Cooperative Forestry Research Unit

Annual Report 2020

THE UNIVERSITY OF MAINE

Center for Research on Sustainable Forests

Cooperative Forestry Research Unit
2020 Annual Report

Edited by Meg Fergusson & Aaron Weiskittel

About the CFRU

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

Citation: Fergusson, M. & Weiskittel, A. (Ed). 2021. Cooperative Forestry Research Unit: 2020 Annual Report. Center for Research on Sustainable Forestry, University of Maine. Orono, ME. 72 p.

Cover illustration: Improved white spruce on the Penobscot Experimental Forest, from the Silvicultural Intensity and Species Composition Study. Photo courtesy A. Weiskittel, used by permission. Report photos provided by project scientists.

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

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

Contents

Chair's Report

This past year has been a challenging time for the CFRU as we learned to cope and work during a global pandemic. More isolation became the norm and video conferences replaced the in-person meetings we are accustomed to. Despite these challenges, the CFRU remained active thanks to the dedication of our Interim Program Leader, Aaron Weiskittel, and his support staff, Leslee Canty-Noyes and Meg Fergusson. Their efforts to adapt to changing circumstances ensured that research advanced, meetings successfully carried on, spruce budworm L2 sampling was conducted, MASN sites were established, and the daily administrative functions of the CFRU continued.

Another notable achievement of 2020 was the signing of the Cooperative Forestry Research Unit Fund description with the University of Maine. I feel this agreement re-establishes the commitment of the University of Maine to the CFRU and clearly defines the expectations of this relationship. A key part of this agreement is the joint funding of the Program Leader position by the CFRU and University. Although the pandemic and ensuing uncertainty has delayed a candidate search for a new Program Leader, I remain confident a solution will be found in the coming months.

The fiscal year 2019-2020 saw 10 ongoing research projects, many of which were multi-year studies. In spite of pandemic-related restrictions, CFRU scientists managed to conduct meaningful research with member contributions that supported and represented a diverse array of topics covering silviculture, modeling, and wildlife habitat. Significant investment into MASN site establishment is the foundation of a new network of research plots across Maine accessible to scientists for research that will directly benefit CFRU membership for many years to come. Only one project from 2020 remains funded through 2021, allowing CFRU contributions to fund new and varied research in the coming year.

I would like to thank the Executive Committee for their dedication and hard work for the CFRU this past year. Their commitment and counsel has been invaluable to me. I would also like to recognize the Advisory Committee members and thank them for their continued support and commitment to maintaining the CFRU as the vibrant research cooperative we know it to be.

Sincerely,

Ian Prior
Chair

Director's Report

FY 2019-20 was unlike any other year in the Cooperative Forestry Research Unit's long history. Covid-19 altered many of our plans and significantly affected our normal activities. Pandemic-related restrictions prevented planned summer field season activities for several ongoing CFRU projects, particularly the Maine Adaptive Silviculture Network. Regardless, I still believe FY2019-20 was a very productive year for the CFRU and the organization remains poised for a bright future in the years to come.

First, the CFRU enacted a gift fund description with the University of Maine that outlines the roles and responsibilities for all parties, which was a direct outcome of several years of discussion. Second, membership remains strong and engaged with well-attended advisory board meetings and stakeholder-scientist involvement. Finally, we have many ongoing and completed research projects, the cornerstone of the CFRU's primary function as an organization, that are outlined in this year's Annual Report.

In this year's Annual Report we include reports on thirteen CFRU projects addressing our member's needs in the areas of habitat & biodiversity, silviculture & management, and inventory & growth modeling. All of these projects have important and direct implications for the management of Maine's working forest, particularly as we transition into a new digital and technology-drive era. I feel we are ready to address and plan for the next challenges that our forests face, whether it be spruce budworm, market uncertainty, or changes in policy. I believe this past year has confirmed that the CFRU remains relevant today and is ready for tomorrow's challenges.

Many thanks go to all of our CFRU members, staff, Project Scientists, as well as the graduate and undergraduate students who made another successful year possible. Special thanks go to our CFRU Executive Committee **Ian Prior** (Chair), **Eugene Mahar** (Vice Chair), **Gordon Gamble** (Financial Officer), **Elizabeth Farrell** (Member-at-Large).

As continually demonstrated, the CFRU continues to deliver a wide array of relevant research findings that contribute to the sustainable management of Maine's working forests. I look forward to continuing to report our key outcomes and achievements in the years to come.

Aaron Weiskittel

Aaron Weiskittel
Interim CFRU Program Leader
CRSF Director

Membership

FOREST LANDOWNERS / MANAGERS

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

WOOD PROCESSORS

Sappi North America

CORPORATE / INDIVIDUAL MEMBERS

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

Executive Committee

Chair

Ian Prior *Seven Islands Land Company*

Vice Chair

Eugene Mahar *LandVest [Frontier Forest, LLC; Clayton Lake Woodlands Holding, LLC; EMC Holdings, LLC, Mosquito, LLC, The Tall Timber Trust]*

Financial Officer

Gordon Gamble, *Wagner Forest Management*

Member-at-Large

Elizabeth Farrell *American Forest Management [BBC Land, LLC]*

Advisory Committee

Kyle Burdick *Baskahegan Company*
Earnest Carle *Downeast Lakes Land Trust*
Tom Charles *Maine Bureau of Parks & Lands*
Ked Coffin *Irving Woodlands, LLC*
Frank Cuff *Weyerhaeuser Company*
David Dow *Prentiss and Carlisle Company, Inc.*
Kenny Fergusson *Huber Resources Corp. [Fallen Timber, LLC; Sylvan Timberlands, LLC; North Woods ME Timberlands, LLC; Solifor Timberland, Inc.]*
Alec Giffen *New England Forestry Foundation*
Jacob Metzler *Forest Society of Maine*
Dan Pelletier *Huber Engineered Woods, LLC*
Mike Pounch *Baxter State Park*
Jim Robbins, Jr. *Robbins Lumber Company*
Matthew Sampson *The Forestland Group, LLC*
Chris Stone *The Nature Conservancy*
Steve Tatko *Appalachian Mountain Club*
Kevin Topolniski *Katahdin Forest Management, LLC*
Nathaniel Vir *Sappi North America*

Research Team

Staff

Aaron Weiskittel (PhD), Director, Center for Research on Sustainable Forests, Interim CFRU Program Leader
Leslee Canty-Noyes (MIS), CFRU/CRSF Administrative Specialist
Meg Fergusson (BA), CRSF Outreach and Communications Specialist

Project Scientists

Aaron Bergdahl (MS), Maine Forest Service
Nicholas Butler USDA-NRCS
Colby Brungard Environmental Soil Consulting
Mindy Crandall (PhD), Oregon State University
Adam Daigneault (PhD), School of Forest Resources, University of Maine
Bethany Muñoz-Delgado (PhD), US Forest Service
Ivan Fernandez (PhD), School of Forest Resources, University of Maine
Carol Foss (PhD), New Hampshire Audubon
Shawn Fraver (PhD), School of Forest Resources, University of Maine
Shane Furze Forest Watershed Research Center, University of New Brunswick
Hamish Greig (PhD), School of Biology and Ecology, University of Maine
Marie-Cécile Gruselle (PhD), Friedrich-Schiller University, Germany
Anthony Guay (MS), The Wheatland Lab, University of Maine
Amanda Klemmer (PhD), School of Biology and Ecology, University of Maine
Daniel Harrison (PhD), Department of Wildlife, Fisheries, and Conservation Biology, University of Maine
Daniel Hayes (PhD), School of Forest Resources, University of Maine
Chris Hennigar (PhD), FORUS Research
David Holmberg (MS), University of Maine
Dave Houston (PhD), SUNY-ESF
Allison Kanoti (PhD), Maine Forest Service
Keith Kanoti (MS), University Forests Office, University of Maine
Laura Kenefic (PhD), Northern Research Station, U.S. Forest Service
Anil Raj Kizha. (PhD), School of Forest Resources, University of Maine
William Livingston (PhD), School of Forest Resources, University of Maine
Maggie Mansfield (MS), University of Maine
Stacy McNulty (PhD), SUNY-ESF
Alessio Mortelliti (PhD), Department of Wildlife, Fisheries, and Conservation Biology, University of Maine
Robert Northington (PhD), Husson University
Shane O'Neill (MS), School of Forest Resources, University of Maine
Joshua Puhlick (PhD), School of Forest Resources, University of Maine
Andrew Richley (MF), School of Forest Resources, University of Maine
Amber Roth (PhD), School of Forest Resources and Department of Wildlife, Fisheries, and Conservation Biology, University of Maine
Brian Roth (PhD), SeedTree
David Sandilands (MS), The Wheatland Lab, University of Maine
Erin Simons-Legaard (PhD), School of Forest Resources, University of Maine
Ethel Wilkerson (MS), Manomet
Patricia Wohner (PhD), Cuckoo Conservation

Graduate Students

Kirsten Fagan PhD (WLE)
Tyler Woollard MS (WLE)
Amay Bolinkar MWC
Luke Douglas MS (SFR)
Bryn Evans PhD (WLE)
Alex Kunnathu George PhD (SFR)
Jamin Johanson PhD (EES)
Zoë Lidstrom MS
Libin Thiakkatil Louis PhD (SFR)
Shane Miller MF

Undergraduate (BS) Students

Noah Coogen
Liam Daniels
Jack Ferrara
Luke Goldman
Joshua Goldsmith
Lauren Keefe
Noel Lienert
Mac MacKenzie
Emily Roth
Emily Tomak
Bennett Wilson
Carolyn Ziegra

Many Thanks to our Partners and Stakeholders:

American Forest Management
Baxter State Park
Clayton Lake Woodlands Holdings
Downeast Lakes Land Trust
J. D. Irving Ltd.
Katahdin Forest Management, LLC
King and Bartlett
LandVest
Maine Agricultural and Forest Experiment Station
Maine Dept of Inland Fisheries and Wildlife
Maine Forest Service
Maine Outdoor Heritage Fund
Maine Research Reinvestment Fund
McIntire-Stennis
National Council for Air and Stream Improvement
North Maine Woods, Inc.
Passamaquoddy Tribe of Indian Township
Pelletier Brothers Inc
Penobscot Valley Chapter of Maine Audubon
Seven Islands Land Co.
The Nature Conservancy
University of Maine:
Center for Research on Sustainable Forests; Dept. of Wildlife, Fisheries, & Conservation Biology; Ecology and Environmental Sciences; School of Forest Resources; Wheatland Geospatial Lab
University of New Brunswick, Forest Watershed Research Center
USDA National Institute of Food and Agriculture
USDA-NRCS
Wagner Forest Management
Weyerhaeuser
William P. Wharton Trust

Financial Report

The CFRU engaged thirty-two members representing almost 8.2 million acres of Maine's forestland this year. CFRU members contributed $427,952 in 2020 to support research activities during Fiscal Year 2020-21. CFRU scientists were able to leverage member contributions for an additional $261,813 to support their research, as well as indirect contributions of $247,541. We thank all of our members for their financial and in-kind contributions, as well as the trust in the CFRU and UMaine that these contributions represent.

Table 1. CFRU Expenses Incurred During FY2019-20

	Principal Investigator	Approved Amount	Amount Spent Sept. 30, 2020
Total Administration		**$205,287.00**	
Administration	Weiskittel	$205,287.00	$16,568.13
Research Projects			
Silviculture & Management		$146,558.33	$0.00
Maine's Adaptive Silviculture Network (MASN)	Weiskittel	$103,976.50	$1,500.00
Quantifying the ecological and economic outcomes of alternative riparian management strategies	Greig	$18,363.24	$0.00
Beech bark disease: 40-year results	Kenefic/Livingston	$1,650.00	$0.00
Small diameter tree harvest	Kizha	$22,568.59	$0.00
Inventory & Growth Modeling		$170,725.38	$0.00
Cartographic depth-to-water mapping	Arp/Weiskittel	$16,000.00	$0.00
Assessing and monitoring soil productivity, carbon storage and conservations on MASN	Puhlick	$31,166.71	$14,541.78
Interdisciplinary spatial modeling: New tools for forest management	Johanson	$50,000.00	$0.00
Mapping forest products	Hayes	$73,558.67	$0.00
Habitat & Biodiversity		$7,159.46	$0.00
Rusty Blackbird use of commercially-managed Spruce-fir forests	A. Roth	$494.89	$0.00
Watershed-scale drivers of temperature and flow of headwater streams in Northern Maine	N. Thompson	$6,664.57	$0.00
Total		$529,730.17	$0.00
Fleet Account	Weiskittel	$51,792.11	$308.24
CAFS 3	Weiskittel	$100,000.00	$73,700.00

Table 2. CFRU Member Contributions Received FY 2019-2020 (for allocation in 2020-21)

CFRU Member	Contributions for Received FY20-21*
FOREST LANDOWNERS / MANAGERS:	
Irving Woodlands, LLC	pending
BBC Land, LLC	$54,259
Wagner Forest Management	$50,295
Weyerhaeuser	$47,059
Clayton Lake Woodlands Holding, LLC	$44,363
Prentiss and Carlisle Company, Inc.	$42,990
Seven Islands Land Company	$42,354
Maine Bureau of Parks & Public Lands	$25,229
Katahdin Forest Management, LLC	$17,517
The Nature Conservancy	$9,681
Fallen Timber, LLC	$13,028
Solifor Timberland Inc.	$9,287
Baskahegan Company	$8,323
Sandy Gray Forest, LLC	$5,840
Sylvan Timberlands, LLC	$5,524
Appalachian Mountain Club	$4,315
Frontier Forest, LLC	$3,115
Downeast Lakes Land Trust	$3,266
EMC Holdings, LLC	$2,363
Baxter State Park, SFMA	$1,725
Robbins Lumber Company	$1,564
Presley Woods, LLC	$1,379
Mosquito, LLC	$1,000
Blue Hill Heritage Trust	
Rangeley Lakes Heritage Trust	
New England Forestry Foundation	$259
TOTAL	$394,735
WOOD PROCESSORS:	
SAPPI Fine Paper	$28,317
TOTAL	$28,317
CORPORATE and INDIVIDUAL MEMBERS:	
Huber Engineered Woods, LLC	
The Forestland Group	$3,000
Forest Society of Maine	$1,000
Si Balch	$500
LandVest	$200
David B. Field	$100
Acadia Forestry, LLC	$100
TOTAL	$4,900
GRAND TOTAL (members):	$427,952
*** Contributions received as of September 30, 2020.**	
(light green)	**Contribution Received**
(blue)	**Contribution Pending**
(yellow)	**New Member**
(red)	**Member Withdrew**

Center for Advanced Forestry Systems

The **Center for Advanced Forestry Systems** (**CAFS**) was established in 2007 to address challenges facing the wood products industry, landowners, and managers of the nation's forestland. CAFS is funded by the National Science Foundation (NSF) Industry/University Cooperative Research Centers Program (I/UCRC) in partnership with CFRU members. The University of Maine has been a CAFS site since 2009 and has served as the lead site since January 2018. UM researchers contribute distinctive expertise related to improving current growth and yield models and broadening understanding about forest management in naturally-regenerated forests of the northeastern US.

In late 2019, UMaine's CRSF successfully led six other universities in gaining funding from NSF for Phase III of CAFS. UMaine was awarded $100,000 per year for 5 years (each site must also have a minimum of $250,000 per year from industry members to support the work of each site). These funds allow UM and other CAFS sites to pursue research projects of national scope, advance research projects that leverage valuable new technologies, and secure the long-term sustainability of the Center's relationships and activities. Phase III plans include greater integration of research efforts and a more nationally relevant focus within four primary research areas: forest management, forest genetics, decision-support tools, and remote sensing.

Over the past year, in the face of the global Covid-19 pandemic, CAFS researchers had to pivot and adapt to move their projects forward. The annual in-person Internal Advisory Board meeting scheduled to occur in Washington State was re-formatted and held virtually in June 2020. Research leaders presented updates on 2 completed and 9 ongoing projects, and 3 new projects were proposed and accepted. CAFS funding supported the research by two UMaine graduate students: Ryan Smith, who is working with SILC on tree form and risk, and Bishnu Waigle, who is working on CTRN with Kasey Legaard. Topics of current research include: improving white pine seedling survival, stand and tree responses to late rotation fertilization, assessing and mapping regional variation in potential site productivity and site carrying capacity, evaluation of machine learning algorithms for mapping tree species distribution, environmental predictors of form and quality in loblolly pine, using hyperspectral imaging to evaluate forest health risk, and a global study of long-term soil productivity experiments. New projects will focus on stand response to thinning, using predictive analytics to decompose site index, and physiological response to commercial fertilization programs in Pacific Northwest forest plantations.

To learn more about CAFS, and to access a pdf of the CAFS Phase 2 Final Report, visit https://crsf.umaine.edu/forest-research/cafs/

Final & Progress Reports

Habitat & Biodiversity

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

Daniel Harrison. Department of Wildlife, Fisheries, & Conservation Biology, University of Maine
Erin Simons-Legaard, School of Forest Resources, University of Maine
Kirstin Fagan (PhD candidate, WLE)
Tyler Woollard (MS program, WLE)

FINAL REPORT

Abstract

We investigated marten responses to three decades of habitat change in commercially managed timberlands in north-central Maine using live-trapping and radio-tracking data on resident martens and a time series of habitat data developed from satellite and aerial imagery. Marten displayed a functional response of increased selection for tall well-stocked forest (>12m mean tree height) as availability decreased within home ranges over three decades, which emphasizes the ecological importance of tall well-stocked forest relative to other habitat types. From the 1994-1997 to the 2018-2019 study periods, the regeneration of large clearcuts conducted during the late 1970-1980s mitigated the ongoing loss of tall uncut forest resulting from timber harvesting. The declining availability of younger regenerating clearcuts suggests such mitigation is unlikely to occur in the future. Future work will evaluate the effect of within-home range patch configuration on marten habitat selection, which will be used to develop predictive, landscape-scale models of marten occurrence and to make recommendations to promote landscape conservation of forest biodiversity.

Project Objectives

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

- Resurvey commercially managed timberlands bordering the western boundary of Baxter State Park for marten by replicating leaf-on season trapping protocols established from 1989–1997 (Katnik 1992, Payer 1999). This objective was completed in 2019.
- Radio-collar and -track marten captured during May–July of 2018 and 2019 to estimate home range boundaries and determine habitat use and selection within resident territories. This objective was completed in 2020.
- Develop a time series of forest characteristics derived from aerial photography and satellite imagery to document patch composition, harvest histories, and harvest intensities across the

landscape. This objective was completed in 2020.

- Evaluate the effects of changes in forest patch structure and spatial configuration on the habitat selection patterns of resident marten within their home ranges from 1989–2019. This is a primary objective in 2021.
- Investigate the effects of cumulative landscape change on patterns of spatial occurrence, home range characteristics, survival, and population density for resident marten monitored in our study area from 1989–2019. This is a primary objective in 2021.

Collared marten entering a trap in T5 R11 WELS, summer 2019.

Approach

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

2. Captured martens were sexed, weighed, evaluated for evidence of lactation; we also extracted a first premolar for age estimation. Marten equipped with VHF transmitters were relocated via ground telemetry (i.e., triangulation) from 2018-2020.

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

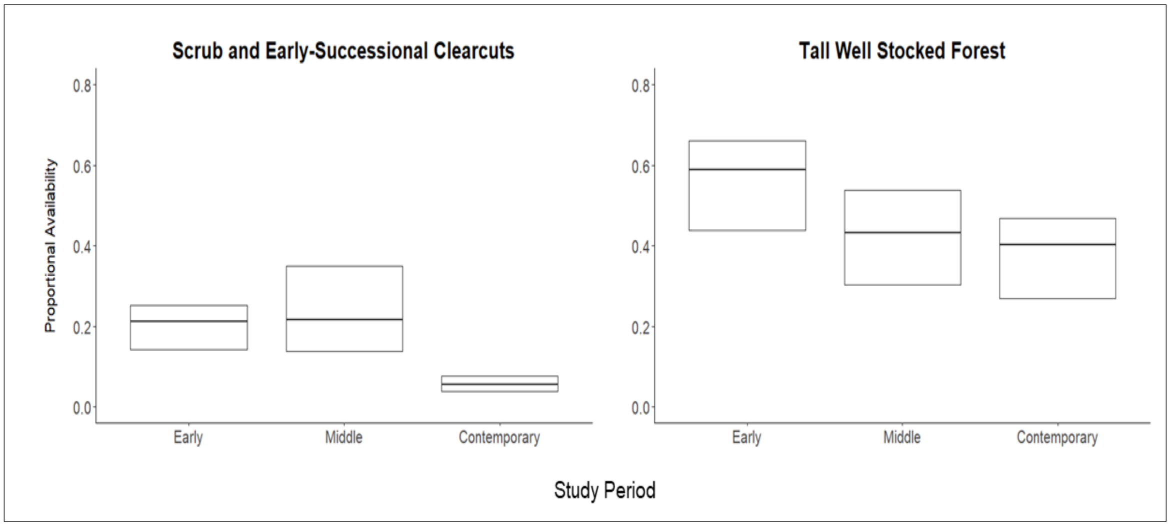


Figure 1. Within home range availability of two habitat types for which functional responses in selection were detected across early (1989-1990), middle (1994-1997), and contemporary (2018-2019) study periods in T4/T5 R11 WELS townships in north-central Maine. Upper and lower boxplot boundaries represent the 75th and 25th percentiles, respectively, while the line marks median availability.

