processing
- Include balsam woolly adelgid presence/absence in notifications to landowners/managers.
- Look at trends in SBW, BWA, and BTM populations over time

PARTNERS/STAKEHOLDERS/ COLLABORATORS

Frank Cuff, Weyerhaeuser
Ked Coffin, J.D. Irving
Jim O'Malley, Huber
Eugene Mahar, LandVest
Ian Prior, Seven Islands Land Co.
Allison Kanoti, Maine Forest Service
Mike Parisio, Maine Forest Service
Joe Bither, Maine Forest Service
Erin Simons-Legaard, University of Maine
Kasey Legaard, University of Maine
David Evanoff, University of Maine

GEOGRAPHIC LOCATION OF PROJECT

Environmental Science Lab at the University of Maine

EXTERNAL/MATCHED FUNDING SOURCES

SOURCE	$ RECEIVED IN FY2023	DIRECT/INDIRECT
USDA Forest Service	$55,000	Direct
MAFES (PI faculty salary; 15%)	$11,397	Direct

HAVE YOU CHECKED OUT THE MOST RECENT SBW TASK FORCE REPORT?

The updated report was released in March 2023 and provides critical updates to the 2016 SBW Task Force report. Speficially, the 2023 report includes updated landowner responses to spruce budworm "hot spots" (7+ L2s/branch) by utlizing the early intervention strategy, or EIS. This management paradigm leans heavily on L2 sampling at a local landscape level to identify hot spots as they develop. EIS aims to interrupt or delay a budworm outbreak by targeting hot spots with BtK, Bacillus thuringiengsis kurstaki, a naturally occuring bacteria that is used as a biological insecticide. The 2023 updated report details how EIS has changed our management response to budworm and provides direction for ongoing and future research, policy, and communications for the various task teams. You can view the report now at sprucebudwormmaine.org.

Maine Spruce Budworm Task Force

REFINING THE ACADIAN MODEL

BEN RICE, MIDGARD NATURAL RESOURCES, LLC
JEREME FRANK, MAINE FOREST SERVICE
NICK CROOKSTON, USDA FOREST SERVICE, RETIRED

PROGRESS REPORT

ABSTRACT

The Acadian model represents the best available science for projection of a diverse range of Maine's forest stand conditions. Over the past year this project has sought to make some basic improvements to that foundation, implementing a significant number of updates and improvements to the Acadian model and integration with FVS. Using USDA Forest Service Forest Inventory and Analysis (FIA) data, an analysis of model performance has been undertaken. Hopefully, the results of this analysis can help provide confidence in the model's performance and accelerate adoption across the region.

PROJECT OBJECTIVES

- Review and refine Acadian model process flow
- Validate growth and mortality functions
- Develop reference and training materials

APPROACH

Review and refine Acadian model process flow

- Update model components
- Assess areas where the process flow performance could be improved
- Improve availability of model functions within the FVS framework

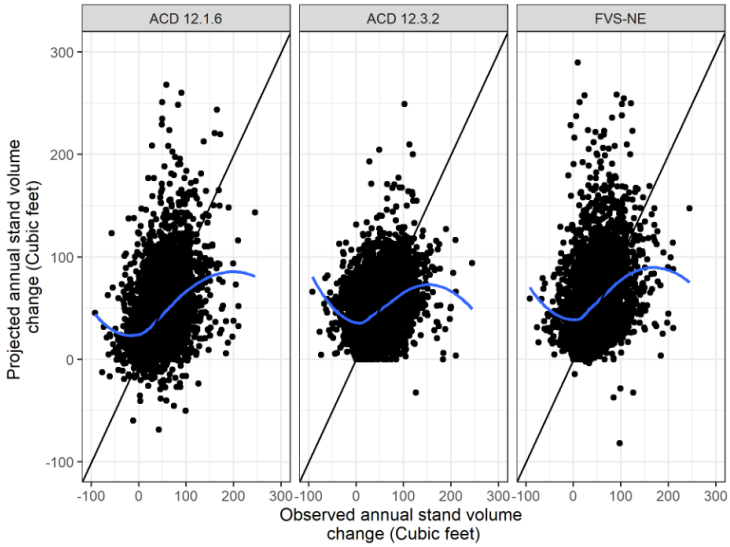


FIGURE 1. Projected and observed stand volume. ACD 12.3.2 is the most recent version of the Acadian model. ACD version 12.1.6 was prior to recent updates involving mortality and stand basal area increment calculations. FVS-NE is the FVS northeast variant. More figures are available in the unedited version of the report.

Validate growth and mortality functions

- Compare model accuracy using the Acadian model (historic and current versions), FVS Northeast variant (FVS-NE) and Open Stand Model (OSM) using USDA Forest Service Forest Inventory and Analysis (FIA) data
- Compare long-term growth projection results from the Acadian model with FVS-NE and OSM

Develop reference and training materials

- Develop model documentation
- Develop and deliver a training session to CFRU members

KEY FINDINGS AND ACCOMPLISHMENTS

Review and refine Acadian model process flow

- An updated mortality approach has been fully integrated and tested
- A new stand basal area increment equation, designed to complement the individual tree diameter increment model, has also been implemented.
- The FVS Acadian variant (FVS-ACD) has been updated to utilize Acadian equations to fill in missing crown ratio and height values
- FVS-ACD also now allows users to pass diameter increment, height increment and mortality calibration factors from the FVS environment
- A strategy to update the model process flow has been mapped out and implementation and testing is planned for year 2 of the project

Acadian model comparison

- FIA data was selected from across northern New England
- Using six version of the Acadian model, FVS-NE and OSM growth models, preliminary stand level and tree level comparisons of the model projections were conducted

FUTURE PLANS

- Complete model assessment and benchmarking
- Implement additional process flow improvements focused on reducing execution times
- Develop reference and training materials for CFRU members

HIGH RESOLUTION LAND COVER AND FOREST TYPE DATA FOR THE STATE OF MAINE

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CLAIRE KIEDROWSKI, EXECUTIVE DIRECTOR, MAINE GEOLIBRARY (RETIRED)

PROGRESS REPORT

ABSTRACT

The Maine High Resolution Land Cover project will produce in partnership a multi-resolution set of land cover products for the state, providing an appropriate level of detail for a wide variety of applications. Data development will include a 1-meter land cover product, consistent with NOAA's Coastal Change Analysis Program (C-CAP), and a 10-meter land cover product including C-CAP classes plus detailed forest type categories developed by the University of Maine Intelligent GeoSolutions group, housed under the Center for Research on Sustainable Forests. Both layers will be readily updatable, with planned updates tied to the 4- to 6-year NOAA C-CAP production cycle to reduce future costs. Regularly updated 1-meter and 10-meter layers will provide statewide land cover and forest type data with unprecedented spatial, temporal, and thematic detail. This next-generation, multi-resolution data will support a broad range of forest sector use cases and applied research topics of importance to the CFRU.

PROJECT OBJECTIVES

- Develop a forest typing scheme (approx. 15 forest types) suitable for remote sensing application throughout the state of Maine given available resources and forest stakeholder priorities;
- Develop methods to harmonize 10-meter satellite-derived forest type predictions with new 1-meter land cover data obtained from digital aerial photography and LiDAR;
- Produce and distribute a statewide 1-meter land cover product (17 categories, including natural vegetation, wetlands, and impervious surfaces);
- Produce and distribute a statewide 10-meter land cover and forest type product (the current plan includes 15 forest type categories plus 16 non-forest and disturbed forest categories);
- Develop a data maintenance plan including a 4- to 6-year update cycle coordinated with federal, state, and university programs to reduce future cost.

APPROACH

- Production of land cover and forest type data will be accomplished through a partnership between the NOAA Office for Coastal Management and UMaine IGS. Production and delivery of the 1-meter land cover data will be coordinated by NOAA. Production and delivery of the 10-meter land cover and forest type map will be coordinated between the NOAA Office for Coastal Management and UMaine IGS, with NOAA responsible for aggregating 1-meter land cover categories to a 10-meter grid and IGS responsible for modeling and mapping the condition of forest pixels at 10-meter resolution.
- Methods used to produce the 1-meter data will be consistent with those used to produce the NOAA C-CAP product line [1], and will include a combination of machine learning applied to digital aerial photography and LiDAR, geographic object based image analysis, expert-based rulesets, and manual editing (Figure 1).

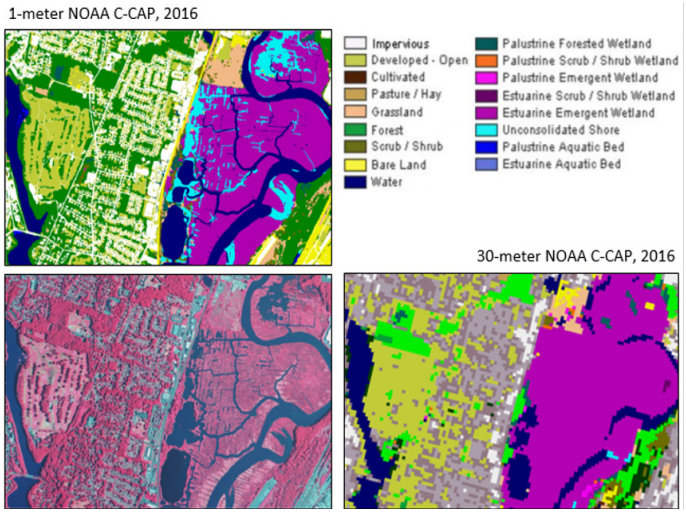


FIGURE 1: Sample landscape demonstrating the spatial detail resolved by the 1-meter NOAA C-CAP High Resolution Land Cover product line, contrasted with the 30-meter NOAA C-CAP Regional Land Cover data.

- Forest classification will rely on machine learning and geographic object based analysis methods developed by UMaine forest scientists [2-3] and implemented with software developed in partnership with the University of Maine Advanced Computing Group.
- Input data will include multi-temporal Sentinel-2 satellite imagery and digital terrain data. Primary training and validation data will be contributed by the USDA Forest Service, Forest Inventory and Analysis Program under an existing collaborative agreement with UMaine (Figure 2).

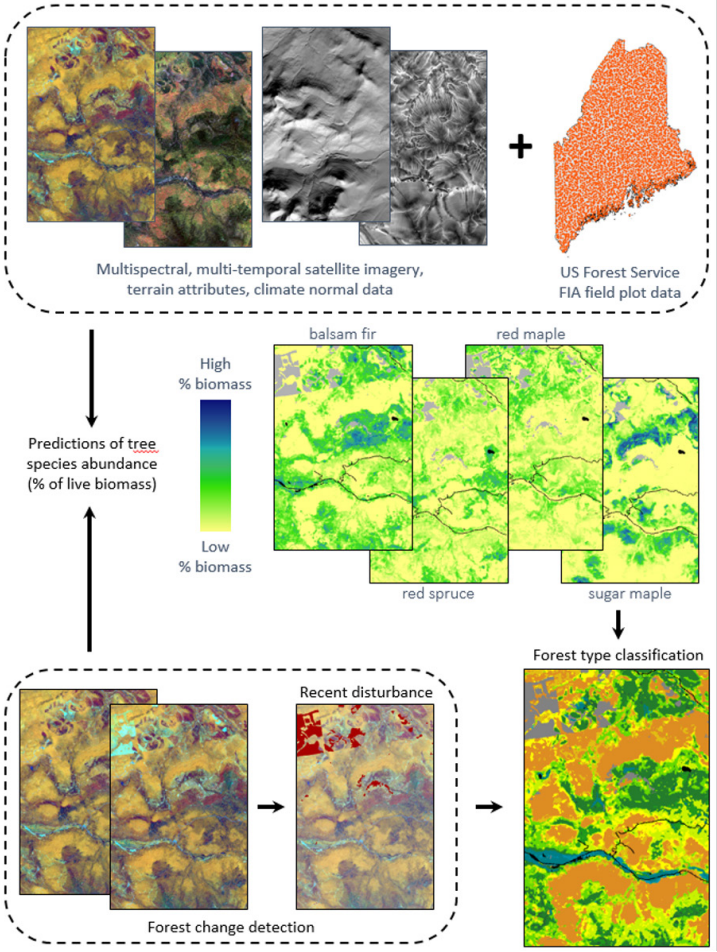


FIGURE 2: Proposed 10-meter forest typing mapping approach, based on the prediction of the relative abundance of approximately 15 individual tree species using machine learning methods developed at UMaine.

