Cooperative Forestry Research Unit

2013 Annual Report

CFRU

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Brian E. Roth, Ph.D., Editor

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 34 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.

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Credits

This annual report is compiled and edited by Brian E. Roth, Associate Director. Design work is done by Pamela Wells of Oakleaf Studios, Old Town, Maine. Individual sections are written by authors as indicated, otherwise by Brian Roth. Photography compliments of CFRU archives, or as indicated.

A Note About Units

The CFRU is an applied scientific research organization. As scientists, we favor metric units (e.g., cubic meters, hectares, etc.) 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, etc.). We use both metric and English units in this report. Please consult any of the easily available conversion tables on the internet if you need assistance.

Cover photo: "Austin Pond Study CTL Harvest by Sam Andrews at Bald Mountain Twp., Maine" – January 16th, 2013

Photo courtesy of Patrick Hiesl

Center for Research on Sustainable Forests

1865 THE UNIVERSITY OF MAINE

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RESEARCH HIGHLIGHTS

SILVICULTURE

- **THE COMMERCIAL THINNING RESEARCH NETWORK (CTRN):** The CTRN was established by the Cooperative Forestry Research Unit (CFRU) in 2000 and continues to grow. This network was originally established with the goal of providing information about how spruce-fir stands that have or have not been pre-commercially thinned (PCT) respond to various forms of commercial thinning (CT). Study sites that have had PCT are used to examine responses due to CT timing and relative amount of removal, while those without PCT are used to examine responses due to CT method and relative amount of removal. Recently, the network has expanded to over 18 experimentally controlled study sites across the state including the Austin Pond and Weymouth Point Studies. Results from the network are being used to improve growth and yield models for Maine's forests.

- **HARVEST PRODUCTIVITY AND COSTS:** Harvest productivity and cost estimates are critical pieces of information used by forest resource managers in Maine when planning successful operations. However, this information is often speculative or derived from estimates developed in other regions with logging equipment and conditions dissimilar to those in New England. Using time and motion studies from over a dozen harvest sites in Maine in 2012/13, final cycle time and productivity equations for whole-tree (feller-buncher, grapple skidder, and stroke delimber) and cut-to-length (processor and forwarder) harvesting systems were developed.

- **THE AUSTIN POND STUDY:** This study was established in 1977 by the CFRU to test the efficacy of seven aerially applied herbicides on conifer release in a regenerating clearcut harvested in 1970. In 1986, each of the original treatment plots was divided in half with one-half receiving PCT. Now we are taking this opportunity to extend this study to final rotation by overlaying a series of CT treatments overtop of the existing design. Working with the variety of forest conditions on the site, five broad types of thinning treatments have been assigned in addition to a "start over" clearcut option.

MODELING

- **MODELING HARDWOODS:** The total amount and distribution of leaves along the length of crowns varies by species and is a key driver in the competitive advantage of one species over another. In order to better predict the performance of individual trees in mixed species stands in the Acadian region, a better understanding of how species and silvicultural intensity affects the leaf area development of young hardwood trees is needed. Using data from the SIComp study site on the Penobscot Experimental Forest, equations were developed for five naturally regenerated hardwood species (red maple, gray birch, paper birch, bigtooth aspen, and trembling aspen) that can be incorporated into growth and yield models.

- **MANAGED STAND MODELING:** Forest managers rely on growth and yield models to assess whether their short-term plans will meet long-term sustainability goals. The Acadian variant of the Forest Vegetation Simulator (FVS) is currently being tested and showing good performance across a range of stand types. However, the model was mostly developed using data from naturally-regenerated stands and the primary management activities represented are various commercial thinning regimes. Consequently, intensive management activities like vegetation control, precommercial thinning (PCT), commercial thinning (CT), and genetics are not well represented. The overall goal of this project is to extend the Acadian variant of FVS to intensively managed stands in the region.

- **LINKING INVENTORY AND LIDAR:** The objective of this study was to investigate the applicability of low density (1-3 pulses per square meter) LiDAR data at the Penobscot Experimental Forest to predict inventory attributes on an area- and individual tree basis. Specifically, this study focused on for predicting maximum tree height, stem density, basal area, quadratic mean diameter, and total volume to use an area-based method. For the individual tree based approach, species classification as well as total height and volume predictions were made. Results suggest that low density LiDAR can be used as a supporting tool in forest management in the Acadian Region if the focus is on stand-level attributes.

WILDLIFE HABITAT

- **FOREST HARVESTING, SNOWSHOE HARES AND CANADA LYNX:** Snowshoe hares are a keystone species affecting plant succession, nutrient cycling, and populations of numerous predators and co-existing prey species in northern forest ecosystems. Maintaining an adequate supply of high-quality hare habitat is central to recovery and management efforts for populations of Canada lynx, which are officially designated is threatened in the lower 48 U.S. states and in New Brunswick, Canada. This report documents results from the monitoring and assessment of snowshoe hare density, seasonal habitat use and Canada lynx seasonal prey composition.

- **SPRUCE GROUSE HABITAT:** Spruce grouse are dependent on conifer dominated forests and are abundant across Canada and Alaska. However, the southern border of their range intersects only the northern edge of the contiguous United States where a recent assessment by the International Association of Fish and Wildlife Agencies concluded that populations are rare or declining. There is also concern that their habitat, mid-late successional coniferous forests and wetlands, are being harvested at accelerating rates in Maine. The goals of this project are to increase our understanding of the effects of commercial forest management in northern Maine on patterns of habitat occupancy, habitat use, and reproductive success of spruce grouse. Data collection across a range of stand conditions is ongoing and consists of occupancy surveys, home range analysis of broods, and monitoring of survival and brood rearing success of adult females.

- **BIRD COMMUNITIES AND FOREST MANAGEMENT**: Several bird species of concern thrive in the coniferous forests of Northern New England with the United States Federal government authorized to manage these species under the U.S. Migratory Bird Treaty Act. While Maine contributes up to 96% of breeding habitat for some of these spruce-fir associated species, their habitat requirements and responses to forest management remain poorly understood. This project uses a series of forest bird community surveys to provide information about habitat associations, how these associations are influenced by management, and which habitat attributes can be promoted to manage species of concern in the future.

Bill Patterson
Chair, Advisory Committee

CHAIR'S REPORT

The 2013 annual report of the Cooperative Forestry Research Unit represents the exceptionally good work of many dedicated scientists, foresters, conservation professionals and staff of the CFRU. While the research and monitoring conducted by the CFRU each year provides the foundation, it is the targeted communication and outreach in the form of seminars, field trips, web-based research library and accessible publications that make the CFRU so unique. A special thank you goes to **American Forest Management**, **Prentiss & Carlisle** and the **Maine Department of Conservation** for stepping up to host our fall 2013 Field Tour. Nothing beats getting out and seeing results first hand with other professionals.

I would like to once again extend my thanks to all of the CFRU member companies, agencies and conservation organizations that consistently provide financial support for this research while also donating the professional staff time that is critical to the operation of the Advisory committee. At 35 members strong and 8.29 million acres enrolled in the CFRU, one might anticipate limited potential for growth. However it seems that each year new cooperators join the unit and continue to expand the diversity and depth of representation in the unit and in 2013 we welcomed the **New England Forestry Foundation** as a new member.

As a participant in the CFRU for 8 years and now completing my term as chair, I continue to find the CFRU a highly rewarding aspect of my work. I have learned a great deal from the research but even more so from the professionals and scientists who work to develop and implement the research agenda each year. Working with such a diverse group of organizations and individuals to achieve a set of common research priorities for the Maine forest is no small task, yet the CFRU is remarkably effective in doing just that.

Robert Wagner
Director, CFRU

DIRECTOR'S REPORT

Many thanks go to our CFRU members, staff, Cooperating Scientists, Project Scientists, and graduate students who made this another productive year for the CFRU. The CFRU remains strong as we approach the end of our fourth decade of operation. Our unique industry / university collaboration has solved many of Maine's most pressing forest management challenges over the years. As one of the oldest forest research cooperatives of its kind in the country, we continue to provide critical leadership on key issues facing Maine's forestland managers in the region and country.

Special thanks go to our CFRU Executive Committee **Bill Patterson** (Chair), **Greg Adams** (Vice Chair), **Mark Doty** (Financial Officer), and **Kevin McCarthy** (Member-at-Large) for their continued leadership and support. **Brian Roth** did a great job as CFRU's Associate Director by continuing the difficult installation of the Austin Pond Third Wave project, maintaining our Commercial Thinning Research Network (CTRN) sites, and managing 20 or so summer students and technicians on a variety of other CFRU projects. Brian also is responsible for assembling CFRU's Annual Report, which does a wonderful job chronicling the unit's accomplishments. **Mohammad Bataineh** continued to provide excellent support as a post-doctoral fellow working on Austin Pond and CTRN modeling efforts. CFRU Cooperating Scientists (**Jeff Benjamin, Dan Harrison, Bob Seymour,** and **Aaron Weiskittel**) continued to provide us with strong research leadership in the areas of forest operations, wildlife habitat, silviculture, and forest modeling. **Cindy Smith** did a wonderful job this year as CFRU office manager.

As demonstrated in the following 2013 CFRU Annual Report, the unit continues to deliver a wide array of relevant research findings that contribute to the sustainable management of Maine's working forests.

Robert G. Wagner

CFRU Director

MEMBERSHIP

Major Cooperators

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

Other Cooperators

Field Timberlands
Finestkind Tree Farms
LandVest

Advisory Committee

William Patterson, Chair
The Nature Conservancy

Greg Adams, Vice -Chair
JD Irving, Ltd.

Mark Doty, Financial Officer
Plum Creek Timber Company, Inc.

Kevin McCarthy, Member-at-large
SAPPI Fine Paper

Members

John Brissette, USFS Northern Research Station

John Bryant, American Forest Management, Inc.

Jason Castonguay, Canopy Timberlands Maine, LLC

Tom Charles, Maine Division of Parks & Public Lands

Brian Condon, The Forestland Group, LLC

Dave Daut, Timbervest, LLC

Everett Deschenes, Old Town Fuel & Fiber

David Dow, Prentiss & Carlisle Company, Inc.

Eric Dumond, ReEnergy Holdings, LLC

Kenny Fergusson, Huber Resources Corporation

Alec Giffen, New England Forestry Foundation

Ian Prior, Seven Islands Land Company

Gordon Gamble, Wagner Forest Management

Brian Higgs, Baskahegan Company

Eugene Mahar, Landvest

Marcia McKeague, Katahdin Forest Management, LLC

Jake Metzler, Forest Society of Maine

Rick Morrill, Baxter State Park, SFMA

David Publicover, Appalachian Mountain Club

Tim Richards, UPM Madison

Jim Robbins, Robbins Lumber Company

Dan Russell, Huber Engineered Woods, LLC

RESEARCH TEAM

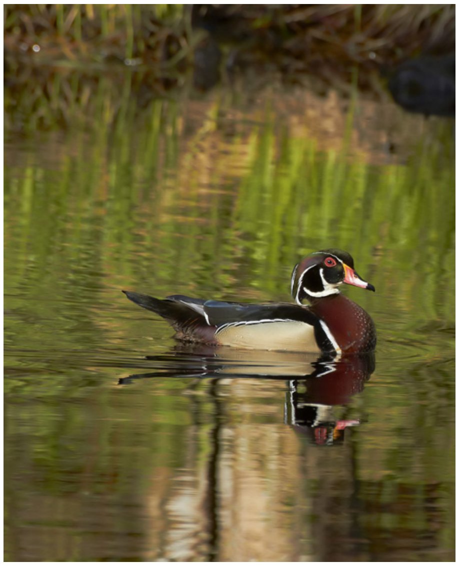
Staff

Robert Wagner, Ph.D., CFRU Director
Director, School of Forest Resources
Director, Center for Research on Sustainable Forests

Brian Roth, Ph.D., Associate, Director

Mohammad Bataineh, Ph.D., Research Scientist

Cynthia Smith, Administrative Assistant



Wood Duck *photo by Pamela Wells*

Cooperating Scientists

Jeffrey Benjamin, Ph.D., Assistant Professor of Forest Operations

Daniel Harrison, Ph.D., Professor of Wildlife Ecology

Robert Seymour, Ph.D., Curtis Hutchins Professor of Forest Resources

Aaron Weiskittel, Ph.D., Assistant Professor of Forest Biometrics and Modeling

Project Scientists

Thom Erdle, Ph.D., Faculty of the University of New Brunswick

Angela Fuller, Ph.D., Assistant Leader, New York Cooperative Fish and Wildlife Research Unit

Chris Hennigar, Ph.D., Faculty of the University of New Brunswick

John Kershaw, Ph.D., Faculty of the University of New Brunswick

David MacLean, Ph.D., Faculty of the University of New Brunswick

Spencer Meyer, M.S., School of Forest Resources, University of Maine

Andrew Nelson, M.S., School of Forest Resources, University of Maine

Ben Rice, M.S. School of Forest Resources, University of Maine

Graduate Students

Patrick Clune (M.S. student - Wagner) - Commercial Thinning

Steven Dunham (M.S. student - Harrison) - Spruce Grouse Habitat

Patrick Hiesl (Ph.D. student - Benjamin) - Logging Productivity and Cost

Andrew Nelson (Ph.D. candidate - Wagner) - Hardwood Regeneration Composition

Sheryn Olson (M.S. student - Harrison) - Snowshoe Hare Population Dynamics

Ben Rice (Ph.D. candidate - Wagner) - Sampling and Modeling Partially Harvested Stands

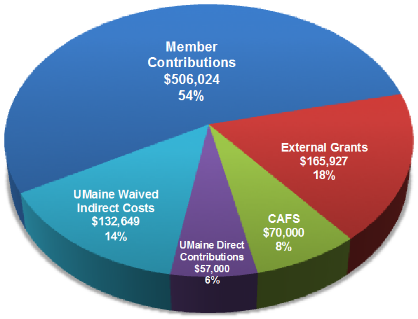
Upper Togue Pond, Baxter State Park - photo by Daniela M. Roth

FINANCIAL REPORT

Thirty-five members representing 8.29 million acres of Maine's forestland contributed $506,024 to support CFRU this year (Table 1-1). These member contributions will be used to support research activities during FY 2013-14. The amount of acreage by our Landowner/Manager members increased by 9,617 acres (0.1%) following a group of land sales and purchases by a number of members. A significant addition this year was welcoming the **New England Forestry Foundation** as a new Landowner/Manager member of CFRU. We look forward to working with them in the coming years. The tons of wood products produced by Wood Processor members declined slightly (50,000 tons or 2.2%) relative to last year. Despite these changes, overall CFRU member contributions increased by $5,917 (1.2%) relative to FY 2011-12. We thank all of our members for their continued financial and in-kind contributions, as well as the trust in the CFRU and UMaine that these contributions represent.

In addition to member financial contribution, CFRU Cooperating and Project Scientists were successful at leveraging an additional $165,927 in extramural grants to support CFRU research projects. In addition to these funds, $70,000 came from the National Science Foundation as part of CFRU's membership in the national Center for Advanced Forestry Systems (CAFS), which is supporting Commercial Thinning Research Network and growth & yield modeling efforts. Thus, a total of $235,927 (26%) came from outside sources to support our research program (figure 1-1). In addition to extramural sources, UMaine provided $57,000 in direct support to CFRU projects in the form of graduate research assistantships and summer student salaries on four projects. Reduced indirect charges on CFRU research projects by the university contributed another $132,649. Therefore, UMaine provided an additional $189,649 or 20% of total funding. In total about 46% ($425,576) of all CFRU funding came from external sources or from direct and indirect support from UMaine.

Fig. 1-1. CFRU Income Sources During FY 2012-13



As a result, for every $1 contributed on average by CFRU's five largest members (Irving Woodlands, Wagner Forest Management, BBC Land, Plum Creek Timber Company, and Prentiss & Carlisle) this year, $7.03 was received from other CFRU member contributions, $4.21 was contributed by external grants through CFRU scientists, and $3.38 was received from UMaine in direct and indirect contributions; for a **total leveraging of $14.62 for every $1 contributed by CFRU's largest members**.

Continued sound fiscal management by CFRU scientists and staff resulted in spending $56,158 (10.4%) less than the $538,505 that was approved by the Advisory Committee for this fiscal year. Every project came in on or under budget. Dr. Dan Harrison requested that the $22,020 surplus on his snowshoe hare project be moved to the following year due to a delay in hiring a graduate student on the project that produced the surplus. The Advisory Committee approved this request at the October 2013 meeting. The remaining unspent balance of $34,138 will be added to the carryover funds that the CFRU Advisory Committee can allocate for future research projects. CFRU research expenses by category this year included 44% on three silviculture projects, 23% on three modeling projects, and 33% on three wildlife habitat projects (figure 1-2).

Fig. 1-2. CFRU Research Expenses During FY 2012-13

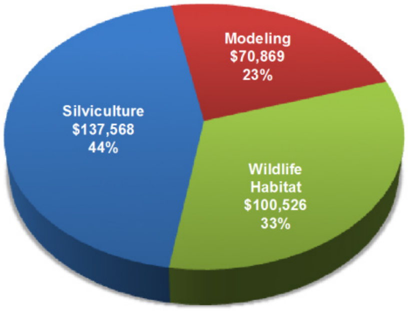


Table 1-1. CFRU Member Contributions Received for FY13-14 (Oct.1, 2012 to Sept.30, 2013).

CFRU Member	Reported for FY11-12		Reported for FY12-13		Change	Assessed Amount	Received as of 10/07/13	Balance Due
LANDOWNER / MANAGER:								
Irving Woodlands, LLC	1,255,000	acres	1,255,000	acres	0	$68,804	$68,804	$0
Wagner Forest Management	1,120,200	acres	1,121,037	acres	837	$61,999	$61,999	$0
BBC Land, LLC	971,538	acres	971,447	acres	-91	$54,328	$54,328	$0
Plum Creek Timber Company, Inc.	884,000	acres	884,000	acres	0	$49,667	$49,667	$0
Prentiss and Carlisle Company, Inc.	807,882	acres	806,419	acres	-1,463	$45,532	$45,532	$0
Seven Islands Land Company	721,261	acres	721,261	acres	0	$40,993	$40,993	$0
Clayton Lake Woodlands Holding, LLC	425,281	acres	451,160	acres	25,879	$26,348	$26,348	$0
Maine Bureau of Parks & Public Lands	400,000	acres	400,000	acres	0	$23,360	$23,360	$0
Katahdin Forest Management, LLC	299,000	acres	299,000	acres	0	$17,462	$17,462	$0
Canopy Timberlands Maine, LLC	294,298	acres	294,194	acres	-104	$17,181	$17,181	$0
The Nature Conservancy	175,863	acres	170,985	acres	-4,878	$9,986	$9,986	$0
Snowshoe Timberlands, LLC	137,720	acres	137,720	acres	0	$8,043	$8,043	$0
The Forestland Group, LLC	147,467	acres	136,965	acres	-10,502	$7,999	$7,999	$0
Baskahegan Corporation	99,487	acres	117,723	acres	18,236	$6,875	$6,875	$0
Sylvan Timberlands, LLC	99,177	acres	105,510	acres	6,333	$6,162	$6,162	$0
North Woods Maine, LLC	84,236	acres	83,409	acres	-827	$4,871	$4,871	$0
Appalachian Mountain Club	65,445	acres	65,489	acres	44	$3,825	$3,825	$0
Simorg North Forest LLC	0	acres	61,643	acres	61,643	$3,600	$3,600	$0
Frontier Forest, LLC	53,338	acres	53,338	acres	0	$3,115	$3,111	$0
Baxter State Park, SFMA	29,537	acres	29,537	acres	0	$1,725	$1,725	$0
Robbins Lumber Company	27,224	acres	26,771	acres	-453	$1,563	$1,563	$0
Timbervest, LLC	110,000	acres	25,191	acres	-84,809	$1,471	$1,471	$0
St. John Timber, LLC	24,845	acres	24,617	acres	-228	$1,438	$1,438	$0
EMC Holdings, LLC	23,526	acres	23,526	acres	0	$1,374	$1,374	$0
New England Forestry Foundation	0	acres	2,880	acres	0	$1,000	$1,000	$0
Mosquito, LLC	16,222	acres	16,222	acres	0	$947	$947	$0
TOTAL	**8,272,547**	**acres**	**8,285,044**	**acres**	**9,617**	**$469,667**	**$469,667**	**$0**
WOOD PROCESSORS:								
SAPPI Fine Paper	1,800,797	tons	1,800,797	tons	0	$22,870	$22,870	$0
UPM Madison Paper	334,150	tons	314,519	tons	-19,631	$3,994	$3,994	$0
Old Town Fuel & Fiber	196,070	tons	164,834	tons	-31,236	$2,093	$2,093	$0
TOTAL	**2,331,017**	**tons**	**2,280,150**	**tons**	**-50,867**	**$28,958**	**$28,958**	**$0**
								$0
CORPORATE & INDIVIDUAL MEMBERS:								
ReEnergy Holdings, LLC						$5,000	$5,000	$0
Huber Engineered Woods, LLC						$1,000	$1,000	$0
Forest Society of Maine						$1,000	$1,000	$0
LandVest						$200	$200	$0
Field Timberlands						$100	$100	$0
Finestkind Tree Farms						$100	$100	$0
TOTAL						**$7,400**	**$7,400**	**$0**
								$0
GRAND TOTAL (35 members):						**$506,024**	**$506,024**	**$0**

Table 1-2. CFRU Expenses for FY 2012-13

	Principal Investigator(s)	Approved Amount	Amount Spent	Balance	% Remaining
Administration		**$193,962**	**$173,384**	**$20,578**	**10.6%**
Administration		$181,446	$173,384	$8,062	4.4%
Silviculture Post-Doc		$12,517	$0	$12,517	100.0%
Research Projects					
Silviculture:		**$150,756**	**$137,568**	**$13,188**	**8.7%**
Commercial Thinning Research Network	Wagner et al.	$55,877	$55,779	$98	0.2%
Austin Pond: Third Wave	Wagner et al.	$56,481	$43,999	$12,482	22.1%
Productivity Cost of Logging Equipment	Benjamin et al.	$38,398	$37,790	$608	1.6%
Modeling:		**$71,111**	**$70,869**	**$242**	**0.3%**
Young Hardwood Silviculture Response G&Y Modeling	Wagner et al.	$22,617	$22,417	$200	0.9%
Extending the Acadian variant of FVS to managed stands	Weiskittel	$18,646	$18,645	$1	0.0%
Linking LiDAR to Ground-Based Inventory	Weiskittel	$29,848	$29,807	$41	0.1%
Wildlife Habitat:		**$122,676**	**$100,526**	**$22,150**	**18.1%**
Spruce Grouse Habitat in Northern Maine	Harrison	$38,500	$38,370	$130	0.3%
Long-term Monitoring of Snowshoe Hare *	Harrison	$55,212	$33,192	$22,020	39.9%
Effects of forest management practices on forest bird communities	Harrison	$28,964	$28,964	$0	0.0%
TOTAL		**$538,505**	**$482,347**	**$56,158**	**10.4%**

***** *Harrison requested carrying forward unspent funds on this project to FY2013-14. Request was approved by CFRU Advisory Committee.*

ACTIVITIES

Advisory Committee

The CFRU is guided by our member organizations through an Advisory Committee. The CFRU Advisory Committee elects officers for the Executive Committee for two-year terms in the positions of Chairperson, Vice Chairperson, Member-at-Large, and Financial Officer. The Vice Chairperson serves as Chairperson after one term, and the past Chairperson moves to the position of Financial Officer for one term. Last year **Bill Patterson** of **The Nature Conservancy** (figure 1-3) assumed the position of Chair while **Mark Doty** of **Plum Creek** moved to the Financial Officer position previously held by **John Bryant** of **American Forest Management/BBC Land, LLC**. **Greg Adams** of **JD Irving, Ltd.** will serve as Chair beginning in 2014.