4. Tyler Woollard's MS thesis focuses on the patch-scale objectives of the study. Patch-scale analyses are using location data for martens collected on our study area during three time periods: 1989–1990, 1994–1997, and 2018–2020. Those analyses have used generalized linear mixed models to estimate the effects of patch structure, habitat availability, and the spatial configuration of patches on patch-scale habitat selection by martens through time.
5. Kirstin Fagan's PhD dissertation focuses on the landscape-scale objectives of the study. Landscape-scale analyses are utilizing data collected across the 3 study periods for martens in T4 R11 and T5 R11 WELS (1989–2020) and for field studies of martens in a neighboring forest reserve (Baxter State Park) conducted during 1994-1997. Those analyses will use a variety of statistical models to evaluate potential changes in marten spatial occurrence, population density, home range area and spatial overlap, survival and cause-specific mortality, and landscape resistance associated with landscape change.

Key Findings / Accomplishments

- The majority (79.2% by area) of regenerating forest in our study that originated from clearcuts conducted during the late 1970-1980s regenerated to mean tree heights comparable to tall uncut forest (>12m) between 40 and 50 years post-harvest. Marten selection for the two forest types (40-50 year old regenerating clearcuts and tall uncut forest) was similar. The combined availability of these two forest types (collectively referred to here as "tall well-stocked forest") decreased significantly within resident marten home ranges between the early (1989-1990) and middle (1994-1997) study periods. In contrast, between the middle and contemporary (2018-2019) study periods the ongoing loss of tall uncut forest (from timber harvesting) was mitigated as the regrowth of the 70-80s clearcuts exceeded 12m. The low availability of younger regenerating forest from more recent clearcuts suggests such mitigation is unlikely to occur in the future (Figure 1).

- Marten displayed a functional response to the availability of tall well-stocked forest (>12 m mean tree height) within home ranges (Figure 2). Selection increased with decreasing availability, which emphasizes the increasing importance of tall well-stocked forest to marten as availability of this habitat has declined through time.
- Selection against recent (<6 m height) and short regenerating (6 m - 9 m height) clearcuts was similar, indicating that marten selection of forest regenerating from clearcuts did not increase until stands exceeded 9 m in height. The combined availability of these two forest types (collectively referred to here as “scrub and early-successional clearcuts”) within resident marten home ranges was similar during the early and middle study periods and was significantly lower during the contemporary period (Figure 1). This likely represents a legacy effect of the transition away from clearcuts after implementation of the Forest Practices Act in 1991.
- Marten displayed a functional response of declining selection (or increased avoidance) of scrub and early-successional clearcuts with greater availability of this habitat type (Figure 2). Declining selection for a habitat that is consistently selected against as it becomes more available suggests increased risk or cost associated with individuals increasing use in proportion to increasing availability.
- Multi-method occupancy models developed with live-capture and camera-trapping data collected in 2019 supported the efficacy of the established capture-based methods used in our study area to assess marten occurrence.

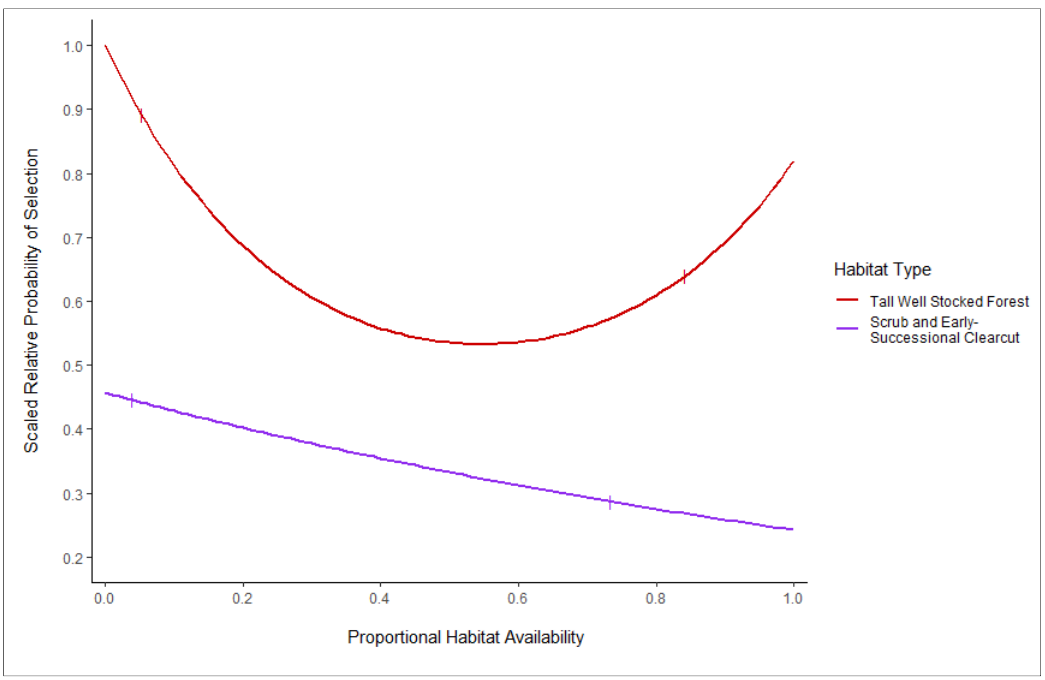


Figure 2. Scaled relative probabilities of selection for two habitat types calculated using the resource selection function predicting the relative probability of patch-scale selection by marten as a function of the proportional availability of habitat types within marten home ranges. Observed ranges of proportional availability of habitat types correspond to the colored vertical lines. Portions of selection curves outside the range of observed proportional availability (depicted as hash marks on the curves) should be interpreted cautiously.

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

- Both cameras and live-traps yielded similarly high cumulative probabilities of marten detection. However, the traditional combination of live-trapping and telemetry (due to the availability of spatial use and demographic information) had a lower false absence rate (2%) than cameras or live-traps alone (32% and 39%, respectively). The live-trapping and telemetry procedures used by this project since 1989 were also effective in reducing the incidence of false positives in estimates of resident marten occupancy, especially for reproductively-valuable, lactating female martens.

Future Plans

- During winter of 2020–2021, efforts will focus on modeling the relationship between marten selection and within-home range patch configuration, as quantified by metrics of patch isolation, area, and edge density.
- We will also develop occupancy models comparing occupancy and residency statistics during the spring residency period and the fall natal dispersal period. This analysis will focus on detections of collared, confirmed resident marten versus uncollared marten, which will allow further inferences about the efficacy of live-trapping as a survey method for resident marten.
- During spring of 2021, we will conduct analyses of cause-specific mortality for resident martens in our study area as a function of habitat variables identified as important by our third-order analyses of habitat selection. These results will be compared with those of similar analyses of Newfoundland marten data to make broader inferences on the effect of home range composition and configuration on marten survival probabilities.

- During summer of 2021, we will develop predictive models of marten occurrence based on field data collected from 2018 and 2019 and compare performance (e.g., survival, density of lactating females) and reliability of our models with previous data collected from 1989–1997.

Partners / Stakeholders / Collaborators

University of Maine: Department of Wildlife, Fisheries and Conservation Biology; Cooperative Forestry Research Unit; USDA National Institute of Food and Agriculture, McIntire-Stennis Project Number MEO-41608; Maine Agricultural and Forest Experiment Station; Katahdin Forest Management, LLC; Pelletier Brothers Inc.

Acknowledgements

We thank the Cooperative Forestry Research Unit for providing funding support. This project is also supported with significant contributions from The University of Maine (Tyler Woollard's stipend and tuition support from September 2018 to May 2020) and from USDA National Institute of Food and Agriculture, McIntire-Stennis Project Number MEO-41608 through the Maine Agricultural and Forest Experiment Station (Kirstin Fagan's stipend and tuition from January 2018 through present, as well as significant funding for equipment, supplies, and field work). We would also like to acknowledge Aaron Pelletier (Pelletier Brothers, Inc.), Scott Joachim (Katahdin Forest Management, LLC), Scott McLellan (Maine Department of Inland Fisheries and Wildlife), and all the folks at the Telos Checkpoint (North Maine Woods, Inc.). Thank you to Crown Prince, Inc. and King Oscar, Inc., and Anne Beerits (Nervous Nellie's Jams and Jellies) for their generous donations of sardines and raspberry jam, respectively, which were essential for baiting trap sites and capturing marten. We thank Angela Fuller (Cornell University) and Mark McCullough (Maine USFWS) for loaning cameras for our live- and camera-trapping comparison study.

Geographic Location of Project

T4R11/T5R11 WELS, northcentral Maine (Telos region) located west of Baxter State Park.

References

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

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

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

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

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

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

Dr. Alessio Mortelliti, Dept. of Wildlife, Fisheries & Conservation Biology, UMaine
Bryn Evans, Dept. of Wildlife, Fisheries & Conservation Biology, UMaine

FINAL REPORT

Abstract

Maine is a working landscape, with extensive forest cover that provides habitat for diverse wildlife species coincident as well as timber harvest industries. The intensity, timing, and configuration of harvest activities have all interacted to modify the landscape and continue to shape the habitat which wildlife use. However, the extent to which carnivore species adapt to land use change is a key knowledge gap that needs to be addressed to ensure proper management and conservation going forward. We are using motion-triggered camera traps, deployed as a natural experiment across the forested landscape of Maine, to help understand the interaction of species among each other and with their habitat. During this third and final year of CFRU funding (October 2019 to September 2020) we a) completed our third year of full scale surveys, b) conducted our third or fourth summer of surveys at permanent sites, and c) published a second peer-reviewed journal article associated with this project (lead by a WFCB undergraduate honors student).

Project Objectives

Our project is a collaborative effort between the University of Maine and the Maine Department of Inland Fisheries and Wildlife, aimed at:

1. understanding the current occupancy patterns many of the carnivore species native to Maine,
2. the efficacy of trail cameras to monitor these species long-term, and
3. the relationships between forest characteristics across the different timber harvest regimes and carnivore population trends.

Photos of marten and fisher co-occurring at a single camera survey site. The interaction between these species varies across their sympatric range, with potential consequences for population viability of the smaller-bodied marten, which we will further study in Maine. These images were recorded over winter 2020 in Baxter State Park

Approach

We are deploying motion-triggered camera traps, an increasingly popular tool for wildlife research (Rovero et al. 2013, Burton et al 2015), across multiple study areas in Maine (Figure 3). Each survey station is comprised of three Bushnell HD trail cameras, spaced 100 m apart, baited with skunk lure and beaver meat (Evans et al 2019, Buyaskas et al 2020). Data collected by camera trapping is then analyzed in an occupancy modeling framework (MacKenzie et al. 2017), where consecutive days of data collection create a detection history of animal visits for all terrestrial species of interest. Occupancy modeling is a flexible, statistically robust approach which accounts for biases in parameter estimates caused by false-absences or temporary unavailability (MacKenzie et al. 2002). The approach offers further biological insights by modeling covariates and provides ecologically relevant information to researchers and managers (Royle et al. 2008).

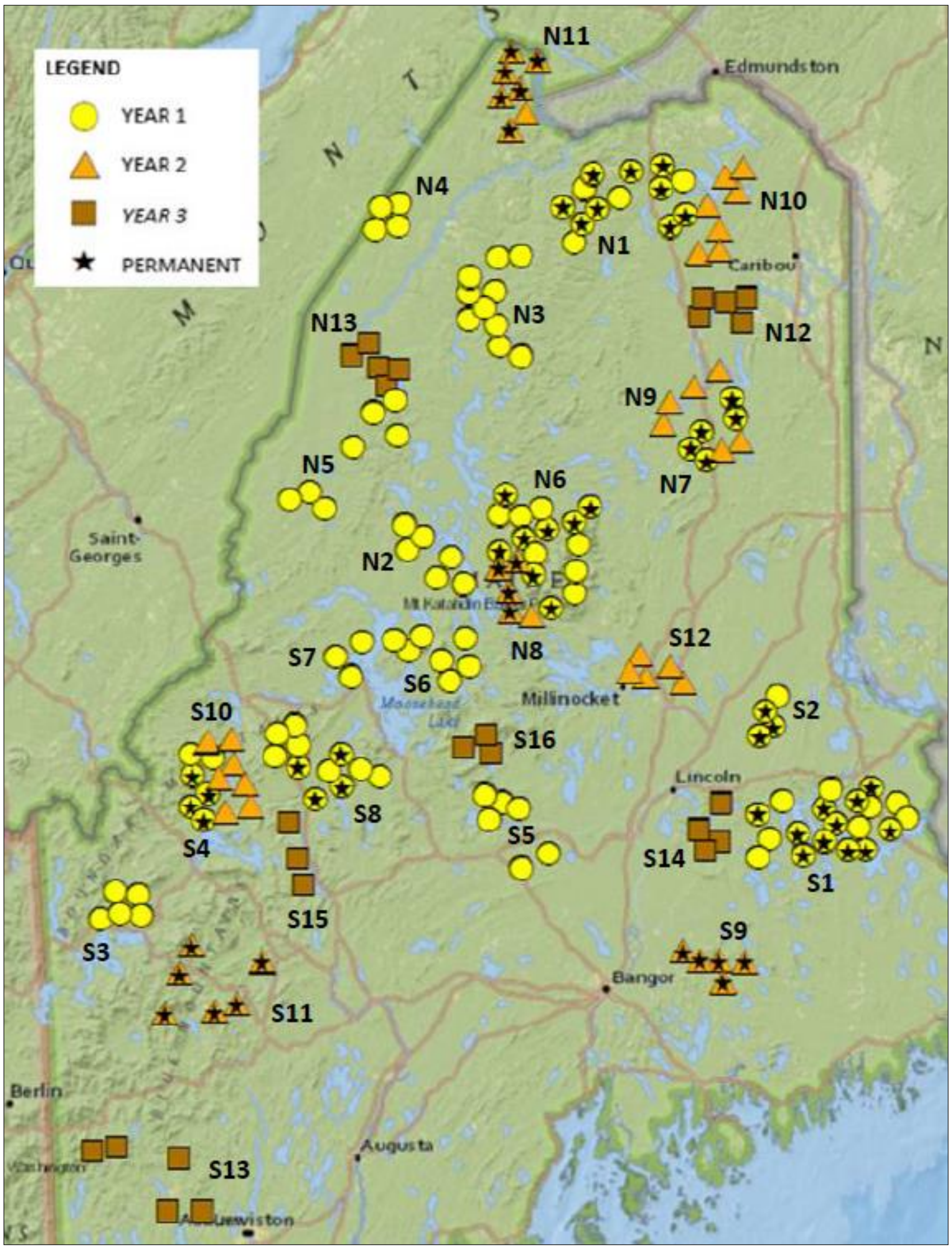


Figure 3. Map of study areas (labeled in black) surveyed over the course of the project.

Our study areas have been selected to create a natural experimental design across landscape factors including: 1) intensity of timber harvest activity, 2) scale of harvested versus unharvest forest patches, 3) latitude and 4) fur trapping impact on several high priority carnivore species (marten, fisher, and coyote).

Key Findings / Accomplishments

- Over the 2019-2020 project year our key accomplishments include the publication of a peer-reviewed article lead-authored by an under-graduate student conducting research for this project. Dr. Mortelliti also brought on a MWC student, Amay Bolinjkar, to look at black bear reproduction and habitat patterns across Maine using multi-state occupancy models (MacKenzie et al 2009).
- To date we have collected over 750,000 motion triggered trail camera images, which are being cleaned and sorted into a multiple year, multiple species dataset.

Future Plans

In the coming months the complete four-year dataset as well covariate information will be cleaned. Key deliverables include a protocol detailing the optimal number and configuration of camera traps that could be used to monitor Maine carnivore species over the long term. Dissertation chapters will focus on marten and fisher interaction; weasel species distribution across Maine; and multiple year occupancy trends.

Partners / Stakeholders / Collaborators

Many public and private entities granted access to their lands for our survey stations, without which this result would not have been possible. Marc Edwards and Eben Sypitkowski went above and beyond to ensure we could collect our multi-year data within Baxter State Park despite Covid-19, and Matt Thurston granted legacy access to King and Bartlett. As always, Al Cowperthwaite with the North Maine Woods was graciously helpful to our project. It was a special pleasure to coordinate with Maine IFW field staff to do winter hands-on knowledge sharing, many thanks to Shevenell Webb for coordinating that, and everything else she does.

Other private landowners that have granted access over the course of this study, in alphabetical order, include: American Forest Management, Clayton Lake Woodlands Holdings, Downeast Lakes Land Trust, J. D. Irving, Katahdin Forest Management, LandVest, Northwoods Management, Passamaquoddy Tribe of Indian Township, Seven Islands Land Co., The Nature Conservancy, Wagner Forest Management, and Weyerhaeuser.

Acknowledgements

Our thanks to Aaron Weiskittel, Leslee Canty-Noyes and Meg Fergusson for continued support from CFRU. Also Rena Carey, Katherine Goodine and Molly Jean Langlais-Parker in WFCB. And a great deal of gratitude to the many undergraduate students that have assisted with field work and data entry.

References

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

Evans, B. E., C. E. Mosby and A. Mortelliti. 2019. Assessing arrays of multiple trail cameras to detect North American mammals. PLoS ONE 14(6): e0217543

MacKenzie, D. I., J. D. Nichols, M. E. Seamans and R. J. Guitierrez. 2009. Modeling species occurrence dynamics with multiple states and imperfect detection. Ecology 90(3):823-835

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

Rovero F, Zimmermann F, Berzi D, Meek P. 2013. "Which camera trap type and how many do I need?" A review of camera features and study designs for a range of wildlife research applications. Hystrix 24(2): 148–156.

Moose calf curious about the camera. Year 3 of study, site S4-02-3-Y3.

Quantifying the Ecological and Economic Outcomes of Alternative Riparian Management Strategies

Hamish Greig, School of Biology, University of Maine
Amanda Klemmer, School of Biology, University of Maine
Robert Northington, Husson University
Shawn Fraver, School of Forest Resources, University of Maine
Eric Miller, University of Maine
Mindy Crandall, Oregon State University
Ethel Wilkerson, Manomet Inc.

Year 2 of 3

Project Objectives

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

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

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

Approach and Activities

- Our fieldwork focused 14 western Maine streams subject to alternative riparian management treatments during the 2001 - 2007 CRFU-funded Manomet headwater stream study. These study sizes encompassed three replicates of each of four alternative riparian management approaches: clear cut harvest with i) no buffer, ii) 11m, or iii) 24 m buffers, and iv) a partial harvest without a buffer. We also included two replicate streams that were unharvested control blocks.
- Over two summers, our team collected and analyzed data on riparian forest composition and timber value; stream habitat quality; aquatic invertebrate communities; fish abundance and condition; riparian insects; and ecosystem processes (litter decomposition rates).
- These data enable us to quantify the ecological outcomes of alternative riparian management approaches and model the timber value differences between the riparian buffer treatments using forest growth and yield programs.

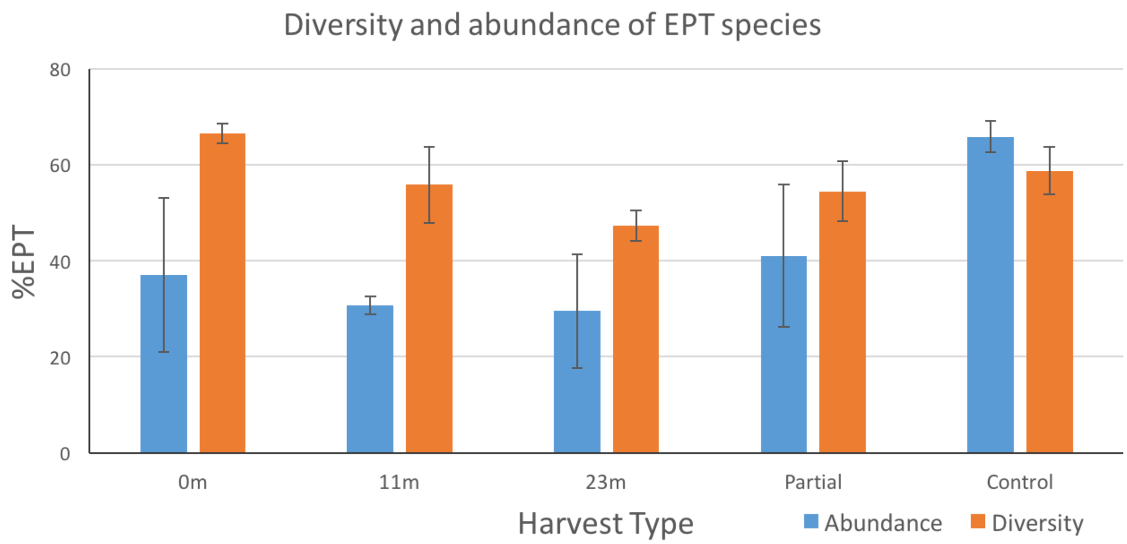


Figure 4. Percent abundance and diversity of EPT taxa (mayflies, stoneflies and caddisflies) among harvest treatments. Means ± 1 SE are calculated with streams as replicates.