- Forest type predictions will be based on the identification of dominant or co-dominant tree species or species groups (e.g., Populus spp.), obtained from 10-meter resolution predictions of species relative abundance (e.g., percent of total live aboveground biomass). Our proposed forest type scheme includes 12 upland classes (4 hardwood, 4 softwood, and 4 mixedwood classes) and 3 lowland or forested wetland classes (Table 1).

KEY FINDINGS AND ACCOMPLISHMENTS

- Developments over the past year have focused on improved data handling algorithms and on more computationally efficient workflows to support statewide mapping. Significant changes to our satellite image processing workflows integrate improvements to automated local image coregistration, haze and cirrus correction, cloud/shadow detection and masking, topographic illumination correction, forest road detection, and disturbance detection to improve machine learning models.
- Haze and cirrus correction incorporates significant improvements over published algorithms, which tended to perform poorly with Sentinel-2 data over much of the state.
- We have developed an alternative cloud/shadow detection algorithm based on gradient boosted regression trees to improve detection accuracy over standard approaches. We continue to refine cloud and shadow detection models, and plan to release our code with a QGIS plugin developed in collaboration with students from the Monroe Community College Geospatial Information Science and Technology program.
- We have developed, tested, and refined a multi-stage machine learning process to improve species predictions in areas where image data are missing due to clouds or cloud shadows. Where image data are complete, we use multi-objective support vector machines to minimize systematic error in species predictions, resulting in improved species discrimination and forest type labeling. Support vector machines, however, are incapable of making predictions where data are incomplete. Where this occurs, we use a collection of gradient boosted regression tree models optimized to mimic support vector machine predictions, resulting in nearly seamless prediction of species distributions despite considerable cloud cover in certain areas of the state.

UPLAND FOREST TYPES (12 CLASSES)		
Aspen Birch	Aspen-Birch mixedwood	Cedar-Black Spruce
Maple-Beech-Birch	Hemlock mixedwood	Hemlock
Oak	Fir-Spruce mixedwood	Fir-Spruce
Red Maple	Spruce-Pine mixedwood	Spruce-Pine
LOWLAND FOREST TYPES (3 CLASSES)		
Hardwood-dominant forested wetland	Mixedwood forested wetland	Softwood-dominant forested wetland
RECENT FOREST DISTURBANCE (1 CLASS)		

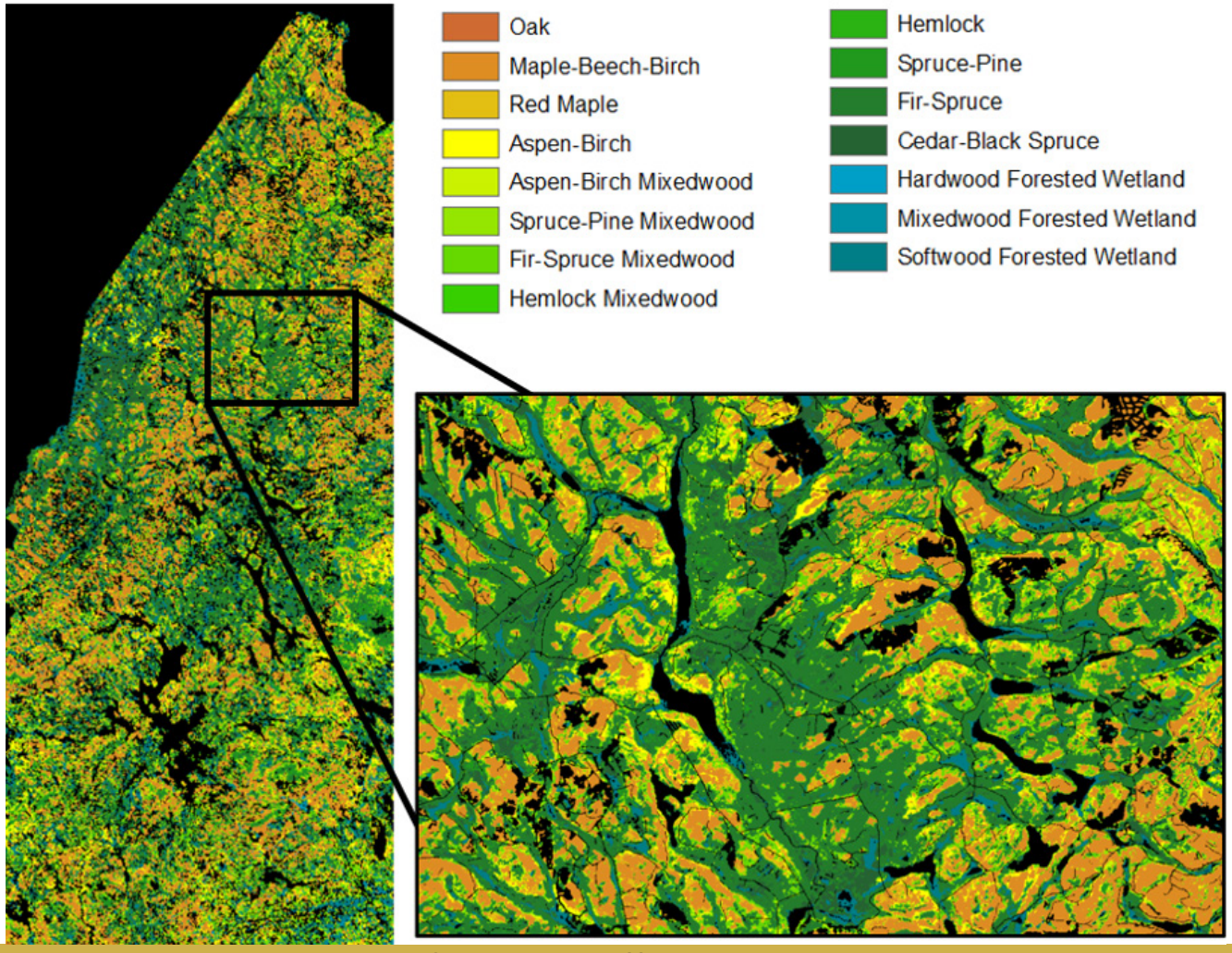
TABLE 1: Proposed forest type and forest disturbance classes for the Maine High Res. Land Cover project, 10-meter land cover and forest type map.

- We have developed and implemented several procedures for improving species and forest type predictions adjacent to abrupt forest edges. To develop robust relationships between 10 m resolution imagery and FIA plots, we average pixel values within neighborhoods that match the nominal area sampled by FIA subplots. This improves predictions overall but causes blurring and significant error adjacent to abrupt edges. We currently identify problematic edges through a combination of a forest road mapping algorithm and traditional edge detection algorithms. We thereafter eliminate or minimize effects on forest predictions through adaptive neighborhood filtering procedures.
- We have made significant progress developing efficient workflows for mapping change using a semi-automated approach based on multi-objective ML that simultaneously minimizes omission and commission error. This approach produces disturbance maps that are both highly accurate (>90% disturbance class accuracy) and unbiased (equal omission and commission error rates). We have improved methods and software to accelerate the collection of reference data to support this disturbance mapping approach, and have tested results using Sentinel-2 imagery to map disturbance at 10 m resolution. A statewide map of recent forest disturbance (2016-2021) will be integrated with forest type and land cover data.
- Species and forest type data production workflows have been tested over a large northern Maine trial area (approx. 5 million acres; Figure 3). Results include relative abundance predictions for 15 species and species groups required for forest type labeling. Cross-validation estimates of mean prediction error are about 5-10% for each species or species group, although a few species were not sufficiently prevalent in this area for reliable error estimation. Cross-validation of preliminary forest type data is in progress.

FUTURE PLANS

- Review and finalization of statewide satellite image selection and processing.
- Training and validation of species relative abundance models for statewide application.
- Statewide forest type prediction and accuracy assessment.
- Statewide forest disturbance mapping (2016-2021) and integration with forest type predictions.
- Development of methods, in collaboration with the

FIGURE 3 (BELOW). Trial data produced to test and finalize species and forest type mapping workflows for statewide data production. Masked areas include non-forest cover types and recent disturbance (2016-2021).



NOAA Office of Coastal Management, to harmonize 10-meter forest type predictions with 1-meter land cover data obtained from digital aerial photography.

- Final production and distribution of statewide 1-meter and 10-meter land cover and forest type data products (including complete metadata conforming to ISO standards). Project deliverables will be published or otherwise released to the general public. Land cover and forest type maps will be distributed directly to the CFRU via the CFRU databank and hosted on the Maine GeoLibrary and NOAA Digital Coast websites.
- Project reporting, including a peer-reviewed publication detailing project partnerships, workflows, outcomes, and maintenance plans.

PARTNERS, STAKEHOLDERS, AND COLLABORATORS

Baxter State Park
Maine Bureau of Parks and Lands
Maine Department of Environmental Protection
Maine Department of Transportation
Maine Library of Geographic Information
Maine Natural Areas Program
NOAA Office for Coastal Management
The Nature Conservancy
University of Maine Advanced Computing Group
USDA Forest Service, Northern Research Station FIA

GEOGRAPHIC LOCATION OF PROJECT

State of Maine (using plot data collected statewide; producing map data statewide)

MEASUREMENTS, MODELS AND MAPS: TOWARD A RELIABLE AND COST-EFFECTIVE WORKFLOW FOR LARGE-AREA FOREST INVENTORY FROM AIRBORNE LIDAR DATA

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FINAL REPORT

ABSTRACT

In this project, we evaluated the use of remote sensing-based inventory methods for their accuracy and effectiveness in enhancing the information provided by traditional, ground-based inventories. We investigated several crucial questions at the forefront of developing so-called "Enhanced Forest Inventories" (EFIs) in Maine based on airborne laser scanning (ALS) data acquisitions. To do this, we conducted a series of case studies comparing different remote sensing and ground-based calibration plot datasets to quantify the impact that varying these key parameters has on EFI model performance. Based on these studies, we found that – as expected – the highest quality LiDAR data paired with dense sampling intensities using fixed area, tree-mapped plots produced the best model results in terms of data fit, error, and bias. However, these comparisons show that using publicly available and lower density LiDAR data sets did not result in significantly lower model performance compared to high-resolution, research-grade data. Furthermore, while high-precision plot location in the field was required in all cases, our results show that good model performance could be achieved with more efficient ground plot data collection such as with using fewer numbers of variable-radius plots. In addition to the quantitative model comparisons, we also worked directly with users to develop EFI map products for each case study and in turn receive their feedback with respect to their quality and usability in their inventory workflows. We have compiled and synthesized these quantitative model comparisons along with the qualitative assessments of this project's results in a "Best Practices Guide" for ALS-based EFI in Maine – a key deliverable of this project that is forthcoming in Spring 2024. Overall, the results of this project demonstrate the promise for implementing EFI projects in Maine's working forests where they can be tailored to the particular remote sensing and ground-based datasets available and still achieve high quality and usable results.

PROJECT OBJECTIVES

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

APPROACH

- In collaboration with forest industry stakeholders, the Wheatland Lab has designed a series of investigations into the use of LiDAR remote sensing to improve forestry inventory programs over large parcels of managed forestland.
- We evaluated ground-based inventory plot designs together with existing, publicly-available ALS data sets to generate EFI map products.
- In a series of demonstrative "case studies", we leveraged several different private, public, and university research forest properties representing a range of conditions in terms of the available ALS and accompanying field calibration plot data.
- We used these case studies to evaluate the impact of calibration plot type, size, layout, and location accuracy on the estimation of forest inventory attributes using machine-learning models that relate the field data to wall-to-wall ALS across the different study areas.
- We worked closely with users to "co-produce" the type of information that they need in a format that is most useful for their workflows.
- We are synthesizing the results and lessons-learned from the various case studies into a "Best Practices Guide" for managers and practitioners planning for and conducting EFIs in Maine's working forests.

KEY FINDINGS/ACCOMPLISHMENTS

- We developed an end-to-end workflow for area-based modeling of ALS data to create gridded maps of predicted EFI variables. This newly implemented method uses the variability in the ALS data (calculated

FIGURE 2. Comparison of traditional stand-level inventory and EFI volume estimates across the Penobscot Experimental Forest. Stands were measured during the summer of 2023.

via principal components analysis, or PCA) to guide the number and placement of ground-based calibration plots. Our workflow uses the lidR package in Program R is used to calculate the LiDAR metrics, the calibration data are prepared and organized in spreadsheets, and randomForest performs the EFI variable prediction modeling. Finally, the results can be quantitatively evaluated in terms of model explanatory power (R2), normalized average error (nRMSE), and bias in matching the predictions to the observations.