Figure 1-3. Advisory Committee Chair, Bill Patterson (The Nature Conservancy).

The Advisory Committee meets three times a year for business meetings. The first business meeting of the fiscal year was held on October 17th, 2012 at the **University of Maine (UMaine)** where **Dr. Chris Hennigar** of **UNB** gave his final presentation of the spruce Busworm mapping project. At the second meeting, held on January 26, 2013 at **UMaine**, five pre-proposals were presented to the Advisory Committee. Of these, all five were approved to advance to the full proposal stage and were presented at the April 24, 2013 business meeting. Five projects were approved for funding beginning on October 1, 2013. Look for updates on these projects in future CFRU functions and annual reports.

Cooperators

The CFRU added two new members in 2013: **ReEnergy Holdings, LLC** represented by **Eric Dumond** and the **New England Forestry Foundation** represented by **Alec Giffen**. There were no major changes in land ownership amongst the CFRU membership.

Personnel

Dr. Mohammad Bataineh continued to serve as the CFRU/USFS **Postdoctoral Research Fellow**. Mohammad earned his Ph.D. from **Stephen F. Austin State University** in **Texas**. Mohammad has continued to be very productive since joining the CFRU, conducting numerous analyses and contributing a number of excellent publications on CFRU projects. **Cindy Smith** joined the CFRU as the permanent replacement for **Rosanna Libby** who retired from the CFRU after four years as Administrative Assistant in 2011. Cindy has done a marvelous job in 2013.

2013 Fall Field Tour

On October 10th, 2013 the CFRU held its annual **Fall Field Tour**. This year's tour entitled **"Overstory Removal and Advanced Regeneration: Challenges and Opportunities"** was held in the Nicatous/Duck Lakes region and was hosted on land managed by **American Forest Management, Prentiss & Carlisle**, and the **Maine Bureau of Parks and Lands**. The tour focused on the challenges and opportunities facing managers when planning harvest entries in shelterwoods, intermediate cuts and final overstory removals. The challenges are how to effectively and economically remove the merchantable timber while protecting the advaced regeneration in the understory. There were presentations by **Tom Charles** (Maine Bureau Parks & Lands), **George Ritz** (Retired MBPL), **David Adams** (DASCO Inc.), **Franklin Leavitt** (Crop Protection Services), **Robert Wagner** (CFRU), **Spencer Meyer** (CRSF), **David Dow** (Prentiss & Carlisle), **Jeremy Miller** (Prentiss & Carlisle),

Mohammad Bataineh (CFRU), **John Bryant** (American Forest Management), **Al LeBrun** (American Forest Management), **Patrick Hiesl** (CFRU) **and Robert Seymour** (CFRU) (figure 1-4).

Students

There currently are six graduate students working on CFRU projects. This year, **Patrick Clune (M.S.), Andrew Nelson (Ph.D.)** and **Patrick Hiesl (M.S.)** graduated. Patrick Clune worked on the 10-year results from the Commercial Thinning Research Network (CTRN) under the supervision of Bob Wagner.

Patrick Hiesl was supervised by Jeff Benjamin and focused on logging productivity and costs. Andrew Nelson's project on the composition of hardwood regeneration was directed by Bob Wagner.

Figure 1-4. CFRU members at the Nicatous Lodge on the Fall Field Tour held on October 18th, 2013.

CENTER FOR ADVANCED FORESTRY SYSTEMS (CAFS)

By Bob Wagner and Aaron Weiskittel

Bob Wagner and Aaron Weiskittel completed the third year of a program funded by the **National Science Foundation** (NSF) Industry/University Cooperative Research Centers Program (I/UCRC) this year. This ten-year program resulted from a partnership between CFRU members and the I/UCRC to support a **University of Maine** research site within the **Center for Advanced Forestry Systems** (CAFS). CAFS unites leading university forest research programs and forest industry members across the US to solve complex, industry-wide problems at multiple scales using interdisciplinary collaborations. The mission of CAFS is to optimize genetic and cultural systems to produce high-quality raw forest materials for new and existing products by conducting collaborative research that transcends species, regions, and disciplinary boundaries.

CAFS is a multi-university center that works to solve forestry problems using multi-faceted approaches and questions at multiple scales, including molecular, cellular, individual-tree, stand, and ecosystem levels. Collaboration among scientists with expertise in biological sciences (biotechnology, genomics, ecology, physiology, and soils) and management (silviculture, bioinformatics, modeling, remote sensing, and spatial analysis) is at the core of CAFS research.

CAFS provides $60,000 per year to the University of Maine and CFRU members to advance growth and yield models for natural forest stands in the Northeast. This funding supported **Matt Russell** (former Ph.D. student) and **Patrick Clune** (M.S. student). Patrick completed his M.S. thesis entitled, "Growth and Development of Maine Spruce-Fir Forests Following Commercial Thinning." We congratulate Patrick on this achievement and wish him the best in his new position as a planning analyst with **Hancock Forest Management** in Vancouver, WA.

In April of 2013, the CAFS Annual Meeting was hosted by the **University of Georgia** in St. Simons Island, GA. The meeting was well attended by scientists, graduate students, and forest industry representatives who met to review and approve all CAFS projects nationwide. (figure 1-5).

Figure 1-5. Kenny Fergusson (Huber) and Gaëtan Pelletier (NHRI) on a regionwide fertilizer experiment on April 11th, 2013.

Silviculture

Commercial Thinning Research Network

Harvest Productivity and Cost

Austin Pond Study

COMMERCIAL THINNING RESEARCH NETWORK: 2013 UPDATE

Brian Roth, Robert Wagner, Robert Seymour, Aaron Weiskittel and Spencer Meyer

Introduction

The CFRU Commercial Thinning Research Network (CTRN), which examines commercial thinning responses in Maine spruce-fir stands, began with two experiments established in 2000. These initial experiments consisted of a dozen study sites on CFRU cooperator lands across the state. The first study was established in mature balsam fir stands on six sites that had previously received pre-commercial thinning (PCT). This study quantifies the growth and yield responses from the timing of first commercial thinning (i.e., now, delay five years, and delay 10 years) and level of residual relative density (i.e., 33% and 50% relative density reduction). The second study, also established on six sites, was installed in mature spruce-fir stands without previous PCT ("No-PCT") to quantify the growth and yield response from commercial thinning methods (i.e., low, crown, and dominant) and level of residual relative density (i.e., 33% and 50% relative density reduction). In 2009, the CTRN was expanded to include a third experiment consisting of three PCT locations on intermediate and low-quality sites and follows an experimental design similar to that of the first study. See previous Annual Reports for a more thorough description of the experimental design and implementation of these first three experiments.

Beginning in 2011, the CTRN was expanded to include previously established thinning studies, such as the Early Commercial Thinning (ECT) and Austin Pond Third Wave projects. In 2011, the ECT study imposed a series of commercial thinning treatments on a combination of trail spacings (50 vs. 80 ft.) and harvest methods (CTL vs. WT) on a mid-quality softwood site (see Early Commercial Thinning Study proposal). In 2012, a 'third wave' of treatments consisting of a commercial thinning was implemented at the Austin Pond study and follows a similar thinning treatment as the first two CTRN experiments (see section on Austin Pond Update in this report). Including these two studies in the CTRN is a cost effective way to capture long-term data since the expense of treatment and plot installation has already been carried by the previous projects. These experiments also have the advantage of unit area replication within locations, which is absent in the first three experiments.

Field Season

The 2013 CTRN measurement crew was adeptly managed by **Derek Brockmann** and consisted of **Brandon Learnard, Stephen Sacks, Sarah Thibeault, Lucas Ashbaugh, Matthew McCullough, Daniel Perry, Dave Jacobs, Jeremiah Burch** (figure 2-1). Additionally, **Stephen Comeau**, a STEM student from **Bangor High School** joined the crew for the first half of the measurement season. This measurement season was less intense than last, given the alternating measurement periods between the various experiments in the network. Generally, annual re-measurements alternate between an extensive measurement (EM) and an intensive measurement (IM) for a period of time following treatment. The extensive measurement consists of DBH and condition which captures information about mortality in a cost effective manner.

Figure 2-1. CTRN measurement crew on the Penobscot Experimental Forest on May 29th, 2013.

In 2013, all 15 CTRN installations, the Austin Pond Study, and the Early Commercial Thinning Study were visited. All CTRN installations had an EM with the exception of Weeks Brook which had an IM as it was thinned in the previous year. Only the PCT half of the Austin Pond Study was re-measured as it had been harvested the year before (IM). A total of 13,325 trees were measured. Each plot had all living trees stem mapped in 2013. Including mapped locations of each tree in the database will be required for future distance-dependent G&Y modeling efforts as well as remote sensing projects such as LiDAR (see 2013 LiDAR Proposal). The CTRN Database now contains almost 26,000 individual trees with over measurements.

Summary

The CTRN database now contains over 172,000 unique measurements on over 26,000 trees on 15 sites plus the Austin Pond Study, the Early Commercial Thinning Study and the Weymouth Point Study. This world-class database continues to provide valuable growth and yield data which is actively being used in multiple modeling projects. Patrick Clune, under the direction of Bob Wagner, has completed the analysis of the first ten years of data for his MS project on a CAFS assistantship. These results are reported in Patrick's MS Thesis.

HARVEST PRODUCTIVITY AND COSTS

Patrick Hiesl and Jeffery Benjamin

Introduction

Over the last year we developed final cycle time and productivity equations for whole-tree (feller-buncher, grapple skidder, and stroke delimber) and cut-to-length (processor and forwarder) harvesting systems. Operations data were collected in 2012 from seven whole-tree and five cut-to-length harvest sites throughout Maine including observations of residual stand damage. During the summer of 2013 we collected additional data to validate the models. This report will highlight cycle time and productivity equations as well as key results of this study to date.

It is important to note that the results of this work have been well received by both the academic community and the forest industry region-wide. We presented our results at the 2013 New England Region Council on Forest Engineering in Orono (Benjamin and Hiesl 2013), the 2013 Council on Forest Engineering meeting in Missoula, MT (Hiesl and Benjamin 2013c), and the 2013 CFRU field tour (Hiesl and Benjamin 2013d). Further, we were also invited to present this work at several workshops with local logging contractors (e.g. Hiesl & Benjamin, 2013c). To increase the use of the results by Maine's forest industry we, in cooperation with the Maine Agriculture and Forestry Experiment Station, produced a field-size booklet with the important cycle time and productivity information both in imperial and metric units (Hiesl and Benjamin 2013g). Production estimates for weight and volume are provided in cords, tons, and m3 per productive machine hour (PMH). Finally, we have published two peer-reviewed articles from this project (Hiesl and Benjamin 2013a; Hiesl and Benjamin 2013b) and we have currently another one in revision (Hiesl and Benjamin 2013h). Over the next year we have plans for a fourth article related to the production balance between grapple skidders and stroke delimbers.

Cycle Time and Productivity

A detailed account of the analysis techniques used to develop each model are provided in the MS thesis by Hiesl (2013), but a brief summary is provided in the following paragraphs. Time and motion study data collected from the 12 harvest sites in 2012 were summarized in a database and then analyzed using R (R Core Team 2012) and the car (Fox and Weisberg 2011) and nlme (Pinheiro *et al.* 2012) packages. To estimate individual tree volumes for the development of productivity equations two steps were necessary. First, five to ten trees per species with different diameters were measured to develop linear regression models of tree height. Then total tree volume needed for feller-buncher and grapple skidder analysis was estimated using Honer's equations (Honer 1967), while the total merchantable volume needed for processor and stroke delimber analysis was estimated using regional taper and volume equations (Li *et al.* 2012; Weiskittel and Li 2012). Average log volume for forwarder logs was calculated using 75 to 100 log measurements per site.

Linear mixed-effects models with a random intercept were developed to predict the cycle time and productivity of each machine. This approach allowed us to use the combination of operator, machine, and site conditions as a random effect, which helped us explain how this combination affects machine productivity. For the processor and stroked delimber analysis a "dummy" variable of species group was created to differentiate between softwood and hardwood species. Two linear regression models were developed for each machine (except feller-buncher) to predict cycle time and productivity, respectively. In order to satisfy the linear regression model assumption of normally distributed residuals, dependent variables cycle time and productivity for all machines were log transformed. The only exception to this was the stroke delimber model where normality was achieved using a square root transformation. The variables stand density, basal area, and removal intensity were not significant in predicting cycle time or productivity for any machine. Feller-buncher and processor models were validated using early commercial thinning data summarized by Benjamin and others (2013). The final models are provided as follows:

Cycle Time Equations

Feller-Buncher

$$\text{Cycle Time}[min] = \exp(-0.888 + 0.136 \times \text{Stem Count } [\#] + 0.017 \times \text{sumDBH [in]})$$

Grapple Skidder

$$\text{Cycle Time}[min] = \exp(1.618 + 0.0005 \times \text{Distance } [ft])$$

Stroke Delimber

$$\text{Cycle Time}[min] = \exp(-1.247 + 0.099 \times \text{DBH [in]} - 0.135 \times SPPGRP[dummy])$$

SPPGRP is a dummy variable with 1 for softwood and 0 for hardwood.

Processor

$$\text{Cycle Time}[min] = \exp(-1.129 + 0.104 \times \text{DBH } [in] - 0.246 \times \text{SPPGRP[dummy]})$$

SPPGRP is a dummy variable with 1 for softwood and 0 for hardwood.

Forwarder

$$\text{Cycle Time}[min] = 24.725 + 0.012 \times \text{Dist.} [ft]$$

Productivity Equations in tons/PMH

Feller-Buncher

No productivity function developed.

Grapple Skidder

$$\text{Productivity}\left[\frac{\text{tons}}{\text{PMH}}\right] = \exp(2.587 - 0.0005 \times \text{Distance [ft]} + 0.328 \times \text{BunchVol [tons]})$$

Stroke Delimber

$$\text{Productivity}\left[\frac{\text{tons}}{\text{PMH}}\right] = (-0.684 + 0.538 \times \text{DBH [in]} + 0.629 \times \text{SPPGRP[dummy]})^2$$

SPPGRP is a dummy variable with 1 for softwood and 0 for hardwood.

Processor

$$\text{Productivity}\left[\frac{\text{tons}}{\text{PMH}}\right] = \exp(-0.015 + 0.309 \times \text{DBH [in]} + 0.317 \times \text{SPPGRP[dummy]})$$

SPPGRP is a dummy variable with 1 for softwood and 0 for hardwood.

Forwarder

$$\text{Productivity}\left[\frac{\text{tons}}{\text{PMH}}\right] = -3.676 - 0.004 \times \text{Dist. [ft]} + 158.891 \times \text{LogVol[tons]} + 0.082 \times \text{\#Logs}$$

Results

Results from this study clearly show the negative impact of stem size on cycle time and productivity for harvesting and processing (figures 2-2 to 2-4). We have known this to be true intuitively, but now we have predictive models that support our assumptions. For the feller-buncher productivity curves (figure 2-2) it is important to note that the estimates shown are based on assumptions of tree size and number of trees per accumulation as described in the 2012 CFRU report (Hiesl and Benjamin 2013e). A very detailed description on how these parameters can be derived in practice is provided in Hiesl & Benjamin (2013f).

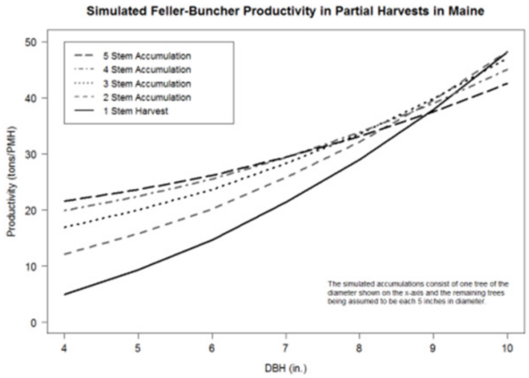


Figure 2-2. Productivity curve for feller-buncher with feller-buncher head accumulations of one to five trees.

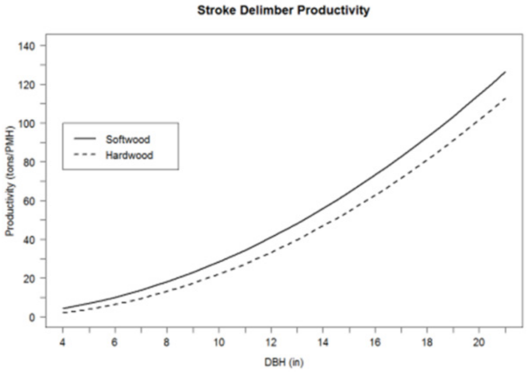


Figure 2-3. Productivity curves for stroke delimber showing the effect of stem size and species.

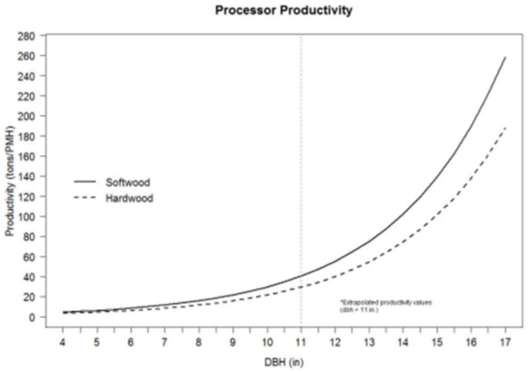


Figure 2-4. Productivity curves for processor showing the effect of stem size and species.

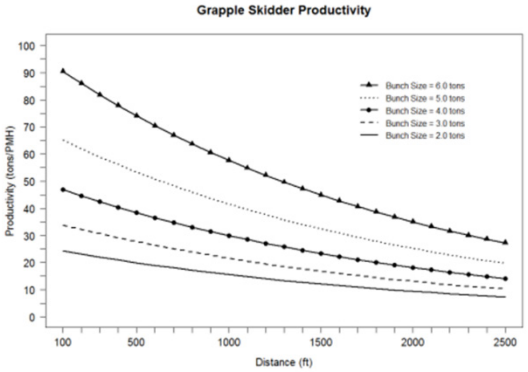


Figure 2-5. Productivity curves for grapple skidders showing the effect of one-way traveling distance and bunch size.

Although distance to roadside is the most influential factor on productivity of transportation equipment (figures 2-5 and 2-6), stem size also indirectly affects skidders and forwarders through changes in load size. Average one-way transportation distances observed were 1300 feet and 1100 feet for grapple skidders and forwarders respectively, but observations up to 2500 feet were also noted. These distances are much longer than those found in other harvesting equipment productivity studies (Bolding *et al.* 2009; Adebayo 2006; Lanford and Stokes 1996) where average skidding distances were closer to 650 feet. The comparison of all five machines studied clearly shows the differences in machine productivity for both whole-tree and cut-to-length systems (figure 2-7) with whole-tree almost twice as productive on an hourly basis compared to cut-to-length. On an annual basis, these differences are lessened due to changes in utilization rates and amount of downtime due to weather between each system. Further, our results confirm that feller-bunchers are approximately twice as productive as grapple skidders and stroke delimbers in whole-tree systems.

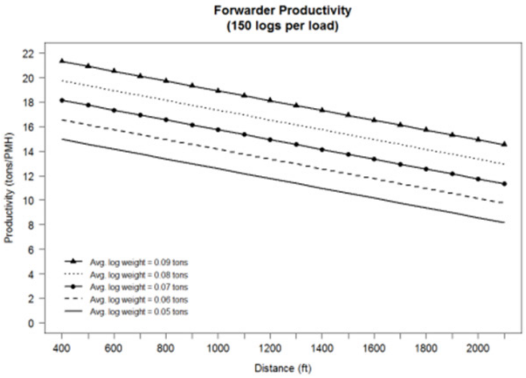


Figure 2-6. Productivity curves for forwarder showing the effect of one-way traveling distance and average log weight with a constant payload of 150 logs.

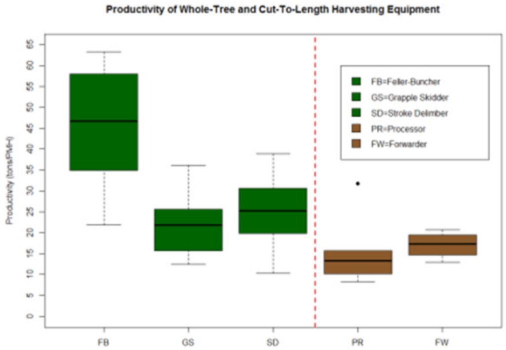


Figure 2-7. Productivity of whole-tree and cut-to-length harvesting equipment.

Future Work and Collaborations

Over the next year, we will focus on improvements to the estimates of machines rates for the common types of logging equipment in this region. We will also continue a joint effort with the Forest Bioproducts Research Institute and FarmBio3[1] to validate the productivity models in early entry thinning and biomass harvesting operations.