Outcomes and Preliminary Findings

- All streams we sampled held diverse insect communities. We encountered a total of 14,500 individuals from 102 species including numerous species of mayflies, stoneflies, caddisflies that are considered sensitive to declines in water quality.
- We did not observe any significant differences in the abundance and diversity of mayflies, stoneflies, and caddisflies among the alternative riparian management treatments although there was a trend towards higher EPT abundance in control streams (Figure 4).
- We did see a legacy of riparian harvest in the relative abundance of different insect species: communities in unharvested control treatments were significantly different from treatments in which harvest occurred in the immediate riparian zone (i.e., blocks with clear cuts and partial harvest) (Figure 5).
- We also observed differences in the feeding guilds of insects among different riparian treatments (Figure 6) with collector-gatherers dominating streams in harvested blocks, whereas streams in unharvested control blocks had a higher proportion of scrapers and a more even distribution of functional guilds.
- The breakdown rate of forest litter in streams did not differ among harvest treatments. This suggests differences in ecological communities did not translate to impaired stream ecosystem function in terms of litter breakdown.
- The opportunity cost of alternative riparian management approaches was highest for unharvested control blocks and lowest for clear cut blocks. The opportunity cost of partial harvest trended higher than blocks in which unharvested 11m and 23m buffers were retained (Figure 7).

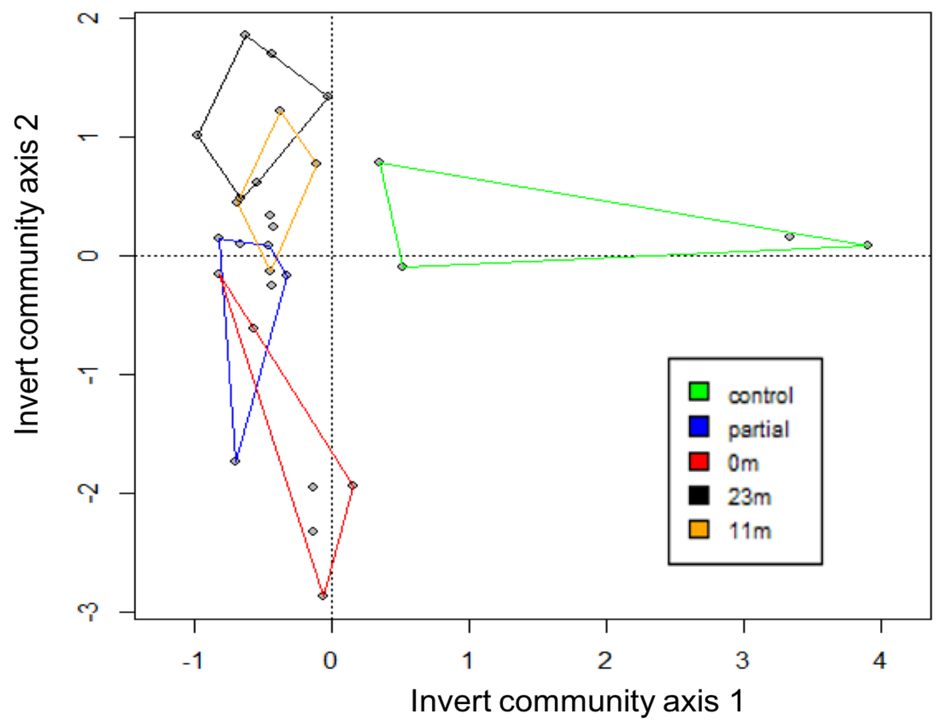


Figure 5. Analysis of invertebrate communities in the 14 streams. Each point is a stream and distance between two points indicates how different their communities are from each other. Streams from the same harvest treatment are enclosed in colored shapes. Communities in control streams (green) were distinct from those in harvested streams, and streams subject to partial harvest (blue) and clear cuts with no riparian buffers (red) were the most different from

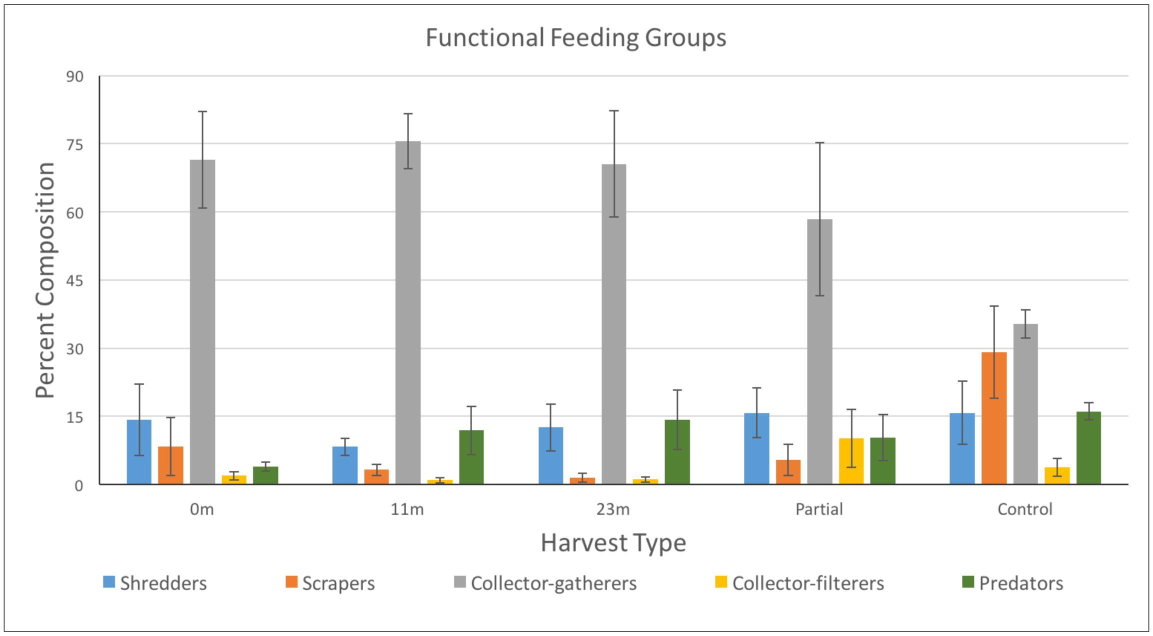


Figure 6. Percent abundance of invertebrate functional feeding groups among harvest treatments. Means ± 1 SE are calculated with streams as replicates. Shredders consume forest leaves, scrapers graze algae, collector-gatherers and collector-filters eat fine detritus particles, and predators consume other invertebrates.

Future Directions

- Our final year will focus on finalizing our data analysis on the ecological and economic outcomes of alternative riparian management approaches, developing manuscripts for peer-review, and producing written summaries and datasets of our results for managers.
- Additional analyses will focus on whether variation in ecological conditions among streams and different harvest treatments can be better understood by including watershed-level information on land cover, geology and human activities.
- We have recruited a PhD student Jack McLachlan who will lead our Objective 1 literature synthesis and white paper that summarizes existing literature on the effectiveness of alternative riparian management strategies in the northeast. This effort will focus on summarizing and expanding literature collated by EES 489 students that we highlighted in our 2019 progress report, and will also identify knowledge gaps that could inform future research directions.

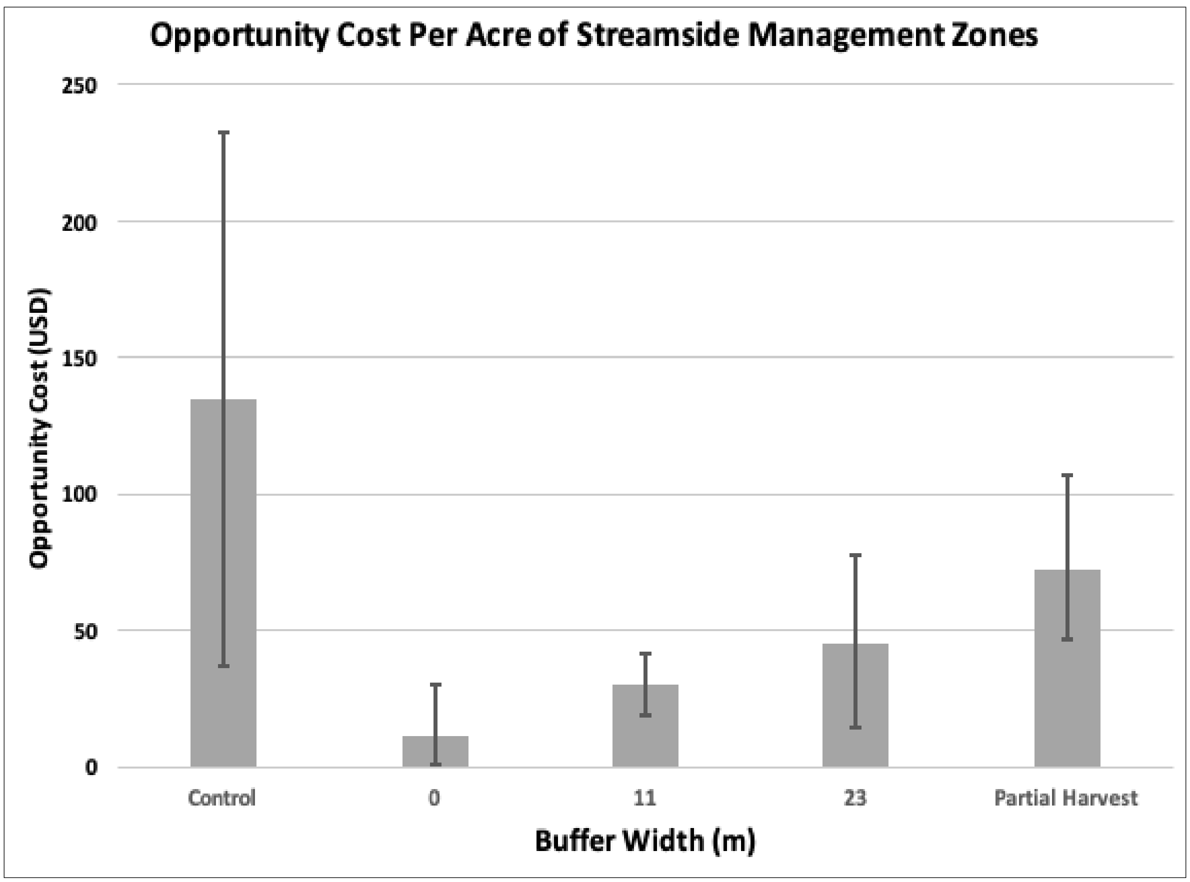


Figure 7. The mean opportunity cost of alternative riparian management approaches calculated from the volume of merchantable current standing timber for each stream site. Values were estimated from the Maine Forest Service's 2017 Stumpage Price Report per tree for pulpwood (tons) and sawlog (thousands of board feet) volume. Where possible, species-specific values were used; where not available, the species was assigned the value from a tree with similar marketability.

Watershed-Scale Drivers of Temperature and Flow of Headwater

Neil Thompson, University of Maine at Fort Kent

Year 2 of 3

Project Objectives

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

Summary

Stream temperature data have been recorded for the second year (Figure 8), with no loss of time or extent due to Covid-19 restrictions. Sample size in the landscape network designed to support predictive modeling of stream temperature regimes was increased from 93 to 180 by reassigning sensors from the Smith Brook watershed (replaced with a greater number of higher-capacity sensors) and collecting air temperature at every other site, rather than every site. Extreme drought conditions in northern Maine in 2019 led to complete drying of a fraction of the streams hosting temperature loggers, complicating but not compromising the originally planned analysis and opening the door to some additional analyses. Preparations for treatment at Smith Brook are continuing as planned; implementation of the management plan may be delayed by one year depending on road construction and needs to collect additional geomorphological data. I have submitted a grant to fund a doctoral student to work specifically on geomorphological questions in the context of both the landscape network and the Smith Brook study. All analyses have been preliminary as we expect publicly funded LiDAR data to be available for the study area shortly.

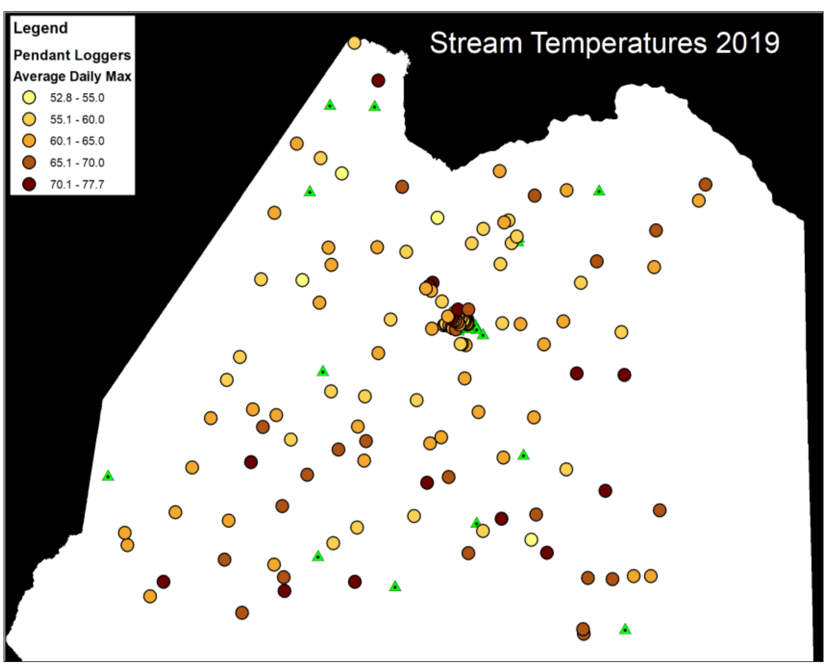


Figure 8. July/August average daily maximum temperature at all sites in 2019; locations of pressure sensors used to record flow metrics identified as green triangles. Sample size has nearly doubled in 2020.

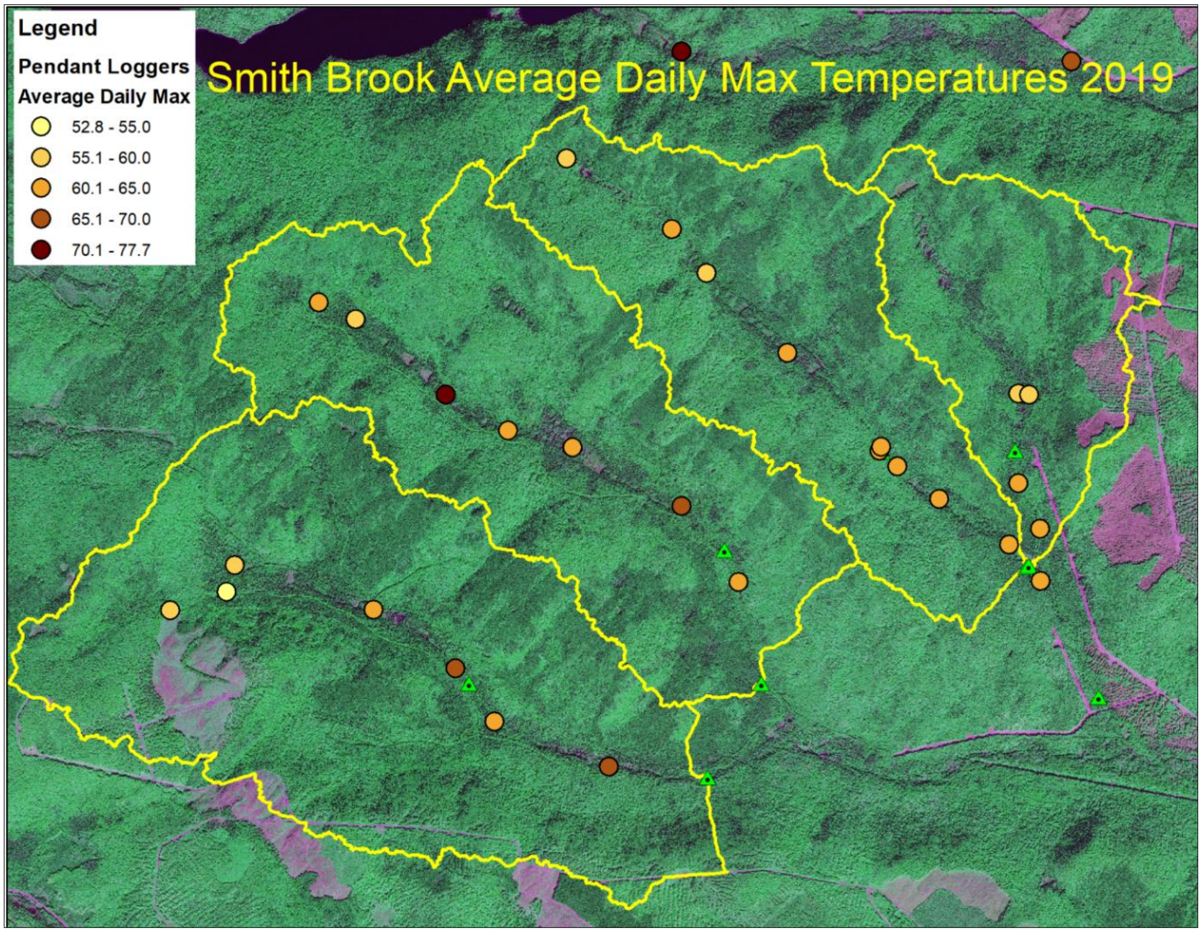


Figure 9. Layout of sensors and preliminary data from Smith Brook, July/August 2019. The sampling network has been enhanced to cover gaps in this dataset, utilizing higher-capacity loggers that can record through the winter.

Approach

- Temperature loggers have been placed in randomly selected 1st and 2nd order streams within in the study area. Metrics, such as average daily maximum temperature, will be used as dependent variables in models with predictors such as stream gradient, watershed size, elevation, harvest level, area in lakes and ponds, beaver dams, etc.
- Temperature loggers have been placed on intervals in each of the three Smith Brook tributaries (Figure 9). The initial 2019 layout has been replaced and enhanced with a greater number of strongly anchored, higher-capacity loggers that will remain in place and record data through the winter (Figure 10).
- We are working with the landowner (JD Irving) to time the construction of roads to implement established management plans on both treated watersheds in the same year.

Key Findings/Accomplishments

Preliminary analyses suggest that stream gradient is strongly correlated to temperature, with higher-gradient (steeper) streams tending to be cooler.

Future Plans

- One more year of data collection is planned for the landscape network; following this collection the results will be published in a peer-reviewed journal
- Repeat all preliminary analyses when data from the statewide LiDAR flight become available.
- I have submitted a WRRI proposal for $40,000 to fund a doctoral student co-supervised with Dr. Sean Smith. If funded, the student will focus on the geomorphological aspects of the study question.
- The Smith Brook study will continue for another 5+ years as planned.

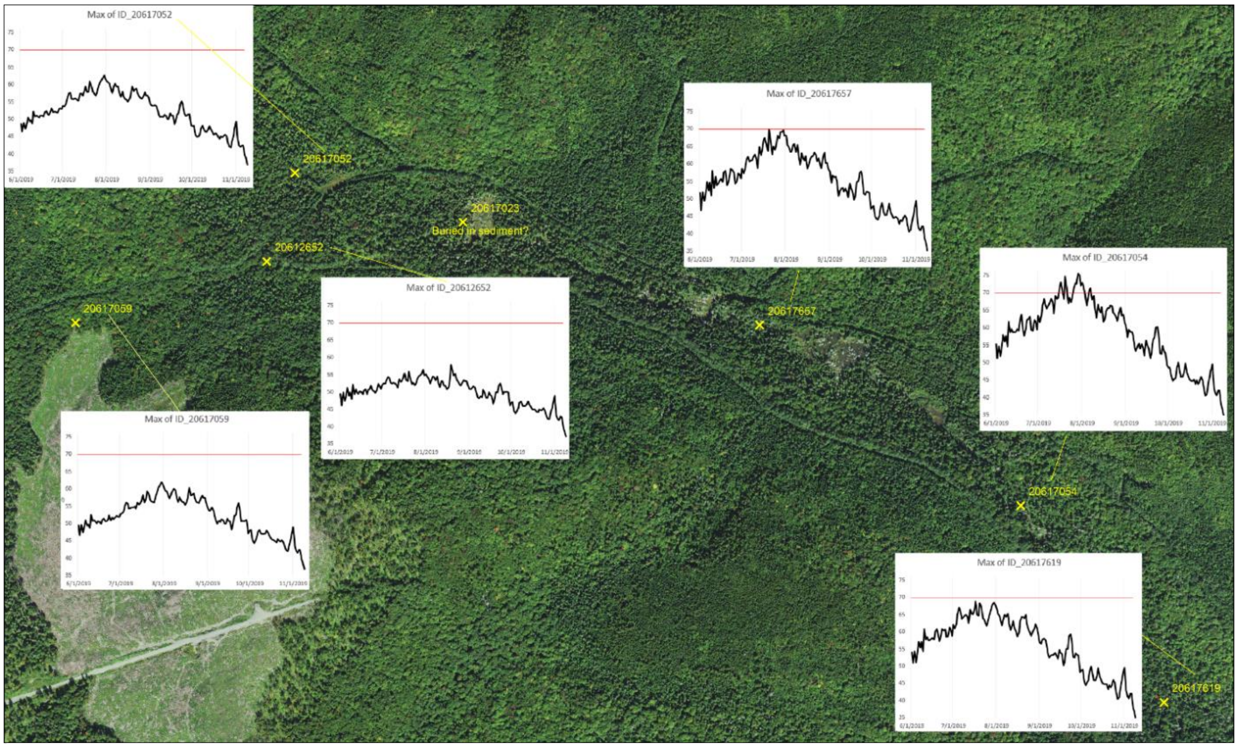


Figure 10. Temperature data for the southern tributary, summer 2019. Red line indicates the 70 degree threshold for brook trout suitability; temperature increase is observed where the cool waters from the hillside meet the impounded waters of the beaver flowages. Several dozen brook trout were observed at this interface on a hot day in July 2020, which was apparently buried in sediment and replaced by a new sensor slightly upstream.