- We implemented this workflow and compared the results across varying LiDAR and calibration plot data for four case studies: Seven Islands - Ashland West, Baskahegan, Rangeley Lakes Heritage Trust – Stephen Phillips Memorial Preserve, and the University of Maine – Penobscot Experimental Forest (PEF). For the PEF, our CFRU project supported the measurement in summer 2022 of 140 new calibration plots located based on the PCA sampling approach. Our CFRU cooperators provided all plot data for the other case study properties.
- In terms of model performance, some variables such as percent softwood and volume can be predicted with less error than others like stem count and basal area.
- The best quantitative results in terms of model performance (R2, nRMSE) was achieved with the PEF and RLHT case studies that had dense sampling intensities using fixed area, tree-mapped plots that were pre-selected and located based on the PCA.
- In all case studies, high-precision plot location using survey grade GPS in the field was required for performing our workflow and achieving acceptable model results.
- The case studies showed good EFI model results with publicly available LiDAR data (leaf-off, <5 pulses per m2) when compared to high-density, research-grade ALS (leaf-on, >15 pulses per m2).
- The case studies showed good EFI model results in some cases where models were trained using fewer numbers of calibration plots and/or variable radius plots when compared to higher sampling intensities with fixed area designs.
- We have received positive feedback from users with respect to the ability of the EFI map products to generally match what is on the ground and overall represent the variability across the key inventory attributes such as softwood percent, basal area, and volume.
- Over the course of this project, the Wheatland Lab conducted four workshops and presentations with a total of 257 participants (including CFRU members and other partners) to introduce the concepts, data, and methods of standard EFI workflows.

FIGURE 1. Wheatland field crew collecting EFI calibration plot data in the Penobscot Experimental Forest: Summer 2022.

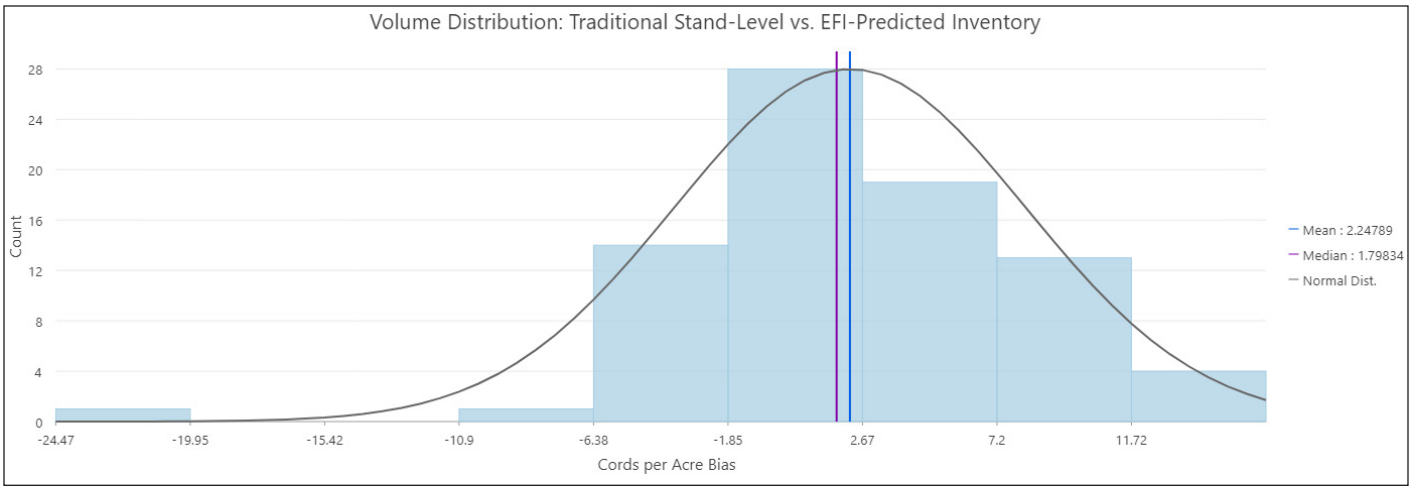

FIGURE 3. Histogram representing the distribution of bias between traditional stand-level and EFI-predicted inventory methods.

FUTURE PLANS

We have completed the remaining analysis of the model results and compared them across the various "experiments" that answer the original questions laid out in our project objectives related to how varying ALS and calibration plot data specifications impact the accuracy and usability of EFI estimates and map products. We are now finishing the compilation of these analyses and synthesizing our findings into a set of recommendations that will form the content of the "Best Practices Guide" for ALS-based EFI in Maine – forthcoming by the CFRU's Spring meeting in 2024. Future research will focus on the problem of updating EFI maps in future inventories, particularly by investigating the role of NAIP-derived canopy height data in modeling. We will continue to work with CFRU members in a variety of ways, including disseminating our current findings in presentations to the stakeholder and science communities, as well as holding workshops and trainings for using these workflows and data products.

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, Baskahegan 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.

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Keith Kanoti, University Forests
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Rangeley Lakes Heritage Trust
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GEOGRAPHIC LOCATION OF PROJECT

Various parcels in Maine. Shapefiles available upon request.

EXTERNAL/MATCHED FUNDING SOURCES

Source	$ Received in FY2023	Direct/Indirect
MTCT	$17,502	Indirect

WHEATLAND GEOSPATIAL LAB

FOREST CARBON AND TIMBER POTENTIAL FOR NORTHERN MAINE'S WORKING FORESTS

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PROGRESS REPORT

ABSTRACT

Forests will play a pivotal role in meeting Maine's climate mitigation target, there's questions about how to simultaneously increase carbon and maintain timber supply. In response, this research: (1) uses a dynamic forest landscape model to project species-level trends in outputs like area, carbon, and harvest across Northern Maine; (2) evaluates how these outputs are influenced management activities, and (3) compares outcomes from various treatments to determine feasible mixes of strategies to enhance forest carbon and timber supply. Results show consistent tradeoffs between carbon sequestration and timber supply, with impacts diminished if managers shift to a land-sparing approach comprised of permanent set-asides and intensive clearcut and planting regimes. We estimate that carbon sequestration can increase by 15-25% over the reference case while still maintaining harvest levels by shifting to a broader mix of intensive and extensive practices. Maine's harvests could grow by 20%, and its forests could still have a positive effect on carbon. Overall, we find that changes in forest management can lead to improved outcomes for both carbon and other forest ecosystem services of interest, provided managers are given the policy, economic, and social incentives to do so.

PROJECT OBJECTIVES

- Use a dynamic forest landscape model (LANDIS) to project species-level trends in area distribution, growth, carbon, harvest, and wildlife habitat across 9 million acres of Northern Maine through 2100;
- Evaluate the influence of forest management activities like (pre)commercial thinning, clearcutting, tree planting, and set asides on aboveground forest biomass, carbon sequestration, and timber supply by product class;
- Compare outcomes from various rates of treatments employed across the landscape to determine feasible mixes of strategies to enhance forest and harvested wood product carbon and timber supply.

APPROACH

Forest Carbon Sequestration Analysis

- Combine economic and biophysical methods to identify the forest carbon sequestration and biomass supply potential for forest NCS practices in Maine. We have identified 10 forestry practices to evaluate in detail using the LANDIS-II forest landscape model.

Stakeholder Input

- We solicited feedback via expert input from several discussions with forest landowners and managers about the findings developed in #1. This helps us better understand whether practices we estimate as cost-effective might work in the real world. Stakeholders included commercial forest landowners, conservation land managers, family forest owners, and forest carbon offset developers.

Alternative Pathways

- We use stakeholder input to develop plausible alternative future pathways to estimate potential uncertainty in NCS mitigation potential under a range of policy and socio-economic futures. These pathways served as key components for the scenarios evaluated in the FCCL project.

Decision Support

- We utilize UMaine's knowledge of forest carbon and timber supply modeling to develop a decision support tool to assist with landscape-level forest management planning. The tool can be used to evaluate impacts of broad management practices on standing inventory, wood harvest, aboveground and harvested wood product carbon, and five indicators of biodiversity.

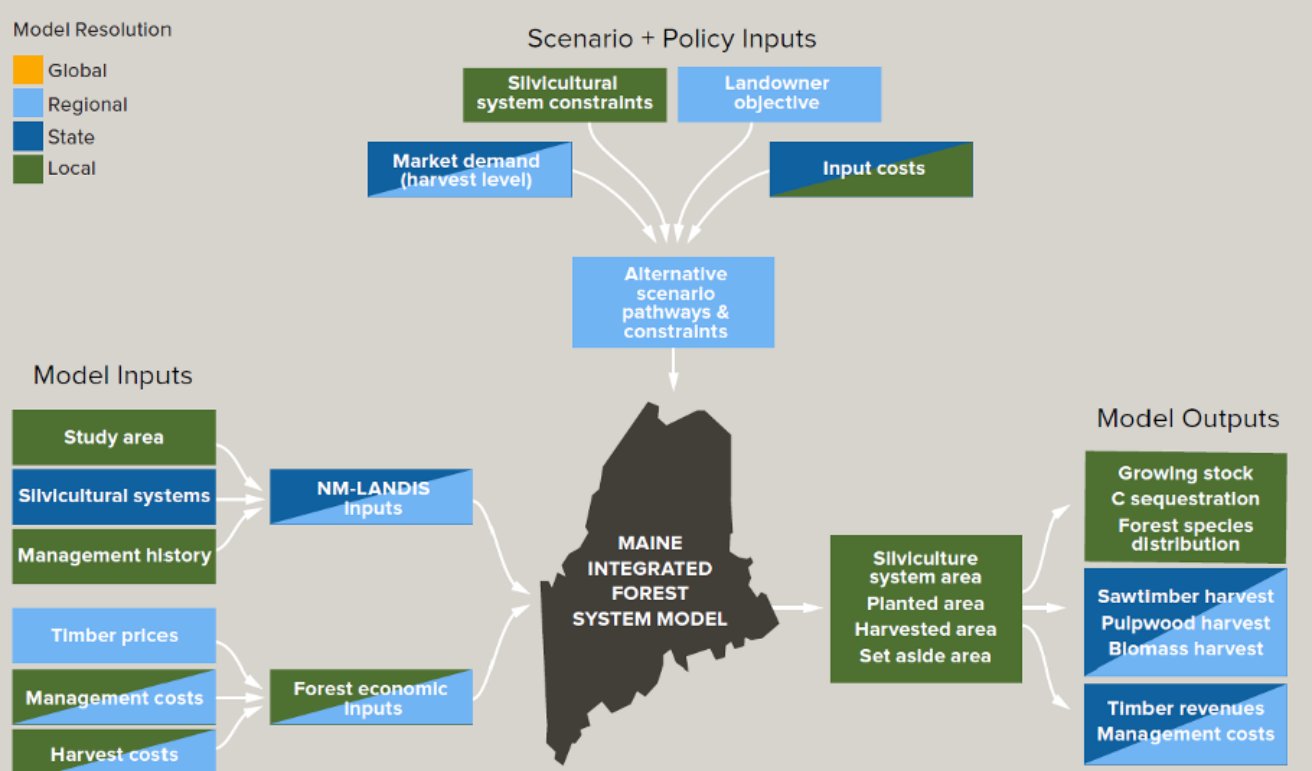

FIGURE 1. Maine Integrated Forest System Model (MIFSM) framework used in study.

KEY FINDINGS/ACCOMPLISHMENTS

- This work has created and utilized a valuable decision support tool, the Maine Integrated Forest System Model (MIFSM), for evaluating the opportunities and tradeoffs involved in deploying silviculture at a large landscape scale to achieve carbon goals (Figure 1).
- A key insight of our work has been to demonstrate that there are multiple ways of combining silvicultural systems across the landscape to increase carbon sequestration while maintaining harvest levels.
- The FCCL study considered 7.6 million acres of predominantly privately owned commercial forest lands in northern Maine. Under current management practices these lands are expected to provide net carbon sequestration estimated at 3.6 million metric tons of CO2 equivalent (MtCO2e) per year over a 60-year time horizon while providing timber harvests of approximately 7 million green tons per year that support the northern Maine forest products sector and rural communities.
- Landscape-scale adoption of certain silvicultural systems has the potential to increase carbon sequestration and storage in harvested wood products (HWPs) without reducing harvests.
- Silvicultural practices with the potential to increase carbon sequestration and storage includes a variety of systems that rely on thinning to improve quality and growth rates and approaches that use clearcutting and planting combined with leaving other areas unharvested.
- Under assumptions that current trends continue in the forest products sector, we project that transitioning a greater share of northern Maine's commercial timberlands to these carbon-enhancing silvicultural systems over the coming decades has the potential to increase carbon sequestration in the forest and in HWPs by upwards of 20% compared with current management practices. This equates to an estimated 0.74 MtCO2e or more of additional CO2e per year across the study area over the 60-year study horizon (Figure 2, pg. 28).
- At the high end, landowners on average would need to be paid approximately $16/ tCO2e to make it profitable for them to adopt alternative silvicultural systems that store more carbon. This equates to an average upfront payment of approximately $151 per acre. These costs are very competitive with other climate mitigation measures like solar and wind energy.
- The transition to alternative silvicultural approaches can provide increased carbon that passes both the "additionality" and "leakage" tests.
- Implementation of carbon-enhancing silviculture across northern Maine's landscape will require innovative policy thinking to ensure more carbon is sequestered without reducing harvests.