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COMMERCIAL THINNING IN THE AUSTIN POND PCT TREATMENTS

Patrick Hiesl, Brian E. Roth, and Jeffrey G. Benjamin

Introduction

The third wave of treatments at the Austin Pond Study involves a series of commercial thinning treatments on the precommercially thinned (PCT) and non-PCT treatments. The PCT treatments were thinned in the winter of 2012/2013 and the non-PCT treatments are to be thinned in the winter of 2013/24. This report describes the PCT harvest. PCT is a common silvicultural treatment used in the early management of conifer forests across North America and Europe (Bataineh *et al.* 2013; Olson *et al.* 2012; Zhang *et al.* 2006). The effects of PCT on tree growth have been investigated and documented for a wide range of forest types (Bataineh *et al.* 2013; Olson *et al.* 2012; Zhang *et al.* 2006; Thompson and Pitt 2003; Brissette *et al.* 1999; Balmer *et al.* 1978), but this treatment represents a significant financial investment of the landowner. Long-term results of growth responses and financial returns by PCT treatments are limited (Wagner *et al.* 2006; Thompson and Pitt 2003); however, results from 40-year growth and yield response on spruce-fir (*Picea rubens* Sarg., *Abies balsamea* (L.) Mill.) stands in west-central Maine treated in combination with early herbicide show that during the period of 13 years to 24 years after PCT the diameter and height increment and subsequently the increment in tree volume was greater than compared to non-PCT trees (Bataineh *et al.* 2013). They further reported that the total stumpage value of PCT stands was on average $907 higher than for non-PCT stands of the same age. Further, a long-term PCT study from New Brunswick, Canada, found that PCT increases diameter growth rates, with responses that are proportional to the thinning intensity (Pitt *et al.* 2013). The same study was cut by a harvester with the results that the harvester productivity increases in proportion to the PCT intensity (Plamondon and Pitt 2013). During a more in-depth analysis the researchers found that this effect was due to the positive effect of PCT on the average stem size. Typically a commercial thinning (CT) is required many years after PCT to further improve stand growth and yield (Pekol *et al.* 2012). Six commercial thinning intensities in spruce-fir stands have been studied over the past decade in Maine (Clune 2013). The intensities were crown, dominant, and low thinning, each with a removal of 33% and 50%, respectively.

Few of the studies mentioned above, however, are concerned with the productivity of harvesting equipment in early entry treatments. Plamondon and Pitt (2013) reported harvesting productivity for harvesters clear-cutting previously PCT stands at spacings of 1.2 m, 1.8 m , and 2.4 m. The harvester productivity reported ranged from 19.3 m^3/PMH (Productive Machine Hour) to 36.2 m^3/PMH for the harvest of control plots and PCT stands. Harvester productivity ranging from 5.49 m^3/PMH to 13.61 m^3/PMH in a 39 year old PCT stand was reported by Brake and others (2007). This study was also conducted in a clear-cut. On a regular basis spruce-fir stands, however, receive a CT after PCT and are not clear-cut. Productivity information for harvesters operating in thinnings can be found in several publications (Spinelli *et al.* 2010; Adebayo *et al.* 2007; Lanford and Stokes 1996), however, little is known whether the stands received PCT. Limited information is available on the effect of thinning treatment intensity on harvester productivity in PCT spruce-fir stands.

During the winter of 2012/2013 a long-term study in west-central Maine (Newton *et al.* 1992), which began as a herbicide trial and was later expanded to a long-term PCT study, received a first entry commercial thinning by a harvester. Four different thinning intensities were prescribed with three to four replicates in a randomized block design. Harvester productivity in each block was recorded and analyzed using ANOVA statistics to show the differences in machine productivity among the different treatment intensities.

Methods

Site

Detailed information about the study site can be found in the publications by Newton and others (1992) and Bataineh and others (2013). The study site is located in Somerset County, Maine (45.20°N, 69.70°W). Mean annual precipitation is

100 cm, with 40% of it occurring June to September. The site was clear-cut in 1970 and naturally regenerated (Newton *et al.* 1992). A herbicide trial was implemented 7 years later. Sixteen years after clear-cut the herbicide trial blocks were divided in half and one half each was pre-commercially thinned to about 1730 trees per hectare (Bataineh *et al.* 2013). In 2012, each of the fifteen harvest blocks had an 809 m^2 (0.2 acre) measurement plot installed with a 100% tally for species, dbh, total height, and height to live crown. Exceptions to this are three plots that were designated as red spruce releases, which included the removal of most other species than red spruce. As the tree removal was upwards 66% no measurements were taken, however, these plots can be assumed to be similar to the other plots and stand conditions. All trees were marked for harvest beforehand. The individual harvest blocks varied in size and totaled 8 hectares. The mean diameter at breast height (dbh) ranged from 13.1 cm to 18.7 cm with stand densities ranging from 1309 to 2594 trees per hectare (table 2-1). There was no statistical difference in the range of site conditions ($p > 0.05$) among the different treatments. All stands were dominated by balsam fir, and also consisted of between 6 and 22% red spruce, 0 to 30% quaking aspen, and 0 to 18% of other tree species such as paper birch, yellow, birch, white pine, and northern cedar (table 2-2).

Table 2-1. Stand information of harvested plots on PCT portion of Austin Pond Study.

Plot	Mean Dbh (cm)	Std. Dev. (cm)	Mean Height (m)	Mean Height to Crown (m)	Stand Density (trees/ha)
1T	13.7	4.2	12.8	7.2	2334
2T	N/A	N/A	N/A	N/A	N/A
3T	15.6	4.4	12.3	6.2	1778
4T	13.1	4.2	11.7	6.4	2470
7T	13.9	4.1	11.3	4.5	1581
8T	N/A	N/A	N/A	N/A	N/A
9T	N/A	N/A	N/A	N/A	N/A
10T	18.7	4.2	13.5	6.4	1309
11T	14.1	3.9	10.8	4.2	1618
12T	12.5	3.9	12.1	6.2	2495
15T	14.0	4.4	12.8	6.9	2198
17T	15.2	4.8	13.4	7.3	2062
21T	13.4	4.8	12.1	6.5	2594
23T	14.2	4.8	12.7	6.8	2297
27T	15.4	5.8	13.1	7.1	1976

Table 2-2. Species composition and treatment of harvested plots.

Plot	BA (m^2/ha)	Balsam Fir (%)	Red Spruce (%)	Quaking Aspen (%)	Other Species (%)	Removal (%)
1T	37.7	51	12	30	7	50
2T	N/A	N/A	N/A	N/A	N/A	RSR[a]
3T	36.7	83	12	1	4	50
4T	36.8	59	19	9	13	50
7T	26.0	81	9	4	6	66
8T	N/A	N/A	N/A	N/A	N/A	RSR[a]
9T	N/A	N/A	N/A	N/A	N/A	RSR[a]
10T	37.6	90	10	0	0	33
11T	27.3	79	21	0	0	33
12T	33.5	58	10	30	2	33
15T	37.1	54	22	20	4	50
17T	41.4	74	10	11	5	66
21T	41.4	57	19	18	6	33
23T	40.6	75	10	1	14	66
27T	42.0	76	6	0	18	66

Note: [a]RSR: Red spruce release is the removal of most trees other than red spruce.

Harvest Productivity

The different treatment plots were harvested by a single logging contractor, Andrews Logging of Atkinson, Maine. A Ponsse Ergo harvester was used to cut and process the trees while a Timberjack 1110 forwarder transported the processed logs to the landing. During the operation the harvester operator was asked to keep a record of harvesting time for each treatment block. Due to the harvest design, up to three treatment blocks were in one row. As the travel time from one trail to another trail would be greater for the second and third block in a row, the harvester operator was asked to only record the time from the harvest block boundary onwards. This ensured that only times that were associated with the immediate harvest were recorded and analyzed. Five different assortments were processed by the harvester: pulpwood (3.6 m), saw logs in three lengths (3.6 m, 4.3 m, 4.9 m), and hardwood / aspen pulpwood in various lengths. To ensure accurate measurements of the harvested volume, we asked the forwarder operator to separate each assortment at the landing by treatment block. As the researchers were not on site at all times, the individual log piles were spray painted with each treatment block number. Forwarder time and productivity was not recorded as the forwarding was impacted by the requests of the researchers.

Researchers sampled the volume of each log pile before it was trucked to the mill and compared those estimates to the total delivered weight of all assortments. As all log piles were transported to mill within one or two days of harvest no difference of log weights between the different truck loads was expected. The percentage of volume of each pile was used in combination with the total delivered weight to estimate the total weight removed from each harvest block in each assortment. Using the weight information for each harvest block and the reported time consumption of the harvester the productivity in tons/PMH (productive machine hour) per treatment block could be calculated. To transform this result into m^3/PMH conversion information from the Maine Forest Service (2012) was used (2.4069 m^3 = 2.1 tons of spruce, fir, or aspen).

Results

The results of the analysis of the harvester data showed that the harvesting time per plot ranged from 117 to 468 minutes and a productivity per productive machine hour between 6.1 and 26.5 m^3/PMH (table 2-3).

Table 2-3. Harvest time and productivity for all harvest sites.

Plot	Harvest Time (min)	Volume Removed (m^3)	Productivity (m^3/PMH)
1T	468	58	7.5
2T	395	63	9.6
3T	290	53	11.0
4T	375	50	8.1
7T	370	58	9.4
8T	458	92	12.0
9T	366	77	12.7
10T	117	52	26.5
11T	160	30	11.3
12T	185	34	11.1
15T	313	69	13.1
17T	370	64	10.4
21T	427	44	6.1
23T	356	46	7.8
27T	361	62	10.3

This range seems large, however, when looking at a boxplot of the data it becomes clear that the majority of the data points are far below the maximum (figure 2-8). This one observation with 26.5 m^3/PMH might have been due to the effect of the researchers on operator speed (Makkonen 1954) as this productivity was encountered in the very first research plot and afterwards never again. Omitting this one data point from the analysis, however, does not change any results and therefore it was included in the following analysis.

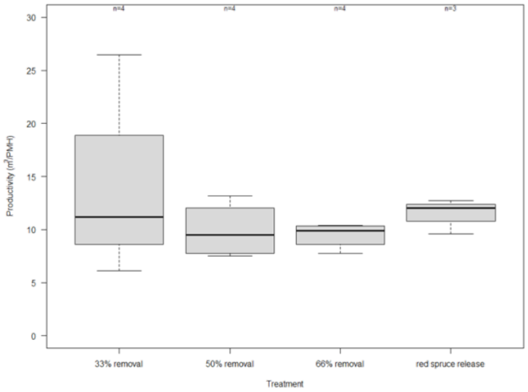

Figure 2-8. Boxplot of the harvester productivity for four different treatments.

An Analysis of Variance (ANOVA) showed that there is no significant difference (Pr(>F) = 0.616) between the treatment groups. A mean plot with 95% confidence intervals also showed that some of the confidence intervals for the treatments are rather large (figure 2-9). The average volume removed per hectare was 106 m^3.

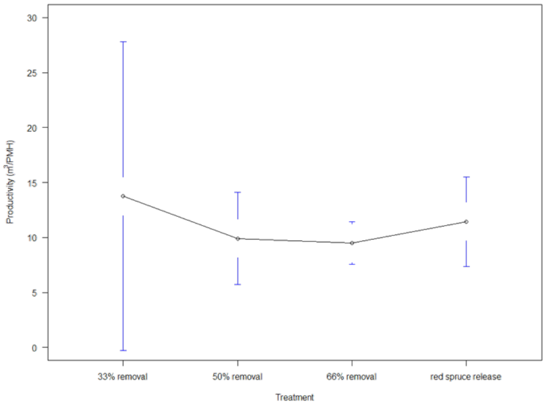

Figure 2-9. Mean plot with 95% confidence interval of the harvester productivity for four different treatments.

A comparison of the Austin Pond harvester productivity with results from the 2011 Early Commercial Thinning study (Benjamin *et al.* 2013) and the 2012 CFRU Harvest Productivity Study (Hiesl 2013) shows that there is no significant difference in harvester productivity (p=0.0653) among the three studies (figure 2-10).

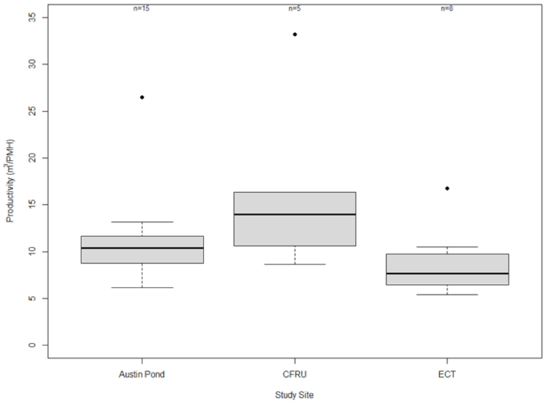

Figure 2-10. Comparison of harvester productivity between three study sites.

Discussion

The results show that there is no difference in the average productivity of a harvester in regards to the harvest intensity. Due to the small sample size of only 3 or 4 plots per treatment we have to be careful in using this information as this relationship might not hold true with a larger sample. It has been found before that the prescription and with it the treatment intensity is an important factor influencing harvester productivity (Légère and Gingras 1998). With this study all trees were marked for harvesting, which might have increased the productivity as the operator did not have to make the decision of which tree to cut. More data from different harvesting operations needs to be collected to validate the results of this study.

The productivity range encountered in this study compares well to the results of (Brake *et al.* 2007), although slightly higher. Their stand volume per hectare was 125 m^3, which was completely removed in a clear-cut. In the present study the average volume per hectare removed was 106 m^3 in various thinning treatments. We would expect a clear-cut harvest with a higher standing volume to be more productive than a thinning operation with smaller average removals. As this is not the case and the fact that (Brake *et al.* 2007) used three different operators the influence of the operator might be the reason for the difference. The effect of operator on harvester productivity has been reported several times and can explain up to 40% of productivity differences (Hiesl 2013; Purfürst and Erler 2011; Lindroos 2010; Kärhä et al. 2004; Ovaskainen *et al.* 2004).

Comparing the results of this study with the productivity of harvesters of an early commercial thinning experiment in a PCT stand (Benjamin *et al.* 2013) and the results of the 2012 CFRU Harvest Productivity Study (Hiesl 2013) shows that no difference (p=0.0653) could be found (figure 2-10). This leads to the reasoning that the research layout and the additional tasks the operator was ask to do did not affect the overall productivity of the harvester operator when compared to common harvester productivities in Maine. But this also suggests that the harvester productivity is not necessarily influenced by trees marked for harvest as the CFRU harvest productivity study had no trees marked for harvest. When comparing the results from this study with the productivity of (Plamondon and Pitt 2013) who also studied the harvest of a clear-cut we can see that their productivity values are much higher than what we have presented. Their stands were 55 and 62 years old, which is 13 and 20 years older than the stand age of the presented study. With increased stand age we can assume a larger stand volume that has been harvest. Considering this it seems reasonable that their productivity is higher.

Overall the results are promising; however, what is missing is a comparison of harvesting productivity of PCT and non-PCT stands. The research site studied also has non-PCT blocks that were supposed to be harvested in 2013 along with the PCT stands. For this a second piece of equipment was employed on site. This small feller-buncher based on a Linkbell excavator, however, was designed for clearing of shrubs and small trees along power lines or on house lots. After an initial trial in a clear-cut and thinning block it became obvious that this machine could not perform the tasked asked. As the harvesting took place in late winter it was impossible to find another contractor to finish the non-PCT harvesting. It is planned for late winter 2014 to employ another piece of equipment to finish the harvesting. With this data available we will be able to compare the harvest productivity of two different machines in PCT and non-PCT stands with different treatment intensities. This information will be valuable and will help to further strengthen the benefits of precommercial thinning.

Acknowledgments

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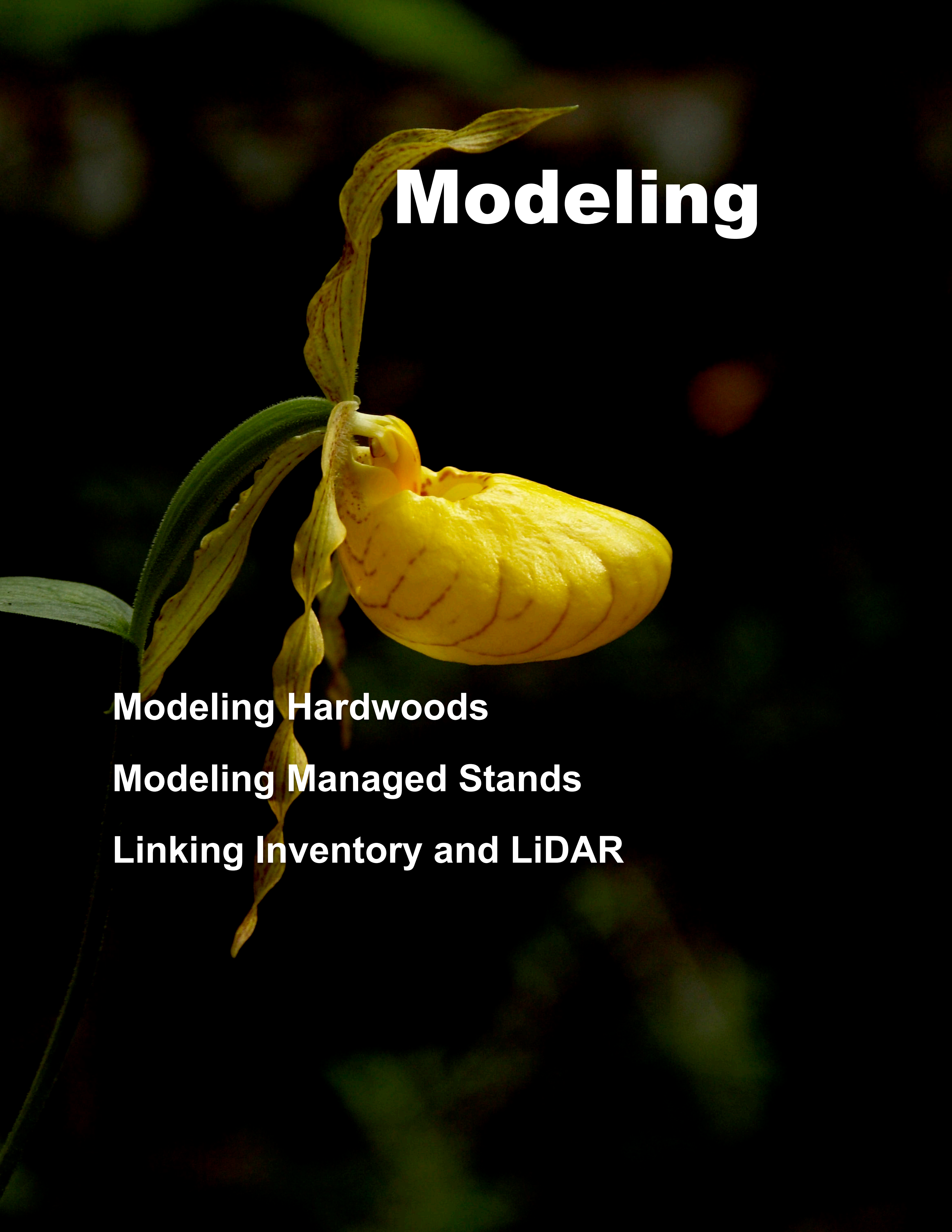

Modeling

Modeling Hardwoods

Modeling Managed Stands

Linking Inventory and LiDAR

MODELING YOUNG HARDWOOD RESPONSES TO SILVICULTURE

Andrew Nelson, Robert Wagner, and Aaron Weiskittel

Background

This report summarizes the second year of a three-year project to refine the prediction of hardwood growth and yield by incorporating the influence of various intensities of silviculture and species composition using results from the Silvicultural Intensity and Competition (SIComp) experiment on the Penobscot Experimental Forest. Specific objectives for this project are to:

- Quantify how naturally regenerated hardwoods respond to different intensities of early vegetation control and precommercial thinning (PCT) under mixedwood conditions.
- Develop a growth model for young hardwood stands (between establishment and crown closure) that includes various intensities of silviculture and species mixture scenarios.
- Integrate the young hardwood stand model into the growth & yield simulator being developed by Weiskittel et al. to simulate future stand development under various levels of silviculture and mixedwood composition.

These objectives are part of an ongoing dissertation research project by Andrew Nelson and will be reported in a completed PhD thesis. This second-year report focuses on the effect of species and silvicultural intensity on the leaf area development of young hardwood trees.

Introduction

In mixed-species stands, such as much of the forests in the Acadian region, coexistence among tree species and individual-tree growth are driven by species differences in the capture of available resources. In particular, species coexistence is largely influenced by variation in crown characteristics in response to light availability. An example from the Acadian region is the mixture of species within a stand with differences in crown form and shade tolerances, such as aspen species and red maple. Aspen species grow rapidly in height to dominate the upper canopy following disturbance, often resulting in crowns with sparse foliage that allow for light to travel through. More shade tolerant species, such as red maple, can survive under the upper canopy because they can capture filtered light through the overstory. Their crowns often spread horizontally to capture as much filtered light as possible.

In recently disturbed forest stands in Maine, the species composition of naturally regenerated trees is often complex, composed of a mixture of fast-growing shade intolerant species, mid- and shade tolerant hardwood species, and slower growing conifer species (Seymour 1995). There is often strong competition for light in these young stands due to high stem densities. Mechanisms likely influencing the eventual dominance of young trees in highly competitive stands include the total production and vertical distribution of leaf area to increase light interception. Currently, differences in leaf area production and distribution among coexisting species in highly competitive young stands is poorly understood. Therefore, to better understand the combined influence of inherent species differences and responses to management intensity on forest productivity, leaf area of young hardwood trees was investigated at two scales of observations, including: (i) the total crown-level, and (ii) vertical distribution in the crown.

Methods

Data for this investigation were collected at the SIComp study site on the Penobscot Experimental Forest (see Nelson and Wagner 2011 Annual Report for full description of the study).