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

Amber Roth, School of Forest Resources & Dept. of Wildlife, University of Maine
Carol Foss, New Hampshire Audubon
Adrienne Leppold, Maine Department of Inland Fisheries and Wildlife

Year 2

Abstract

The Rusty Blackbird (*Euphagus carolinus*) is a spruce-fir obligate that has experienced a steep population decline since the 1970s. The species response to intensive commercial forestry practices within their breeding range has yet to be assessed. Our research seeks to evaluate Rusty Blackbird nesting and fledgling habitat selection and survival in intensively managed forests in Maine and New Hampshire that contain practices such as precommercial thinning and regenerating clearcuts. Through the use of radio telemetry, GIS, and habitat measurements, we have begun to describe how the species is using these commercial landscapes. Birds during the 2019 field season were confirmed nesting in wetlands, naturally regenerating stands, and stands that had undergone precommercial thinning. A second field season was planned for summer 2020, but had to be cancelled due to the COVID-19 pandemic. A second field season is now planned for summer 2021, and will incorporate new study sites where precommercial thinning is practiced. The results of our research will be used to revise management guidelines for the species in the Northeast.

Project Objectives

- Describe Rusty Blackbird nest and fledgling site selection at both stand and within-stand scales in commercially managed forest in New Hampshire and Maine.
- Describe habitat and vegetation characteristics associated with Rusty Blackbird nest and fledgling survival.
- Propose forest management recommendations to forest owners to manage their lands for successful Rusty Blackbird breeding.

Approach

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

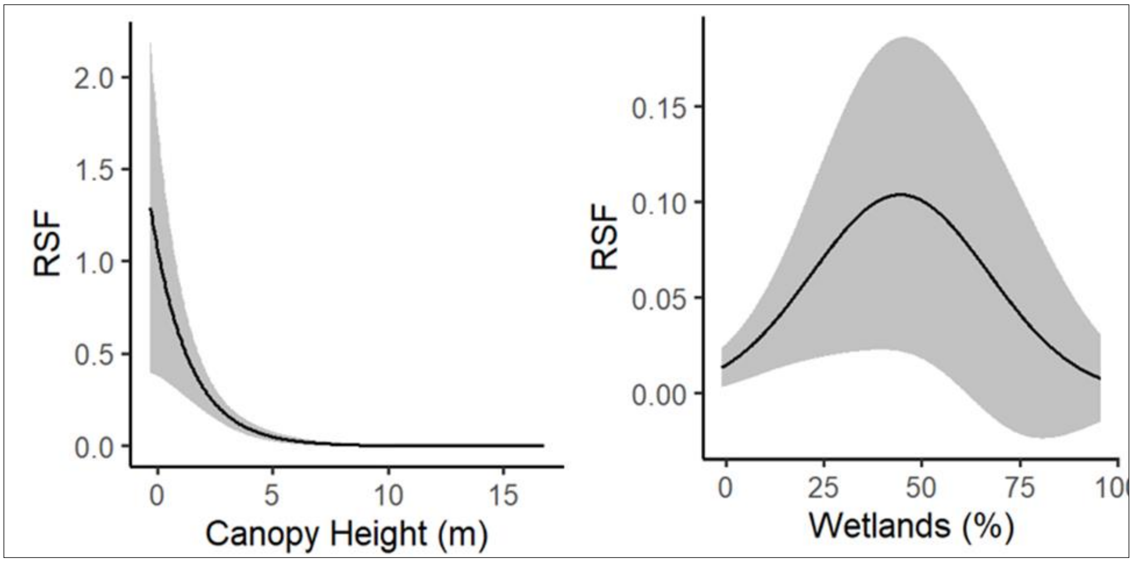


Figure 11. Resource Selection Function (RSF) estimates for canopy height and precent cover of boreal wetlands from the top ranked Rusty Blackbird nest site selection model at the stand scale in Maine and New Hampshire.

Key Findings / Accomplishments

- Preliminary analysis of 2019 field season data is complete for nest site selection and survival in New Hampshire and Maine, and almost complete for fledgling site selection in Maine (GIS data pending for Maine and New Hampshire, fledgling location and survival data pending for New Hampshire).

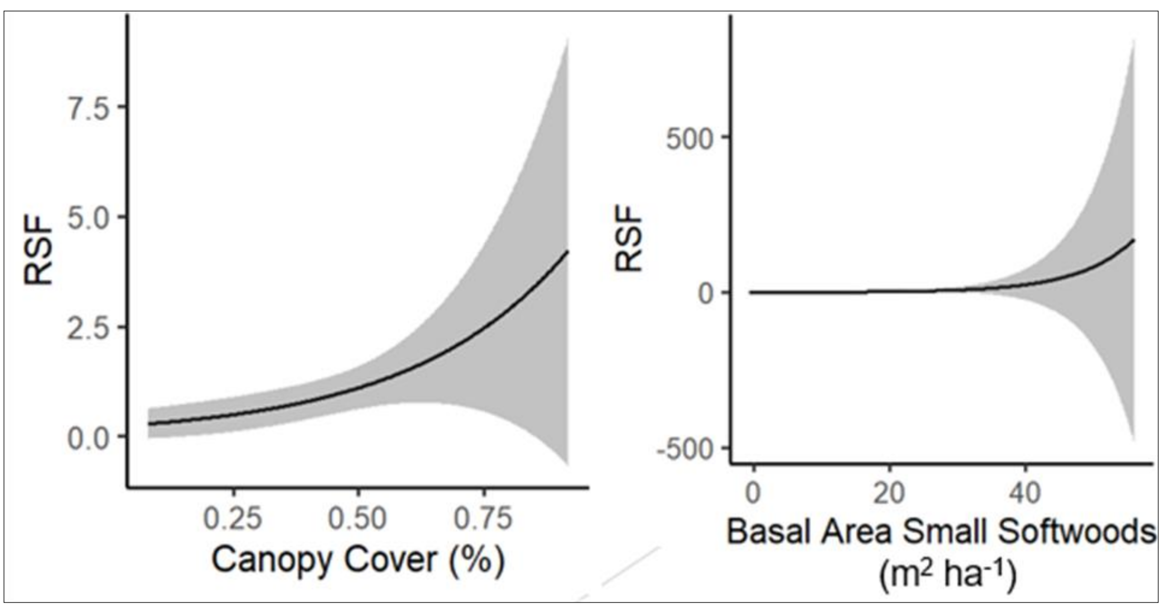


Figure 12. Resource Selection Function (RSF) estimates for percent cover of low slope (0-8%) soils and relative number of small trees (DBH ≤ 10cm) from the top ranked Rusty Blackbird fledgling habitat selection model in Maine.

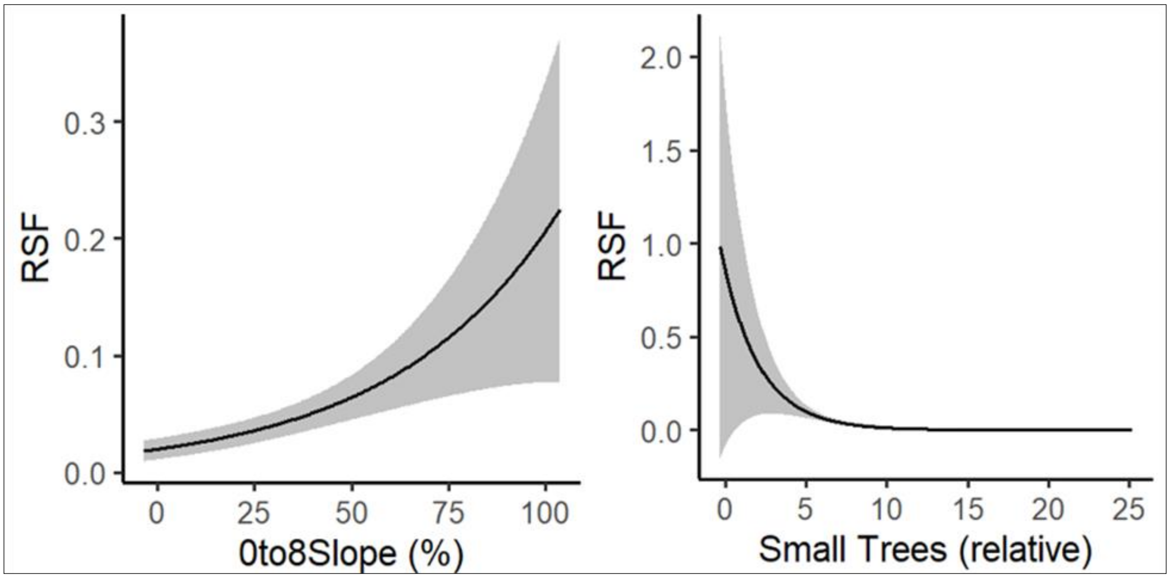


Figure 13. Resource Selection Function (RSF) estimates for canopy cover and basal area of small softwoods (DBH ≤ 10cm) from the top ranked Rusty Blackbird nest site selection model at the within-stand scale in Maine and New Hampshire.

- High ranking preliminary models for nest site selection include canopy height and percent wetland cover along a quadratic curve at the landscape scale (Figure 11). High ranking models at the within-stand scale include canopy cover and basal area of small (DBH ≤ 10cm) softwood trees (Figure 13).
    - Our data suggest that Rusty Blackbirds are selecting for nest sites with canopy heights below 5m, canopy cover around the nest of 60% or more, and, and basal area of small softwoods greater than 40 m^2 ha^{-1}.
- High ranking preliminary models for fledgling site selection include low slope (0-8%) soils and relative number of small trees (DBH ≤ 10cm) (Figure 12).
    - Our data suggest that Rusty Blackbird fledglings are selecting for sites with an increasing proportion of low slope soils and a low relative number of small trees compared to the surrounding landscape.
- High ranking nest survival models include percent canopy cover and percent cover of young softwood stands (seedling or sapling stage).

Future Plans

- While a second field season was planned for spring/summer 2020, it had to be cancelled due to the COVID-19 pandemic. A second field season is planned for spring/summer 2021.
- Seven Islands Land Company has granted us permission to use their holdings for Rusty Blackbird fieldwork. These areas contain more instances of precommercial thinning and will be incorporated into the 2021 field season. Preliminary scouting conducted during summer 2020 confirmed that Rusty Blackbird nesting pairs were using these areas.

Acknowledgements

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

Partners / Stakeholders / Collaborators

Cooperative Forestry Research Unit
J.D. Irving Limited
Maine Agricultural and Forest Experiment Station
Maine Department of Inland Fisheries and Wildlife
Maine Outdoor Heritage Fund
Maine Research Reinvestment Fund
National Council for Air and Stream Improvement
Penobscot Valley Chapter of Maine Audubon
Seven Islands Land Company
University of Maine at Fort Kent
University of Maine Presque Isle
Wagner Forest Management
Weyerhaeuser Company
William P. Wharton Trust

Geographic Location of Project

Kibby Township, Maine; Errol, New Hampshire

Silviculture & Management

Long-Term Outcomes of Beech Bark Disease: 40-Year Results

Laura Kenefic, U.S. Forest Service, Northern Research Station
Dave Houston, State University of New York, College of Environmental Science and Forestry, Adirondack Ecological Center
Bethany Muñoz Delgado, U.S. Forest Service, Northern Research Station
Stacy McNulty, State University of New York, College of Science and Forestry, Adirondack Ecological Center
William Livingston, University of Maine, School of Forest Resources

Year 2 of 3

Abstract

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

Cooperators

Allison Kanoti, Maine Forest Service
Aaron Bergdahl, Maine Forest Service
Keith Kanoti, University of Maine

Project Objectives

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

Approach

- Re-establish and re-measure two historical BBD monitoring plots on the PEF (approximately 1-acre beech-dominated plots established in 1979 by Forest Service scientist Dave Houston as part of a regional study (Houston et al. 2005)).
- Digitally record and archive historical data, stem maps and preliminary data summaries. (Data were collected annually from 1979-1992).
    - Tree attributes: diameter at breast height (DBH), crown class, crown chlorosis (yellowing), crown thinness, and tree condition (from good to dead).
    - Evidence of BBD: height zones, wax amount and cover as evidence of *C. fagisuga* (none to very heavy), tarry spots as evidence of *Neonectria* infestation, dead bark (strip canker, necrosis, or callusing), *Neonectria* fruiting, and evidence of *Xylococculus* (insects).
    - In addition – potentially disease-tolerant trees will be recorded based on evidence of raised lesions instead of or in addition to sunken cankers.
- Infestation and infection indices will be developed in accordance with methods of Houston et al. (2005) for comparison of current findings to historical research.
- Mortality probabilities will be modeled in accordance with methods of Cale and McNulty (2018) to determine effect of BBD severity and DBH on tree time-until-death.
- Use historical and newly collected data to evaluate relationships between presence and abundance of lesions (as an indicator of BBD tolerance) and historical and current growth and vigor of survivor trees.
- Develop management recommendations with consideration of commodity production and biodiversity / wildlife values of trees with BBD.

Key Findings/Accomplishments

- Using the information provided by Dave Houston, PEF staff were successfully able to locate plot (management unit, MU) 102 and the historical stems that had been mapped. Two annual inventories have been conducted in this plot since that time (2019 and 2020). In 2020, new GPS locations were recorded for the stems in this plot and synthesized into Figure 15. 141 historical and ingrowth beech trees were mapped.

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

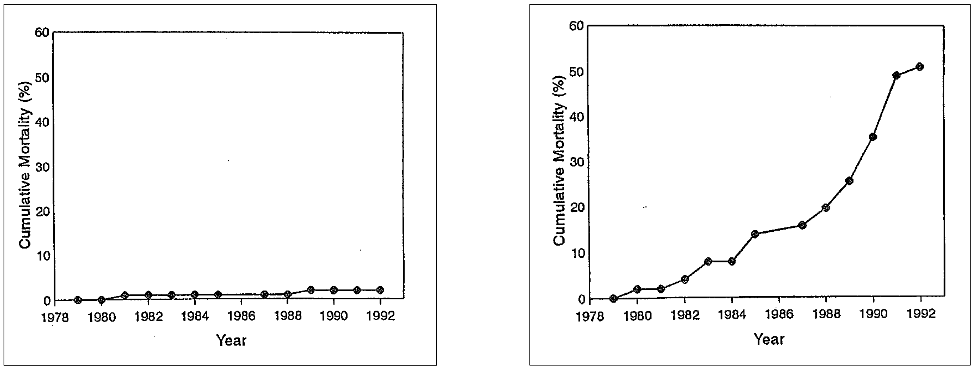


Figure 14. Mortality, 1979-1992. Cumulative mortality of beech in PEF plots 102 (left) and 103 (right) from historical data. Graphs from Houston et al. (2005).

- Using the same information, plot 103 and its mapped trees were not able to be located in the field. Based on the known cumulative mortality trend displayed in Figure 14, it was concluded that the representative beech trees in this plot had apparently experienced 100% mortality.
- Following this realization, the location for a new replication plot (MU102A) was determined on the PEF in collaboration with the University of Maine and added to the study for future continued measurement starting in July, 2019. Two annual inventories have been conducted in this plot since that time. In 2020, initial GPS locations for the stems in this plot were recorded and a stem location map was created. 185 trees were mapped.
- Figure 16 shows the relationships between canker/lesion percent occurrence in the bottom two meters of the bole with crown condition (current) and DBH growth (historical and current). Early results suggest that higher relative presence of lesions rather than cankers is associated with better vigor (crown condition) and growth, i.e., that the tree is more likely to be tolerant to BBD.

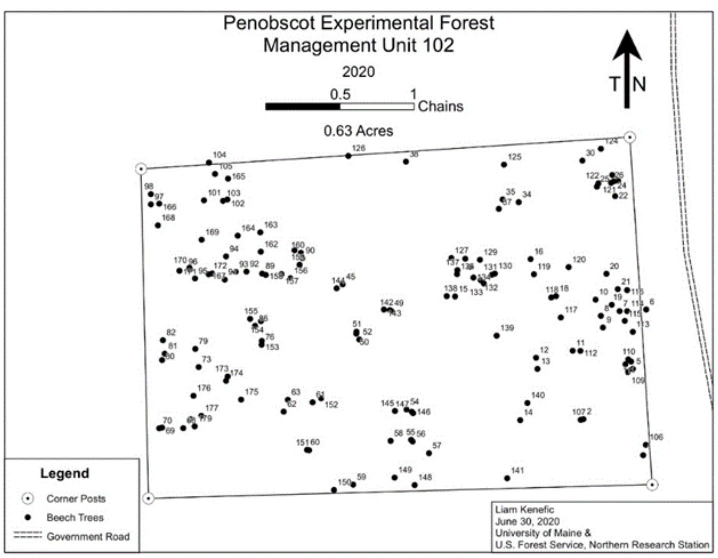


Figure 15. MU102 stem location map of all beech stems within the plot. GPS data were updated to sub-meter accuracy in June 2020.

- In 2019, a field tour and workshop for CFRU members was scheduled to be led by co-principal investigators Dave Houston and Stacy McNulty, but was cancelled due to a medical emergency. We hope to hold this event after the covid-19 pandemic.
- In 2019, a special session on beech bark disease was organized by PI Laura Kenefic at the New England Society of American Foresters Annual Winter Meetings. Presentations were later reprised and made available as webinars by Ralph Nyland through ForestConnect

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

(https://www.youtube.com/watch?v=11TTog0Lgb4&feature=youtu.be) and by Stacy McNulty through the Center for Research on Sustainable Forests (https://www.youtube.com/watch?v=qHqmE2pxngg&t=8s).

- University of Maine School of Forest Resources undergraduate student Lauren Keefe completed her senior capstone project using historical and new data from this study under the guidance of co-principal investigator William Livingston: Quantification of Tolerance to Beech Bark Disease. Though preliminary, Lauren's findings were that trees with greater area of necrophylactic periderm (lesions) have higher growth rates, less crown dieback, and reduced infection and infestation rates, with substantial evidence to prove necrotic lesions as a quantifiable symptom of tolerance correlated with healthier trees afflicted by beech bark disease. The illustrations in Figure 13 are from her work.

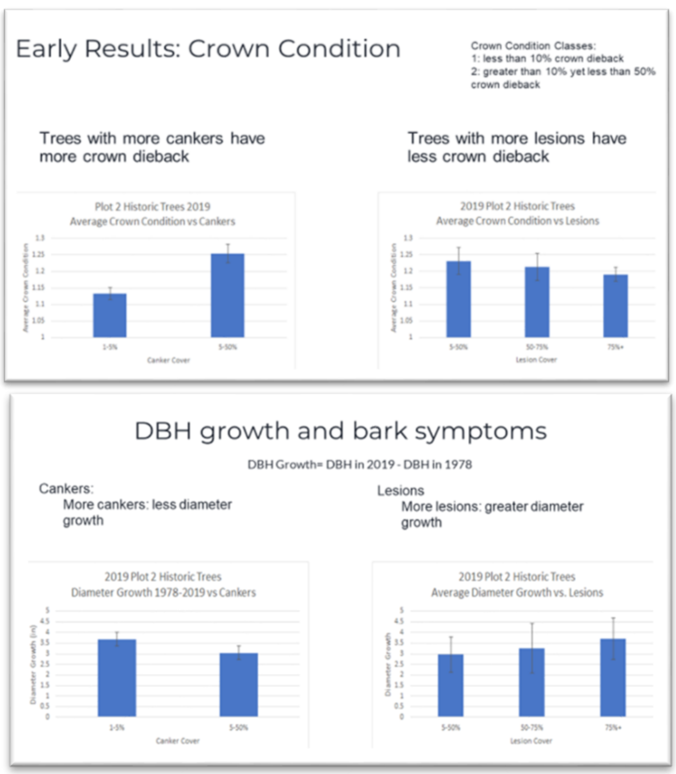


Figure 16. *Data synthesis of preliminary canker/lesion cover vs crown class/condition (top) and DBH growth (bottom) results from the 2019 annual inventory in MU102 at the PEF. Source: capstone presentation by Lauren Keefe, June 2, 2020, University of Maine.*

Future Plans

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

Acknowledgements

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

References

Houston, D.R.; Parker, E.J; Perrin, R.; Lang, K.J. 1979. Beech bark disease: A comparison of the disease in North America, Great Britain, France and Germany. Eur. J. For. Pathol. 9:199-211.

Houston, D.R.; Rubin, B.D.; Twery, M.J.; Steinman, J.R. 2005. Spatial and temporal development of beech bark disease in the northeastern United States. In: Evans, C.A., Lucas, J.A.; Twery, M.J. Proc. of the Beech Bark Disease Symp. Gen. Tech. Rep. NE-331. Newtown Square PA, U.S. Dept. Agric., For. Serv., Northern Research Station.