FUTURE PLANS

- Publish scenario dashboard via Tableau for interactive presentation of scenario results
- Develop fact sheets and other briefs highlighting study findings
- Draft manuscript that evaluates effects of alternative climate and socioeconomic futures on Maine's commercial forests

FIGURE 2. Forest Carbon for Commercial Landowners scenario estimates for northern Maine forest area, carbon sequestration & timber harvests by silvicultural treatment.

ACKNOWLEDGEMENTS

We thank members of the Forest Carbon for Commercial Landowners technical and steering committee for their input on many of the forest management options and scenarios featured in this research project.

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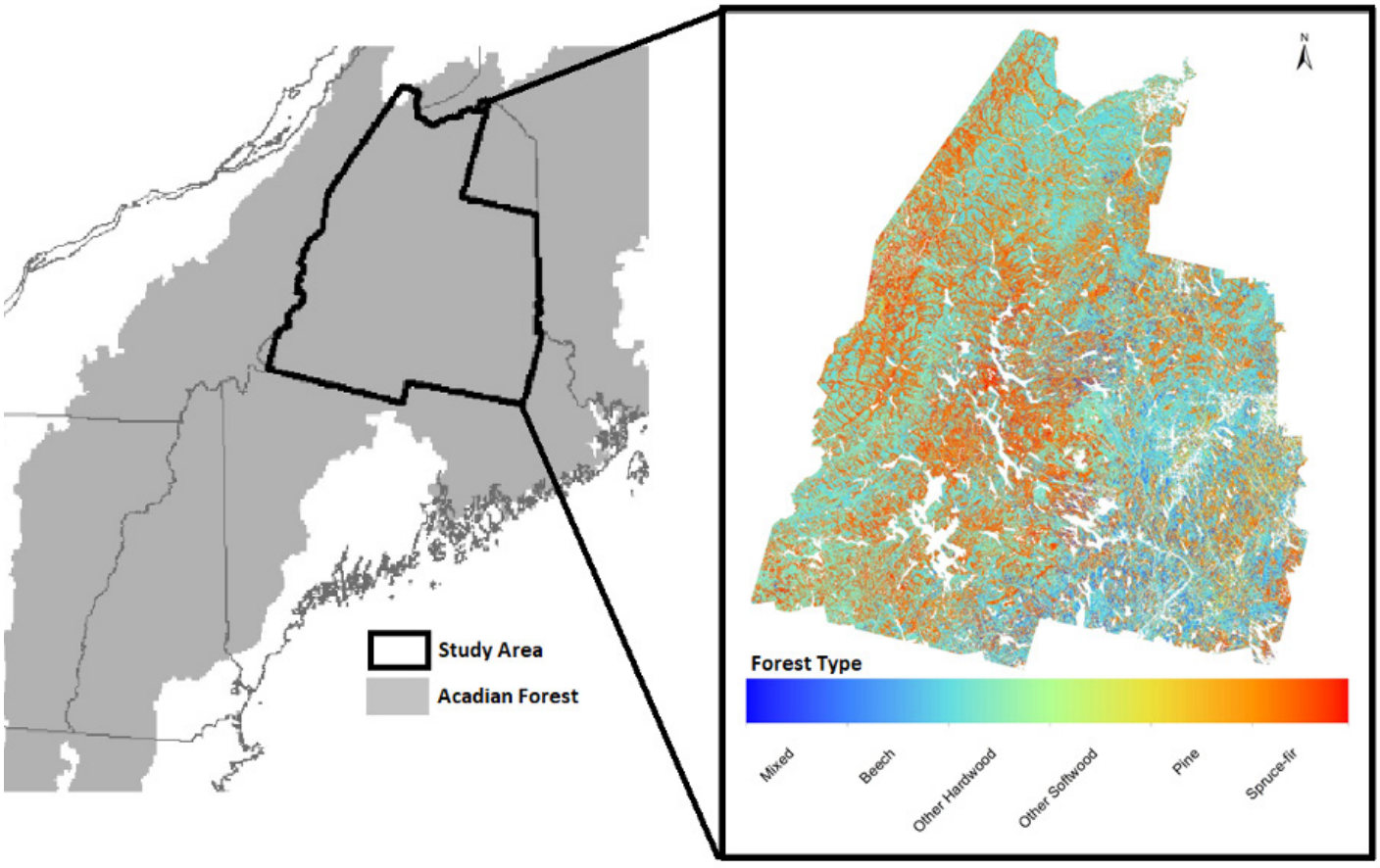
Ethel Wilkerson, Spatial Informatics Group

EXTERNAL/MATCHED FUNDING SOURCES

Source	$ Received in FY2023	Direct/Indirect
NEFF / FCCL	$91,500	Direct

GEOGRAPHIC LOCATION OF PROJECT



SOIL CARBON SEQUESTRATION DYNAMICS POST-HARVESTING: EFFECT OF STAND CHARACTERISTICS AND SITE FACTORS

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PROGRESS REPORT

ABSTRACT

Forest soils are one of the major carbon pools that stores more than half of the forest organic carbon and is considerably crucial in driving the productivity of forest site. It is essential to understand the impact of forest management, particularly timber harvesting and the characteristics of the stand and site, on the dynamics of soil carbon. The main objectives of the study are to i) Determine the relationship between various stand and site level factors that influence the dynamics and identify most crucial factors for soil carbon dynamics ii) Identify the relationship between timber harvest intensity on the long-term dynamics in forest soil carbon post-harvesting. The results from this research would have significant impacts on forest management practices in the region by providing future directions that can be used to evaluate various harvesting practices, stand characteristics, and management decisions, especially for maintaining or enhancing forest soil carbon in the region. The CFRU members can use the results of this study to explore alternative harvesting strategies for maximizing forest soil carbon in their stands. This would ultimately help landowners identify and implement silvicultural prescriptions and best management practices that have a positive effect on soil carbon.

PROJECT OBJECTIVES

- Determine the relationship between various stand and site level factors that influence the dynamics and identify the most crucial factors for soil carbon dynamics.
- Identify the relationship between timber harvest intensity on the long-term dynamics in forest soil carbon post-harvesting.

APPROACH

The proposed study will primarily be conducting meta-analysis which include three stages in data collection and analysis starting with the detailed search for published articles reporting the changes in soil carbon as well as stand conditions pre- and post-harvesting. For accomplishing Objective 1, the data collected from the selected articles will be analyzed using generalized boosted regression models with soil carbon loss as the response variable and stand and site level variables as explanatory variables. Generalized boosted models is a machine learning algorithm that used regression trees and boosting to improve the predictive accuracy through cross validations and reducing the errors on the predictions. The higher accuracy in prediction is achieved through optimizing variables and by minimizing the error at each decision-tree. The method is used because of the robustness of collinearity associated with various compounding variables, missing values, and to avoid over fitting of the data (1,2). The results from the boosted regression trees will provide the relative importance of each of the variables that allows to narrow down the further analysis. The variables with higher relative importance will be included in the mixed effects model.
Objective 2 will develop a model based on results from objectives I and evaluate the potential impact of the most important stand and site variables on soil C across Maine's diverse forest landscape. We hypothesize that the variations in the soil carbon post harvesting will be positively correlated to harvesting intensity variables because with the optimum allocation of space and resources will promote growth of the residual trees or vegetation. We also hypothesize that since the carbon sequestration peaks during the younger stands, the change in soil carbon with respect to the control will be much varying in the first 2-3 decades. The results from the recent meta-analysis also suggest that there is high variability in the weighted soil carbon in the younger stands.

The results from the previous meta-analyses showed that there is high variability in the effect sizes particularly in the earlier years after harvesting which could be a potential trade off but including multiple variables and boosted regression could result in better predictive outcomes (2,3). However, the figure is not accounting for the variability due to other factors hence, the study results

will be drawing overall inferences using the models that include major variables and explore the dynamics of forest carbon. The lack of reporting of different variables could be a potential issue in the study as it was also encountered by the previous meta-analyses however, since the studies included in the analysis will be control-treatment studies, more reporting of variables are expected.

Expected recommendations and findings include a set of variables that are from the timber stand inventory and their effect on the variations of soil carbon after harvesting. Since these variables are based on the forest stand inventory, it can be used for supporting the managerial decisions at the stand level to have better recovery of the stands after harvesting.

KEY FINDINGS/ACCOMPLISHMENTS

- A meta-analysis approach was used to acquire data from peer-reviewed journal articles.
- A total of 1389 observations were taken from 89 published articles between 1979 to 2022.
- The study locations spanned across different continents and countries (Table 1).
- There were numerous articles with the very minimum amount of data available which resulted in a high number of missing data points. This also resulted in rejecting many articles reviewed.
- About one fifth of the articles on soil carbon had usable data.
- 26 variables were selected, including site characteristics (slope, area harvested, etc.), stand conditions (basal area per hectare, average diameter at breast height, average tree heights, species composition, etc.), silvicultural treatments (prescriptions and harvest residue treatment), and operational factors (harvesting method adopted).

COUNTRY	NO. OF OBSERVATIONS
South Africa	77
Australia	48
Brazil	30
Canada	71
Chili	72
China	58
Denmark	36
Germany	64
Greece	10
Italy	16
Malaysia	24
Mexico	14
Nepal	2
New Zealand	10
Russia	1
South Korea	292
Spain	78
United Kingdom	2
United States	483
Grand Total	1388

FUTURE PLANS

- Currently the data is being organized and checked for missing values.
- Research Reports will be submitted to CFRU Winter Annual meeting
- The project will be one of the chapters in Graduate Thesis of Nasheeda Yasmin
- The abstract has been accepted as an oral presentation for the SOMEN and NEMO conference in Knoxville Tennessee from 8th to 11th of October 2023.
- Statistical analysis will be performed on these variables using boosted regression and linear mixed effect model in R.
- The results will explore alternative harvesting strategies for minimizing the loss of forest soil carbon.
- The manuscript will be sent to an appropriate peer reviewed journal by Spring 2024.

EXTERNAL/MATCHED FUNDING SOURCES

None.

CARBON FOOTPRINT OF THE PREDOMINANT MECHANIZED TIMBER HARVESTING METHODS IN THE NORTHEASTERN US

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FINAL REPORT

ABSTRACT

Even though the forests are considered carbon neutral, timber harvesting activities to attain the forest management objectives leave a carbon footprint. This study assesses 1) the carbon footprint of whole-tree (WT), cut-to-length (CTL), and hybrid cut-to-length (Hyb CTL) harvest methods and processes involved from felling to trucking in the Northeastern region of the US. The internationally accepted Life cycle assessment (LCA) was done to assess the carbon footprint using TRACI v 2.1 impact assessment method in Simapro 9.3.0.3 software and followed ISO 14040 and 14044 standards. The databases were USLCI and US-EI 2.2. The system boundary of cradle-to-gate LCA was from stump to mill gate and the functional unit was 1 tonne of green round wood (Figure 1). The results showed that the WT method (11.57 kg CO2 eq) had the highest average carbon footprint followed by Hyb CTL (11.09 kg CO2 eq) and CTL (9.91 kg CO2 eq) methods. The trucking (8.51 kg CO2 eq) to the processing facility was the major contributor among the processes. These results can be used as the upstream processes for the future LCAs for the various wood products manufactured in the region.

PROJECT OBJECTIVES

- Assess the carbon footprint of mechanized timber harvest methods in the Northeastern US
- Assess the carbon footprint of the various processes involved in timber harvesting for different harvest methods
- Evaluate the variation in the carbon footprint for the summer and winter harvest.