Five naturally regenerated hardwood species (red maple, gray birch, paper birch, bigtooth aspen, and trembling aspen) were selected for this investigation (figure 3-1). For each naturally regenerated species, between 13 and 17 trees were sampled across three management intensities (untreated control, thinning, and thinning + enrichment planting) and a range of tree diameter. Each tree was cut at the ground line, and stem diameter above the root collar, DBH, total height (HT), and crown length (CL) were measured. The diameter and length of each branch was measured on every tree. A subset of branches were randomly selected for leaf area measurements. Branch leaf area models were created to predict the leaf area of every branch on the tree, then summed to obtain total crown leaf area. The vertical distance of each branch from the crown base was also measured on every tree so that vertical leaf area distributions models could be developed.

Figure 3-1. Derek Brockmann samples biomass on the SiCOMP experiment.

Nonlinear mixed-effects models were fit for total crown leaf area, testing tree level metrics, such as diameter at breast height (1.37 m above the ground), total tree height, and crown length as covariates in the models.

The vertical distribution of leaf area within tree crowns was modeled using a right-truncated Weibull distribution, defined as:

$$p(X) = \left(\frac{1}{\eta}\right)^{\beta} \beta X^{(\beta-1)} e^{-\left(\left(X/\eta\right)^{\beta} - \left(\gamma/\eta\right)^{\beta}\right)}$$

Where X was the relative vertical depth of the leaf area from the top of the tree, η is the Weibull scale parameter, β is the Weibull shape parameter, and γ is the Weibull truncation point.

Results

Across all species, the following three-parameter nonlinear mixed-effects model for crown leaf area (CLA) with dbh and crown length (CL) as covariates provided the best fit to the observed data:

$$CLA = b_1 DBH^{b_2}\ \mathrm{e}^{(b_3+\varphi_i)(DBH/CL)}$$

where $b_{1\text{-}3}$ are fixed effects parameters, φ_i is the random effect of management intensity, and other variables are defined above. The percentage of variance explained (R^2) was > 96% and residual standard error < 0.61 m^2 across species for the CLA models (table 3-1). The final equation included management intensity as a random effect for the naturally regenerated hardwood species. Among the species, the estimated parameters provided a wide range of CLA estimates. For instance, predicted CLA ranged from 3.26 m^2 for trembling aspen to 9.85 m^2 for gray birch at the mean DBH of 4.2 cm and median CL of 4.1 m.

Relative leaf area peaked in the middle third of the crown for all the naturally regenerated species, ranging from a relative depth into the crown of 0.44 for paper birch to 0.65 for trembling aspen (figure 3-2). A similar pattern among the species was found for absolute vertical leaf area of a mean sized tree with DBH of 3.9 cm and CL of 3.8 m, where the peak in absolute leaf area ranged from a depth into the crown of 1.7 m for paper birch to 2.7 m for trembling aspen.

Discussion

CLA was also found to vary substantially among the species, across the range of tree sizes sampled. For instance, at the mean DBH and CL among all naturally regenerated trees, predicted CLA ranged from 3.26 m^2 for trembling aspen to 9.85 m^2 for gray birch. The substantial differences among the species may be due to inherent differences in partitioning of growth to leaf area production. The proportion of biomass partitioned to various components often varies by species and is often correlated with their ability to tolerate shade (Niinemets 2006). For instance, species with strong shade avoidance strategies tend to allocate less biomass to foliage and more to woody structures since they often cannot maintain positive carbon balances in shaded conditions (Niinemets 1998). This is one possible reason for the differences in CLA found between red maple and the aspen species, since red maple is considered moderately tolerant of shade (Walters and Yawney 1990), and both aspen species are considered intolerant of shade (Laidly 1990; Perala 1990). For instance, red maple CLA was predicted to be 67% and 136% greater than bigtooth aspen and trembling aspen, respectively, for the average size tree.

Paper birch and gray birch CLA were substantially greater than the aspen species, even though both birch species are also considered intolerant of shade. Differences between these two genera may be explained by inherent differences in crown characteristics, but also from the management history at the site. The median DBH of trembling aspen and bigtooth aspen were 5.1 cm and 5.6 cm, respectively, when compared to paper birch (1.4 cm) and gray birch (1.3 cm). Thus, the aspen trees in this investigation likely were part of the original cohort of trees that regenerated following the harvest in 1995. The small diameter of birch trees suggests many of the trees likely regenerated following treatment application in 2004 when stand densities were substantially lower due to thinning. Therefore, the lower CLA of the aspen species may be due to a combination of lower biomass allocation to foliage and stand conditions at the start of the experiment, when stem densities of shade intolerant hardwood species were high (Nelson *et al.* 2013). Inherent autecological crown characteristics among the genera are also likely influencing the differences, since the prediction of CLA in the untreated control for birch was 67% greater than aspen for the averaged sized tree.

We hypothesized that vertical leaf area distribution would either be constant across the length of the crown or show a peak in the upper third of the crown due to weak apical dominance and sympodial crown forms of hardwood saplings, similar to previous research (Niinemets 1996). However, the results showed that the patterns of vertical leaf area differed by species, expressed both as relative and absolute leaf area. For instance, relative leaf area was almost evenly distributed along the vertical crown length for gray birch, but peaked at 0.65 from the top of the crown for trembling aspen. Comparatively, the distribution of red maple and paper birch relative leaf area peaked at 0.51 and 0.49 from the top of the tree, respectively. The distribution of absolute leaf area was similar for red maple and paper birch with the greatest amount of leaf area being 2 m from the top of the mean sized tree. The vertical distribution of leaf area has also been shown to peak in the middle of the crown across a range of shade tolerances in conifer species (Garber and Maguire 2005; Weiskittel *et al.* 2009) and shade intolerant hardwood species (Forrester *et al.* 2012; Alcorn *et al.* 2013) suggesting a common pattern across species and shade tolerance classes.

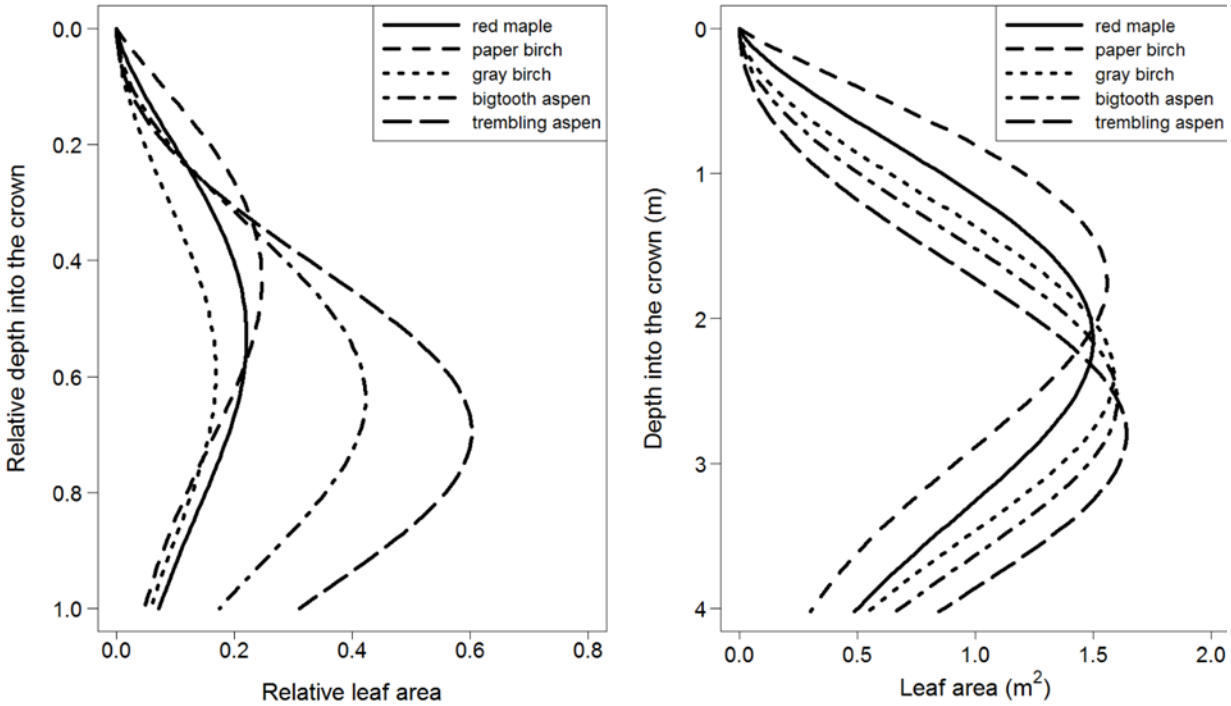

Figure 3-3. Relative and absolute vertical leaf area for five naturally regenerated hardwood species fit with the right-truncated Weibull distribution. The Weibull shape and scale parameters are least-square means estimates from ANOVA models testing for differences among species.

Table 3-1. Tree-level leaf area parameter estimates, standard error of parameters, and p-values. R^2 for the fixed effects only, the R^2 when the random effect of management intensity is added to the model, and residual standard error are shown to demonstrate the fit of the models. Models were fit as nonlinear mixed-effects models.

	b_1			b_2			b_3			Fit Statistics		
Species	Estimate	SE	p-value	Estimate	SE	p-value	Estimate	SE	p-value	R^2 fixed	R^2 fixed + random	Residual standard error (m^2)
Red maple	0.1172	0.0343	0.014	1.7104	0.1192	<0.001	1.6918	0.1902	<0.001	0.985	0.985	0.165
Paper birch	0.7569	0.0684	<0.001	2.2520	0.0424	<0.001	-0.8978	0.1277	<0.001	0.999	0.999	0.105
Gray birch	0.2076	0.1457	0.188	1.0639	0.2500	0.0021	2.3032	1.2665	0.102	0.853	0.992	0.166
Bigtooth aspen	0.5260	0.2055	0.027	2.2374	0.1766	<0.001	-1.0232	0.1767	<0.001	0.961	0.961	0.609
Trembling aspen	0.3118	0.1094	0.021	2.0394	0.1514	<0.001	-0.5766	0.1641	0.008	0.947	0.974	0.303

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EXTENDING THE ACADIAN VARIANT OF THE FOREST VEGETATION SIMULATOR TO INTENSIVELY MANAGED STANDS

Aaron Weiskittel, John Kershaw, and Chris Hennigar

Introduction

The Acadian variant of the Forest Vegetation Simulator (FVS) is currently being tested and showing good performance across a range of stand types (Weiskittel *et al.*, 2013). However, the model was mostly developed using data from naturally-regenerated stands and the primary management activities represented are various commercial thinning regimes. Consequently, intensive management activities like vegetation control, precommercial thinning (PCT), commercial thinning (CT), and genetics are not well represented.

The overall goal of this project was to extend the Acadian variant of FVS to intensively managed stands in the region. The specific objectives were to:

(1) compile a regional database of permanent plots in intensively managed stands;

(2) test the performance of the current equations across a range of intensive management activities;

(3) develop equation modifiers to improve prediction performance; and

(4) provide long-term projections of various management regimes.

Methods

Initially, existing datasets that included intensive management activities were identified and access to the data was requested (table 3-2). Once the necessary data was obtained, the data were compiled into a standardized database. This included tables for tree, plot, stand, and management treatment information. All tables were standardized to metric, used US Forest Service Forest Inventory and Analysis (FIA) species codes, and removed explicit use of original dataset owner for proprietary reasons. Using plot locational information, climate site index, depth to water table, and other key site attributes were obtained. The tree data was cleaned using custom-built algorithms and plot-level statistics were computed. New datasets continue to be identified and obtained. Once the data is fully compiled, the analysis will proceed in multiple steps. First, the component equations that currently compromise the FVS-AD will be tested using the database. The individual tree equations would include total tree height, height to crown base, diameter increment, height increment, crown recession, and mortality. For each observation, mean bias and absolute bias would be computed and assessed for trends. Given that equation bias could happen for a variety of reasons above and beyond the true influence of forest management, performance of the equations would be evaluated using an equivalence test. If the prediction error exceeds the specified threshold (e.g. 10-15%) the equation would be considered significantly biased and further refined.

Second, when a component equation is deemed significantly biased, a species- and management-specific modifier function would be developed using the data available for analysis. This modifier function would adjust the predictions of a base FVS-AD component equation to better reflect the different management activities. For PCT and CT, the equation would rely on time since treatment, the amount of basal area removed, the type of thinning, and the ratio between mean pre-treatment DBH to post-treatment DBH. For other management activities, the modifier would include covariates relevant to the management activity. The modifier parameter estimates would be estimated using linear and nonlinear mixed effects to better separate between the plot- and management-specific responses.

Table 3-2. Currently available managed stand sample sources for the Acadian Forest.

Source	Source	Geographic region	Stand types	Sample points	Age of establishment	Last age re-measured†
CFRU	Commercial Thinning Research Network	Northern Maine	PCT and CT fir-spruce stands	48‡	20-70	30-80
	Austin Pond	Northern Maine	Herbicide and PCT spruce-fir stands	208	39	49
US Forest Service	Penobscot Experimental Forest Compartment Study	Central Maine	Various silvicultural methods in mixedwood stands (e.g. shelterwood, fixed-diameter, etc.)	723	10-25	70-85
	Penobscot Experimental Forest Study 58	Central Maine	PCT in mixedwood stands	32	15	47
Canadian Forest Service	Green River thinning trails	Northwestern New Brunswick	PCT and CT fir-spruce stands	48	15	60-65
	Maritime genetic improvement test sites	Nova Scotia & New Brunswick	Red, Norway, white and black spruce plantations of various genetic stock	15‡	0	40-50
New Brunswick Dept. of Nat. Res.	Cooperative Permanent Sample Point Network	New Brunswick	White and black spruce and jack pine plantations	402	5-10	5-30; mostly 10-20
			PCT spruce-fir and fir-spruce stands	379	15-40	20-60; mostly 20-30
	Cooperative Temporary Sample Point Network	New Brunswick	White and black spruce and jack pine plantations	2,148*	20-25	-
			PCT spruce-fir and fir-spruce stands	1,183*	25-30	-
	Temporary sample points with destructive stem-analysis	New Brunswick	White and black spruce and jack pine plantations	136*	30-40	-
			PCT spruce-fir and fir-spruce stands	54*	25-35	-
Nova Scotia Dept. of Nat. Res.	Nova Scotia Permanent Sample Points	Nova Scotia	Mostly spruce and pine plantations, spruce-fir PCT and CT softwood selection method	650	0-35	20-60
			Hardwood selection method	350	-	-
J.D. Irving, Limited	New Brunswick Permanent Sample Points	New Brunswick	White and black spruce plantations; with a high proportion of plantations CT 1-2 times	505	10-25	30-50; mostly 30-40
	New Brunswick genetic improvement test sites	Southern New Brunswick	White and black spruce plantations of various genetic stock	25‡	0	20-25
			Hardwood selection method	350	-	-

* Single point-time sample of forest inventory. Trees are not marked and plot is not revisited; ‡ Permanent block sample plots. Block samples are generally larger (20m X 20m or more) plots and include between 5-10 replicates within each block sample; † Most permanent sample points were re-measured quinquennially.

Table 3-3. Attributes of the dataset. DBH is diameter at breast height, HT is total tree height, HCB is height to crown base, ΔDBH is annual diameter increment, ΔHT is annual height increment, and ΔHCB is annual crown recession.

			Plot re-measurements				Tree re-measurements (outliers excluded)								
Management Group	**Plots**		**Total**	**Avg**	**Max**		**Total**	**DBH**	**ΔDBH**	**HT**	**ΔHT**	**CR**	**CW**	**ΔHCB**	**Decay**
Maine	**10,985**	-	**30,481**	**14**	**30**	-	**551,019**	**495,867**	**281,977**	**382,373**	**165,322**	**426,879**	**4,837**	**158,475**	**30,151**
None	9,369		25,993	2.8	12		478,222	427,302	241,369	326,262	136,780	369,511	3,944	133,685	26,691
Partial Cut	1,391		3,743	2.7	3		40,755	37,360	17,171	29,438	11,968	33,981	-	11,510	3,376
PCT	45		289	6.4	12		26,700	26,244	21,117	23,171	15,176	18,510	893	11,891	-
Planted	180		456	2.5	3		5,342	4,961	2,320	3,502	1,398	4,877	-	1,389	84
New Brunswick	**4,095**	-	**15,088**	**13**	**28**	-	**1,410,834**	**1,021,258**	**633,244**	**634,344**	**379,228**	**803,627**	**329,671**	**261,675**	**2,749**
None	2,324		8,988	3.9	7		661,260	613,187	388,631	87,100	45,751	425,535	2,221	27,317	2,125
Partial Cut	205		414	2.0	4		61,127	54,684	19,929	14,222	5,085	11,201	11,903	3,502	500
PCT	508		1,611	3.2	9		383,685	204,056	130,757	246,529	150,859	205,056	116,167	133,987	86
Planted	1,058		4,075	3.9	8		304,762	149,331	93,927	286,493	177,533	161,835	199,380	96,869	38
Nova Scotia	**3,574**	-	**18,554**	**22**	**37**	-	**733,315**	**662,375**	**443,648**	**586,014**	**380,759**	**219,028**	**-**	**101,217**	**-**
None	2,413		11,250	4.7	9		427,185	395,417	256,803	378,954	241,498	169,791	-	80,729	-
Partial Cut	807		5,690	7.1	9		215,730	186,094	125,599	182,750	121,914	49,237	-	20,488	-
PCT	53		302	5.7	8		17,238	14,939	11,895	4,540	3,383	-	-	-	-
Planted	301		1,312	4.4	11		73,162	65,925	49,351	19,770	13,964	-	-	-	-
PEI	**731**	-	**4,843**	**21**	**30**	-	**287,533**	**287,527**	**212,824**	**21,773**	**16,864**	**20,554**	**-**	**15,894**	**-**
None	153		1,007	6.6	11		71,470	71,467	52,923	4,643	3,607	4,374	-	3,329	-
Partial Cut	40		293	7.3	9		14,644	14,643	10,910	1,278	1,001	1,208	-	923	-
Planted	538		3,543	6.6	10		201,419	201,417	148,991	15,852	12,256	14,972	-	11,642	-
Quebec	**683**	-	**2,134**	**6**	**10**	-	**82,842**	**70,209**	**31,284**	**12,334**	**4,676**	**235**	**-**	**3**	**-**
None	359		911	2.5	5		34,605	32,447	14,840	5,692	2,268	140	-	3	-
Partial Cut	324		1,223	3.8	5		48,237	37,762	16,444	6,642	2,408	95	-	-	-
Total	**20,068**	-	**71,100**	**76**	**135**	-	**3,065,543**	**2,537,236**	**1,602,977**	**1,636,838**	**946,849**	**1,470,323**	**334,508**	**537,264**	**32,900**

Finally, the final will be included in the FVS-AD to project the long-term consequence of various planting, vegetation control, PCT and CT treatments in the Acadian region. Modifiers would be adjustable for local conditions in two main ways: 1) self-calibration (i.e., auto-calibration) of modifiers to reflect tree-level current diameter and height growth rates (if available in tree list), and 2) manual mortality and growth modifier that override commands by species, time period, and tree diameter range. The base FVS-AD and modifiers developed from this study will be incorporated into an open source dynamic link library (DLL). An additional wrapper executable will be developed to support command-line interaction with the DLL. This software architecture will allow the main model (DLL) to be called directly from other third-party applications if desired; e.g., Microsoft Excel and Access, R, and other custom software graphical user interfaces. To demonstrate the implications of the developed modifiers, various management regimes will be projected with and without the modifiers and compared to long-term experimental locations like the Austin Pond Study.

Results

A total of 3,065,543 individual tree observations from 20,068 plots were obtained (table 3-3). These plots consist of CFRU and US Forest Service research installations in Maine as well as permanent and temporary sample points in New Brunswick and Nova Scotia (figure 3-3). These plots have received varying levels of site preparation (e.g. bedding, ripping), vegetation control (herbicide and conifer release), PCT, CT, and genetic improvement. Several are long-term experimental sites with over 30-60 years of continual periodic measurements. The majority of sites have tagged individual trees with numerous repeated measurements and cover a range of site conditions.

Preliminary analysis using the CFRU Commercial Thinning Research Network Data suggested strong performance of the FVS-ACD total height and height to crown base equations across a range of stand histories and treatment types on average (figure 3-4). However, there was quite a bit of variation in the data, which may be related to site or time since treatment. In general, the total height equation appeared to overpredict red spruce height in the PCT stands, while the no PCT sites showed the highest variation in the ratio between observed to predicted height to the crown base.

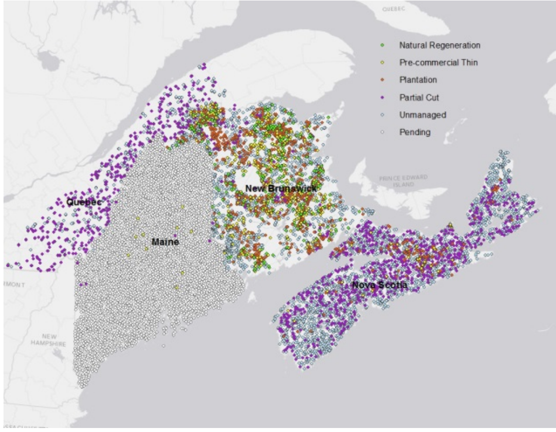

Figure 3-3. Locations of 20,068 plots consisting of CFRU and US Forest Service research installations in Maine as well as permanent and temporary sample points in New Brunswick and Nova Scotia.