Cale, J.A.; McNulty, S.A. 2018. Not dead yet: Beech trees can survive nearly three decades in the aftermath phase of a deadly forest disease complex. For. Ecol. and Manage. 409:372-377.

(Left) University of Maine undergraduate student Lauren Keefe with Dave Houston and his resistant beech tree at the PEF.

(Right) Lauren Keefe learning field identification and beech bark disease sampling protocols from Dave Houston.

Maine's Adaptive Silviculture Network (MASN)

Aaron Weiskittel, Center for Research on Sustainable Forests, University of Maine
Anil Raj Kizha, School of Forest Resources, University of Maine
Amber Roth, School of Forest Resources & Dept. of Wildlife

Year 4 of 5

Summary

This is the fourth year of a five-year project to establish a new region-wide study series: Maine's Adaptive Silviculture Network (MASN). The MASN study will be the backbone for new research in areas of growth and yield, wildlife habitat, harvest productivity, regeneration dynamics, remote sensing of inventory, forest health, and others. There has been much interest from researchers wishing to take advantage of these study sites to address research problems of interest to CFRU membership. In 2020, an installation was established and forest management treatments were implemented at what was referred to as the 'SILC Mill' site in the 2019 CFRU annual report. Seven Islands Land Company desired to update the name of the installation to 'Nashville Plantation,' which is located between Ashland and Portage Lake along Route 11.

Project Objectives

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

Approach

- Working with regional forest managers, identify potential areas with uniform soils, drainage class, topography, stand type, and recent harvest history.
- For each installation, delineate four to seven units and randomly assign and implement various forest management treatments representing the full range of harvest scenarios found in Maine. One unit will be a delayed harvest.

Retention of pole-sized trees and larger trees such as this maple in the Improvement Cut unit at Nashville Plantation (photo credit: Joshua Puhlick).

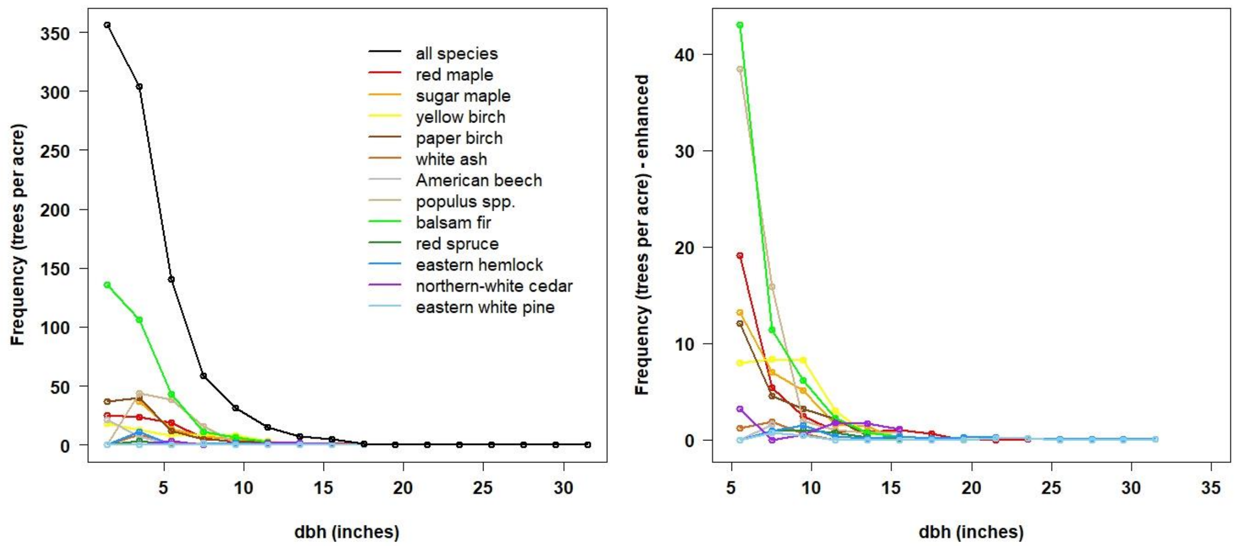


Figure 1717. Diameter distributions (before harvest) at Nashville Plantation derived by Puhlick from CFRU variable radius plot data of trees ≥ 1 inches DBH. Average BA, TPA, weighted diameter, and percent softwood were 130 ft^2 ac^{-1}, 1160 trees ac^{-1}, 6.1 inches, and 35%.

- Across a grid of permanent sample points at each installation, collect pre- and post-harvest data (Figure 17), including overstory and degree photography, high-resolution aerial imagery, and more.

Key Findings/Accomplishments

- The pre-harvest inventory of the Nashville Plantation installation was conducted in 2019.
- At Nashville Plantation, timber harvesting was conducted from mid-July to September 2020.
- In addition to the standard MASN treatments assigned to units within installations, Joshua Puhlick (University of Maine, School of Forest Resources) and Seven Islands Land Company foresters added an Improvement Cut treatment to one of the units at Nashville Plantation.
- The Improvement Cut treatment involved retaining the seed sources of tree species such as yellow birch, sugar maple, and red spruce, which were scattered throughout the unit. Large eastern hemlocks were also retained to meet biodiversity and carbon storage objectives. Other objectives included maintaining a multi-aged structure and plans to regenerate yellow birch in gaps during the next harvest.
- At Nashville Plantation, David Sandilands and Tony Guay (University of Maine, School of Forest Resources and Wheatland Geospatial Lab) used a new UAV platform to gather remote sensing imagery after timber harvesting and leaf-off (Figure 18).
- Aaron Weiskittel and Joshua Puhlick secured funding from the National Council of Air and Stream Improvement to forecast future carbon stocks on the MASN.

Future Plans

- Conduct the post-harvest inventory of variable radius plots at the Nashville Plantation installation (summer 2021).
- Work with collaborators to identify locations for additional installations (winter-summer

2021).

- Develop a methodology for ensuring that the integrity of past and current research studies is maintained as future studies are added to the MASN (winter-summer 2021). This will include establishing a GIS database with the locations of existing studies.

Acknowledgements

We thank Shawn Bugbee, Jason Desjardin, and Pat Boyd (Seven Islands Land Company) for organizing and overseeing the timber harvesting operations at Nashville Plantation.

Diverse range of tree sizes and species after cutting by the first machine of the harvesting system in the Improvement Cut unit at Nashville Plantation (photo credit: Joshua Puhlick).

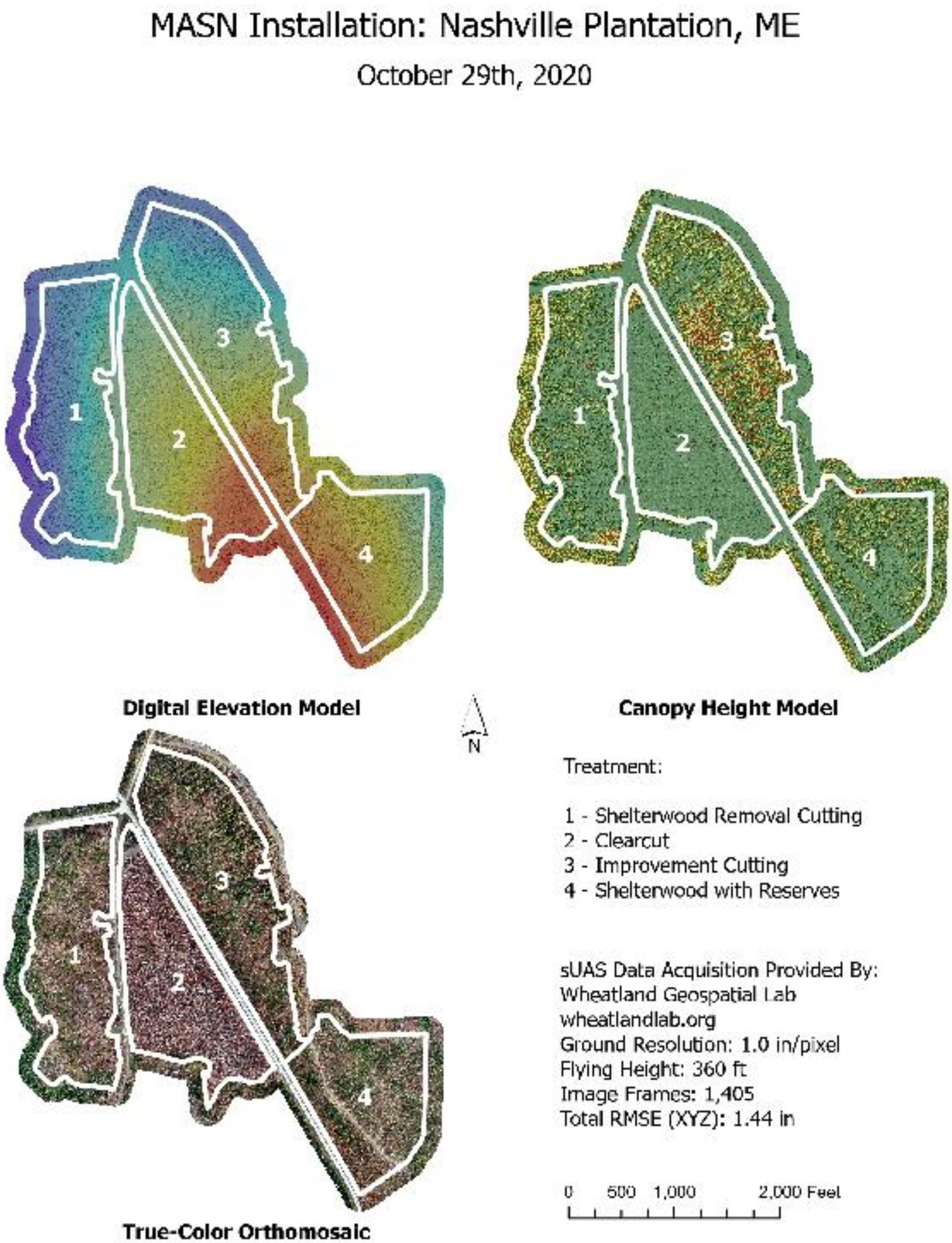


Figure 18. Remote sensing imagery of Nashville Plantation after timber harvesting and leaf off. Imagery provided by the University of Maine's Wheatland Geospatial Lab.

Retention of downed woody material in the Improvement Cut unit at Nashville Plantation (photo credit: Joshua Puhlick).

Quantifying Regeneration Outcomes and Logging Residues in the Maine Adaptive Silviculture Network

Nicole S. Rogers, University of Maine Fort Kent, Applied Forest Management Program
Laura S. Kenefic, U.S. Forest Service, Northern Research Station
Bethany Munoz Delgado, U.S. Forest Service, Northern Research Station
Amber Roth, School of Forest Resources, University of Maine

FINAL REPORT

Abstract

Regeneration establishment and success is a crucial component of management for Maine's northern hardwood and mixedwood forests. However, regeneration response can be highly variable. Biotic and abiotic factors including silvicultural treatment, site quality, herbivory, and logging residues can contribute to this regeneration uncertainty. The Maine Adaptive Silviculture Network (MASN) offers a unique opportunity to explore the influence of these factors under management scenarios common across Maine's commercial forestlands. We quantified regeneration at three MASN sites across located in central and northern Maine. Overstory composition varied at each site and included two mixedwood forests and one northern hardwood forest. Regeneration surveys identified browse damage at each site, although browse intensity varied by location. We also found heavy logging reside at each site with variability in volume by site and harvesting system.

Project Objectives

The primary goal of this project was to provide forestland owners and managers with information on regeneration outcomes and logging residues under different silvicultural treatments and harvesting systems common across Maine's commercial forestland. We also explored the impact of logging residues and other influential factors on regeneration response. The objectives used to meet these goals were as follows:

1. Collect detailed baseline regeneration and residue data from the Maine Adaptive Silviculture Network
2. Quantify regeneration density, stocking, and composition after harvesting in mixedwood and northern hardwood forests
3. Quantify volume, composition, and distribution of logging residues after harvesting in mixedwood and


Browse damage on a red maple at the AFM site during summer

northern hardwood forests

4. Evaluate the impact of logging residues, site, treatment, operations, overstory conditions, and browsing on natural regeneration

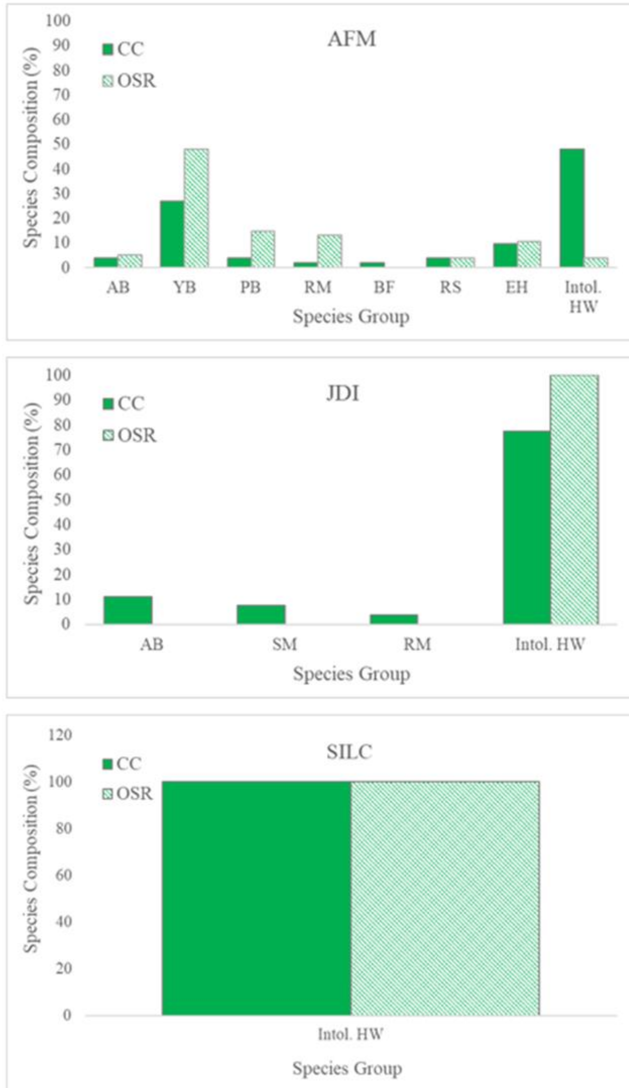


Figure 19. Species composition of established regeneration (stems ≥ 15 cm in height) by site and treatment.

Approach

General Methods

- Utilize three MASN sites across the state of Maine: American Forest Land (mixedwood) in Grand Falls, JD Irving (northern hardwood) in T16R8, and Seven Islands Land Company (northern hardwood) in T13R15 (Figure 19).
- Collect data in two experimental units at each site: the overstory removal treatment and the clearcut treatment.
- Remeasure existing overstory and understory vegetation plots, and collect new measurements of regeneration and logging residues. Field measurements were collected during summer months two years after harvest (2019 for AFM, 2020 JD Irving and Seven Islands).

Overstory Plots

- Following existing MASN protocols, overstory density, basal area, and species composition were measured
- The number of overstory plots treatment varied from 8 to 15

Understory Vegetation Plots

- Percent cover of tree species and understory vegetation was measured following MASN protocol on existing understory vegetation sub plots
- We added measurements of density and browse damage by species and size class
- Regeneration size classes were 0 to 15 cm, 15.1 to 30 cm, 30.1 to 91 cm, 91.1 to 183 cm, and > 183 cm to < 2.5 cm dbh
- When present, we classified the browsing agent based on the type damage i.e. clipped (snowshoe hare) or ripped (white-tailed deer or moose).

Moose sign at the SILC site, summer 2020.

Regeneration and logging residue sampling at the SILC site, summer 2020.

Measurement of Logging Residues

- Logging residues on overstory plots was quantified using three randomly established10 m line transects
- Residues along the transects were classified by size i.e. fine woody material to coarse woody material following protocol from Benson and Johnston (1976) and Brown (1974, 1971). Fine woody material (< 7.6 cm at point of line intersection) will be tallied by size classes on portions of each transect (Brown, 1974).
- Logging residue on understory vegetation plots was also quantified, this time using three randomly established 1 m transects
- Calculation of residue volume follows the same steps outlined for overstory plots
- All logging residues were for current conditions without any manual manipulation

Regeneration Exclosures

- Two regeneration exclosures were established at the AFM site during Summer 2019
- Additional exclosures were intended at the JDI and Seven Islands site, but were not established due to increased travel expenses following updated University of Maine System COVID-19 safety protocols

Key Findings / Accomplishments

- Ample regeneration at each site although composition and browse varied by location
- Browse damage was most prevalent at the AFM site and least prevalent at the JDI site
- Browse damage was from moose, deer, and hare

Future Plans

- During winter 2020/2021 we intend to finish all data cleaning and regeneration modeling, including finalized estimates of logging residue volume. Residue volume will be quantified following the protocols by Van Wagner (1968), Brown (1974), and Woodall and Moleon (2010). To assess the relationship between regeneration success, logging residue volume, and browse we will generate mixed-effects models. During this time, we will also transfer all cleaned data to the CFRU for inclusion in the CFRU data bank.

- By Spring 2021 our aim is to identify publication options for this research in regional peer-reviewed journals. Additionally, we would be interested in sharing results at any future MASN field tours.

Table 1. Total and established regeneration by site and treatment. Established regeneration includes stems ≥ 15 cm in height.

Site and Treatment	Total Regneration (stem ha^{-1})	± Std.Dev.	Established Regneration (stem ha^{-1})	± Std.Dev.
AFM Clearcut	2778	345	1279	157
AFM Overstory Removal	4381	284	3319	230
SILC Clearcut	2729	295	885	89
SILC Overstory Removal	5237	618	2655	268
JDI Clearcut	9205	1106	2932	315
JDI Overstory Removal	6771	1206	1770	197

Table 2. Percent of understory vegetation plots where browse damage was recorded by site

Site	% of plots
AFM	21
SILC	16
JDI	8

Acknowledgements

We would like to thank the summer student involved in this research for their help collecting the field data essential to the project. We would also like to thank Leslee Canty-Noyes for her help keeping us on track.

Partners / Stakeholders / Collaborators

U.S. Forest Service, Northern Research Station

Geographic Location of Project

Central and northern Maine

References

Brown, J.K., 1974. Handbook for Inventorying Downed Woody Material. U.S. Dep. Agric. For. Serv. Intermt. For. Range Exp. Station. Gen. Tech. Rep. INT-16 24.

Brown, J.K., 1971. A Planar Intersect Method for Sampling Fuel Volume and Surface Area. For. Sci. 17, 96–102.

Van Wagner, C.E., 1968. The line intersect method in forest fuel sampling. For. Sci. 14, 20–26.

Woodall, C.W., Monleon, V.J., 2008. Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA program. U.S. Dep. Agric. For. Serv. North. Res. Station. Gen. Tech. Rep. NRS-22. https://doi.org/10.2737/NRS-GTR-22

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

Anil Raj Kizha, Assistant Professor of Forest Operations, School of Forest Resources, UMaine
Adam Daigneault, Assistant Professor of Forest Conservation, and Recreation Policy, School of Forest Resources, UMaine
Shane O'Neill, Forest Industry Business Development Manager, School of Forest Resources, UMaine

Year 1 of 2

Abstract

A major challenge to sustainable management of industrial timberlands in Maine is the abundance of small-diameter trees (SDT) and its limited utilization. Recent inventory estimations from FIA has reported the average diameter at breast height for the region is around 3 in. In general, the high cost of harvesting and low-value of the end-product along with the fluctuating markets have adversely impacted the utilization of SDT. This proposal is a continuum on-going project and will document methods to optimize SDT extraction and logistics, generate stump-to-gate price trends across silvicultural prescriptions, identify incentives and constraints within the market, and to promote the use of SDT for energy production. CFRU members can use the results generated to explore alternative harvesting strategies and potential markets for managing SDT stands. This would ultimately help the members in implementing better silvicultural prescriptions for stands predominant with SDT. A major product of this research is to disseminate the knowledge gained with stakeholders, including forest managers and timberland owners. It would also include presenting the results in local, state, and regional professional conferences and workshops. Dissemination will also be done in the form of peer-reviewed articles and a graduate thesis.

Project Objectives

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

Approach

- The field study was conducted during July and August of 2018 on an industrial timberland property in northern Maine.
- An additional chipping operation was conducted in Western Maine.