APPROACH

Internationally accepted Life cycle assessment (LCA) was done to assess the carbon footprint using TRACI v 2.1 impact assessment method in Simapro 9.3.0.3 software following ISO 14040 and 14044 standards. The databases were USLCI and US-EI 2.2. The system boundary of cradle-to-gate LCA was from stump to mill gate and the functional unit was 1 tonne of green round wood.

KEY FINDINGS/ACCOMPLISHMENTS

The results of LCA showed that the WT method (11.57 kg CO2 eq) had the highest average carbon footprint

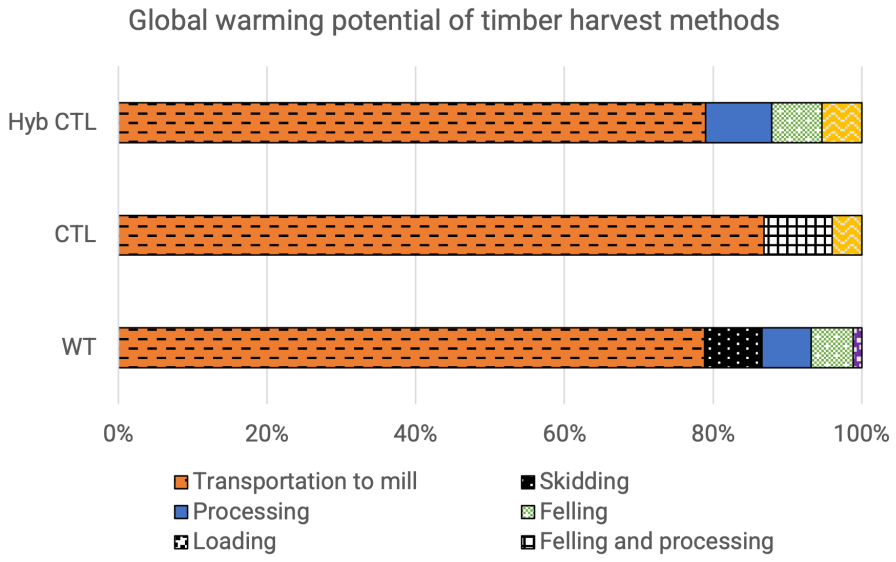

FIGURE 2. Global warming potential (kg CO2 eq) of whole-tree (WT), cut-to-length (CTL), and hybrid cut-to-length (Hyb CTL) timber harvest methods to produce 1 tonne of roundwood.

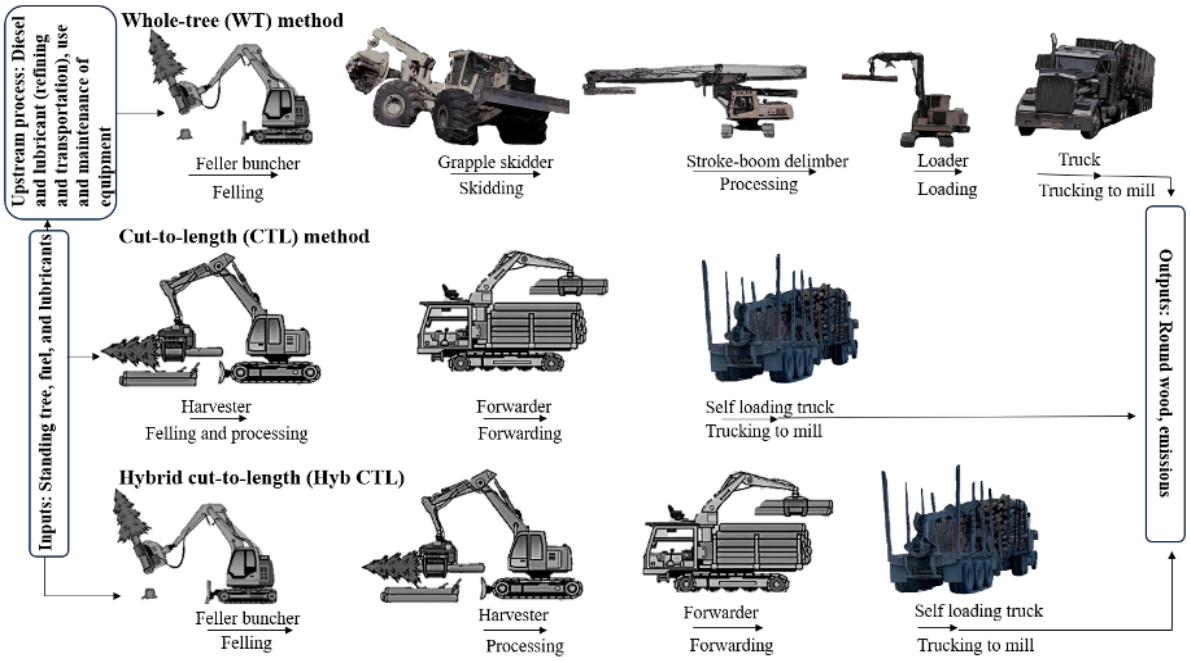

FIGURE 1. System boundary of three harvest methods common to the Northeastern US. (Source of feller buncher, harvester, and forwarder depictions: rinya.maff.go.jp)

followed by Hyb CTL (11.09 kg CO2 eq) and CTL (9.91 kg CO2 eq) methods. The trucking (8.51 kg CO2 eq) to the processing facility was the major contributor among the processes. These results can be used as the upstream processes for the future LCAs for the various wood products manufactured in the region.

HARVEST METHOD	AVERAGE	SUMMER	WINTER	RANGE
WT	11.57	11.69	11.50	2.10 to 26.19
CTL	9.91	9.88	10.10	2.39 to 20.48
Hyb CTL	11.09	10.96	11.34	3.53 to 21.70

TABLE 1. The average global warming potential (kg CO^2 eq, fuel-based system) by season of whole tree (WT), cut-to-length (CTL), and hybrid cut-to-length (Hyb CTL) to produce 1 tonne of green round wood.

ACKNOWLEDGEMENTS

The research was funded by the United States Department of Agriculture National Institute of Food and Agriculture (McIntire-Stennis project number # ME042415 through the Maine Agricultural and Forest Experiment Station (MAFES), United States Department of Agriculture, Agricultural Research Service (0204-41510-001-98S), Cooperative Forestry Research Unit (CFRU) grant (5533981-20-54958-5250280).

Our sincere thanks to the forest management companies who provided us with the field data and Poonam Khatri, USDA Forest Products Laboratory, Wisconsin for validating the results.

GEOGRAPHIC LOCATION OF PROJECT

Northeastern US

PARTNERS/STAKEHOLDERS/ COLLABORATORS

Ian Prior, Seven Islands Land Company
Irving
Kyle Burdick, Baskahegan Company
Ray C. Berthiaume, Wagner Forest Management
Maine Custom Woodland
Professional Logging Contractors (PLC) of Maine
Steven Bick, Northeast Forests, LLC

EXTERNAL/MATCHED FUNDING SOURCES

None.

AMERICAN MARTEN: REFINING THE UMBRELLA SPECIES CONCEPT IN MAINE

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PROGRESS REPORT

ABSTRACT

The umbrella species concept was proposed as a way to use single species habitat requirements, typically a larger-bodied habitat specialist species with large area requirements, as a guide for ecosystem management. Although intuitively appealing the umbrella species concept is not without criticism, particularly when the efficacy of a prospective umbrella has not been tested. The American marten has previously shown promise as an umbrella species in Maine based on potential habitat overlap with other species, but the degree to which the presence of marten is associated with, for example, increased species richness on-the-ground has not been rigorously evaluated. This project builds on a legacy of CFRU-funded projects that have resulted in the development of a long-term dataset of marten occurrence in central Maine. We will compile biodiversity information collected using remote technologies (camera traps and acoustic monitors) and compare patterns of species occurrence and richness with marten use intensity. Results from this project will provide a detailed accounting of the vertebrates covered by the "umbrella" of marten habitat conservation.

PROJECT OBJECTIVES

The goal of this project is to revisit and refine the role of American marten as an umbrella species for mature forest vertebrates in the Northern Forest Region. Supporting objectives are to:

- Use long-term live-trapping data collected in our study area (T5 R11 WELS and T4 R11 WELS) to develop a stratified grid system (high, medium, low marten use) for biodiversity sampling.
- Use camera trap data collected in 2019 to identify patterns of mammal occurrence with the stratified grid.
- Deploy acoustic monitors within grid strata to identify patterns of bird occurrence.
- Evaluate associations between marten occurrence and metrics of biodiversity (e.g., species richness).

APPROACH

- In Spring/Summer of 2022, we deployed acoustic monitors across 60 sites distributed across a regular sampling grid (cell size based on average home range size for a female marten in Maine) in T5 R11 WELS and T4 R11 WELS. This grid was previously established in 2019 for camera trapping and is aligned with the long-term network of live traps used to document marten habitat use and selection in previous CFRU-funded projects. Sampled sites were selected to represent a combination of forest type (hardwood, softwood, mixed) and recent use by marten use status (high, medium, no use).
- Monitors were set to record at dawn and dusk for 2+ hours and left in place for at least 10-days.
- We are using AI software designed for bird song identification (https://birdnet.cornell.edu/) to develop a species occurrence list for each site. Songbird data will be used to identify species with high co-occurrence with marten and to evaluate relationships between marten use intensity and species richness (total and per taxonomic group).
- Spatial patterns of species richness and relative abundance will also be compared to available maps of forest composition and structure, developed using Sentinel satellite imagery and LiDAR data from 2017 acquisition for statewide mapping.

PHOTO 1. American marten captured at a baited camera during the 2019 spring field season.

KEY FINDINGS/ACCOMPLISHMENTS

- In Year 2 we compiled bird species lists for half of the 60 selected sites and conducted a preliminary analysis comparing species lists between for high

use vs. no use sites located in softwood stands.

- Softwood stands included 111 (high use) and 106 (no use) identified bird species. Although overlap between species lists was high (approximately 85%) overall, a handful of birds only occurred at one site type. For example, the boreal chickadee was detected in softwood stands with high marten use, but was absent in softwood stands with no marten use.
- In addition to songbird identification, development of a canopy height model from 2017 Li-DAR and 2021 NAIP were both completed for our study area.

FUTURE PLANS

Over the coming months we will be compiling species lists for the remaining sites. Once complete we will evaluate patterns of species richness and relative abundance relative to forest composition, canopy height, and other metrics of forest structure derived from LiDAR or NAIP.

Species lists will also be compared amongst marten use classes to identify species with high co-occurrence with marten use, and to evaluate general relationships between marten use intensity and species richness (total and per taxonomic group).

PARTNERS/STAKEHOLDERS/ COLLABORATORS

Kevin Topolinski, Acadian Timberlands
Chris Stone, The Nature Conservancy

GEOGRAPHIC LOCATION OF PROJECT

T5 R11 WELS and T4 R11 WELS

EXTERNAL/MATCHED FUNDING SOURCES

None.

THIRTY YEARS OF CHANGE IN COMMERCIAL 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

PROGRESS REPORT

ABSTRACT

Motivated by national declines in bird populations (Rosenberg et al. 2019), in 2021 we began the complete replication of a major study of birds and commercial forestry we conducted in the early 1990s in the greater Moosehead Lake region (Hagan et al. 1997). Forestry practices (and therefore bird habitat) have changed significantly since the early 1990s. What impact, positive or negative, have these changes had on breeding bird populations? The collection of all field data was completed in 2022. In 2023 we have focused on analyzing and publishing the results and public outreach. We will complete the 3-year project by January 2024, with the exception of installing the birding trail through the commercial forest near Greenville next summer.

The results have been surprising, especially in light of national and regional declines in bird populations. About two-thirds of the 47 species we could analyze statistically increased in abundance since the early 1990s. One-third declined in abundance. Most of the abundance changes were a result of increases or decreases in density (birds per acre) and not changes in abundance of habitat (i.e., forest type). The few species that are declining continentally and within our study area merit more scrutiny to see if there is anything commercial landowners could do to help conservation of these species. Some species could be moving out of our region due to climate change range shifts, and others could be declining because of problems on their wintering grounds. At this point we are struggling to make substantive management recommendations because the situation in the commercial forests of Maine appear very good for bird conservation. The forests of Maine's unorganized territories still function like a 10-million-acre "bird sanctuary," even more so than they did 30 years ago.

American Redstart. Photo from J.Hagan, CFRU presentation October 2023.