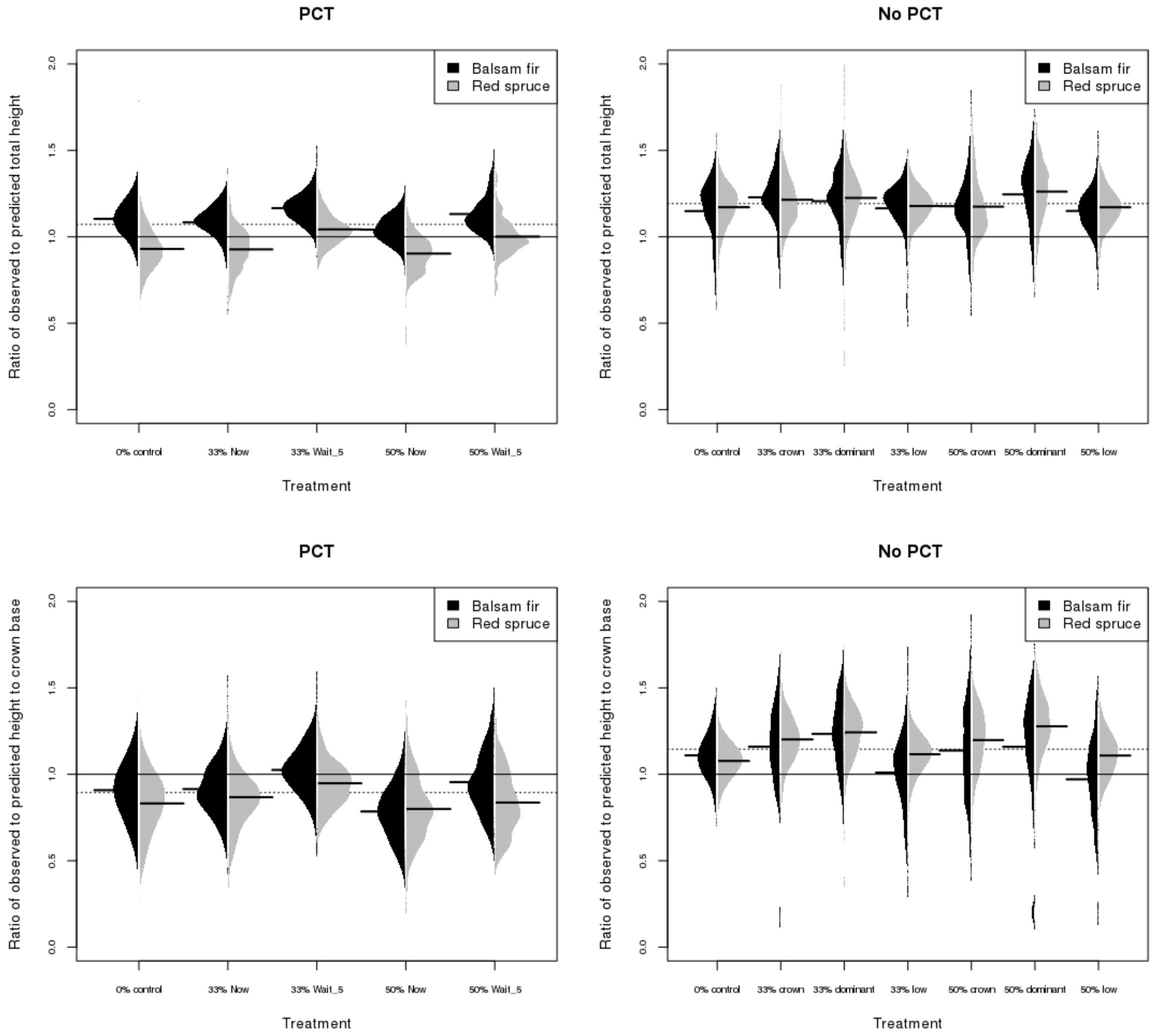

Figure 3-4. Ratio of observed to predicted height (top) and height to crown base (bottom) by PCT history, treatment type, and species for the CFRU Commercial Thinning Research Network. The predicted values were estimated using the regional equations of FVS-ACD.

Discussion

Forest management activities greatly modify residual stand structure and composition, which can make it difficult for regional growth and yield models to accurately predict stand response to treatment. Previous research has clearly shown the Northeastern Variant of FVS (FVS-NE) to be biased in predictions of stand growth response to forest management (Bataineh *et al.* 2013; Saunders *et al.* 2008). However, it is difficult to detect whether this bias is due to inherent limitations of FVS-NE or because the model doesn't modify its predictions for certain management activities. This project is attempting to overcome this limitation by ensuring that FVS-ACD accurately reflects both the short- and long-term response to forest management. By compiling an extensive regional database of permanent research plots that have had a range of forest management treatments, this project has a good opportunity to achieve this objective.

It is important that the majority of the managed stand data is coming from Canada and not Maine, which may limit the model's generality. Currently, the only managed stand data is the CFRU CTRN and the Austin Pond Study. These study sites have a wealth of data associated with them, but are not fully representative of the sites where forest management occurs in Maine. Efforts are currently underway to obtain additional managed stand data in Maine. This will be important to ensure that the model is behaving properly across the range of conditions for which it was parameterized for.

Ideally, the regional equations will need limited modification to represent the range of forest management activities. Based on a limited preliminary assessment of the total height and height to crown base equations, they appear to performing quite well for various CT treatments and may not need modification. Diameter and height increment will likely be a different story as growth tends to be more response to management when compared to allometric attributes like total height or height to crown base. Capturing this variation and attributing it to features of the forest management activity like the intensity and type of thinning will be key for success.

Another aspect of this project will involve representing and interpreting these forest management activities in a software system. The Open Stand Model (OSM) has been modified to represent a range of management activities. This includes planting and various thinning regimes. In addition to these changes, OSM has been modified in two important ways, which should improve its abilities to represent alternative forest projection scenarios. The first is that height and height to crown base predictions can be localized when existing measurements are available. Second, a maximum size-density line that is applicable to mixed-species stands was developed using permanent plots in New Brunswick. This should ensure that stands don't exceed realistic values, even for longer projections (>100 years).

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TESTING THE ABILITY OF LIDAR TO PREDICT VARIOUS FOREST INVENTORY ATTRIBUTES IN MANAGED STANDS OF MAINE

Rei Hayahsi, Aaron Weiskittel, Steve Sader, and John Kershaw

Summary

The objective of this study was to investigate the applicability of low density (1-3 pulses m^{-2}) LiDAR data to deploy an area-based and an individual tree-based approach. Specifically, this study focused on for predicting maximum tree height, stem density, basal area, quadratic mean diameter, and total volume to use an area-based method. Also, this study focused on species classification as well as total height and volume predictions to use an individual tree-based method. The research was conducted at the Penobscot Experimental Forests in central Maine, where a range of stand structures and species composition is present and generally representative of northern Maine's forests.

Overall, this study found that LiDAR tended to underestimate maximum tree height and volume. The maximum tree height and volume models had R^2 values of 86.9% and 72.1%, respectively. In contrast, the individual tree equations did not perform well for either prediction of species composition and volume. Although it was difficult to develop models with a high R^2 due to complexities of Maine's forest structures and species composition, the results suggest that low density LiDAR can be used as a supporting tool in forest management for this region if the focus on stand-level attributes.

Introduction

To predict forest inventory attributes such as stem volume, conventional field measurement protocols tend to establish a limited number of plots in each stand, and assume that they are representative to the entire stand. In the case of Maine's forests, uniform conditions within a stand may not be met because widely used silvicultural treatments such as a shelterwood system tend to create highly variable structures and species composition within each stand. On the other hand, LiDAR senses an entire management area, and more reliable predictions could be achieved over the highly variable forests. However, LiDAR has seen relatively limited application for assessing forest inventory attributes in Maine.

LiDAR based forest inventory predictions can be deployed using two different approaches, namely area-based methods (*e.g.* Woods *et al.* 2011) or individual tree-based methods (*e.g.* Falkowski *et al.* 2008). In general, the individual tree-based methods require LiDAR pulse density greater than 5 pulses m^{-2}, while the area-based methods require 1-2 pulses m^{-2}. In the area-based methods, forest inventory attributes are predicted at a plot-level, such as m^3 ha^{-1} in case of stem volume, while model calibration data through certain field measurement are necessary. A parametric (*e.g.* stepwise regression) or a non-parametric (*e.g.* random forest) statistical technique is used to develop plot-level prediction models. In contrast, in the individual tree-based methods, forest inventory attributes are predicted in a tree-level, such as m^3 $tree^{-1}$ in case of stem volume, and summed to a stand-level. However, the approach requires accurately discriminating individual trees, but previous results have shown that accuracy of this seemed to depend on a choice of segmentation techniques, and forest structures.

In this report, we evaluated the use of LiDAR to predict key forest structural attributes across a range of stand structures and species compositions. In addition, we investigated the feasibility of two different approaches, area-based and individual tree-based, to predict those forest inventory attributes. This study was conducted in the Penobscot Experimental Forest (PEF) in central Maine.

Methods

LiDAR System Specifications

Area-based approach

Airborne discrete-return laser scanner data were acquired using an Optech Gemini 246 instrument in the late October 2010. LiDAR data was intended to collect under a leaf-off condition, but most deciduous trees in the PEF kept leaves at that time due to an abnormal prolonged summer period in 2010. The laser pulse intensity was 1064 nm. Mean laser point density was 1.1 pulses m^{-2}, and the sensor collected up to 4 pulse returns.

Individual tree-based approach

Airborne discrete-return LiDAR data were acquired using a VQ-480, a component of NASA Goddard's LiDAR, Hyperspectral and Thermal (G-LiHT) airborne imager system, in late June 2012. The laser pulse intensity was 1550 nm. Mean laser point density was 3.0 pulses m^{-2}, and the sensor collected up to 4 pulse returns.

Inventory Attributes Data

Area-based approach

We collected model calibration data from eleven replicated management units (total of 22 silvicultural treatment units) in the PEF. Within these 22 management units, a total of 117 permanent sampling plots were established with a range of 3-7 fixed, nested circular permanent sampling plots. On each 0.02-ha (1/20th-acre) permanent sampling plot, diameter at breast height (DBH) were collected from all trees with a DBH greater than 6.35 cm (2.5 inches) between 2003 and 2010 depending on the management unit. On each 0.08-ha (1/5th-acre) permanent sampling plot, DBH was collected from all trees with DBH greater than 11.25 cm (4.5 inches). On a subsample of permanent sampling plot (n = 117), the total height (HT) and height to crown base were measured on all trees within the 0.08-ha plot.

Based on DBH and HT, total tree volume was calculated using a species-specific taper equation. Given the differences between plot measurement and acquisition of the LiDAR data in the fall of 2010, the Acadian Variant of the Forest Vegetation Simulator was used to project DBH and HT to a common year. All LiDAR data was processed in FUSION v3.30 developed by the US Forest Service Pacific Northwest Research Station (McGaughey 2013). The software sorted raw LiDAR data into LiDAR metrics containing a number of potential predictor variables of inventory attributes. In our case, 97 potential predictor variables were created. To calibrate prediction models, FUSION extracted raw LiDAR data from 117 0.08-ha circular plots in the management units.

Random forest, a non-parametric regression approach, was deployed to calibrate maximum tree height (m), stem density (stem ha^{-1}), QMD (cm), basal area (m^2 ha^{-1}) and volume (m^3 ha^{-1}) prediction models. The 'randomforest' package is available in R statistical software v2.15.

Individual tree-based approach

We used a total of 1,694 stem mapped tree data in six replicated management units in the PEF. On each 0.08-ha plot, DBH was measured on all trees greater than 11.25 cm (4.5 inches). HT of twenty five percent of those DBH trees were measured between 2003 and 2011, and were spatially mapped based on azimuth and distance from each plot center.

Given the differences in dates between tree measurement and acquisition of the LiDAR data in the summer of 2012, the Acadian Variant of the Forest Vegetation Simulator was again applied to project DBH and HT to a common year. Based on simulated DBH and HT, total stem volume was estimated using a species-specific taper equation.

FUSION v3.30 extracted 98 potential predictor variables from the raw LiDAR data at each of mapped stem locations in the field. Although horizontal accuracy in geodetic information in LiDAR data is generally controlled within sub-meter accuracy (Evans *et al.* 2009), it is still difficult to assess horizontal accuracy. To account for certain horizontal error and different crown shapes and sizes among individual trees, FUSION metrics were extracted for a 4 m radius circular area around the mapped individual trees locations.

Random forest was deployed to classify species type (softwood and hardwood), and softwood species (spruces [red, white, black], balsam fir, and other softwood). To deploy supervised classifications based on the random forest technique in this study, we assumed that overall crown shapes and branch patterns between hardwood and softwood species are different. Also, among softwood species in the PEF, those tree elements are different enough that certain variables in the LiDAR metrics could correlate to shapes of softwood species. Classified species type data and classified softwood species data were used as a covariate for height and volume predictions. Consequently, three different sets of calibration data were used to predict individual tree height and volume: (1) LiDAR metrics only; (2) LiDAR metrics with classified species type; and (3) LiDAR metrics with classified softwood species.

Results

Area-based method

Overall, the random forest technique satisfactorily produced a volume prediction model, but the rest of inventory prediction models did not reach anticipated accuracy levels (table 3-4). We only report the results of stem density, QMD and basal area predictions in Table 3-4, while maximum tree height and total volume are described in detail below.

Maximum tree height

Our preliminary analysis indicated that a variable of maximum height elevation was strongly correlated to field measured maximum height. Thus, we did not develop a maximum height prediction model through random forest.

In general, LiDAR underestimated the maximum tree height by 1.89 ± 2.06 m, regardless of silvicultural treatments and species composition, while an agreement between field and LiDAR measured maximum height was strong (table 3-4). In particular, the diameter-limit and shelterwood units had a constant trend over the LiDAR measured maximum heights as both root mean square errors (RMSEs) were relatively small (figure 3-5a). The unmanaged units had the largest mean bias and RMSE as the largest variation between underestimation and overestimation. Also, LiDAR tended to greatly underestimate in softwood plots (Figure 3-5b) as greater mean bias and RMSE than hardwood plots.

Table 3-4. Developed prediction models with the three most key predictor variables with respect to mean square error in random forest with the coefficient of determination (R^2), mean bias (MB) with standard deviation (SD), and root mean square error (RMSE).

Attribute	Key variables (mean square error)	R^2 (Adj R^2)	MB (SD)	RMSE
Maximum Tree Height (m)	Height maximum elevation	0.869 (0.867)	1.89 (± 2.06)	2.80
Stem Density (trees ha^{-1})	5th percentile height (3.302) Height kurtosis (5.982) Height L-skewness (6.198)	0.287 (0.280)	9 (± 5013)	4993
Quadratic Mean Diameter (cm)	Percent 1st return above mean (6.591) Percent 1st return above 1 m (7.854) 25th percentile height (8.363)	0.489 (0.434)	-0.05 (± 3.69)	3.68
Basal Area (m^2 ha^{-1})	Percent all returns above 1 m (7.262) Height L-kurtosis (7.564) 99th percentile height (7.614)	0.344 (0.339)	0.03 (± 13.07)	13.01
Volume (m^3 ha^{-1})	90th percentile height (7.795) 20th percentile height (8.7245) 75th percentile height (9.757)	0.721 (0.719)	1.81 (±66.96)	66.70

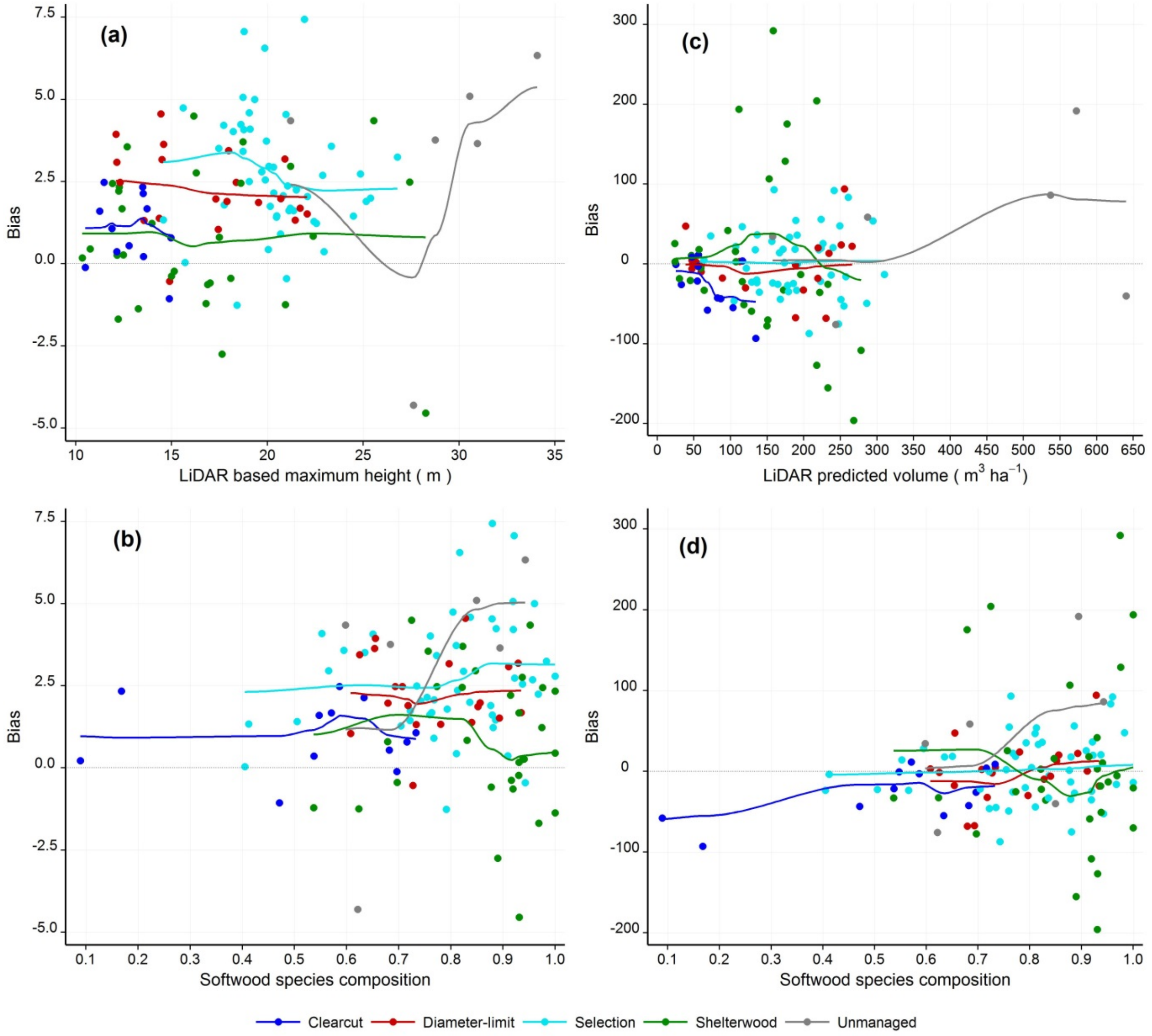

Figure 3-5. Scatterplot of maximum tree height and volume prediction biases (observed - predicted; m and m^3 ha^{-1}) over LiDAR predicted values with lowess regression splines for the different silvicultural treatments **(a** and **c)**, and plot species composition based on basal area **(b** and **d),** respectively.

Stem volume

In general, LiDAR underestimated the volume by 1.81 ± 66.96 m^3 ha^{-1} across silvicultural treatments and species composition (table 3-4). The prediction bias in the clearcut and diameter-limit units was fairly constant as those RMSEs were relatively small while predictions particularly in the shelterwood and unmanaged units varied over the predicted volume as those RMSEs were large (figure 3-5c). In general the model underestimated the volume in the selection and unmanaged units while overestimated in the diameter-limit and clearcut units. The prediction in the shelterwood units was varied between underestimation and overestimation with increasing the predicted volume. Except for the selection units, prediction biases tended to increase with increasing the softwood species composition (figure 3-5d).

Individual tree-based method

The random forest technique calibrated three individual tree height and stem volume prediction models based on (1) LiDAR metrics only; (2) LiDAR metrics with classified species type; and (3) LiDAR metrics with classified softwood species. Overall, those models did not reach anticipated accuracy levels. We only report the result of the height and volume models based on (2) and (3) in Table 3-5, while the model based on (1) and the results of species classification are described in detail below.

Species type classification and softwood species classification

For the 1,694 softwood and hardwood trees, the random forest technique was used to classify them into softwood or hardwood. While overall accuracy was about 85%, Kappa statistics was almost 0% (table 3-6a). For the 1,394 softwood trees, the random forest technique was again used to classify them into spruces (black, red and white), balsam fir, or other softwood. While overall accuracy was about 56%, Kappa statistics was 0% (table 3-6b).

Tree height prediction

Using only LiDAR metrics, the model slightly underestimated tree height by 0.01 ± 3.47 m regardless of silvicultural treatments and species type, while an agreement between field measured and model predicted heights was weak (table 3-6). In general, tree heights in the clearcut and diameter-limit units were slightly overestimated, while trees in the selection units were underestimated (figure 3-5a). This model underestimated hardwood to a greater extent than softwood heights (figure 3-6b). Tree heights in the dominant crown position were also underestimated, and overestimated in the codominant and intermediate crown positions (figure 3-6c). In particular, trees in the intermediate crown position were increasingly overestimated with greater predicted heights.

Table 3-5. Developed prediction models with the five most key predictor variables. The classified species type and the classified softwood species were derived through supervised classification using the random forest technique based on the LiDAR metrics.

Attribute	Covariates	Key variables (mean square error)	R^2 ($Adj\ R^2$)	MB (SD)	RMSE
Height (m)	LiDAR metrics	Percent 1st returns above mean (13.01) Percent all returns above mean (15.31) 20th percentile height (15.95) 75th percentile height (21.23) 95th percentile height (22.85)	0.269 (0.269)	0.011 (3.47)	3.47
Height (m)	LiDAR metrics + Classified species type	10th percentile height (10.66) 75th percentile height (11.66) 10th percentile height (11.82) 95th percentile height (14.94) Classified species type (17.32)	0.292 (0.291)	0.007 (3.41)	3.41
Height (m)	LiDAR metrics + Classified sw species	All returns above 1 m (9.01) Mean height (11.28) 90th percentile height (12.85) 95th percentile height (13.41) Classified softwood species (29.66)	0.378 (0.377)	0.018 (3.26)	3.26
Volume (m^3)	LiDAR metrics	30th percentile height (10.80) 70th percentile height (10.89) 99th percentile height (10.93) 90th percentile height (11.00) 95th percentile height (12.08)	0.166 (0.166)	0.000 (0.37)	0.37
Volume (m^3)	LiDAR metrics + Classified species type	80th percentile height intensity (10.68) Elevation variance (10.85) 30th percentile height (12.49) Height standard deviation (12.68) 80th percentile height (12.92)	0.165 (0.164)	0.002 (0.37)	0.37
Volume (m^3)	LiDAR metrics + Classified sw species	Percent 1st returns above mean (6.52) 30th percentile height (9.24) Height standard deviation (11.53) 70th percentile height (11.81) Classified softwood species (31.03)	0.296 (0.295)	0.000 (0.36)	0.36

Table 3-6. The results of species type classification (hardwood or softwood) and the softwood classification (spruces, balsam fir and other softwood) through supervised classification using the random forest technique. **(a)** Accuracy assessment in the species type classification; and **(b)** accuracy assessment in the softwood species classification.