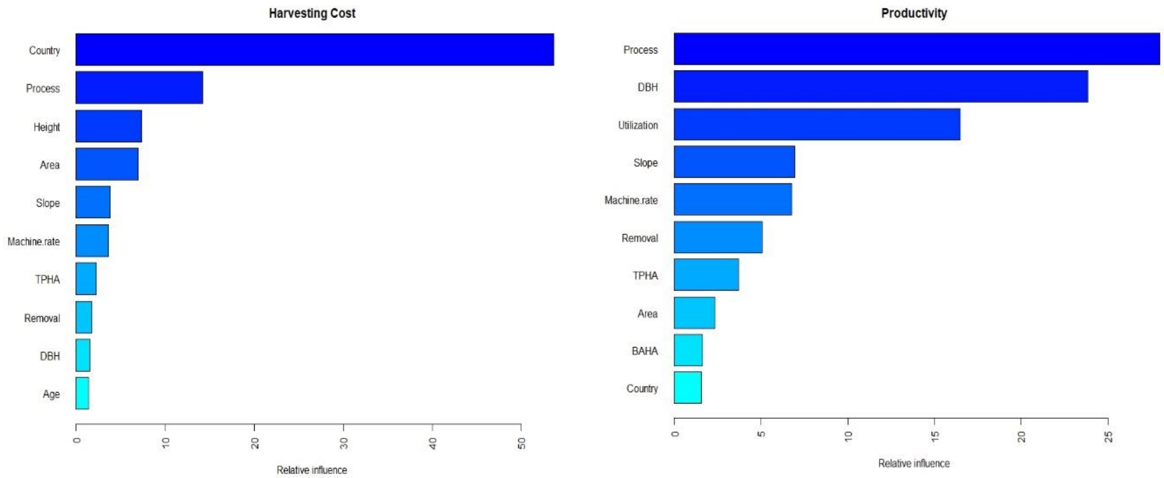


Figure 20. Relative importance of stand level variables for cost and productivity (preliminary results).

- The PI has included an additional objective; i.e., to evaluate the stand damage due to harvesting operation. Two field studies have been completed as a part of this new objective (Table 3 and see photo below).
- Completed review of articles for quantitative analysis of the effect of stand and terrain conditions on the cost and productivity of harvesting operations (Figure 20, Figure 21Figure 22).
- Modelled the supply chain logistics for raw materials using ArcGIS Network Analysis (Table 4, Figure 22).
- Survey has been created for landowners and foresters to quantify the constraints in harvesting SDT.

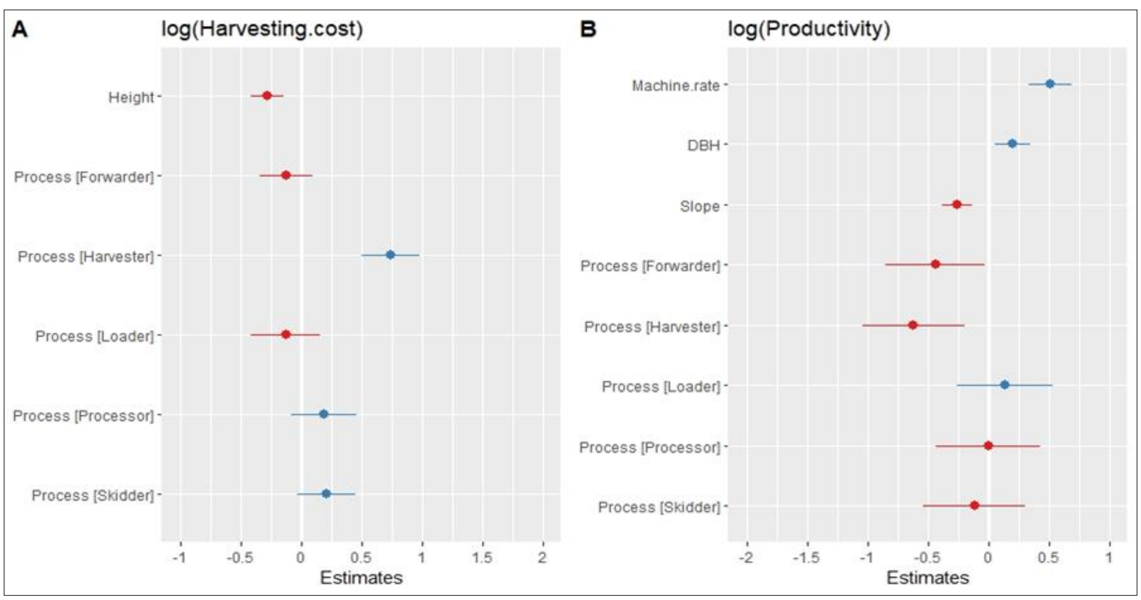


Figure 21. Regression model results for cost and productivity with the effect sizes of independent variables used (preliminary results).

Table 1. Cost (US$ m^{-3}) and productivity (m^3 PMH^{-1}) of each operational phase in whole-tree (WT) and hybrid cut-to-length (Hyb-CTL) harvesting methods for the sawlog component.

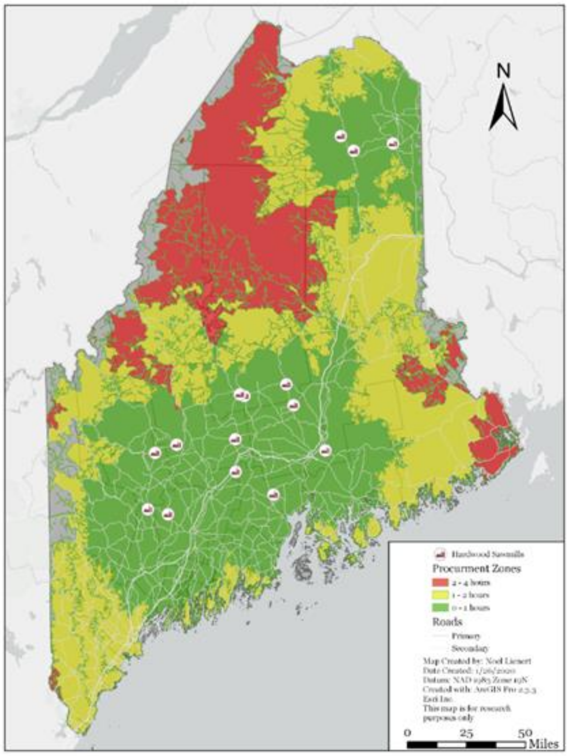
Operational Phase	Cost		Productivity	
	WT	Hyb-CTL	WT	Hyb-CTL
Felling	2.70	2.98	44.84	40.62
Extraction [a]	4.57	10.40	21.72	10.99
Processing	2.75	2.64	36.14	37.64
Loading	1.28	1.28	61.62	61.62
Total	**11.30**	**17.30**	NA	NA

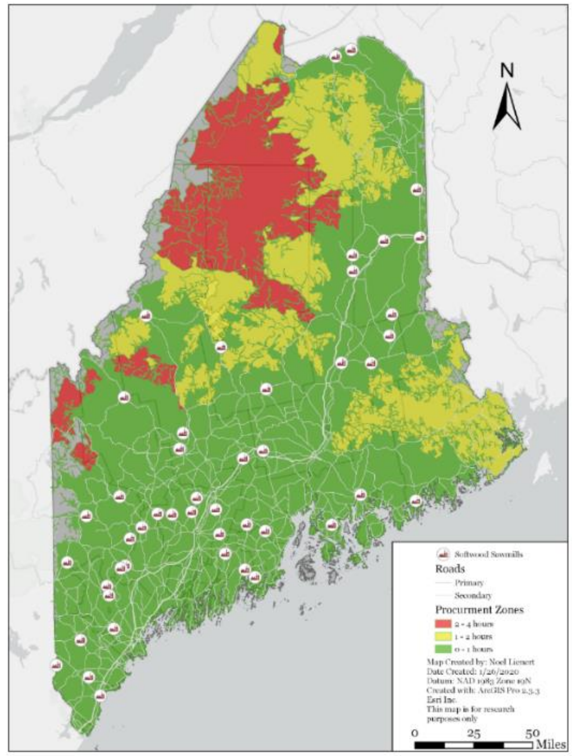
[a] **Extraction for WT and Hyb-CTL operations were skidding and forwarding, respectively**

Key Findings / Accomplishments

- Calculated the cost and productivity of whole tree (WT) and hybrid cut-to-length (Hyb-CTL) operations in Northern Maine and presented as e-poster (Table 1).
- Calculated the cost of integrated harvesting of small-diameter trees dominated stand using two apportioning methods has been published as conference proceedings.
- Developed a novel method for estimating the cost of producing wood chips solely from SDT which is applicable for similar situation in Maine where there is no markets for biomass products (Table 2).
- Conducted a detailed review of timber harvesting studies from the past 25 years for quantitative analysis of the effect of stand and terrain conditions on the cost and productivity of harvesting operations.

Illustrations of severity index (SI) and damages incurred on the tree due to timber harvesting operation. SI were based of visual observation.





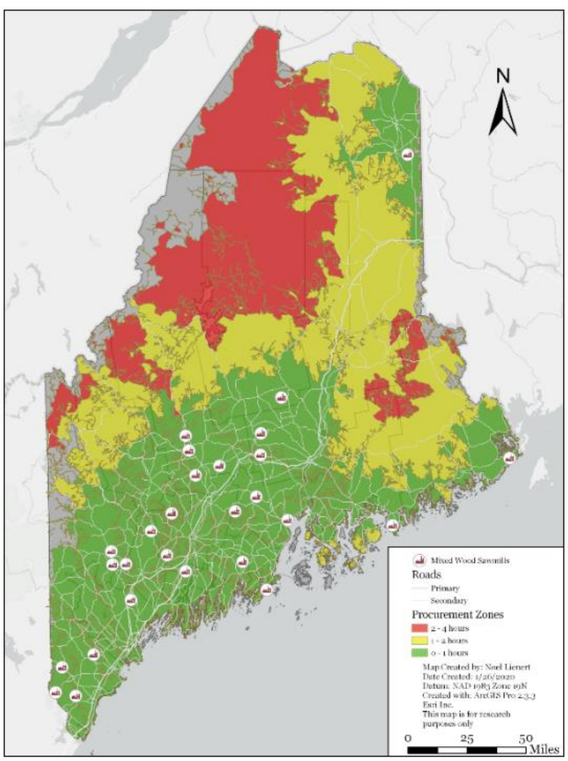


Figure 22. Procurement zones for stationary hardwood (upper left), softwood (upper right), and mixed (lower left) sawmills in Maine

Table 2. Comparison of estimated costs of SDT and sawlogs for joint product, by-product and exclusive product allocations.

Operational phases	Total cost	Joint product		By-product		Exclusive Product	
		SDT	Sawlog	SDT	Sawlog	SDT	Sawlog
Felling	2.70	1.70	1.00	N/A	2.70	12.52	2.44
Extraction	4.57	2.88	1.69	N/A	4.57	19.68	4.83
Processing	2.75	N/A	2.75	N/A	2.75	NA	2.68
Chipping	3.07	3.07	N/A	3.07	N/A	15.32	NA
Loading	1.28	N/A	1.28	N/A	1.28	NA	1.28
Total	**14.37**	**7.65**	**6.72**	**3.07**	**11.30**	**47.53**	**11.23**

Table 3. Tree damages normalized for stand-level for the various treatment blocks on a per hectare basis. The number of damages and trees damaged obtained from the transects were divided with the total inventoried area for respective treatment blocks.

	Study Site I			Study Site II	
	DLC I	**CTR I**	**OSR I**	**DLCII**	**CTR II**
Total number of tree damaged	47	65	131	52	95
Total number of wounds	80	102	186	152	240
Average number of wound. tree^{-1}	1.70 (±0.07)	1.57 (±0.08)	1.42 (±0.04)	2.92 (±0.22)	2.53 (±0.15)
Residual stand damage transects (ha)	2.03	1.87	2.01	6.31	11.81
Wood harvested. ha^{-1a}	113.74	98.00	168.84	102.78	81.89
Number of wounds. ha^{-1}	39	55	93	24	20
Tree damaged. ha^{-1}	23	35	65	6	12

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

[a] The total wood harvested from each block obtained from the scale tickets were divided with the area of treatment block

Table 4. Forest area (in hectares) classified to different procurement zones based on one-way travel time to deliver primary wood products to the stationary sawmills in the state of Maine, USA.

Zone	Travel time	Hardwood	Softwood	Mixed wood	Total
Zone 1	0 - 1 hours	383,455	568,833	784,957	1,737,245
Zone 2	1 - 2 hours	327,882	346,367	558,973	1,233,222
Zone 3	2 - 4 hours	178,181	289,927	570,866	1,038,974
All Zones	Total Area	889,518	1,205,127	1,914,796	4,009,441
Forest Area in State	All Forest	1,028,490	1,379,713	2,116,947	4,525,150

Future Plans

- Meta-analysis article is under preparation and will be submitted to journal in January 2021.
- Survey of the landowners and foresters will be conducted in December 2020 (Approved by IRB). The results will be completed in the spring of 2021.

Acknowledgements

We would like to express our gratitude to Brian, Stephen Dunham, and Jenna Zukswert, as well as CFRU members for their support and help in various stages of the study. Our appreciation goes to all the foresters, contractors and machine operators associated with Irving Woodland LLC and Weyerhaeuser for their involvement in the operational aspect of the study.

Partners / Stakeholders / Collaborators

- Irving Woodland LLC
- Weyerhaeuser

Geographic Location of Project

Fort Kent, ME (MASN site)

INVENTORY & GROWTH MODELING

Assessing and Monitoring Soil Productivity, Carbon Storage, and Conservation on the Maine Adaptive Silviculture Network

Joshua Puhlick, School of Forest Resources, University of Maine
Marie-Cécile Gruselle, Friedrich-Schiller University, Jena, Germany
Ivan Fernandez, School of Forest Resources, Climate Change Institute, University of Maine
Brian Roth, SeedTree Organization

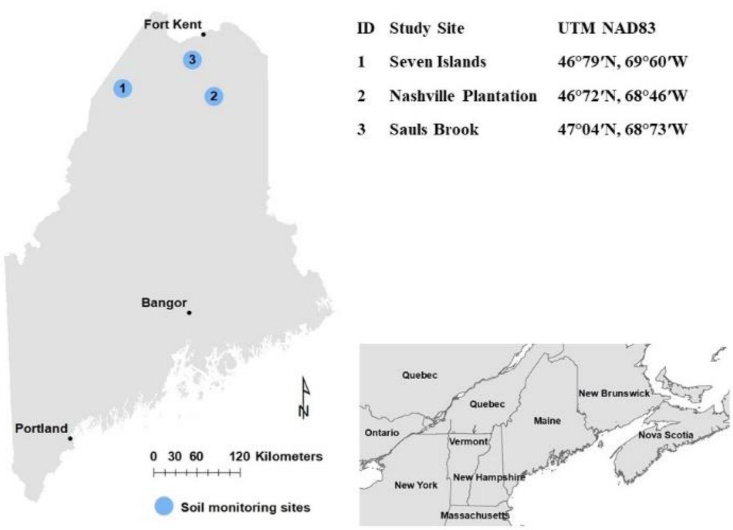
Year 2 of 3

Abstract

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

Background

Puhlick, Gruselle, and Fernandez were awarded a SFI Conservation grant for assessing and monitoring the influence of forest management practices on soil productivity, C storage, and conservation in the Acadian Forest Region. As part of the SFI grant agreement, soils were sampled on two of the Maine Adaptive Silviculture Network (MASN) installations. The influence of different forest management treatments (crop tree release, irregular shelterwood, and partial harvesting) on soils will be investigated. These efforts will inform SFI Forest Management Principles and Standards.



ID	Study Site	UTM NAD83
1	Seven Islands	46°79′N, 69°60′W
2	Nashville Plantation	46°72′N, 68°46′W
3	Sauls Brook	47°04′N, 68°73′W

Figure 23. Locations of MASN installations where soils were collected for this project.

Project Objectives

- Evaluate the influence of different forest management practices on soil productivity, C storage, and conservation across operational-scale research installations in Maine.

- Develop a database of forest management effects on aboveground and belowground C pools and soil physical and chemical properties in the Acadian Forest Region.
- Conduct analyses of archived data to inform the SFI Forest Management Standard and forest management practices promoting the sustainability of soil resources.

Soil Productivity

Background and Methods

Soil nutrient stocks and other metrics of soil productivity are important for assessing forest health and C dynamics. In 2018 and 2019 (before and after timber harvesting), soils were collected in northern hardwood stands managed by J.D. Irving and Seven Islands Land Company at the Sauls Brook and Seven Islands MASN installations (**Error! Reference source not found.**1). The soils of both installations f ormed in glacial till and included Monson and Ragmuff series. Sauls Brook also included the Abram series, which consisted of very shallow soils ranging in thickness from 3-25 cm from the top of the mineral soil to slate bedrock. Soil samples from 52 quantitative soil pits and 150 organic horizons were collected over both years. Soil nutrient stocks and metrics related to soil productivity were derived using results from laboratory analyses on soils collected from quantitative soil pits. Only pre-harvest soil chemical data were available at the time of this report (Figure 24).

Summary

Pre-harvest carbon to nitrogen ratios of soil organic horizons indicated that nitrogen in organic materials exceeded microbial growth requirements and that excess nitrogen was available to plants. For the organic horizon plus mineral soil from the top of the B horizon to a depth of 30 cm or bedrock, P, Ca, Mg, and K stocks varied by installation. For instance, Sauls Brook had lower Ca and Mg stocks compared with Seven Islands, which likely contributed to the higher percentage of American beech and lower percentage of sugar maple at Sauls Brook. There were also significant differences in the effective base saturation in the upper B horizon between installations, with the Sauls Brook installation having values shown to adversely affect sugar maple. Hence, soil properties will be drivers of future species composition and carbon trajectories, and these

Irregular shelterwood treatment at the Sauls Brook MASN installation (photo credit: Joshua Puhlick).

Partial harvest treatment at the Sauls Brook MASN installation (photo credit: Joshua Puhlick).

Partial harvest treatment at the Seven Islands MASN installation (photo credit: Joshua Puhlick).

trajectories will likely vary by specific harvest areas across the landscape.

Pre-harvest live tree C stocks

- Aboveground live tree C stocks were similar among installations and similar to older mixed-species stands on the Penobscot Experimental Forest (Puhlick et al. 2019).
- The proportion of the total aboveground C in live trees ≥ 1.3 cm dbh that included sugar maple was quantitatively greater at the Seven Islands compared to the Sauls Brook installation. Also, no American beech trees were detected on permanent plots for measuring forest attributes at the Seven Islands installation.
- Nutrient stocks, with the Seven Islands installation having greater Ca and Mg stocks, likely influenced aboveground C stocks and species composition

Soil Compaction

At the Sauls Brook and Seven Islands installations, 550 soil samples were collected to determine mineral soil bulk density for evaluating soil compaction after harvesting. Details are included in the soil compaction article cited in the Products section of this report.

Core ideas

- Mineral soils with low bulk densities were the most susceptible to compaction.
- Locations along trails closest to landings were susceptible to compaction.
- Soil moisture and the first machine influenced the effectiveness of slash matting.

CFRU member input and questions

- Greg Adams, Gordon Gamble, Kenny Fergusson, and Ian Prior provided valuable input on the results of the soil compaction study.
- A goal of forest managers is to minimize the amount of the total harvest area in trails, which confines most soil compaction to a relatively small area.
- Are there trade-offs in using slash to minimize soil compaction in trails?
- Did past timber harvesting influence the observed soil bulk densities within trails?

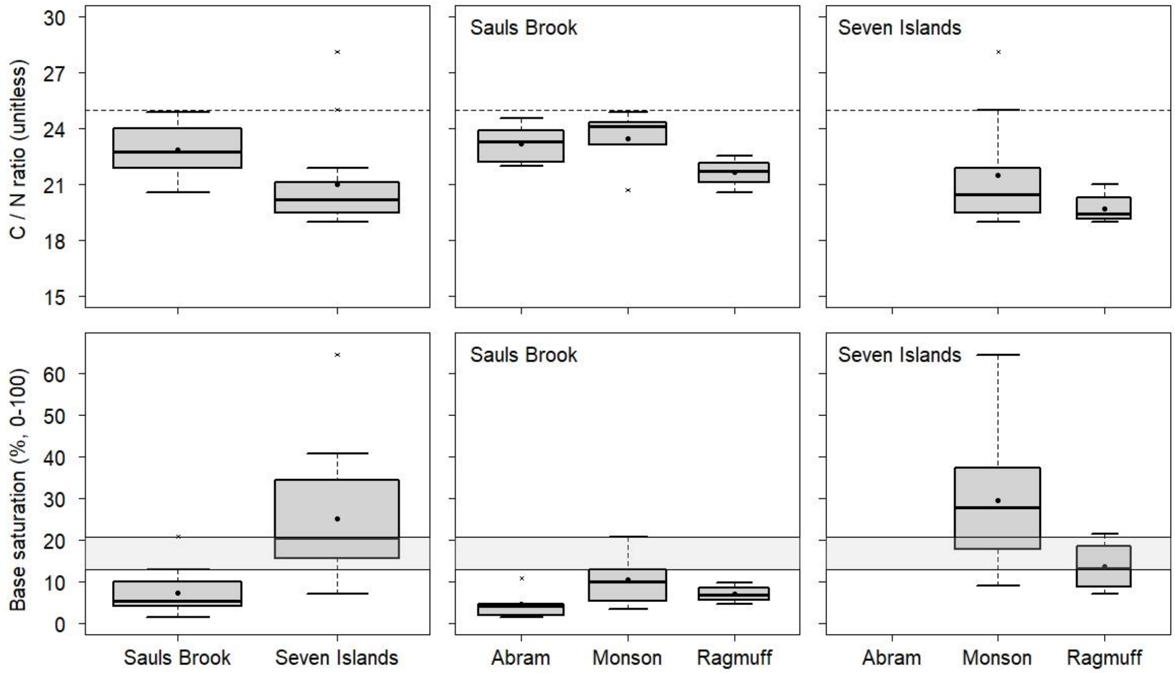


Figure 24. Descriptive statistics for the C/N ratio of the organic horizon and effective base saturation of the 0-5 cm depth increment of the mineral soil B horizon by installation (Sauls Brook and Seven Islands) and soil series (Abram, Monson, and Ragmuff). Black horizontal lines and black dots represent the median and the mean, respectively. The boxes define the interquartile range (25-75% quartile) and the vertical lines represent the whiskers of maximal 1.5 times the interquartile range. Values depicted as x's beyond the whiskers may be considered outliers.