PROJECT OBJECTIVES

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

- 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.
- Compare habitat availability (i.e., forest types) today with availability in the study area from 30 years ago.
- Compare and contrast changes in landbird abundance and diversity in Maine's commercial forest to regional and national bird population trends.

Identify silvicultural practices that could enhance national-scaled bird conservation goals going forward

- Describe changes in habitat structure as a result of changes in silvicultural practices in the one-million-acre (4-million-ha) study area.
- 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.
- 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.

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

- Create a web-based "story map" about the contributions of commercial forests to bird conservation.
- Create a self-guided, roadside birding trail to enhance eco-tourism in Maine's commercial forest.
- 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 bird species have increased and which have decreased in our 1-M-acre study area 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 public outreach mechanisms to demonstrate the conservation value of commercial forests, such as a self-guided birding trail near Greenville, and various short videos to be distributed through social media.

KEY FINDINGS/ACCOMPLISHMENTS

- All fieldwork has been completed. Analysis, writing, and publication of results are in progress and on track to be completed by January 2024.
- About two-thirds of the 47 species we could analyze statistically showed increases in abundance since the early 1990s. The increases in abundance were mostly due to increases in density (birds per acre), not dramatic changes in habitat (i.e., forest type).
- About one-third of species decreased in abundance since the early 1990s. Again, most of the declines were due to declines in density (birds per acre), not habitat loss.
- We identified a small subset of species that are declining both continentally and in our commercial forest study area. These species merit further scrutiny to determine whether there is anything commercial landowners could do differently to help conserve these species.
- Some of these species may be moving northward due to climate change and out of our study area (e.g., Canada Jay, Boreal Chickadee, Lincoln's Sparrow). Others could be declining because of habitat loss on the wintering ground in the southeast U.S. or the neotropics, not because of habitat loss in the

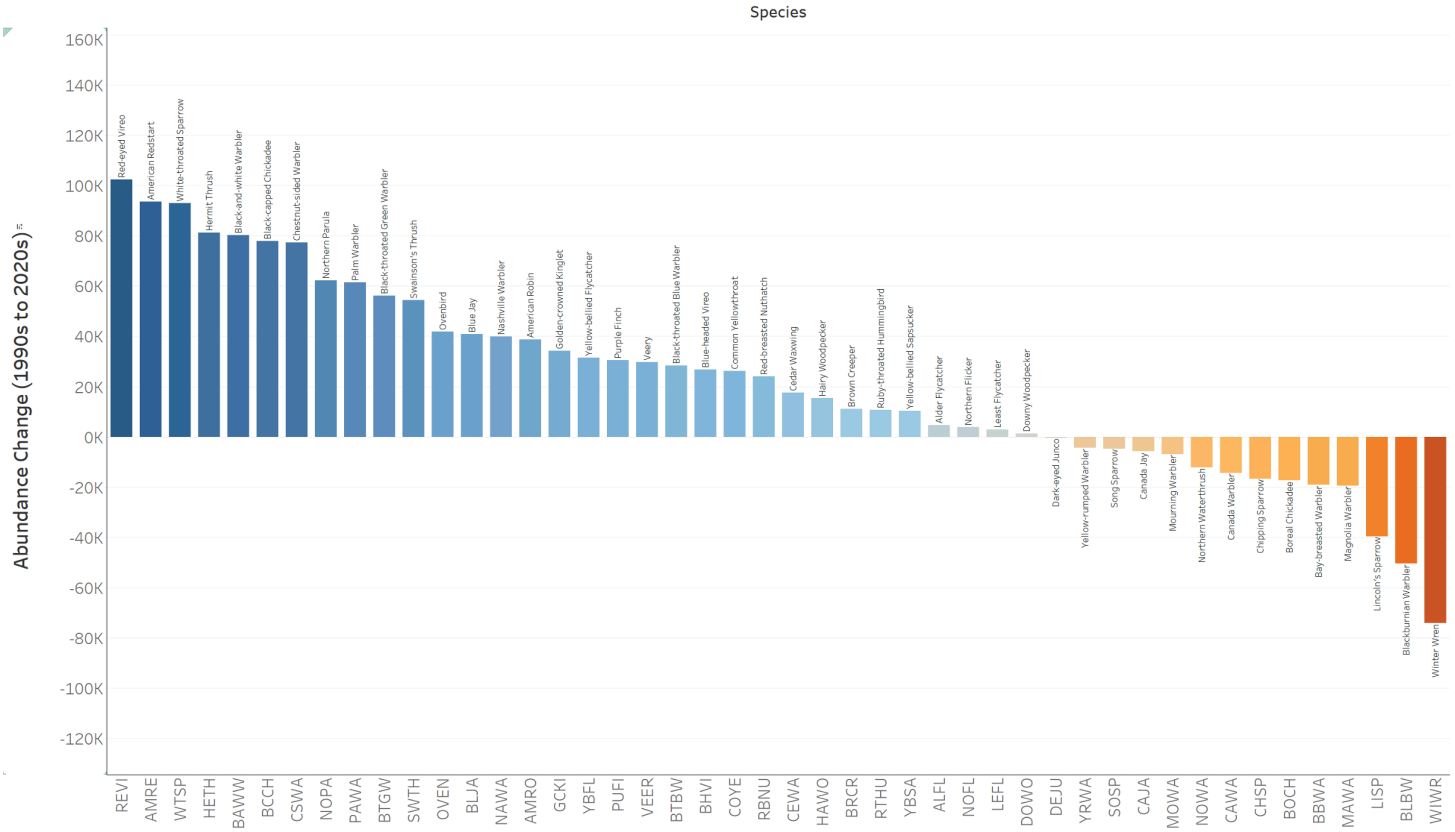
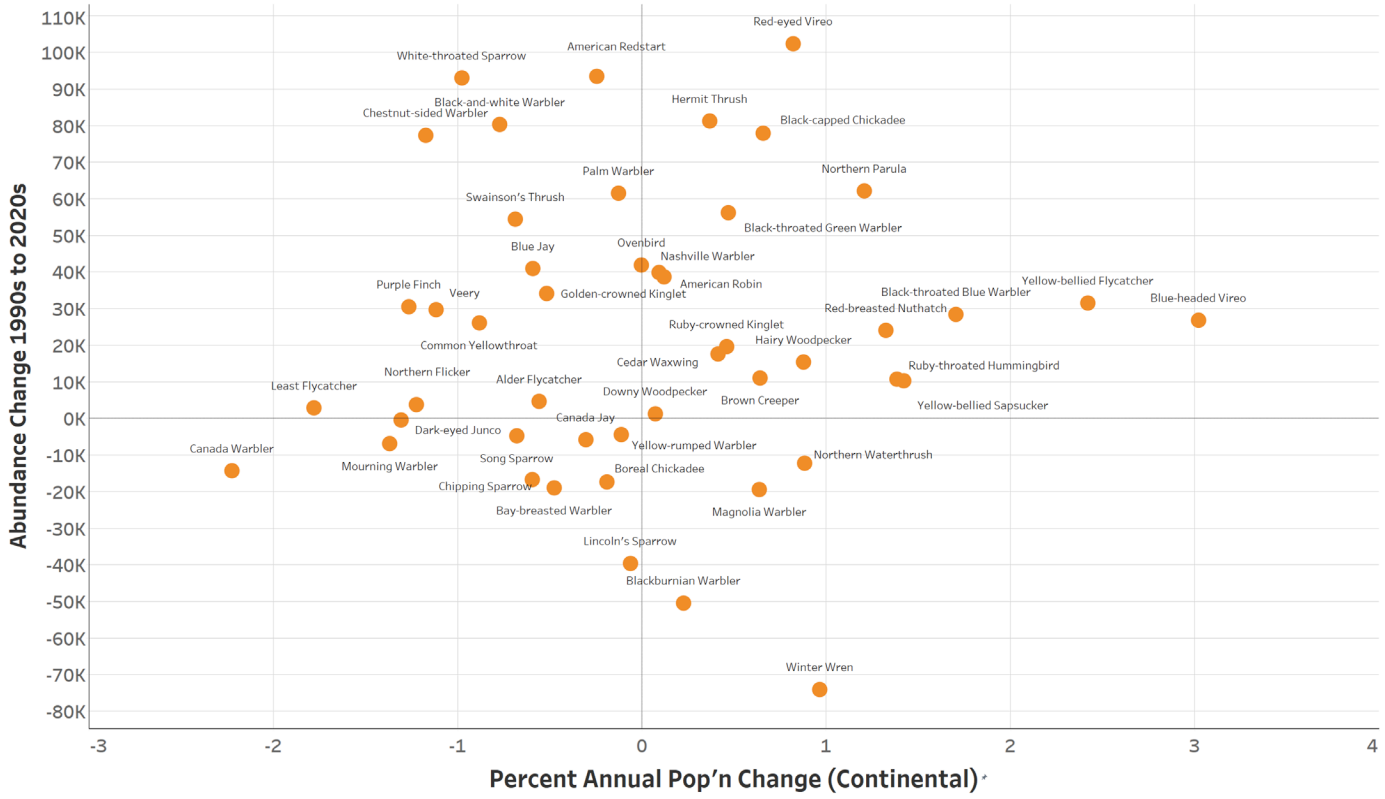


FIGURE 2. Abundance changes of 47 bird species within our 588,000-ac study area. Blue bars indicate increases in abundance and orange bars indicate decreases. As an example, there were an estimated 100,000 more Red-eyed vireos in the landscape in the 2020s relative to the early 1990s; there were about 70,000 fewer Winter Wrens in the 2020s.

FIGURE 3. The relationship between abundance change of 47 bird species over the last 30 years within our commercial forest study landscape (Y-axis) and population changes of the same species at a continental scale, as determined by the North American Breeding Bird Survey (X-axis). What is interesting is the lack of correlation between the two. This suggests population processes in our commercial forest landscape are different from forces affecting populations nationally.



commercial forests of Maine (e.g., Canada Warbler).

- Our study area lost both clearcut habitat and mature forest types (Height '4's, Canopy closure A or B). The abundance of one species, the Blackburnian Warbler, might have been impacted by the loss of these older forest age classes.
- The widespread increases in abundance in our study contrast dramatically with a recent 2022 study by our colleagues in New Brunswick (Betts et al. 2022). The differences between the studies could be due to different methods of study, different forest practices in Maine and New Brunswick, or both. Our forthcoming scientific manuscripts will explore the possibilities.

FUTURE PLANS

We plan to complete all deliverables for this project by January 31, 2024, which includes two submitted scientific manuscripts for peer-review publication and a popular, accessible report for commercial forest landowners that summarizes our findings. We will complete installation of the birding trail near Greenville in June 2024, with the help of Appalachian Mountain Club and Weyerhaeuser.

ACKNOWLEDGEMENTS

We thank all our landowner partners—Weyerhaeuser, Huber, LandVest, and Appalachian Mountain Club. We are especially grateful to LandVest for providing us with free housing at the Ragmuff logging camps in 2021 and 2022. We are also grateful to an amazing group of hardworking twenty-somethings who got up every morning at 3:30 AM in June, 2022, to get to their bird survey points by sunrise: Hannah Mirando, Ryan Andrews, Jaylan Winstanley, Jude Dickerson, Ben Shamgochian, Molly Lynch, Josh Kolasch, Kelsi Anderson, and Jonah Levy. We also thank Anna Siegel, our 17-year-old Outreach Coordinator, who

PHOTO 2. The 2022 field crew entering data. From left to right, clockwise: Ryan Andrews, Jude Dickerson, Jalen Winstanley, Hannah Mirando, Jonah Levy, Ben Shamgochian, Kelsi Anderson. Photo by J. Hagan.