(a)		**Observed**				
		Hardwood	**Softwood**	**Total**	**User's accuracy**	**Commission error**
Predicted	**Hardwood**	101	199	300	0.34	0.66
	Softwood	51	1343	1394	0.96	0.04
	Total	152	1542	1694		
	Producer's accuracy	0.66	0.87			
	Omission error	0.34	0.13			
			Overall accuracy		**Kappa statistics**	
			0.85		0.00	

(b)		**Observed**					
		Spruce	**Balsam fir**	**Other softwood**	**Total**	**User's accuracy**	**Commission error**
Predicted	**Spruces**	76	83	134	293	0.26	0.74
	Balsam fir	47	284	162	493	0.58	0.42
	Other softwood	51	138	419	608	0.69	0.31
	Total	174	505	715	1394		
	Producer's accuracy	0.44	0.56	0.59			
	Omission error	0.56	0.44	0.41			
				Overall accuracy		**Kappa statistics**	
				0.56		0.00	

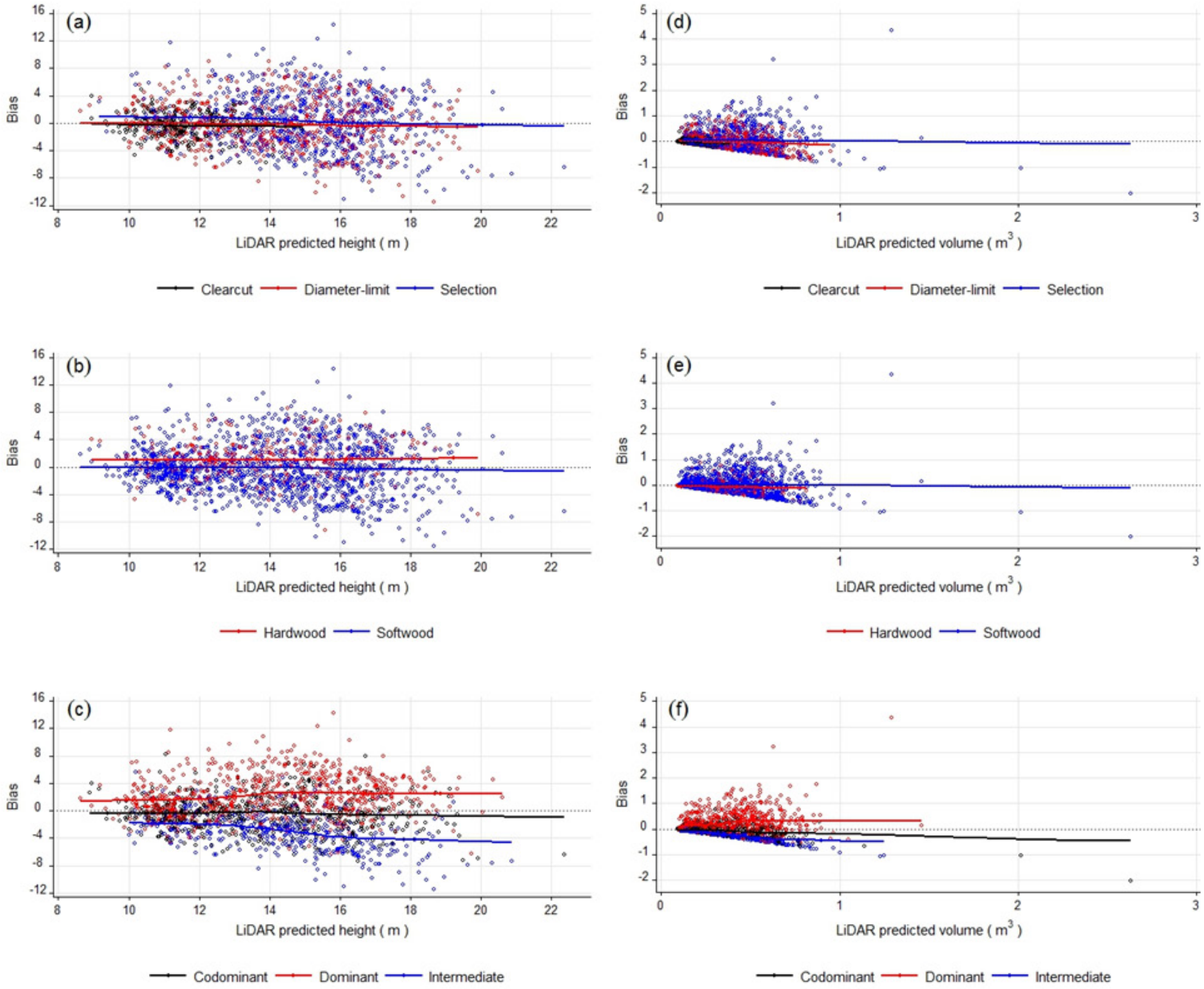

Figure 3-6. Individual tree height and volume prediction models were developed based on LiDAR metrics. Scatterplot of tree height and volume prediction biases (observed - predicted; m and m^3) over LiDAR predicted values with lowess regression splines for the different silvicultural treatments **(a** and **d)**, species type **(b** and **e)**, and crown positions **(c** and **f)**.

Stem volume prediction

An individual tree volume prediction model was developed based on LiDAR metrics only. The model had noticeable bias for overestimating volume by < 0.01 ± 0.37 m^3 (table 3-6 and figures 3-6d though f). Unlike the tree height prediction model based on LiDAR metrics only, this model underestimated softwood, and overestimated hardwood volumes. However, like the height prediction model, this model underestimated tree volumes in the dominant crown position, while overestimating in the codominant and intermediate crown positions (figure 3-6f).

Discussion

Area-based method

Silvicultural treatments and species composition

The unmanaged units tended to results in large prediction errors. For instance, the unmanaged units had the highest bias in the maximum height and volume predictions. Although total area of unmanaged units is smaller than other four management units, it tends to have the highest variability and the six sampling plots might not have accounted for this variability. Also, management units with softwood species composition greater than 80% tended to result in large prediction errors. For example, the volume prediction tended to be greatly toward underestimation in the softwood species dominant plots. In general, the plots with the highest softwood composition had multiple layer canopy structures in the PEF, which can be problematic for prediction using LiDAR metrics.

Maximum Tree Height

The maximum tree height in plots was generally underestimated, and such result was similar to most other studies (*e.g*. Magnusson *et al.* 2007). A number of laser pulses likely returned from below treetops, and prediction in the softwood dominant plot had a larger underestimation than the mixedwood plots. The RMSE of 2.75 m between field measured and the LiDAR measured maximum heights in this study was similar to those observed by Means *et al.* (2000) and Jensen *et al.* (2006) who also used a low pulse density LiDAR. In contrast, Magnusson *et al.* (2007) pointed out that achievable accuracy levels in tree height predictions depends also on canopy structure. For example, uniformly distributed canopy height structural stands may not require the use of high pulse density LiDAR.

Volume

The developed plot-level volume (m^3 ha^{-1}) had the highest R^2 value of the various equations evaluated in this study (0.72), which was relatively similar to other studies such as (van Aardt *et al.* 2006, Hawbaker *et al.* 2010). Like this analysis, both of these studies were based on low pulse density LiDARs. However, the accuracy of volume prediction models is likely influenced by not only pulse density, but also the stand types examined. For example, Jaskierniak and others (2011) developed models with R^2 values of 0.59-0.80 based on 2 pulses m^{-2} in an eucalyptus forest in Australia, while Means and others (2000) developed models with high R^2 values based on a low pulse density in a Douglas-fir (*Pseudotsuga menziesii* (M.) Franco.) dominated forest in Oregon. When compared to the PEF, the stand structures in these aforementioned studies are relatively simple. Like this study, van Aardt *et al.* (2006) and Hawbaker *et al.* (2010) conducted the study in mixed softwood-hardwood forests in Virginia and Wisconsin, respectively, which would have stand structures similar to the PEF. Woods *et al.* (2011) also worked in a mixed softwood-hardwood forests in Ontario, Canada and were able to achieve a much lower RMSE than our study. Woods *et al.* (2011) likely did this by stratifying their study area into four stand types based on species composition rather than past silvicultural treatments. Likewise, Anderson and Bolstad (2013) found that stratification of models by forest type was necessary to improve prediction accuracy.

In this study, the volume prediction as well as other inventory attributes was particularly problematic in the shelterwood and unmanaged units, due to the high structural variability between plots within each of these management units. Shelterwood systems tend to leave a small number of large trees in the overstory with the intent of promoting a greater number of young trees and seedlings in the understory. Likely, a greater number of field plots or larger size plots would be needed to account for this large variability Anderson and Bolstad (2013).

Individual tree-based method

Individual tree height and volume prediction models showed weak correlations between field measured and model predicted values. Although mean bias in each model was relatively small, the RMSE was large (table 3-5). Besides the complex forest structure in the PEF, a reason why the results did not reach anticipated accuracy levels is that erroneous georegistration between individual tree locations and LiDAR point cloud seemed to leave a profound effect on the individual tree height and volume predictions. To predict aboveground carbon density, Asner *et al.* (2009) reported that prediction errors was negligible due to erroneous georegistration between calibration plots and extracted LiDAR metrics plots in an area-based approach. However, Means *et al.* (2000) reported that prediction error in aboveground carbon density tended to increase with increasing spatial resolution (*e.g.* smaller calibration plots in size).

Species Type Classification and Softwood Species Classification

Although intensity-related variables were available in our LiDAR metrics, we did not have an appropriate tool and other auxiliary data to calibrate for flying attitudes, terrain conditions, and atmospheric conditions for the intensity values. While Korpela *et al.* (2010) calibrated intensity values based on range-distance, and used the random forest technique to classify Norway spruce, Scots pine and birch, selected important classification variables were all intensity-related variables

In the species type classification, kappa statistics in this classification was almost 0%, which indicated that the agreement of correctly classified softwood and hardwood was purely by chance. Hardwood crowns tend to have different shapes depending on species, position in the crown and stem density when compared to softwoods. Thus, omission error in the hardwood classification was large (table 3-6a). Korpela *et al.* (2010) had relatively lower classification accuracy in birch than Scots pine and Norway spruce, and noted that relative height differences within birch influenced in intensity values returned from the uppermost canopy surfaces. Reitberger *et al.* (2008) and Vauhkonen *et al.* (2009) found that LiDAR data acquisition under a leaf-off condition had a better classification result in the species type classification because returned intensity-related variables were much different between softwood and hardwood.

Softwood species crown shapes are relatively similar among the species examined; therefore, height-related variables were not effective for classifying softwood species. As kappa statistics was 0%, this classification result was purely by chance. While Holmgren and Persson (2004) mainly used intensity-related variables to classify between Scots pine and Norway spruce, they had a lower classification accuracy for Scots pine because crown shapes of Scots pine varied depending on growth conditions. On the other hand, Suratno *et al*. (2009) reported that similar pulse return characteristics were observed among different species during a species classification process if those species grow in similar stand conditions such as a crown closure level or stem density; however, pulse intensity characteristics were dissimilar among species. Thus, for future refinements, the model needs to include appropriately calibrated intensity-related variables. Additionally, Li *et al.* (2013) reported that greater pulse density improved in the classification accuracy, and return pulses should have been described in both vertical distribution and horizontal distribution for each individual crown.

Individual Tree Height Prediction

Although an agreement between field measured and model predicted individual tree height in all three models was weak (table 3-5), one notable result was that predicted individual tree heights were associated with field-assessed crown positions. This association would be improved if we could improve horizontal accuracy between stem mapped trees and LiDAR point cloud. In the tree height prediction models, tree heights in the dominant crown position were constantly underestimated with greater predicted height. Most previous studies reported that LiDAR sensors tended to underestimate tree heights (*e.g.* Clark *et al.* 2004) because low pulse density LiDAR likely resulted in insufficient direct hit on treetops (*Falkowski et al.* 2006). Although Wang and Glenn (2008) reported that heights of conical crown shape of softwood trees tended to be underestimated to a greater extent than an ellipsoidal crown shape of hardwood trees, this study observed an opposite result as hardwood heights were generally underestimated. One reason might be that hardwood crown shapes in the PEF might be described as similar to a narrow and rounded shape due to increased crown competition. Another reason might be that the low pulse density LiDAR sensor used in this study could not sufficiently sense individual hardwood trees in the intermediate crown position, which were partially overtopped by trees in the dominant and codominant crown positions. Gonzalez-Ferreiro *et al.* (2013) noted that some pulses were reflected from the inside of crown rather than crown surfaces. Brandtberg *et al.* (2003) found that larger trees tended to be underestimated, but smaller trees were overestimated in height predictions. Based on our results, those lower canopy LiDAR pulses were returned primarily from dominant or codominant crowns, which resulted in overestimated heights of these smaller trees.

While we added the classified species type as an additional covariate in the height prediction model, it did not improve the predictions greatly. However, when we compared the field observed species type as a covariate (instead of the classified species type), the R^2 value was again barely improved. Therefore, it is inferred in this study that there was a limited relationship between individual tree height and species type due to the wide range of tree height between and within hardwood and softwood species in the mixed forest environment of the PEF.

Stem volume prediction

An agreement between field measured and model predicted individual tree volume in all three models was weak (table 3-5). The field measured volume was derived using a species-specific taper equation, which requires individual tree DBH data besides total height data. Although this study did not report individual tree DBH predictions based on LiDAR metrics, we had low model fits during preliminary analysis. Therefore, due to relatively low accuracy of both height and DBH predictions, our individual tree method would not be an appropriate approach for the individual tree volume prediction. Yu *et al.* (2010) used similar pulse density LiDAR data as our study to deploy an individual tree-based method for volume prediction in a Scots pine and Norway spruce dominating boreal forest. Based on successfully matched trees between segmented and field located trees, relative RMSE of 21.58% was achieved. Also, Yu *et al.* (2010) and Yu *et al.* (2011) reported that omission errors during segmentation process in an individual tree-based method largely affected volume prediction while segmentation accuracy depended on stand structures. For example, segmentation accuracy was higher with lower stem density plots or larger DBH trees; therefore, higher volume prediction accuracy could be achieved for the lower stem density plots or the larger DBH trees in the individual tree-based method. In this study, the volume prediction model for softwood tree had a better model fit than the model for both hardwood and softwood trees. Thus, a high accuracy result in the species type classification would lead to improve the volume predictions to stratify trees between softwood and hardwood.

Conclusion

In general, the area-based method using the low density LiDAR in this study was able to develop high R^2 models for maximum tree height and volume predictions, despite a wide range of stand structure and species composition mixtures examined. However, there were certain stand structures and species composition mixtures where low density LiDAR was ineffective. Although costs of LiDAR data acquisition for large areas are still relatively high, this study highlights that use of LiDAR based inventory attribute predictions are a valuable option for achieving efficient and effective forest assessment from a variety of spatial scales, even in regions dominated by naturally-regenerated, mixed species stands.

On the other hand, the individual tree-based method using low density LiDAR data in this study for tree height and volume predictions did not result in high level accuracy and precision. While we initially hypothesized that the LiDAR metrics and individual tree height would be correlated to some degree, the low density LiDAR data used in this analysis was not sufficient for tree-level predictions. Also, we hypothesized that each tree species would have a rather unique crown shape and branching pattern, but our LiDAR data was not capable of distinguishing between either hardwood or softwood species. One possible explanation is that the mixed species and multi-age forest structure of the PEF promoted high competition for both hardwood and softwood trees, which has resulted in similar crown characteristics between and within a species.

As future work for the area-based methods, we need to investigate how different model development algorithms, such as random forest and nonlinear mixed effects model, as well as how low and high density LiDAR influence on prediction bias. Also, developed prediction models in this study need to be tested at other parts of the Acadian region forests, such as in New Brunswick, Canada whether the models predict same level accuracy and precision.

For the individual tree-based methods, it is important to investigate how horizontal accuracy between LiDAR point cloud and individual trees in the field are matched. Also, we need to investigate calibration methods for LiDAR intensity values for species classification. Additionally, it should be compared forest inventory predictions deployed by area- and individual tree-based approaches to be summed to a stand-level.

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ESTABLISHMENT OF PERMANENT SAMPLE PLOTS IN PARTIALLY HARVESTED STANDS

Aaron Weiskittel and Benjamin Rice

Introduction

The effects of partial harvesting on residual stand growth and development are relatively unknown and a network of permanent sample plots will be useful in shedding light on these current deficiencies. More specifically, long data from such plots will help us assess whether current growth and yield models are adequate for partially harvested stands and to make necessary changes to the models to more accurately reflect post partial harvest growing conditions. This undertaking is also important to individual land owners and land managers as well as the entire forestry sector of the state, with policy and economic implication relevant to Maine’s future. Below we describe our techniques for establishment of permanent sample plots and some general features of the plots.

Methods

Permanent sample plots were established in stands included in other partial harvesting research that were partially harvested between 2000 and 2010. In selecting stands, stands were stratified by the four biophysical regions represented within the study area (Aroostook Hills, Central Mountains, Boundary Plateau and Western Mountains) and stand composition (i.e., hardwood and mixedwood). A total of eight stands were randomly selected (figure 3-7). Three plots were established in each selected stand. The plots were randomly selected from previously measured partial harvesting research plots.

Plot establishment consisted of plot monumentation, overstory tree measurement, seedling and sapling measurement and assessment of nearby trails. Plot monumentation entailed recording the plot center location with a professional grade GPS unit, installation of rebar to mark the plot center and photographing of the plot. These steps should help in relocation of the plot for remeasurement in the future.

The overstory tree plot established at each selected plot is a 1/10 acre circle (radius of 37.2 feet). For each tree (≥4 inches DBH) within the plot, distance and azimuth from the tree to plot center was recorded to facilitate relocation of individual trees. Data recorded for each tree included species, DBH, a tree condition code and damage type and location. For a random subsample of trees (20%), we recorded total height and height to the base of the live crown. Similarly, DBH and species, where identifiable were recorded for snags within the plot. A numbered tag set at approximately 10 inches above ground level was affixed to each live tree and snag within the plot.

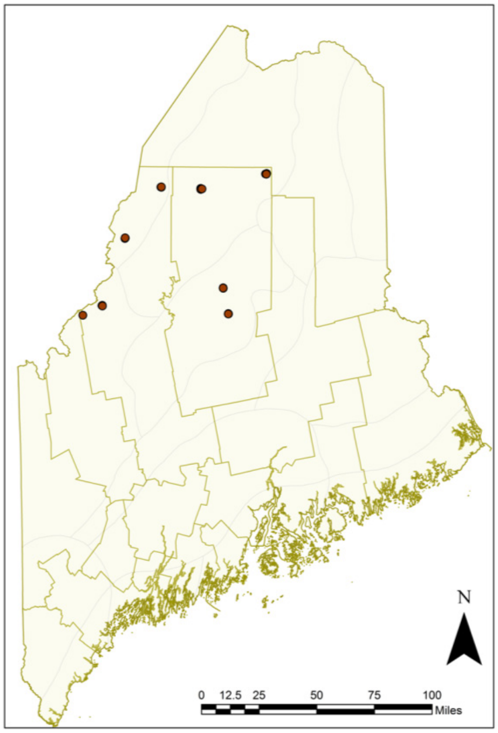

Figure 3-7. Locations of partial harvesting permanent sample plots in Maine.

We also established a 1/100 acre (11.78 foot radius) circular sapling subplot nested within each overstory plot. All trees between 2 and 4 inches DBH within the sapling subplot were tagged as in the overstory plot. For each sapling, we recorded species, DBH, height, and a tree condition code.

A 6 foot radius regeneration subplot was established within each plot. For each stem <2 inches DBH within the regeneration subplot, we recorded species and height class (0.5-1 foot; 1-2 feet; 2-3 feet; 3-4.5 feet; >4.5 feet but less than 2 inches DBH). We also estimated the percentage of the plot area covered by several classes of potentially competing vegetation, as well as bare ground.

In order to develop relationships between the individual tree responses and the harvest patters, the field crews took GPS centerlines of all machine trails within approximately 75 feet of plot center. These line features were then imported into ArcGIS.

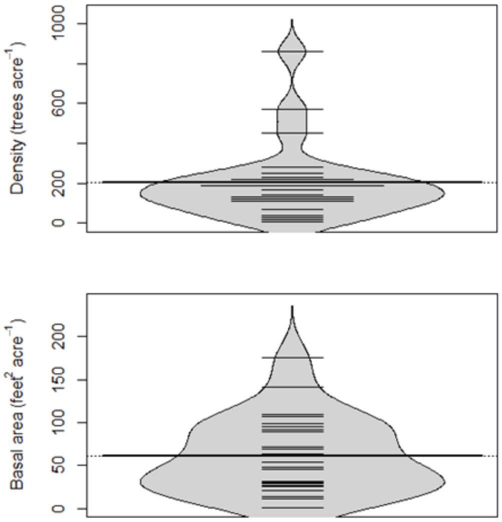

Figure 3-8. Permanent sample plot stem density and basal area. The black horizontal line indicates the overall mean.

Results

In total the field crew measured 1117 live trees and 104 snags in 24 plots. As has been shown in other partial harvesting research projects, the residual stand structure was highly variable. Within the plots basal area of trees >4 inches DBH ranged between 1 and 175 ft^2 ac^{-1} and density ranged between 10 and 860 trees per acre (figure 3-8). 71% of all regeneration sub plots contained some raspberry cover and 13% contained > 50% raspberry cover.

Discussion

Establishment of these permanent sample plots is only the first step in this effort. Re-measurement of these plots will allow us to test current model performance in the areas of changes in height to crown base, diameter increment and height increment. We will also gain insight into post-harvest mortality and ingrowth patterns. This dataset may also be useful in addressing larger issues surrounding the effectiveness of different distance-dependent and distance-independent at explaining individual tree growth. The distance-dependent measures of interest include area potentially available (APA) and exposed crown surface area, while the distance-independent measures would be crown competition factor (CCF) and basal area in larger trees (BAL). This project will also begin to investigate the post-harvest dynamics of partially harvested stands, an issue important to efforts to quantify, improve, and sustain productivity of Maine's working forests.