Note: For the C/N ratio, nitrogen becomes limiting to plants at values above ~25 (Caplin III et al. 2002). For a study in the Adirondacks of NY, USA, Lawrence et al. (2018) found that Al mobilization occurred in soils when base saturation values of the upper B horizon were below 13%, soils at or near the Al mobilization threshold can have base saturation values of 13-20.8%, and soils were buffered from Al mobilization above 20.8%.

Considerations and responses to CFRU member questions

- Side trails were well-spaced (~ 20 m apart from one another) across the harvest areas.
- Slash matting in trails is most effective during wet weather conditions. Our findings indicate that some slash could be dispersed outside of trails during dry weather conditions. Slash dispersed outside of trails has been shown to have many benefits, which include the incorporation of slash into soils through decomposition that can improve soil physical and nutrient properties, as well as, slash providing tree regeneration protection from herbivory.
- There was only evidence of a few old logging trails at Sauls Brook. Hence, past harvesting likely had no or minimal effect on the observed soil bulk densities. Details of the harvest history are included in the soil compaction article.


Crop tree release treatment at the Seven Islands MASN installation (photo credit: Joshua Puhlick).

Table 1. Mean ± standard deviation of forest attributes associated with permanent plots by installation. Data are

from measurements of trees ≥ 1.3 cm diameter at breast height.

Attribute	Installation	
	Sauls Brook (*N* = 15)	Seven Islands (*N* = 14)
Aboveground live tree C (Mg ha^{-1})	86.9 ± 22.9	91.6 ± 24.4
Sugar maple C (% of total aboveground live tree C)	36.6 ± 24.6	51.2 ± 26.5
Red maple C (% of total aboveground live tree C)	10.6 ± 13.2	21.3 ± 14.5
Yellow birch C (% of total aboveground live tree C)	11.8 ± 12.1	17.8 ± 14.2
American beech C (% of total aboveground live tree C)	22.4 ± 13.1	0 ± 0

N is the number of plots.

Nashville Plantation

In 2020 (before timber harvesting), soils were sampled in mixedwood stands of a third MASN installation (Nashville Plantation), which is managed by Seven Islands Land Company. Soil samples from 18 quantitative soil pits and 54 organic horizons were collected. The soil pits were located adjacent to permanent plots for measuring other forest attributes. Live trees and snags were measured on the permanent plots before and after timber harvesting. This fall, the soil samples were processed in the laboratory and subsamples were sent to the Analytical Laboratory and Maine Soil Testing Service for chemical analyses.

Non-native earthworms

To our surprise, we discovered non-native earthworms at the Nashville Plantation installation. This is the second installation where earthworms were detected. Puhlick, Fernandez, and Wason drafted and submitted a manuscript on these discoveries and highlight the importance of minimizing new introductions of earthworms in working forests of northern Maine because of their dramatic alteration of the forest floor and soil dynamics.

Mixedwood stand at the Nashville Plantation MASN installation (photo credit: Joshua Puhlick).

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

Considerations

- While more surveys should be conducted to estimate the extent of current earthworm invasions in forests of northern Maine, best management practices to minimize new introductions of earthworms, such as cleaning equipment before transport, should be developed and considered when working in areas known to have earthworms.
- Developing these practices is crucial because earthworm invasions are almost impossible to eradicate unless earthworms are not well established or are found in discrete locations (Callaham et al. 2006).
- It is critical for natural resource managers that we identify the extent of these invasions and the potential impacts they may have on ecosystem function.

Future Plans

- Compute pre-harvest total ecosystem C stocks for Sauls Brook and Seven Islands and investigate relationships between forest C and soil metrics (winter 2021).

- Compute post-harvest total ecosystem C stocks for Sauls Brook and Seven Islands by forest management treatment. Investigate potential differences in soil C and nutrient stocks among the different forest management treatments (winter/spring 2021).
- Review and make any revisions to the preliminary soil productivity analyses (winter/spring 2021).

Acknowledgements

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

Partners / Stakeholders / Collaborators

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

References

Callaham, M.A., Gonzalez, G., Hale, C.M., Heneghan, L., Lachnicht, S.L., and Zou, X.M. 2006. Policy and management responses to earthworm invasions in North America. Biol. Invasions **8**(6): 1317-1329. doi: 10.1007/s10530-006-9016-6.

Caplin III, F.S., Matson, P.A., and Mooney, H.A. 2002. Principles of Terrestrial Ecosystem Ecology. Springer Science and Business Media LLC, New York.

Lawrence, G.B., McDonnell, T.C., Sullivan, T.J., Dovciak, M., Bailey, S.W., Antidormi, M.R., and Zarfos, M.R. 2018. Soil base saturation combines with beech bark disease to influence composition and structure of sugar maple-beech forests in an acid rain-impacted region. Ecosystems **21**(4): 795-810. doi: 10.1007/s10021-017-0186-0.

Puhlick, J.J., Fraver, S., Fernandez, I.J., Teets, A., Weiskittel, A.R., and Kenefic, L.S. 2019. Site quality, disturbance, and vegetation effects on carbon storage and accumulation in old, mixed-species stands in central Maine, USA. Nat. Areas J. **39**(4): 429-441. doi: 10.3375/043.039.0406.

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

Daniel Hayes, School of Forest Resources, University of Maine
Anthony Guay, Wheatland Geospatial Laboratory, University of Maine
David Sandilands, Wheatland Geospatial Laboratory, University of Maine
Aaron Weiskittel, Center for Research on Sustainable Forests, University of Maine

Year 2 of 3

Abstract

In its second year, this project is carrying out ongoing investigations into the use of LiDAR remote sensing analysis to enhance the design and operation of inventory programs for Maine's forest industry stakeholders. The research conducted here is evaluating ground-based inventory plot designs together with existing, publicly available Airborne Laser Scanning (ALS) data sets processed in a high performance computing environment for workflow efficacy in generating geospatial data products useful for forest management. In our initial investigations, we have partnered with the Seven Islands Land Company (SILC) in using their inventories to evaluate the impact of plot type, size and location accuracy on model prediction of forest inventory attributes derived from relating field data sampling with wall-to-wall LiDAR measurements.

Our initial investigations have highlighted some of the challenges in linking plot data with the LiDAR models – particularly with variable radius plots with large locational error. However, the results showed opportunities to improve the process and outcomes with alternative plot designs and ALS data sets that became the focus of investigations over this second year of this project. The results of these analyses continue to emphasize the importance of high-quality calibration data inputs to Lidar-based EFI models, including the use of large, fixed radius plots located with high precision GPS. Over the third year, we are continuing to add additional datasets to these comparisons for more robust results and to reduce uncertainties. Currently, we are working with additional datasets from SILC and the Baskahegan Company, along with new "end-to-end workflow" demonstration projects starting up with Katahdin Forest Management (KFM), the Rangeley Lakes Heritage Trust (RLHT), and Stephen Phillips Memorial Preserve Trust (SPMPT). All of these statistical results from the various comparisons along with more general "lessons learned" on the workflow will be organized within a "Best Practices Guide" for Maine EFI. Importantly, we will continue to work closely and collaboratively with CFRU members, including holding stakeholder workshops and trainings.

Project Objectives

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

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

Approach

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

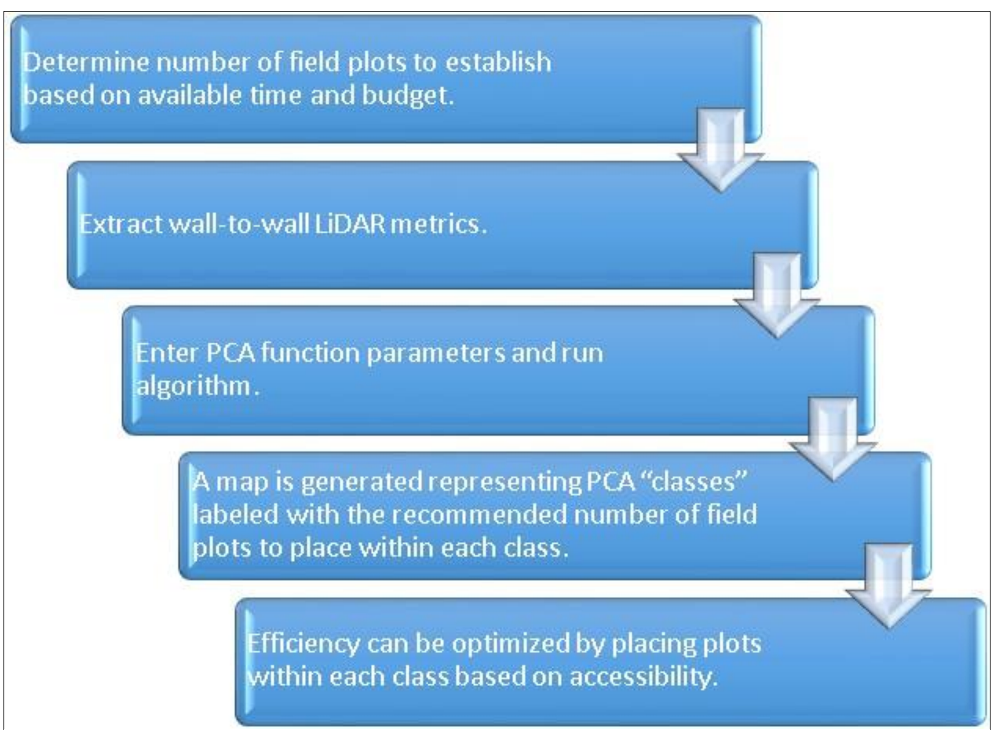


Figure 25. PCA-based workflow for plot stratification.

- Finally, findings from these applied research investigations will be vetted within the community through scientific publications and conference presentations, and disseminated to stakeholders through annual hands-on workshops and a “best practices guidelines” report to be delivered at the end of the project.

Key Findings / Accomplishments

- A comprehensive, flexible and efficient workflow has been developed (and continues to be improved upon) for building, applying and evaluating EFI prediction maps using an area-based approach. The lidR package (Romain 2018) in R is used to calculate the LiDAR metrics, the variable-radius calibration plot data are prepared and organized in spreadsheets, and randomForest (Breiman 2001) is used to perform the EFI variable prediction modeling.
- Wall-to-wall EFI maps of percent softwood, stem density, quadratic mean diameter, basal area and volume were generated for the entire Ashland West and Baskahegan study areas.
- Compared to models built from variable-radius plots (Ashland West), models consistently performed better and returned lower measures of root mean squared error (RMSE) when fixed-radius plots (Baskahegan) were used for calibration. To maintain consistency, this comparison was made using a similar number of plots, located with high-accuracy (survey-grade) GPS. Volume was omitted from this portion of the analysis due to the different units modeled (cubic feet per acre vs. cords per acre) (Table 1).
- Applied research questions relating to plot sampling design are being addressed through comparisons of calibration plot stratification by LiDAR metrics to traditional grid and random sampling methods. Principal component analysis (PCA) is being used as a technique to capture the full range of stand conditions based on the structural variability of wall-to-wall LiDAR metrics (Figure 25). PCA-based, structurally guided field sampling has been instituted for both Rangeley Lakes Heritage Trust and Stephen Phillips Memorial Preserve Trust ownerships (Figure 26) and will be established as the sampling design for Katahdin Forest Management lands.

Table 1. Comparison of Root Mean Squared Error (RMSE) in estimating various EFI metrics between models based on variable-radius vs. fixed-radius calibration plots.

Metric	Variable-Radius	Fixed-Radius	Difference (Improvement)
PSW	25	20	20.0%
TPA	243	206	15.2%
QMD	2.44	1.70	30.3%
BA	57	37	35.1%

- An introductory seminar and follow-on workshops are being planned for winter and summer 2021. The seminar will provide an introduction to EFI concepts and a demonstration of standard EFI workflows. The workshops will focus on hands-on learning opportunities for building EFI maps and summary data products, and how to most effectively use them for subsequent analyses and field use.

Future Plans (Year 3)

- We are continuing to investigate several research questions on plot design, placement, and LiDAR data density for their impacts on EFI model performance and applicability across various project objectives. Specifically, we have expanded these analyses by acquiring plot data from the Canadian Forest Service and high-density airborne LiDAR from NASA to analyze a larger set of comparisons designed to address key parts of the workflow to be reported in the "Best Practices" guidelines deliverable.
- EFI model performance comparisons include (1) calibration plot stratification by LiDAR metrics and existing stand type vs. grid and random sampling designs, (2) calibration plot type (fixed- vs. variable-radius) and location accuracy, and (3) LiDAR point density and type (leaf-on vs. leaf-off).
- We are expanding our stakeholder collaborations to include a greater number of CFRU members in model development, data analysis and technology transfer. This includes EFI development and custom tech transfer workshops with Baskahegan Company, and PCA-based plot stratification and an EFI pilot test with KFM. EFI development will also continue with RLHT and SPMPT, and likely include tech transfer workshops.

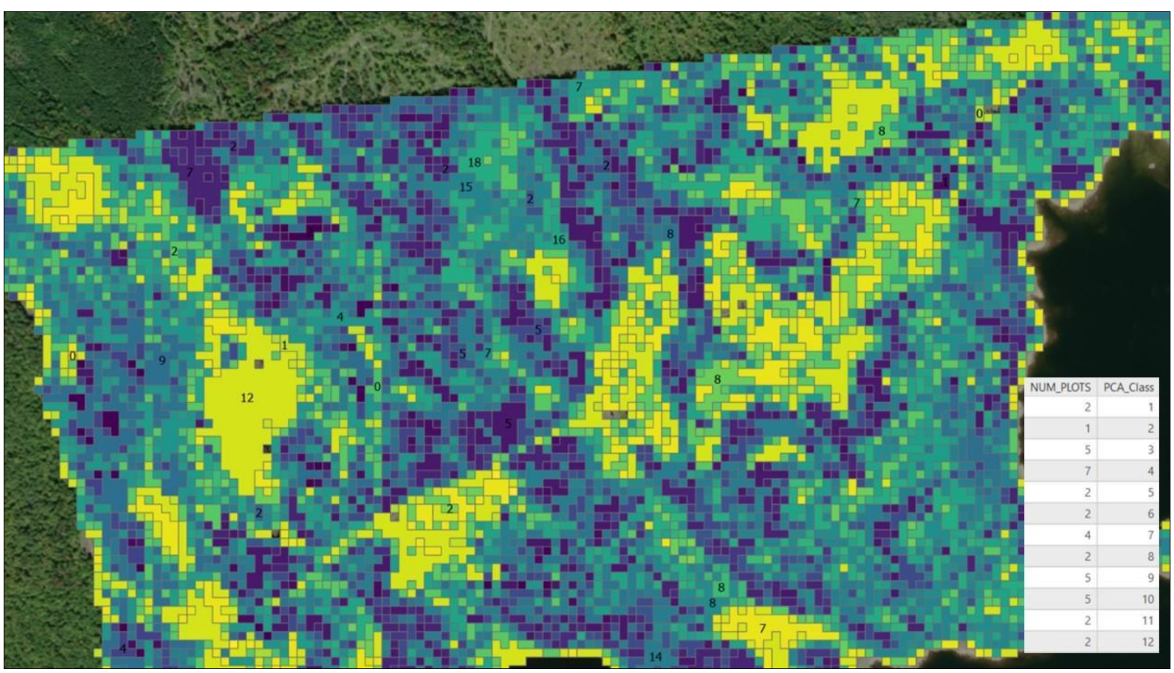


Figure 26. Sample PCA map output that depicts cells representing PCA classes. A statistical algorithm (created by Doug Pitt: Quantitative Silviculturist for Natural Resources Canada) suggests how many of the total desired plots to place within each PCA class in order to fully capture the forest's structural variability.

- We will continue to adhere to our timeline of project deliverables and associated communications plan, including holding technical workshops for CFRU members, disseminating our current findings in presentations to the stakeholder and science communities, and delivering an annual report to the CFRU members on this project's progress, results-to-date and future plans.

Acknowledgements

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

Partners / Stakeholders / Collaborators

Seven Islands Land Company, Baskahegan Company, Rangeley Lakes Heritage Trust, Stephen Phillips Memorial Preserve Trust, Katahdin Forest Management

Geographic Location of Project

Seven Islands Land Company, Ashland West property, and other locations throughout Maine, USA, and New Brunswick, Canada.

Reference

Roussel, J.-R. et al. (2018) 'Package "lidR"', p. 82. https://cran.rproject.org/web/packages/lidR/lidR.pdf.

Spruce Budworm L2 Survey

Neil Thompson, University of Maine at Fort Kent

Year 4

Summary

Counts of spruce budworm second larval instar (L2) overwintering on spruce and fir branches are used to estimate population levels in the following year. The 2019/2020 L2 survey identified a total of 69 L2s at 29 sites, more than double the total count of any previous year, and field surveys in spring 2020 identified larvae and defoliation in the vicinity of the sites with a nonzero L2 count. None of these sites would likely have been identifiable in a conventional aerial survey; populations remain low in comparison to the outbreak that ended in the 1980s but are the highest since the previous outbreak. Many of these are likely the offspring of moths flown in from Quebec on July 15 and 20, 2019, as models indicate these flights landed in the areas where the population was identified. New Brunswick's Early Intervention Strategy relies on L2 data to guide their ongoing population control effort. A threshold of seven L2 per branch has been defined as the tipping point where natural limiting factors are insufficient to control population growth, making the area represented by the site a candidate for insecticide application to supplement natural mortality. We have increased the sampling intensity in areas with observed population increase in 2019/2020 to match the density used in New Brunswick's EIS program. The highest L2 numbers in winter 2019/spring 2020 were in the St. John Valley on lands now owned by CFRU cooperators. Sites with a nonzero L2 count in 2019/2020 were prioritized for early sampling and delivery to the lab in New Brunswick; nineteen sites on CFRU ownership have been processed and none of these have approached the threshold used in New Brunswick. Follow-up sampling is in progress near sites with low but nonzero counts to search for any hotspots not detected in initial sampling.

Project Objectives

- Repeat sampling on established L2 network to describe population change over time and provide early warning of outbreak development.
- Enhance the established L2 network to the standard of the New Brunswick EIS program in areas where a population is known to have grown as a result of 2019 inflights from Quebec.
- Follow up on potential hotspots with supplemental sampling to identify any population growth as early as possible.

Approach

- Collect one branch from the mid-crown of each of three trees at each sample site during the fall or winter. Locations are based on the established sampling network and enhanced in the area of population growth to the density utilized in New Brunswick.
- Branches are transported to the Canadian Forest Service Insect Laboratory in Fredericton, NB for processing. Data are returned in a raw format and mapped for reporting and to support further sampling.

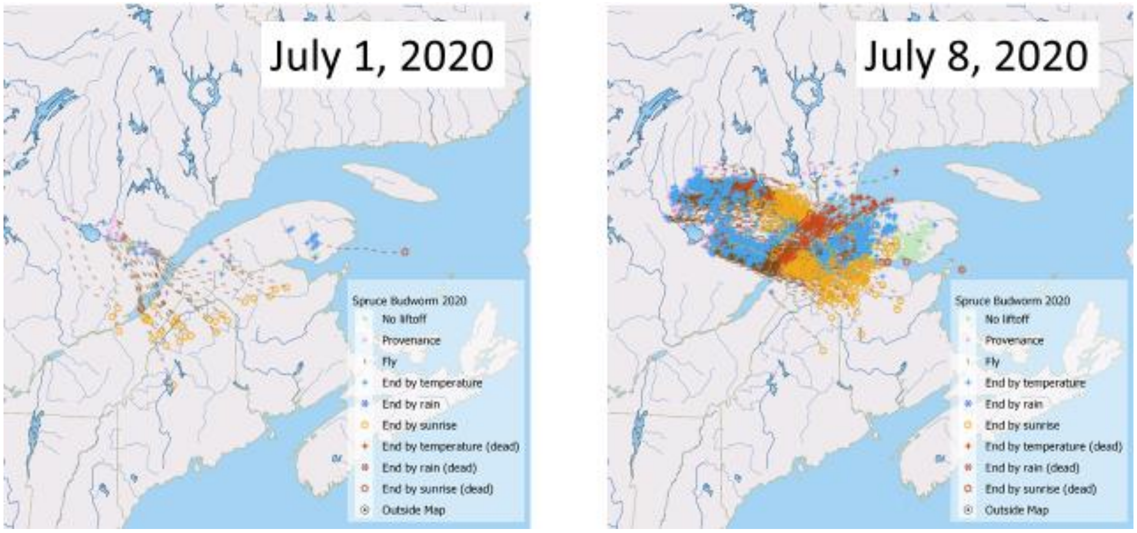


Figure 27. Budworm flights summer 2020. Images courtesy of R. Saint-Armant, Canadian Forest Service.