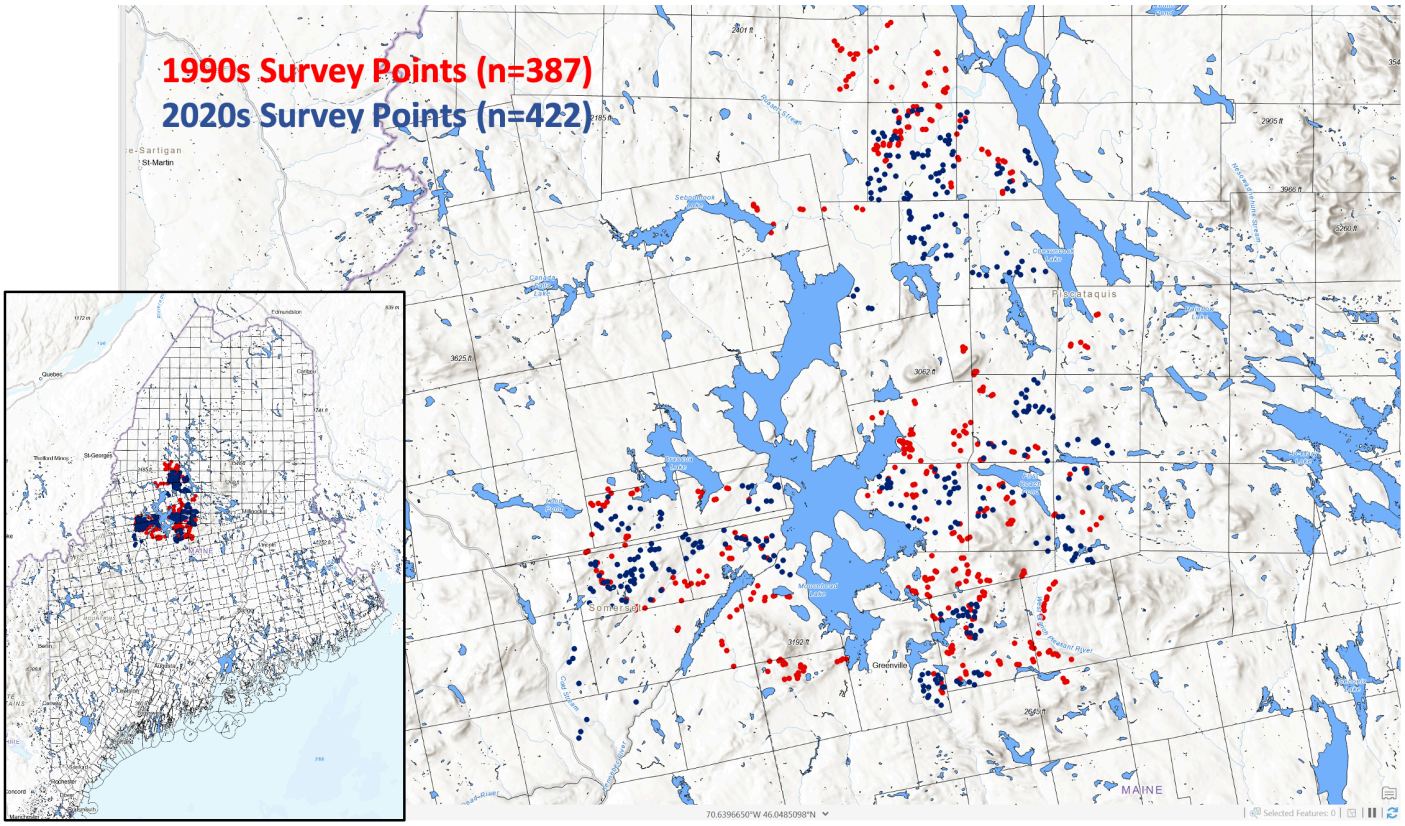


FIGURE 1. Location of 1990s and 2020s bird study survey points in the Moosehead Lake Region of Maine.

arranged most of our public outreach activities. Steve Tatko and Jenny Ward at AMC have been tremendously helpful in thinking through the planned birding trail through the commercial forest near Greenville. Of course, we thank all our funders, especially the members of the CFRU who enthusiastically supported the replication of this important and interesting study. Ph.D., graduate, and undergraduate students who worked on this project include Jonah Levy, Kelsi Anderson, Hannah Mirando, Ryan Andrews, Jaylan Winstanley, Jude Dickerson, Ben Shamgochian, Molly Lynch, and Josh Kolasch.

GEOGRAPHIC LOCATION OF PROJECT PARTNERS/STAKEHOLDERS/ COLLABORATORS

Landvest
Huber Forest Resources
Weyerhaeuser
Appalachian Mountain Club

EXTERNAL/MATCHED FUNDING SOURCES

SOURCE	$ RECEIVED IN FY2023	DIRECT/ INDIRECT
National Fish and Wildlife Foundation	$62,500	Direct
NCASI	$17,500	Direct
The Betterment Fund	$20,000	Direct
Horizon Foundation	$7,500	Direct
MTCT	$35,000	Direct

USING EDNA FOR BIODIVERSITY AND RARE SPECIES MONITORING

NOAH CHARNEY, DEPARTMENT OF WILDLIFE, FISHERIES, AND CONSERVATION BIOLOGY, UMAINE
ERIN GREY, SCHOOL OF BIOLOGY AND ECOLOGY, UMAINE
ERIK BLOMBERG, DEPARTMENT OF WILDLIFE, FISHERIES, AND CONSERVATION BIOLOGY, UMAINE
AARON WEISKITTEL, CENTER FOR RESEARCH ON SUSTAINABLE FORESTS, UMAINE

PROGRESS REPORT

ABSTRACT

In the first year of this project, we reviewed available genetics resources for species identification with eDNA, sequenced DNA from vertebrates and invertebrates to fill genetic reference library gaps, consulted with CFRU partners to identify research priorities, and performed lab and field work to better understand sampling limitations and overall performance of eDNA for monitoring forest biodiversity. We prepared and submitted 189 pilot eDNA samples from 12 wetlands for metabarcoding of eukaryotes, aquatic invertebrates, and vertebrates in forested wetlands. From April to August 2023, we paired a suite of traditional surveying methods (funnel trapping, visual encounter surveys, passive photography) with 192 eDNA samples from 30 wetlands in central Maine to validate eDNA against conventional monitoring approaches for wildlife species, focusing on amphibians, mammals, and birds. Finally, we designed and tested 16 eDNA primers for distinguishing blue-spotted salamanders from other Ambystoma. With our pilot study and ongoing research, we hope to compile a broad list of taxa that can be detected with eDNA in forested wetlands, identify important sampling requirements and environmental covariates affecting species detection rates, and expand on the ecology of Maine's rare and threatened forest-dwelling fauna.

PHOTO 1. Blue-spotted salamander, Ambystoma laterale. Photo NH Fish and Game Department.

PROJECT OBJECTIVES

- Review available genetic sequences for Maine fauna and identify missing species
- Compile genetic reference libraries for eDNA monitoring studies
- Assess spatial and temporal variability of eDNA in forested wetlands and examine environmental and sampling limitations on species detection rates
- Develop and validate eDNA assays for rare salamander monitoring in Maine
- Compare eDNA surveys with conventional wildlife monitoring techniques

APPROACH

- Issued surveys and had conversations with CFRU partners about eDNA interests, questions, and concerns.
- Compiled a complete list of terrestrial and freshwater wildlife species (as well as select aquatic breeding invertebrates of conservation concern) occurring in the northeastern United States—highlighting species in Maine. Performed a sequence gap analysis to identify current coverage of species in available online genetic reference libraries.
- Prepared and submitted tissue samples for mitogenome sequencing to fill high priority reference library gaps.
- Performed a pilot study consisting of eDNA sampling (250-ml water samples) from 12 forested northeastern wetlands in 2020 and 2021.
- Multiple water samples (at least 2, maximum of 24) taken from each wetland on each occasion to examine fine-scale patterns of biodiversity with eDNA over space, time, and among wetlands with distinct suites of species (Figure 1).
- All samples were processed in the lab to extract DNA, remove PCR inhibitors, and amplify and sequence DNA using different metabarcoding primers for all vertebrates (12s-Riaz), aquatic insects (CO1-Elbrecht), invertebrates (CO1-Leray), and eukaryotes (18s-Comeau).
- Conducted a landscape-scale validation study relating eDNA and conventional biodiversity monitoring approaches in forested wetlands in central Maine from April–August 2023 (Figure 2).

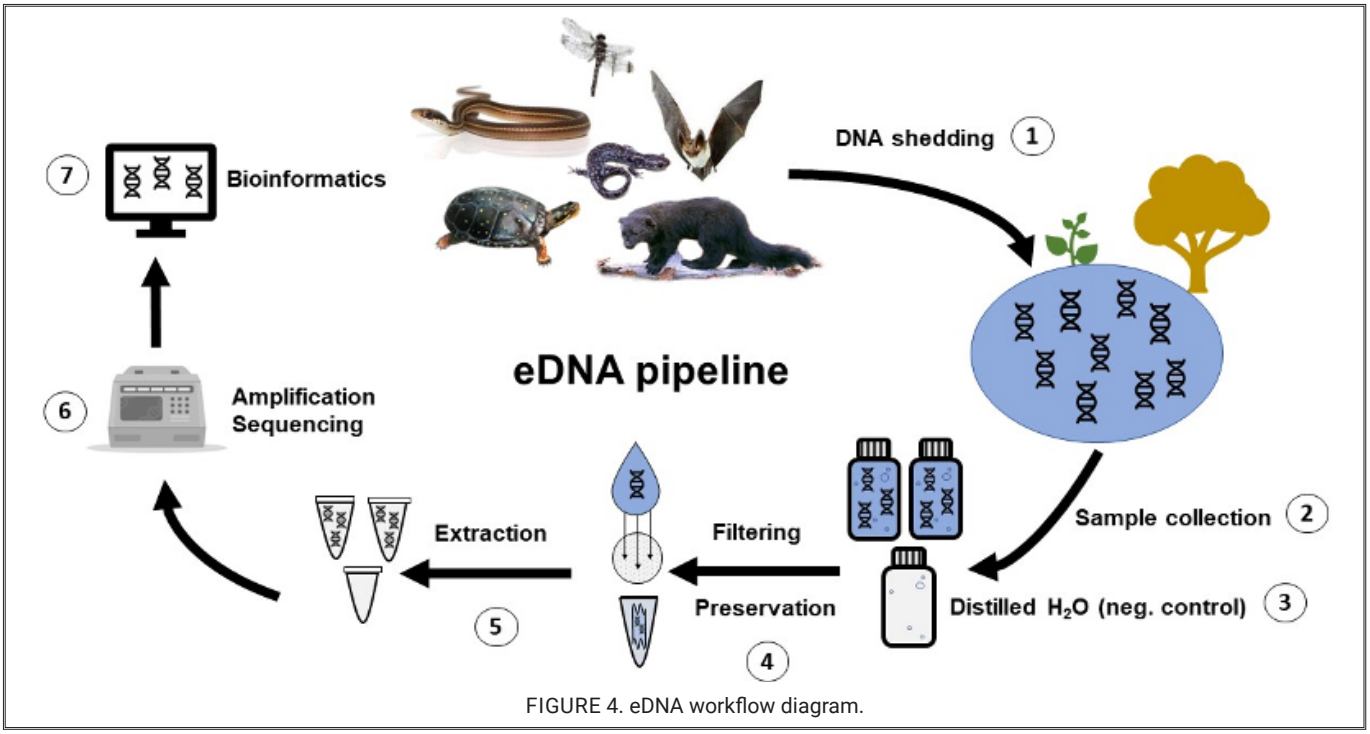


FIGURE 4. eDNA workflow diagram.

- Multiple (2–4) water samples filtered from each wetland on each occasion for future eDNA analysis.
- Collected water chemistry data (temperature, pH, conductivity, DO) concurrently with all eDNA to identify potential limiting factors for species detection.
- Performed conventional monitoring concurrently with eDNA at a subset of monitoring sites included (1) amphibian funnel trapping surveys, (2) amphibian egg mass counts, and (3) passive camera trap surveys.
- Designed and tested eDNA primers for detecting and distinguishing members of the blue-spotte
- salamander complex in New England from water samples.