Table 3-7. Attributes of the 24 permanent sample plots.

Attribute	Mean	SD	Min	Max
Overstory stem density (# ac^{-1})	202	190	10	860
Sapling stem density (# ac^{-1})	263	293	20	1300
Seedling stem density (# ac^{-1})	22,029	13,435	770	53,900
Basal area (ft^2 ac^{-1})	72.7	52.5	13.6	215.7
Quadratic mean diameter (in)	5.9	1.8	2.5	10.6
% softwood basal area	41	39	0	96

Wildlife

Snowshoe Hare and Canada Lynx

Spruce Grouse

Forest Bird Communities

RELATIONSHIPS AMONG FOREST HARVESTING, SNOWSHOE HARES AND CANADA LYNX IN MAINE

Daniel Harrison, Sheryn Olson, David Mallet, Angela Fuller, and Jennifer Vashon

Background and Project Overview

Maine's Acadian sub-boreal forests have structural and species compositional characteristics similar to boreal forests resulting from past silvicultural practices. Stands of dense, advanced sapling-stage regeneration of balsam fir are common across many landscapes and support high population densities of snowshoe hares (*Lepus americanus*). Although hare densities in these managed stands are lower than hare densities observed near the peak of hare cycles in boreal forests, snowshoe hares densities exceed 0.75 hare/ha across many stands through time, and are the dominant component of the prey base supporting a diverse array of mammalian and avian carnivores.

In the Acadian forests of Maine, where much of the critical habitat for the U.S. federally threatened Canada lynx (*Lynx canadensis*) occurs, hares are expected to predominate in diets of lynx, especially during winter, and lynx population demographics are associated with hare densities. Boreal forest hare populations exhibit classic 10-12 year cycles and reach low densities of 0.2 to 0.6 hares per hectare (Poole 1994, Staples 1995, Murray 2000), during which lynx fecundity declines, lynx increase home range sizes and juvenile survival and recruitment is reduced (Slough and Mowat 1996, O'Donoghue *et al.* 1997). In Maine among all our forest stand types we monitored, snowshoe hares have averaged less than one hare per hectare since 2008, and average less than 0.6 hares per hectare in mixed deciduous-conifer and selection harvest stand types (figure 4-1). When hares decline to less than 0.7 hares per hectare, Acadian landscapes may be less suitable for lynx (Simons-Legaard et al. 2013). Current forest management prescriptions combined with successional changes in dense 30 to 40 year old conifer stands are expected to reduce high-quality hare habitat substantially by 2037 (Simons 2009). Thus, this study is designed to evaluate temporal and spatial dynamics of hares in the Acadian forest, to evaluate evidence for cyclicity in hare populations, and to evaluate changes in the relative occurrence of hares in lynx diets between seasons and between periods of high and low hare density.

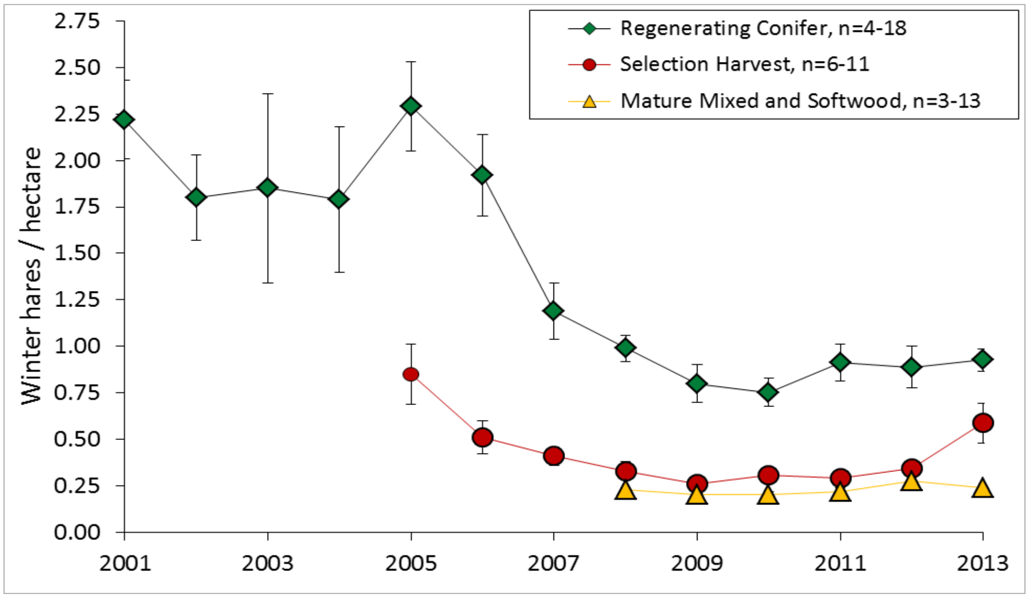

Figure 4-1. Preliminary (do not cite) snowshoe hare densities during winter in three forest stand types: regenerating conifer dominated stands 25 -40 years post-clearcutting; selection harvests; and mature conifer and mixed conifer-deciduous stands (pooled). Whiskers span the mean ± one standard error.

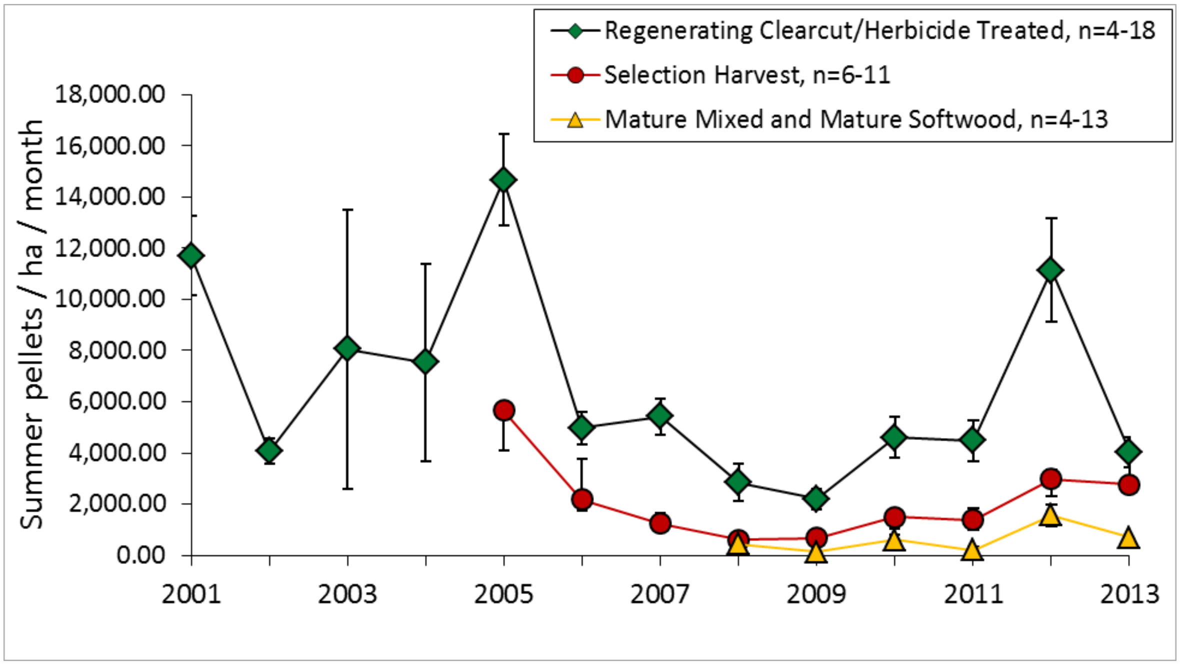

Figure 4-2. Preliminary (do not cite) snowshoe hare fecal pellet densities during summer in three forest stand types: regenerating conifer dominated stands 25 -40 years post-clearcutting, selection harvests, and mature conifer and mixed conifer-deciduous stands (pooled). Whiskers span the mean ± one standard error.

Summary of 2013 Activities

Snowshoe Hare Density Monitoring Program

Since 2001 in the north Maine woods we have monitored snowshoe hare densities by counting, then clearing fecal pellets from 28 subsampled plots in each of 30 established stands that represent four harvest and silvicultural treatments. Previous work in our lab documented that pellet densities are reliable surrogates of hare density and allow rather precise estimates of hare densities during the over-winter season. We conduct sampling semi-annually in May and October to assess over-winter densities and to derive a summer index of hare densities across space and time. As of 2013, forest stand treatments include the following stand types:

1) 18 regenerating conifer-dominated 25 to 40 year old stands that were herbicide (Glyphosate) treated 3 to 5 years post clearcut;
2) 7 selection harvest stands;
3) 4 mature stands at least >50 years since last cut; and
4) a partial harvest group including ten overstory removal and shelterwood retention stands.

Our laboratory has validated that winter hare densities can be accurately estimated from counts of snowshoe hare fecal pellets over a range of 0.5 to 2.4 hares per hectare (Homyack *et al.* 2006). Figure 4-1 presents results of winter hare densities from 2001 – 2013. Summer snowshoe hare populations fluctuate from births and juvenile recruitment, and we have not corroborated summer fecal pellet counts with hare abundance estimates derived from capture-mark-recapture efforts. Thus summer results are displayed as fecal pellet densities (figure 4-2).

From 2006 through 2009, inter-annual winter hare densities exhibited a decline in two stand types, regenerating conifer-dominated and selection harvest stands, whereas mature stand types showed no trend over time (figure 4-1). Since 2009, winter hare densities have remained stable. Summer hare densities exhibited similar trends until 2012, when fecal pellet densities increased in regenerating conifer stands, though 2012 may have been anomalous (figure 4-2).

Hare Seasonal Habitat Assessment

The goal of this portion of the hare study is to determine whether snowshoe hares use different forest stand types differentially by season in response to changing food and cover resources. Primary objectives are to determine:

1) Whether different forest stand types exhibit shifts in seasonal use by hares; and

2) Which seasonal changes in structural and species compositional attributes of those stands are most strongly associated with seasonal shifts in hare use among all stands.

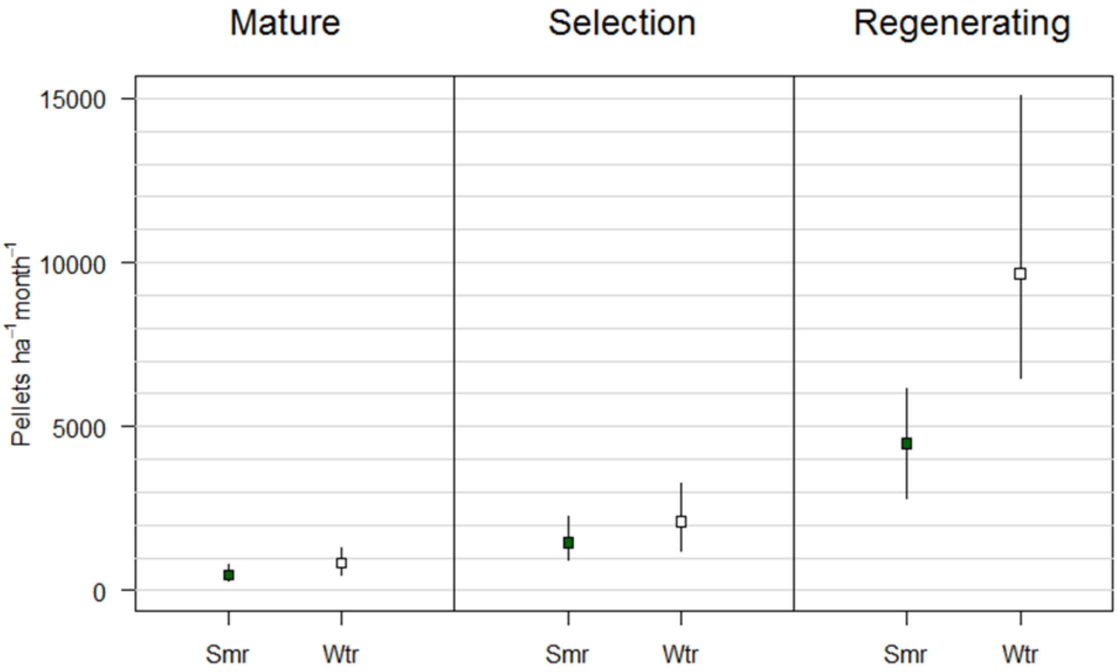

Figure 4-3. Preliminary (do not cite) snowshoe hare fecal pellet densities in summer and winter in three forest stand types: pooled mature conifer and mixed conifer-deciduous stands (Mature, n=33 summer stands, n=38 winter), selection harvests (Selection, n=75 per season), and regenerating conifer dominated stands 25-40 years post-clearcutting (Regenerating, n=120 per season). Significant seasonal shifts in hare pellet densities occur in the Regenerating stand type, compared to Mature and Selection harvest stands. Whiskers are 95% credible intervals generated with 10,000 Markov Chain Monte Carlo iterations about the mean.

Sheryn Olson completed the field habitat vegetation measurements summer 2012 for her Master's thesis project. She collected seven habitat variables to examine understory cover and species composition in 20 plots surveyed within 29 stands during summer 2011 and from six additional stands during summer 2012 (three mature conifer and three regenerating conifer). From January through March 2012, Sheryn and crews collected three winter habitat variables from 10 plots in 28 stands during a winter field season conducted across > 1400 km^2 of northern Maine. We are using hare pellet counts as the response variable from three summer and three winter periods spanning winter 2010 to summer 2013.

We compared three stand types: Regenerating Conifer, Selection Harvest and Mature (both mixed and conifer dominated) seasonal fecal pellet counts from the eight year period of 2008 – 2012. Results indicated that hares do not shift activities as much seasonally in mature and selection harvested stands (figure 4-3), where they maintain low densities throughout the year, as compared to regenerating conifer stands, which support intermediate hare densities in summer and significantly higher hare densities in winter.

Sheryn has completed the analysis of objective two and is currently compiling the results. Preliminary results of which habitat covariates may influence seasonal hare use of stands suggest that percentage of mid-story coverage independent of both species composition and season may be the most important effect influencing higher snowshoe hare pellet densities among all forest stand types consistent with recent work throughout North America in British Columbia (Sullivan *et al.* 2010), Wyoming (Berg *et al.* 2012), Washington (Lewis *et al.* 2011), and in Maine (Fuller and Harrison 2013).

Seasonal Food Habits of Lynx

Canada lynx are considered specialist predators of snowshoe hares, and can depend on snowshoe hares for up to 97% of their diet (Apps 1999), but are capable of using other prey and may exhibit shifts in diet both seasonally and when hares are at low density. Seasonal prey switching has been documented to occur during summer when a greater diversity of potential prey species are available. In Nova Scotia, 93% of winter lynx scats contained snowshoe hare, while only 70% of summer scats contained snowshoe hare (Parker et al. 1983). Near Maine, on the Gaspé peninsula, Québec, hares were 58% of lynx summer diet, but increased to 85% during winter (Fortin and Huot 1995).

To evaluate the range in dietary diversity that lynx may exhibit in Maine, we collected scats during winter during a period of relatively high hare abundance and, conversely, in summer during a period of lower hare abundance. We contracted with the University of Washington's Center for Conservation Biology (CCB) Canine Detection Unit to collect summer lynx scats, which would be difficult to find without trained scat detection dogs (figure 4). We collected 235 scats, and had all scats analyzed at CCB's genetics laboratory to definitively identify those deposited by lynx and to determine the gender of the lynx. We have 175 summer lynx scats confirmed to be produced by lynx, and 62 winter scats verified as deposited by lynx from tracks on snow. Scats have been pre-processed and analyses to determine diet composition in scats is scheduled for winter 2014. A report summarizing seasonal diets of lynx in is anticipated by April 2014.

Figure 4-4. Samson is rewarded for detecting lynx scat, July 2011.

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PATCH OCCUPANCY, HABITAT USE, AND POPULATION PERFORMANCE OF SPRUCE GROUSE IN COMMERCIALLY MANAGED CONIFER STANDS

Stephen Dunham and Daniel Harrison

Background and Project Overview

Spruce grouse (*Falcipennis canadensis*) are a species of forest grouse dependent on conifer dominated forests (Boag and Schroeder 1992, Storch 2000) (figure 4-3). Although abundant across Canada and Alaska, the southern border of their range intersects extends only marginally into the northernmost of the contiguous United States. Coincidentlaly, a recent assessment by the International Association of Fish and Wildlife Agencies concluded that populations in the southeastern portion of the species' range including those in New England and New York are rare or declining (Williamson *et al.* 2008). The southeastern extent of the geographic range of spruce grouse coincides with southeastern distribution of red and black spruce within the Acadian forests of Maine, northern New Hampshire, northernmost Vermont, the Adirondacks region of New York State, as well as the eastern maritime provinces of Canada. Within this region, spruce grouse are listed as endangered in Vermont and New York, and are a species of conservation concern in New Hampshire.

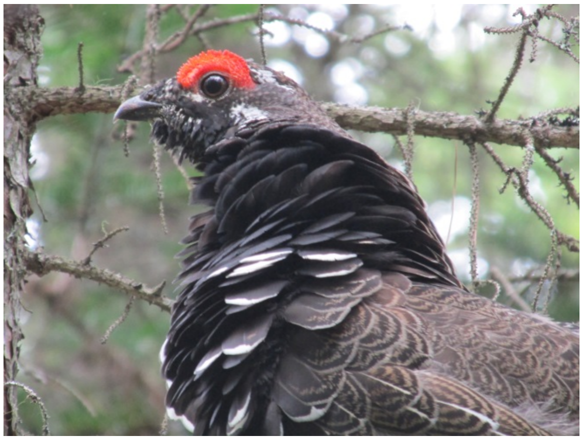

Figure 4-3. Spruce Grouse in Maine.

Although there is no hunting season on the species in Maine, little else is known about their current status. Legaard and Sader (unpublished data, Maine Image Analysis Laboratory, University of Maine, Orono) have disclosed recent information suggesting that mid-late successional coniferous forests and coniferous forested wetlands are being harvested at accelerating rates in Maine, which could imply that the habitats that spruce grouse have been traditionally considered to inhabit may be declining. Thus, a better understanding of patterns of habitat occupancy across a range of stand conditions and a comparison of spruce grouse occupancy and population performance between residual mature and actively managed conifer stands is needed to assess the current and future status of spruce grouse habitat in commercially managed forests in the southeastern portion of the species range.

Spruce-grouse inhabit mid-successional conifer forests and coniferous forested wetlands (Ross 2007). Clearcutting has been shown to reduce the survival and reproductive success of spruce grouse by causing movements into adjacent uncut buffer strips (Turcotte et al. 2000, Potvin and Courtois 2006). Additionally, Lycke *et al.* (2011) reported that male spruce grouse were less likely to occur in commercially thinned versus un-thinned stands in Quebec. To the contrary, populations of spruce grouse in protected portions of the Adirondack forest continue to decline as the forest matures (Bouta and Chambers 1990, Ross 2007).

The extent that some management approaches in conifer stands may maintain or increase habitat quality for spruce grouse is unknown. Spruce grouse have been documented to occur in plantations and PCT stands (Boag and Schroeder 1992, Homyack 2003), and Rattie *et al.* (1984) reported that over half of sites occupied by grouse had lowest live limb heights between 1.5 and 4.5 meters. Although those conditions may be common in mature, uncut, lowland conifer stands, we hypothesize that favorable conditions for spruce grouse may also be created in some plantations and precommercially thinned (PCT) fir-spruce stands within the Acadian Forest.

Thus, a better understanding of the occupancy and survival of spruce grouse within intensively managed conifer stands is essential to the understanding of current habitat quality across the region. The goals of this project are to increase our understanding of the effects of commercial forest management in the Acadian balsam fir- and red and black spruce-dominated stands on patterns of stand-scale occupancy, habitat use, survival and brood rearing success.

Progress During FY 2013

Occupancy surveys

During the month of May and into the beginning of June we performed three cantus call surveys within 28 conifer stands (table 4-1, figure 4-4). Of these, 16 were occupied by spruce grouse. Of the >60 flutter flights heard, we captured 17 new males and had 20 refighting's of previously marked birds. We successfully captured one female during a May cantus survey and heard several more that we were unable to capture.

Table 4-1. Location, stand treatment, occupancy by male spruce grouse detected during cantus call surveys, and number of females equipped with VHF transmitters within 30 conifer-dominated stands studied in northern Maine during May-October 2013.

Stand	**Northing**	**Easting**	**Stand Treatment**	**Male Occupancy**		**Marked Males**		**Radioed Females**	
				2012	**2013**	**2012**	**2013**	**2012**	**2013**
MSW3	5114593	0468528	Mature Softwood	Y	N	1	0	0	0
MSW9	5088849	0476112	Mature Softwood	N	N	0	0	0	0
MSW10	5112809	0467144	Mature Softwood	N	Y	0	0	0	0
MSW11	5116481	0468210	Mature Softwood	Y	N	0	0	2	0
MSW12**	5114040	0506349	Mature Softwood	-	-	-	-	-	0
MSW13**	5109086	0504369	Mature Softwood	-	-	-	-	-	1*
JH01C	5096050	0487450	Advanced Regen	Y	Y	4	2	3	0
JH02C	5095454	0490399	Advanced Regen	N	N	0	0	0	0
JH03C	5098147	0484328	Advanced Regen	Y	Y	0	3	2	1*
JH04C	5103344	0485151	Advanced Regen	Y	Y	1	0	0	2
JH05C	5097403	0492861	Advanced Regen	N	N	0	0	0	0
JH54C	5101360	0485954	Advanced Regen	-	Y	-	1	-	2
JH56C	5095916	0491619	Advanced Regen	-	Y	-	1	-	0
TLRG1	5089276	0488189	Softwood Regen	-	Y	-	0	-	2 (1)*
TLRG2	5086768	0478018	Softwood Regen	-	Y	-	1	-	2
TLRG3	5080222	0477284	Softwood Regen	-	N	-	0	-	0
1-1-T	5095457	0488242	10y post PCT	Y	Y	3	3	1	1
1-2-T	5092585	0478833	10y post PCT	Y	N	1	0	1*	0
1-3-T	5094656	0490237	10y post PCT	Y	Y	0	1	0	0
1-4-T	5092928	0488228	10y post PCT	Y	Y	1	2	1	1*
1-5-T	5096155	0476768	10y post PCT	Y	Y	1	2	1	0
15Y1	5100288	0491362	15y post PCT	N	Y	0	0	0	0
15Y2	5097643	0475526	15y post PCT	Y	Y	1	1	0	0
15Y3	5110730	0464625	15y post PCT	Y	Y	3	0	1	0
6-4-T	5102028	0485802	15y post PCT	Y	Y	1	1	3	0
6-6-T	5102769	0487173	15y post PCT	N	N	0	0	0	0
AF1	5104765	0486425	Selection	-	N	-	0	-	0
AF2	5105055	0487799	Selection	-	N	-	0	-	0
AF5	5088187	0490175	Selection	-	N	-	0	-	0
AF7	5097072	0486927	Selection	-	N	-	0	-	0

*Female did not have enough locations to be included in analysis

**Stands added during the brood surveys

Radio-Telemetry

During June and early July we conducted chick distress call surveys to elicit the response of brood rearing females. We also surveyed 2 new mature softwood stands within the Baxter Scientific Forest Management area. We captured 13 females during those surveys and fitted them with colored bands, and 11 of those also received necklace mounted VHF radio transmitters. One female died shortly after receiving her radio-transmitter. Thus, counting the female we captured during the cantus surveys, we had 13 radioed birds.