Key Findings/Accomplishments

- L2 count in 2019/2020 was more than double previous years (2014: 11 | 2015: 33 | 2016: 11 | 2017: 32 | 2018: 25 | **2019: 69**), but remains low compared to historical outbreaks and likely below the detection threshold of conventional aerial surveys. The strategy is working as a means of early detection of population development.
- None of the nineteen priority-resample sites on CFRU ownerships that had nonzero L2 in 2019 exceeded the threshold of seven L2 per branch in 2020, suggesting that local population growth has not yet initiated an outbreak condition.

Future Plans

- Continue L2 monitoring surveys; expand the effort from a detection level density to a monitoring/response density in the vicinity of populations identified in the current surveys
- Continued 2020/2021 sampling in the vicinity of known populations may yet identify hotspots

Acknowledgements

We would like to thank all of the CFRU landowners who have contributed their time and resources to the collection of branches this year and in previous years. Special thanks to Jacob Pliskaner and Andrew Boutin at UMaine and Jackson Ashby at UMFK for receiving and processing branch samples. These students have been integral to the entire effort.

References

Johns, Robert C., et al. "A Conceptual Framework for the Spruce Budworm Early Intervention Strategy: Can Outbreaks be Stopped?." *Forests* 10.10 (2019): 910.

MacLean, David A., et al. "Positive results of an early intervention strategy to suppress a spruce budworm outbreak after five years of trials." *Forests* 10.5 (2019): 448.

Liu, Eric Ye, et al. "Economics of early intervention to suppress a potential spruce budworm outbreak on Crown land in New Brunswick, Canada." *Forests* 10.6 (2019): 481.

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

Colby Brungard, Environmental Soil Consulting
Shane Furze, University of New Brunswick Forest Watershed Research Center
Chris Hennigar, FORUS Research
Jamin Johanson, USDA-NRCS

Year 1 of 3

Abstract

This cross-disciplinary project is producing a suite of raster layers–terrain, wetness, soil properties, forest management, and productivity–that have practical utility to forest managers. Year one focused on pre-processing existing spatial and soil point data for spatial prediction of five soil properties using machine learning techniques, 838 soil point observations, and 48 environmental covariates. Preliminary models yielded promising results (RMSE ≈ 20cm) that should improve with an additional 2,500 soil point observations, and refinement of model covariates and statistical methods in year two. Year one also commenced preliminary work on wet areas mapping (WAM), soil-based forest management algorithms, and pre-processing of LiDAR point cloud data requisite for forest productivity modeling in the 1.25 million acre pilot area. The project is on track to deliver soils, wetness, management, and productivity layers for the pilot area by the end of year 2, and expand these to northern Maine in year 3.

Project Objectives

- Combine soil data with LiDAR-derived WAM, terrain and landform layers to produce a suite of soil property layers using digital soil mapping techniques.
- Incorporate relevant soil property layers with LiDAR-derived WAM to produce a soil-adjusted wetness layer (depth to water table).
- Produce three custom forest management layers derived from soils, wetness, and terrain layers.
- Produce layer of forest productivity estimates using remotely sensed data (LiDAR-based biomass and satellite-based stand age), and correlate productivity with soils, wetness, terrain, and climate factors to predict site index for hardwood, softwood, and mixedwood forest types.
- Assess accuracy of soils, wetness, and productivity layers and create raster layers that express model accuracy (e.g. in terms of RMSE) and bias spatially.

Approach

- Gather and pre-process new and existing soil description data (texture, parent material, depth to water table/bedrock, etc.), along with LiDAR and other relevant remotely-sensed data for spatial analysis in the pilot area.

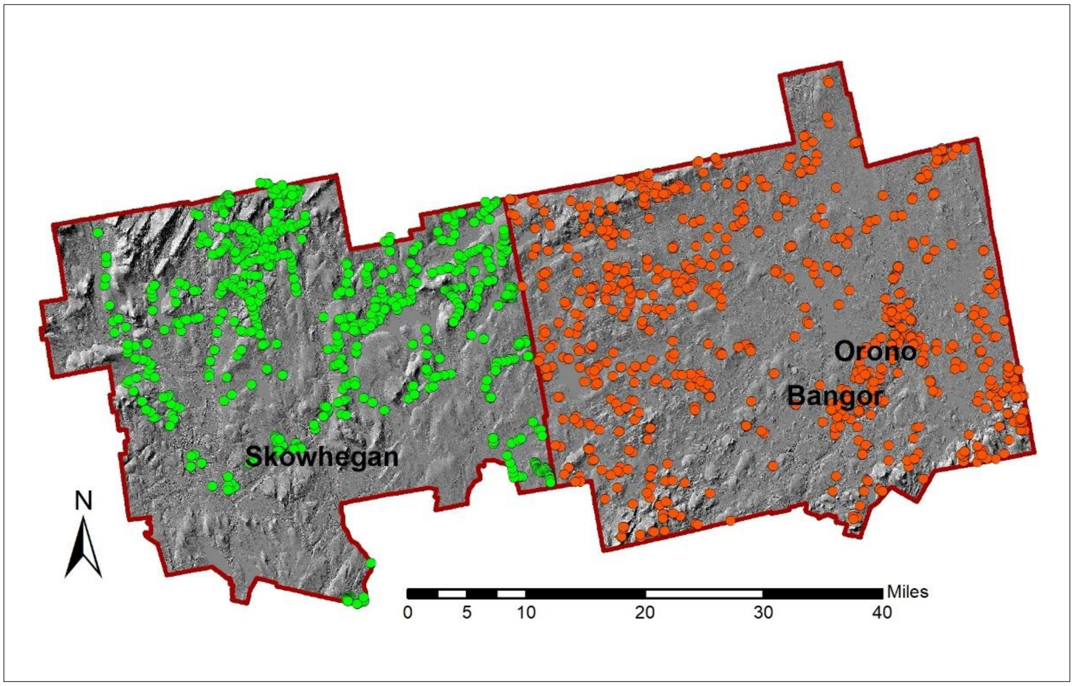


Figure 28. Two sets of soil data points in 1.25 million acre pilot area in southern Somerset County (642 points, green) and southern Penobscot County (838 points, orange). Preliminary analyses (Fig. 2) are based solely on the 838 points in Penobscot County.

- Use well-established terrain analysis, digital soil mapping, and hydrology modeling techniques to generate environmental spatial layers that are useful for modeling site productivity, harvest operability, general harvest season, and soil rutting hazard.
- Use machine learning techniques to spatially predict soil properties by combining thousands of field observations from NRCS soil survey with environmental spatial layers as model covariates. Validate the model with an independent dataset or cross-validation. Generate uncertainty layers that show the spatial variability of soil model performance.
- Develop a calibration for WAM according to soil properties, such that areas with deep or coarse-grained soils reflect deeper water tables and areas with shallow fine-grained soils reflect shallower water tables. Compare the differences between calibrated and uncalibrated WAM, and validate model performance with independent dataset or cross-validation.
- Create logic-based algorithms that generate forest management interpretation layers for harvest operability, harvest season, and soil rutting hazard comparable to existing NRCS soil survey interpretations.
- Use freely available layers of canopy height, biomass, and hardwood content, fit non-linear models of LiDAR-derived biomass estimates and age across hardwood, softwood, and mixedwood types and assess model performance. Relationships and interactions between modeled biomass and site layers (soils, WAM, climate, terrain) will be explored with machine learning techniques to produce an estimated forest productivity layer.

Key Findings / Accomplishments

- 838 soil data points, 36 LiDAR-based terrain derivatives, and 12 spectral layers were compiled and processed for first round of preliminary analyses in 1.25 million acre pilot area.
- 642 additional soil data points have been compiled and processed in preparation for a

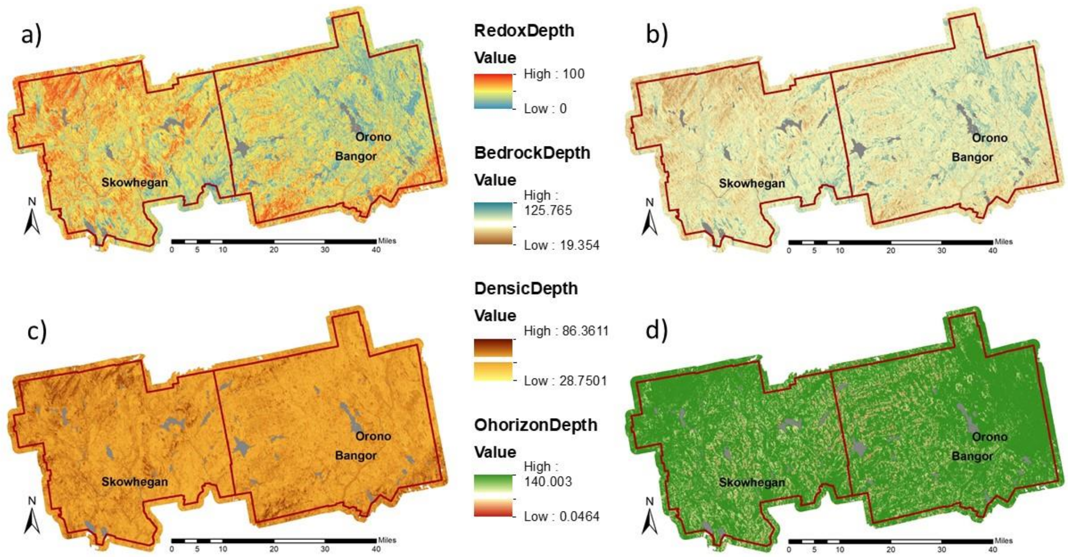


Figure 29. Preliminary spatial predictions of a) soil depth to bedrock, b) soil depth to seasonal water table, c) soil depth to restrictive layer, and d) depth of organic soil surface layer. Depths depicted in cm, with RMSE approximately 20cm for all four soil properties.

second round of preliminary analyses (including more than 100 new field observations, Figure 28), and more than 2,000 soil data points are still being mined and added to the dataset to further refine spatial predictions. Development of additional covariate layers is also ongoing to boost model performance.

- Preliminary spatial prediction of soil properties based on just 838 points and 48 covariate layers resulted in acceptable error levels (RMSE approx. 20cm) for depth to bedrock, depth to seasonal water table, depth to root-restrictive soil layer, depth of organic soil surface, and soil texture (surface). Multiple machine learning algorithms were applied, and random forests produced the best spatial models (Figure 29).
- LiDAR-based WAM has been initiated for the pilot area.
- LiDAR point cloud data has been pre-processed and other spatial layers compiled in preparation for forest productivity modeling.

Future Plans

- Improve soil model accuracy and finalize soil property layers (and associated uncertainty layers) by increasing the number of soil data points and exploring additional covariate layers and modeling algorithms in year 2.
- Validate soil models with an independent field dataset, or with cross-validation.
- Incorporate soil property layers into the production of soil-adjusted WAM, forest management layers, and forest productivity layers in the pilot area in year 2.
- Extrapolate soil models to a 4.5 million acre area in northern Maine (Figure 30). Replicate the forest management interpretation layers and forest productivity layers in the northern

area using the best digital elevation product available (LiDAR still pending release for all of the north area except JD Irving property).

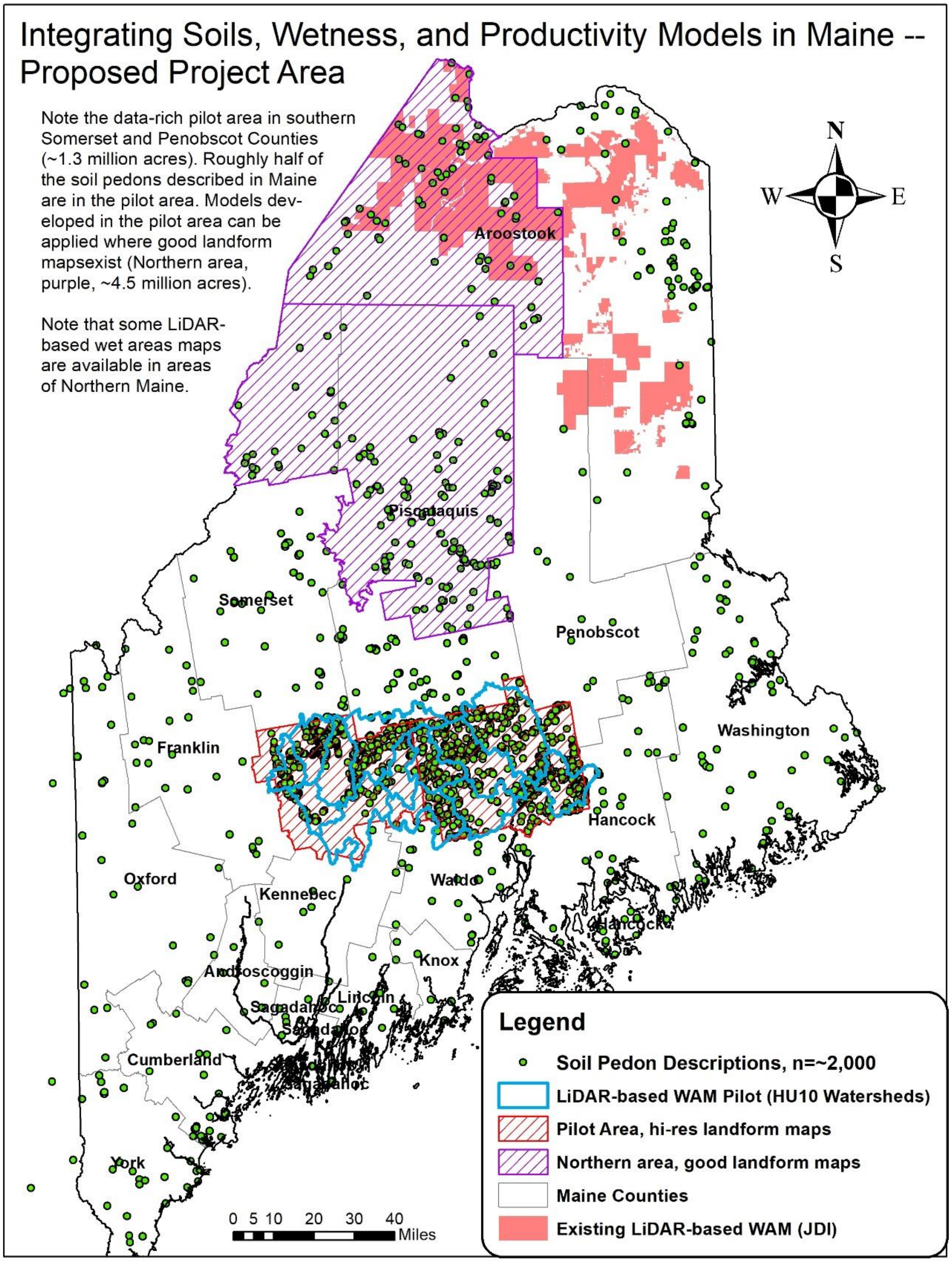


Figure 30. Map of project extent, including a 1.25 million acre pilot area in central Maine, and a 4.5 million acre area in Northern Maine. These two areas were selected based on the availability of data needed for spatial prediction.

Products Delivered

Preliminary R scripts, soil property layers, and model uncertainty layers are under continuous revision, and are available upon request.

Partners / Stakeholders / Collaborators

Paul Arp and Jae Ogilve, University of New Brunswick, Forest Watershed Research Center
Nicholas Butler, USDA-NRCS

Geographic Location of Project

Pilot Area – 1.25 million acres in southern Somerset and Penobscot Counties, ME.
North Area – 4.5 million acres in northern Maine.

Appendix: Project Outputs

Refereed Journal Publications (6)

Buyaskas, Michael, Bryn E. Evans and Alessio Mortelliti. 2020. Assessing the effectiveness of attractants to increase camera trap detection of North American Mammals. Mammalian Biology 100: 91-100. DOI 10.1007/s42991-020-00011-3

Kizha AR, Nahor ER, Coogen N, George AK, Louis LT. 2019. Residual Stand Damage across Varying Silvicultural Prescriptions. Forest Chronicle (under review).

Louis LT and Kizha AR. Wood biomass recovery cost under different harvesting methods and market conditions. International Journal of Forest Engineering. 2020 (in press).

Louis LT, Kizha AR, Daigneault A. 2020. Stand level variation in Timber Harvesting Cost and Productivity: A Meta-analysis. Journal of Cleaner Production (in preparation).

Puhlick, J. J. and I. J. Fernandez. 2020. Influence of mechanized timber harvesting on soil compaction in northern hardwood forests. *Soil Sci. Soc. Am. J.* 84(5): 1737-1750. doi: 10.1002/saj2.20127.

Puhlick, J. J., I. J. Fernandez, and J. W. Wason. 2021. Non-native earthworms invade forest soils in Northern Maine, USA. *Forests*. 12, 80. doi: 10.3390/f12010080.

Conference Papers (3)

Fagan, K.E., D.J. Harrison, E.M. Simons-Legaard, and T.F. Woollard. 2020. Challenging the assumed superiority of camera- versus capture-based surveys for assessing occupancy: A case study with a cryptic forest mustelid. Presentation. The Wildlife Society Annual Meeting, September 28-October 2, Virtual.

Louis LT, Kizha AR. 2019. Comparing the cost of harvesting sawlog and small-diameter trees from different silvicultural prescriptions utilizing two harvesting methods. Session: Forest harvesting systems. 42nd Annual Meeting of the Council on Forest Engineering and 52nd International Symposium on Forestry Mechanization (FORMEC), October 6-9, Sopron, Hungary

Woollard, T. F., D.J. Harrison, E. M. Simons-Legaard, and K.E. Fagan. 2020. A longitudinal study of shifting habitat selection by American martens in response to 30 years of extensive forest harvesting. Presentation. The Wildlife Society Annual Meeting, September 28-October 2, Virtual.

Presentations, Workshops, Meetings, Field Tours (8)

Douglas L. 2020. "The Rusty Blackbird Project – 2019 Inez Boyd Environmental Research Award Recipient Presentation." Digital presentation for the Penobscot Valley Chapter of Maine Audubon, sent out to chapter members during May 2020. Link: https://video.maine.edu/media/The+Rusty+Blackbird+Project+-+2019+IBERA+Recipient+Presentation/1_c7hyo2cs

Douglas, L. and A. Roth. 2020. "Rusty Blackbird use of commercial spruce-fir forests of northern New England." Oral presentation for 27Th Annual Conference of The Wildlife Society, 2020. This presentation was also posted on International Rusty Blackbird Working Group's (IRBWG) website. Link: http://rustyblackbird.org/2020-symposium-presentations-at-the-wildlife-societys-annual-conference/

Kenefic, L. S. and J. J. Puhlick. 2020. Carbon outcomes of silvicultural alternatives at the Penobscot Experimental Forest. Maine Climate Table, Forest Carbon Discussion Group (co-presentation, oral presentation), Online Webinar. September 23, 2020. Recording available online: https://crsf.umaine.edu/resources-2/

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

Louis LT, Kizha AR, Daigneault A. 2019. Global sensitivity analysis of integrated harvesting cost under various stand conditions and machine attributes. 42nd Annual Meeting of the Council on Forest Engineering and 52nd International Symposium on Forestry Mechanization (FORMEC), 6-9 October 2019, Sopron, Hungary.

Louis, L.T, Kizha, A.R, Daigneault A. 2020. Predicting Uncertainties in Timber Harvesting Cost and Productivity. October 30. SAF National Convention (virtual).

Louis, L.T, Kizha, A.R.. 2020. Exclusive Product Allocation: Costing Small-diameter Trees in Maine. October 2. Umaine Student Symposium (virtual).

Puhlick, J. J. 2020. Strategies for enhancing long-term carbon sequestration in mixed-species, naturally regenerated northern temperate forests. Sustainable Forestry Initiative Inc. Sounding Board (oral presentation), Online Workshop. May 20, 2020. Recording available online: https://www.forests.org/conservation-impact-project/

Newspapers / Periodicals / Television / Web Pages

Daniel Harrison served as a guest speaker on two YourForest podcasts, which were distributed for audio listening in the U.S. and Canada.

Forests for Wildlife with Daniel Harrison, December 9, 2020, https://yourforestpodcast.com/episode-1/2020/12/8/96-forests-for-wildlife-with-daniel-harrison

Valuing Forests with Milo Mihajlovich, Robert Wagner, and Daniel Harrison, November 18, 2020, https://yourforestpodcast.com/episode-1/2020/11/17/95-valueing-forests-with-milo-mihajlovich-robert-wagner-and-daniel-harrison

Theses (1)

Tomak, E. 2020. “Temperature and nest parasitism and Rusty Blackbirds (*Euphagus carolinus*) by bird blow flies.” Undergraduate thesis for the College of Natural Sciences, Forestry, and Agriculture.

Capstone (2)

Coogen, Noah. 2019. Analyzing Residual Stand Damage under different Harvesting Methods in the Northern Maine Acadian Forest. School of Forest Resources.

Lienert, Noel. 2020. Procurement Zones in the Maine Forest Product Industry using Network Analysis. School of Forest Resources.

Other Publications (1)

Roth, E., J. J. Puhlick, and I. J. Fernandez. 2020. Relative risk of soil nutrient depletion among different intensities of biomass removal during timber harvesting in Maine, USA. University of Maine, Center for Undergraduate Research Final Report.