KEY FINDINGS/ACCOMPLISHMENTS

- Obtained 12 survey responses from CFRU stakeholders and held follow-up discussions revealing broad interest in eDNA for monitoring different vertebrates and invertebrates, including common and rare / threatened species, as well as general concerns about accuracy and regulatory implications.
- Reviewed genetic sequences for 725 freshwater and terrestrial vertebrate (and additional invertebrate) species in Maine and adjacent regions, identifying several priority species for genomic sequencing to fill reference library gaps.
- Addressed eDNA reference library gaps by successfully sequencing mitochondrial genomes of 14 freshwater taxa, including:
- Four species of fairy shrimp (Knobbed-lipped Fairy Shrimp, Eastern Fairy Shrimp, Smooth-lipped Fairy Shrimp, Spiny-Tailed Fairy Shrimp)
- Two species of dragonfly (Ebony Boghaunter, Ringed Boghaunter [State Endangered])
- Two species of turtle (Wood Turtle [Species of Greatest Conservation Need], Spotted Turtle, [State Threatened])
- Six species of amphibian (Four-toed Salamander, Spotted Salamander, Blue-spotted Salamander [Species of Greatest Conservation Need], Jefferson Salamander, Marbled Salamander)
- 189 eDNA samples from pilot study submitted for metabarcoding.
- 192 eDNA samples collected from central Maine from 32 wetlands.
- Performed amphibian trapping surveys at 15 sites for a total of 431 trap-nights. Captured 772 frogs

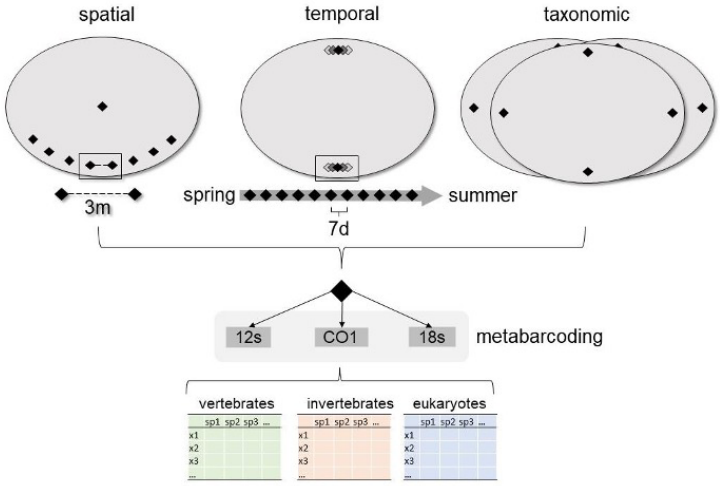


FIGURE 1. Sampling and sequencing scheme for pilot eDNA study. Spatial sites included three wetlands sampled every three meters along pool perimeters in June 2020. Temporal sites included two wetlands sampled weekly from March to August 2021. Taxonomic sites included seven wetlands varying in known salamander assemblages that were sampled at four cardinal locations along pool perimeters in July 2021. All samples were processed in the lab to extract and amplify DNA and sequenced at three mitochondrial regions (12s, CO1, and 18s) targeting different types of organisms.

and salamanders, comprising six different species, including unisexual and blue-spotted salamanders. Collected 73 salamander tissue samples to validate eDNA assays for monitoring cryptic amphibian species. Compared performance of eDNA with several alternative aquatic funnel traps for monitoring amphibians, including a novel deep-water trap that yielded greater detections of unisexual / blue-spotted salamanders.
- Captured the oldest known wild unisexual Ambystoma (10-12 years-old) in history, expanding natural history accounts for the salamander lineage.
- Performed egg mass counts of amphibians at 15 sites where eDNA was collected.
- Recorded >5,000 images of wildlife activity at eight eDNA monitoring sites from April to August 2023. Collected eDNA from all camera trapping sites on four occasions (spring, early summer, midsummer, late-summer) to examine how eDNA compares to passive game cameras for detecting wildlife over multiple seasons.

FUTURE PLANS

- Continue to acquire and submit tissues for mitogenome sequencing to address outstanding reference library gaps in Maine.
- Complete analysis of pilot study data to better understand how different sampling strategies relate to different levels of detection of species in forested wetlands. Draft and submit manuscript for peer-reviewed publication.
- Finalize assays for rare and threatened amphibians.
- Process and analyze eDNA and comparative monitoring data from 2023 to understand how eDNA detections of amphibians, birds, and mammals relate to traditional counts and observations of rare, common, and cryptic species. Draft and submit manuscript for peer-reviewed publication.
- Consult with CFRU stakeholders to identify priorities for a broader, statewide eDNA study of biodiversity in Maine's forested wetlands.

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GEOGRAPHIC LOCATION OF PROJECT

- Orono, ME — 44.8831° N, 68.6719° W
- Old Town, ME — 44.9342° N, 68.6453° W

PARTNERS/STAKEHOLDERS/ COLLABORATORS

- Jacob Kubel, Natural Heritage & Endangered Species Program, Massachusetts Division of Fisheries & Wildlife
- Alyssa Kaganer, Cornell Wildlife Health Lab, Cornell University
- Paula Blanco-Ortiz, Cornell Wildlife Health Lab, Cornell University
- Samara Davis, Ossining High School
- Mark Stoeckle, Program for the Human Environment, The Rockefeller University

EXTERNAL/MATCHED FUNDING SOURCES

SOURCE	$ RECEIVED IN FY2023	DIRECT/ INDIRECT
MA Division of Fish & Wildlife	$9,008	Direct
MAFES	$27,118	Indirect
VPR	$5,200	Indirect

Harrison Goldspeil collecting eDNA samples from a vernal pool in Old Town, Maine. Harrison is a PhD student at UMaine and is a key researcher on this project.

APPENDIX

PUBLICATIONS AND PAPERS

Ashish, Alex. Carbon footprint of the predominant mechanized timber harvesting methods in the Northeastern US (Manuscript submitted to the International Journal of Life Cycle Assessment) 2023.

Goldspiel, HB, Hoffmann, K, Charney, ND. In review. Ambystoma laterale-jeffersonianum complex (Unisexual Ambystoma). Longevity.

Daigneault, A., E. Simons-Legaard., A. Weiskittel. Can carbon, timber, and biodiversity outcomes be simultaneously optimized across extensive, complex, managed forests? A landscape-level application of Maine, USA. Under Review at Forest Policy and Economics.

Levy, J., J. Hagan, M. Reed, P. McKinley, J. Gunn, and K. Anderson. Responses of a boreal bird assemblage to thirty years of change in commercial forest management (1992-2023) and implications for regional and national bird conservation. Ecological Society of American Annual Meeting, Portland Oregon. August 6-11, 2023. (link)

Ray, D., Robert Seymour, Shawn Fraver, John-Pascal Berrill, Laura Kenefic, Nicole Rogers, Aaron Weiskittel. 2023. Relative Density as a Standardizing Metric for the Development of Size-Density Management Charts. Journal of Forestry. https://doi.org/10.1093/jofore/fvad029

Walker, T., A. Daigneault, et al. 2023. Can Northern Maine's Commercial Forests Store More Carbon Without Reducing Harvest? Report prepared for the Forest Carbon for Commercial Landowners (FCCL) Initiative. March 2023. Available here.

Wei, X. J. Zhao, D. Hayes, A. Daigneault, H. Zhu. 2023. A life cycle and product type based estimator for quantifying the carbon stored in wood products. Carbon Balance and Management 18(1). https://doi.org/10.1186/s13021-022-00220-y

THESES

Ashish, Alex. "Carbon footprint of the predominant mechanized timber harvesting methods in the Northeastern" In progress.

Willsey, Stephanie, "Developing an Enhanced Forest Inventory in Maine Using Airborne Laser Scanning: The Role of Calibration Plot Design and Data Quality" (2023). Electronic Theses and Dissertations. 3759.
https://digitalcommons.library.umaine.edu/etd/3759

Woodyard, Logan, "Quantifying the Carbon Sequestration and Economic Potential of Natural Climate Solutions from Maine's Working Forests" (2022). Electronic Theses and Dissertations. 3744.
https://digitalcommons.library.umaine.edu/etd/3744

PRESENTATIONS, WORKSHOPS, MEETINGS, & FIELD TOURS

Anderson, K. "The 30-Year Bird Study" project presentation at the Downeast Spring Birding Festival, North Trescott, Maine, May 26-29, 2023.

Fernandez, I. et al. 2022. "Carbon Inventorying and Modeling: Integration and Evaluation. Michigan State University Forest Carbon and Climate Program (FCCP) Expert Panel. September 2022. https://www.youtube.com/watch?v=IQq2F_XdR4I&t=2s

Goldspiel, HB, Hoffmann, K, Charney, ND. 2023. "Deep-water funnel traps improve capture rates of cryptic salamanders in the Ambystoma laterale complex." Poster presented at the Northeast Partners in Amphibian and Reptile Conservation meeting (NEPARC), 25 July, 2023, Middletown, CT, USA.

Goldspiel, HB, Kubel, JE, Grey, EK, Charney, ND, Blanco-Ortiz, P, Kaganer, A, Davis, S, Stoeckle, M. 2023. "Disentangling

a cryptic salamander complex with eDNA: a landscape assessment tool for the Ambystoma laterale-jeffersonianum complex." Talk given at the Joint Meeting of Ichthyologists and Herpetologists, 15 July, 2023, Norfolk, VA, USA.

Hagan, J. Changes in the Forest: A thirty-year view of the ecology of Maine's working forest. Forest Society of Maine Director's Circle Event, September 20, 2023, Freeport, Maine.

Hagan, J. Project Update: Thirty years of change in commercial forest management in Maine and implications for regional and national bird conservation. March 30, 2023, NCASI Northern Region Meeting (virtual).

Hagan, J. Project Update: Thirty years of change in commercial forest management in Maine and implications for regional and national bird conservation. September 11, 2023. NCASI Northern Region Meeting (virtual).

Hagan, J. Thirty years of change in commercial forest management in Maine and implications for regional and national bird conservation (1992-2023). September 6, 2023, SFI State Implementation Committee Meeting, Augusta, Maine.

Herold, N., Legaard, K., and Kiedrowski, C. 2022. How a land cover data partnership is working in the state of Maine. Fall 2022 Northeast Arc Users Group, November 8, 2022, Omni Mount Washington Resort, Bretton Woods, NH.

Kenefic, L. Robert Seymour, Carolyn Ziegra, Nicole Rogers, Keith Kanoti. 2023. Northern Conifer Silviculture Guide. Presentation at the New England Society of American Foresters Annual Winter Meeting. 15 March 2023.

Legaard, K., Guay, A., Kiedrowski, C., Simons-Legaard, E., and Bundy, K. 2022. State of Maine high resolution forest type and biomass mapping using multi-source remote sensing and FIA plot data. 2022 Forest Inventory and Analysis Science Stakeholder Meeting, November 17, 2022, Minneapolis/St. Paul, MN.

Levy, J. "The 30-Year Bird Study" project presentation at the Acadia Birding Festival, June 1-4, Mount Desert Island, June 1-4, 2023.

Levy, J. Thirty years of change in commercial forest management in Maine and implications for regional and national bird conservation (1992-2023). "Birds Across New England: The Audubon Regional Conservation Symposium" January 28, 2023, Bristol, RI.

Rice, BH; Weiskittel, AR and Crookston, NL. 2023. FVS Acadian Variant. Growth Model User's Group 2023.

Rice, BH. 2023. Forest Vegetation Simulator (FVS) overview and Acadian variant updates. University of Maine Cooperative Forestry Research Unit, Spring Webinar, May 18, 2023.

Walker, T., Daigneault, A. 2022. "Can Northern Maine's Commercial Forests Store More Carbon Without Reducing Harvest?" Stakeholder presentation to Maine Forest Products Council members. December 2022.

Walker, T., Daigneault, A. 2023. "Can Northern Maine's Commercial Forests Store More Carbon Without Reducing Harvest?" Stakeholder presentation to State of Maine policymakers. January 2023.

Walker, T., Daigneault, A. 2023. "Can Northern Maine's Commercial Forests Store More Carbon Without Reducing Harvest?" Stakeholder presentation to Maine Non-governmental Organizations. January 2023.

Weiskittel, AR; Kershaw, JA; Crookston, NL; Rice, BH and Prior, I. 2023. The Acadian Variant of the Forest Vegetation Simulator: Evolution, Assessment, and Future Development. The 6th Forest Vegetation Simulator Conference, Fort Collins, CO, March 7- 9, 2023.

Weiskittel, A., Simons-Legaard, E. 2022. "Assessing Landscape-Scale, Climate-Smart Forest Management Strategies: Is it Possible?" Michigan State University Forest Carbon and Climate Program (FCCP) 2022-23 Learning Exchange Series. November 2022. https://www.canr.msu.edu/news/2022-23-forests-and-climate-learning-exchange-series-assessing-landscape-scale-climate-smart-forest-management-strategies

NEWS, PERIODICALS, TELEVISION, WEB PAGES

Forest Carbon for Commercial Landowners Report Website: https://newenglandforestry.org/connect/publications/fccl/

Hagan, J. 2023. Ten Million Acres of Bird Habitat in Northern Maine. Bird Observer, Vol 51(2):97-110. (link)

Hagan, J. Interviewed for Sierra Club radio podcast on “30x30” land conservation goal, Portland Maine, September 1, 2023 (recorded but not yet aired)

Wilson, H. “Study shows growth among birds in North Maine Woods” Portland Press Herald, July 30, 2023. (link)

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