During the period from June to 30 September we located all VHF-equipped females using radio telemetry. One additional bird was captured during a telemetry location, giving us a total of 14 radioed birds. However, 6 birds were predated during telemetry activities and do not have enough locations to be included in analysis. One additional female was predated at the very end of the monitoring period but had 29 live locations and will thus be included in the analysis. Thus we have an additional 8 females to add to the 14 females tracked in 2012, giving us a sample size of 22 female home ranges.

Vegetation Measurements

Vegetation measurements were taken at all the PCT stands, and the two new mature softwood stands following protocols developed during companion snowshoe hare studies. These measurements exist for all other stands and focus on metrics that describe stand structure, especially overhead and lateral cover. Additionally, we sampled 15 telemetry locations from each of the 2012 female home ranges during this summer. Nest vegetation measurements were also collected at 12 nest locations.

Future Plans

Data analysis has begun for both the occupancy surveys and habitat use portions of the project. Preliminary results will be shared in a presentation at the 2014 North East Association of Fish and Wildlife Agencies Conference as well as the Spring CFRU Meeting. Occupancy surveys and brood surveys will be conducted in Summer 2014. Vegetation measurements for the 2013 telemetry locations will also be conducted during this time. A small number of additional radios may be placed on females during the summer to increase the power of home range analyses. The project is scheduled to for completion by December 2014.

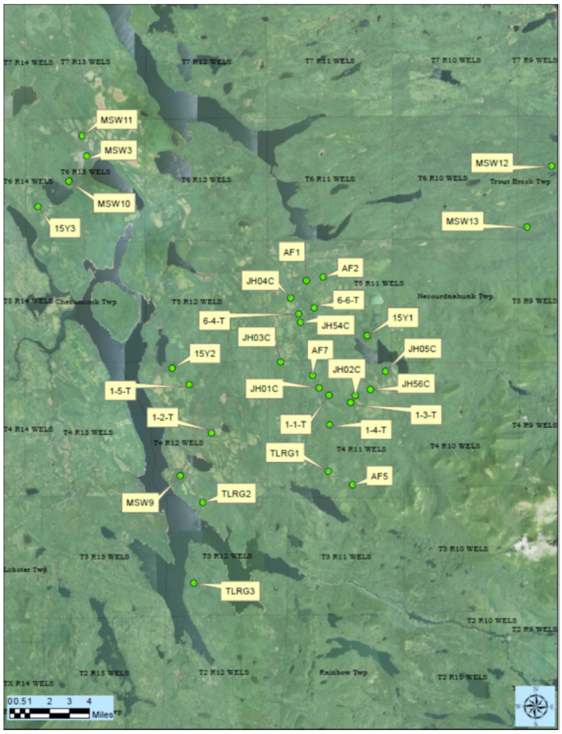

Figure 4-4. Locations of 30 stands studied during May-September 2013 within 6 townships (T3R12, T4R11, T4R12, T5R11, T6R13, and Trout Brook), Piscataquis County, Maine.

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BIRD COMMUNITIES OF CONIFEROUS FORESTS IN THE ACADIAN REGION: HABITAT ASSOCIATIONS AND RESPONSE OF BIRDS TO FOREST MANAGEMENT

Brian Rolek, Daniel Harrison, and Cynthia Loftin

Background and Project Overview

Several bird species of concern thrive in the coniferous forests of Northern New England. Cape May (*Setophaga tigrina*) and Bay-breasted Warblers (*Setophaga castanea*) have been declining within the Acadian Region since region-wide monitoring began with the USGS Breeding Bird Survey in 1966 (Sauer *et al.* 2012, figure 4-5). The United States Federal government has the authority to manage these species under the U.S. Migratory Bird Treaty Act. Maine contributes up to 96% of breeding habitat for some of these spruce-fir associated species, and population declines are not well understood. Most forestlands composed of coniferous forests where these species reside are commercially owned and managed. Habitat requirements for these species are not well understood, and their responses to various forms of forest management are uncertain. Standardized region-wide surveys used for assessing populations may not be comprehensive enough to fully understand population trends (i.e. USGS Breeding Bird Survey) and some common surveys used to inform management agencies occur when some species of concern are absent (i.e. Audubon Christmas Bird Count). Furthermore, these surveys do not typically account for detection error, where a species can be present but goes undetected by volunteers.

Our goals are to investigate factors influencing the distribution and abundance of species that represent the bird community of Acadian coniferous forests and to assess the influence of prevalent silviculture techniques on the Acadian forest bird community. Our objectives include:

(1) to quantify and define the composition and forest associations of coniferous bird communities across several silvicultural conditions including regenerating conifer stands 25-40 years post-harvest, mature softwood, overstory removals, precommercially thinned stands, selection harvests, and shelterwood harvest;

(2) to model the influences of silvicultural practices on coniferous forest bird communities while accounting for detection error;

(3) use data at both landscape and fine scales to determine habitat attributes that can be promoted in future stands to enhance the presence of conifer-associated species; and

(4) provide accessible and interpretable results for silviculturalists that can be used to manage species of concern.

Progress in 2013

Our research in 2013 focused on two components: bird community surveys in 110 forest stands and vegetation surveys within stands west of Baxter State Park and in the Musquacook Lakes region of northern Maine (heareafter referred to as North Maine Woods sites).

Field Site Establishment

Our sites are located within the Acadian Forest Region which coincides roughly with Bird Conservation Region 14 (figure 4-6). We established survey points on in the North Maine Woods, with the Scientific Forest Management Area of Baxter State Park, and at four National Wildlife Refuges (Nulhegan Basin Division of the Silvio Conte NWR, Umbagog NWR, Moosehorn NWR, and Aroostook NWR). We attempted to sample 5 stands within each of our 6 silvicultural treatments at every site; however, this goal was not reached at all sites because of the available distribution of forest management types (tables 4-2 and 4-3). We surveyed 110 forest stands with approximately 3 to 8 survey locations per stand during June and July 2013.

Occupancy Surveys

We used point count surveys to count all bird species. We navigated to preset locations, and counted the number of bird species that were audibly and visually detected for 10 minutes. Details for our protocols generally followed Hamel (1996). All point counts occurred within four hours of civil dawn when most birds are most active and singing. We returned to each location for a total of three repeated surveys. Repeated surveys allow us to account for the probability that an undetected bird was present during a survey. We surveyed with 1832 point counts from 1 June to 1 August. We recorded 19,431 detections of 123 species. Additional to birds, we recorded detections of red squirrel (*Tamiasciurus hudsonicus*), because they are known nest predators of many passerine birds in New England.

Future Plans

In 2014, we will expand our vegetation surveys to include National Wildlife Refuges and analyze our current vegetation data from our North Maine Woods sites. We will continue point counts throughout all locations to obtain multi-season bird community and species data and will begin exploratory statistical analyses in 2014. A third field season will be conducted in spring and summer 2015 and we expect to complete analyses and report writing in 2016.

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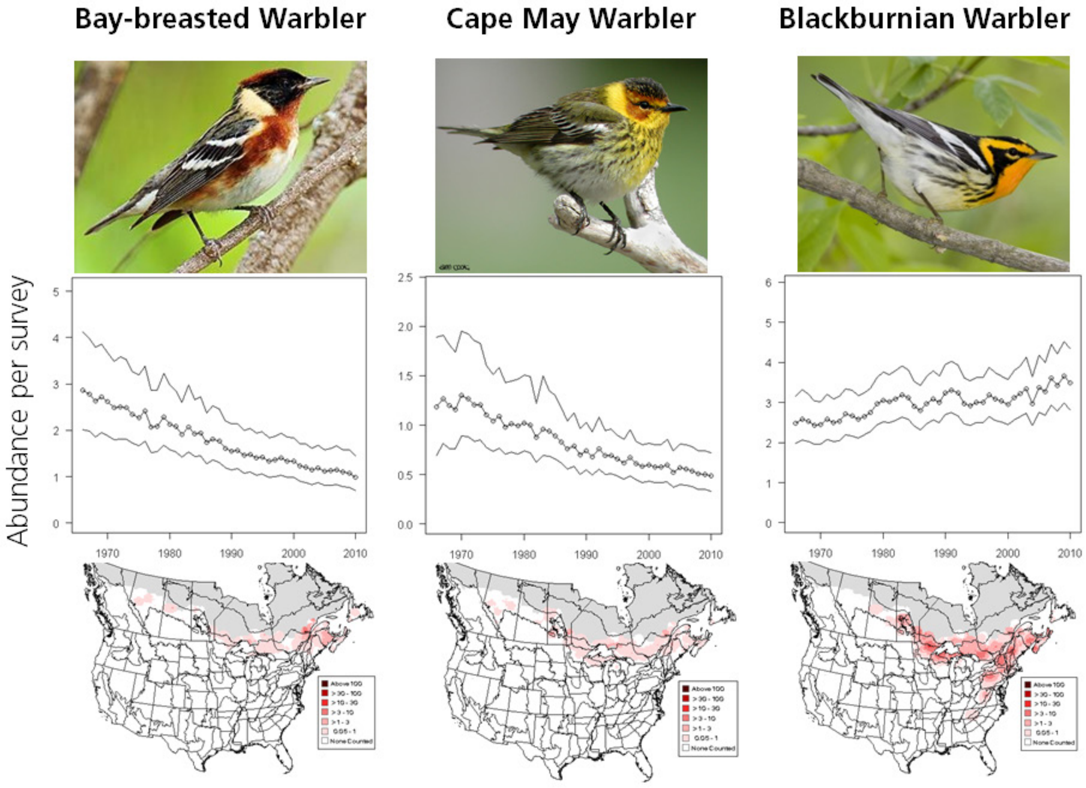

Figure 4-5. Several species of concern, their estimated population trends in Bird Conservation Region 14 from USGS Breeding Bird Survey data, and breeding distributions. Photo credits: Bay-breasted Warbler by Bill Majoros, Cape May Warbler and Blackburnian Warbler were used from the USGS Breeding Bird Survey website.

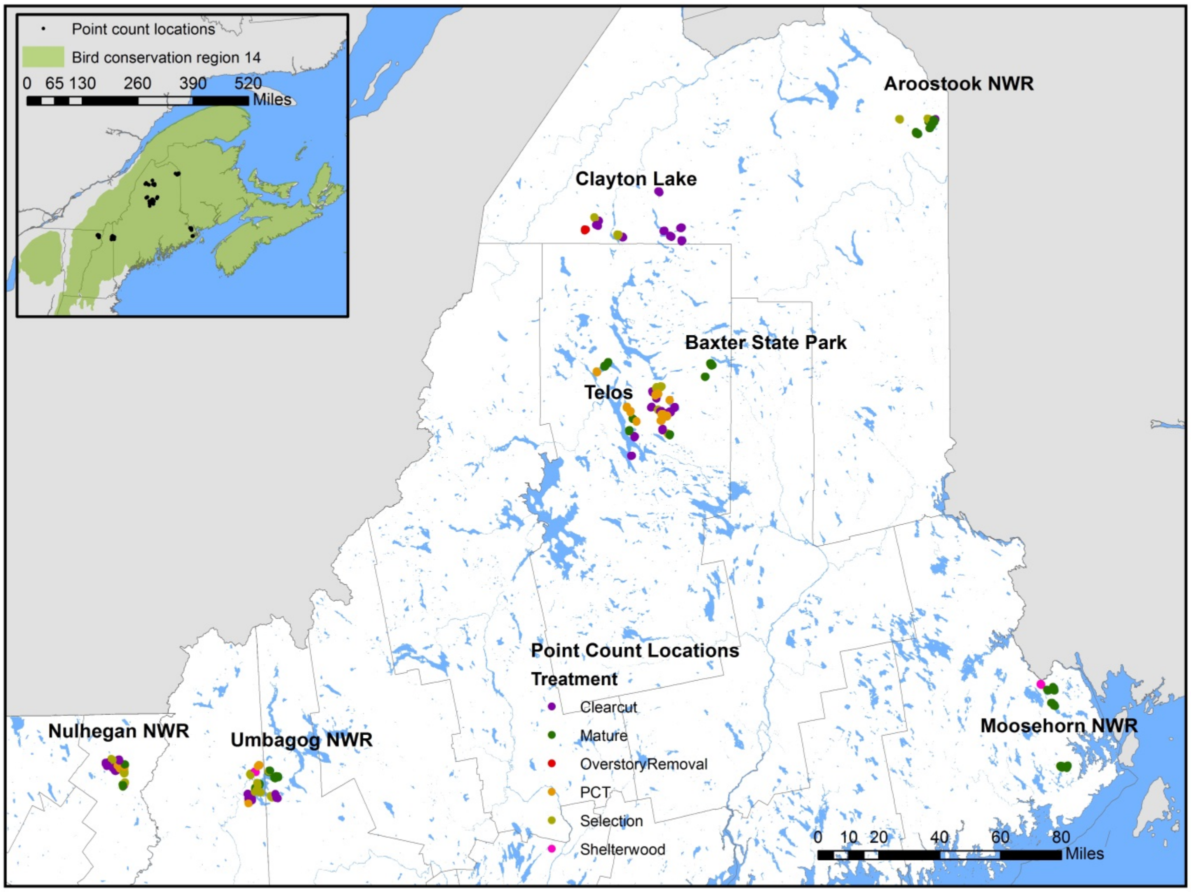

Figure 4-6. Survey locations distributed throughout northern New England where we conducted point counts of birds during 1 June – 1 August 2013.

Table 4-2. The number of point count locations in each treatment class at each property that was surveyed in 2013.

	Number of point counts in each treatment						
Site	Conifer Regen	Mature	Overstory Removal	PCT	Selection	Shelterwood	Total
Aroostook NWR	3	28	0	0	9	0	40
Clayton Lake	49	0	5	0	12	0	66
Moosehorn NWR	0	46	0	0	0	6	52
Nulhegan NWR	56	12	0	39	34	3	144
Telos	61	31	0	43	26	0	161
Umbagog NWR	23	51	0	20	47	7	147
Total	192	168	5	102	127	16	610

Table 4-3. The number of stands in each treatment class at each property that was surveyed in 2013.

	Number of stands in each treatment						
Property	Conifer Regen	Mature	Overstory Removal	PCT	Selection	Shelterwood	Total
Aroostook NWR	1	9	0	0	2	0	12
Baxter State Park	0	2	0	0	0	0	2
Clayton Lake	8	0	1	0	2	0	11
Moosehorn NWR	0	8	0	0	0	1	9
Nulhegan NWR	6	2	0	5	5	1	19
Telos	10	5	0	10	4	0	29
Umbagog NWR	6	6	0	4	10	2	28
Total	31	32	1	19	23	4	110

Table 4-4. Abundance per survey from 2013 surveys for each species and silviculture treatment. These raw estimates have not been adjusted for detection probability.

	Detections per survey					
Common Name	Conifer Regen	Mature	Overstory Removal	PCT	Selection	Shelterwood
American Black Duck	0.002					
Alder Flycatcher	0.073	0.040		0.026	0.021	0.063
American Bittern		0.008				
American Crow	0.036	0.159	0.133	0.085	0.071	0.229
American Goldfinch	0.010	0.541	0.067	0.016	0.018	
American Redstart	0.135	0.050	0.133	0.056	0.084	0.021
American Robin	0.281	0.328	0.667	0.088	0.196	0.333
American Woodcock	0.009			0.007		
American Three-Toed Woodpecker	0.005	0.006			0.003	
Bald Eagle		0.004				
Baltimore Oriole	0.005				0.003	
Black-And-White Warbler	0.108	0.245		0.036	0.076	0.458
Bay-Breasted Warbler	0.064	0.002	0.067	0.059		
Black-Backed Woodpecker		0.008				
Black-Capped Chickadee	0.323	0.419	0.133	0.493	0.361	0.521
Barred Owl	0.002	0.004				
Belted Kingfisher	0.002	0.012			0.003	
Blue-Headed Vireo	0.144	0.221	0.333	0.062	0.136	0.063
Blackburnian Warbler	0.028	0.193		0.033	0.173	0.063
Blue Jay	0.295	0.262	0.333	0.288	0.275	0.396
Blackpoll Warbler	0.047	0.004			0.005	
Bobolink		0.002				
Boreal Chickadee	0.214	0.076	0.133	0.222	0.039	
Brown Creeper	0.017	0.080		0.020	0.110	0.042
Black-Throated Blue Warbler	0.031	0.229		0.029	0.319	0.083
Black-Throated Green Warbler	0.458	0.529	0.333	0.304	0.364	0.333

Table 4-4 Continued	Conifer Regen	Mature	Overstory Removal	PCT	Selection	Shelterwood
Broad-Winged Hawk	0.002	0.014		0.013	0.018	
Canada Goose	0.003	0.032		0.016		0.021
Canada Warbler	0.210	0.099		0.137	0.157	0.208
Cedar Waxwing	0.168	0.135		0.075	0.089	0.188
Chipping Sparrow	0.016	0.010		0.023	0.010	
Cape May Warbler	0.003	0.006				
Common Grackle	0.012		0.067			
Cooper's Hawk	0.005					
Common Loon	0.028	0.070	0.067	0.026	0.039	0.042
Common Merganser	0.002					
Common Nighthawk		0.012		0.003	0.003	
Common Raven	0.033	0.042	0.067	0.082	0.086	
Common Yellowthroat	0.278	0.147	0.200	0.255	0.168	0.208
Chestnut-Sided Warbler	0.056	0.060	0.067	0.036	0.071	0.083
Downy Woodpecker	0.028	0.014	0.067	0.007	0.029	
Eastern Kingbird		0.002				
Eastern Phoebe	0.002	0.012			0.010	0.042
Eastern Wood-Pewee		0.060			0.037	
Evening Grosbeak	0.007					
Fox Sparrow	0.028					
Great Blue Heron	0.002					
Great-Crested Flycatcher	0.003	0.002		0.003	0.008	0.021
Golden-Crowned Kinglet	0.436	0.694	0.467	0.703	0.550	0.375
Great Horned Owl		0.010				
Gray Jay	0.014	0.099		0.046	0.021	
Gray Catbird	0.002	0.020		0.010	0.003	0.083
Hairy Woodpecker	0.033	0.024		0.023	0.029	
Herring Gull				0.007		
Hermit Thrush	0.665	0.905	0.467	1.046	0.919	1.042
House Finch					0.003	
Killdeer		0.002				
Least Flycatcher	0.094	0.109		0.052	0.039	0.021
Lincoln's Sparrow				0.010		
Mallard	0.002					
Magnolia Warbler	0.939	0.531	0.667	1.052	0.670	0.833
Merlin	0.009					
Mourning Dove	0.024	0.048		0.003	0.018	0.042
Mourning Warbler	0.003			0.016		
Myrtle Warbler	0.314	0.207	0.133	0.477	0.202	0.167
Nashville Warbler	0.460	0.252	0.200	0.386	0.390	0.542
Northern Cardinal		0.012			0.005	
Northern Goshawk		0.002		0.003		
Northern Parula	0.099	0.392	0.133	0.098	0.448	0.167

Table 4-4 Continued	Conifer Regen	Mature	Overstory Removal	PCT	Selection	Shelterwood
Northern Waterthrush	0.113	0.103		0.085	0.086	0.250
Northern Rough-Winged Swallow	0.002					
Orange-Crowned Warbler				0.007		
Olive-Sided Flycatcher	0.030	0.054		0.016	0.016	0.083
Osprey		0.006		0.003		
Ovenbird	0.139	0.604	0.067	0.225	0.639	0.542
Pied-Billed Grebe					0.003	
Philadelphia Vireo	0.003			0.010	0.005	
Pine Siskin	0.002					
Pine Warbler	0.042	0.137		0.026	0.052	0.021
Pileated Woodpecker	0.024	0.036	0.067	0.026	0.058	0.042
Purple Finch	0.182	0.014	0.067	0.075	0.042	0.021
Rose-Breasted Grosbeak	0.016	0.002		0.010	0.024	
Red-Breasted Nuthatch	0.194	0.511		0.235	0.369	0.229
Ruby-Crowned Kinglet	0.194	0.054		0.193	0.081	
Red Crossbill	0.002					
Red Squirrel	0.214	0.533		0.392	0.359	0.292
Red-Eyed Vireo	0.356	0.272	0.267	0.369	0.634	0.271
Red-Shouldered Hawk				0.007		
Red-Tailed Hawk	0.003					
Ruby-Throated Hummingbird	0.009	0.002		0.007	0.024	
Rusty Blackbird	0.007	0.002				
Ruffed Grouse	0.007	0.014	0.467	0.013	0.063	
Red-Winged Blackbird	0.002	0.020		0.003	0.005	0.021
Savannah Sparrow	0.007	0.012			0.010	
Slate-Colored Junco	0.059	0.123		0.157	0.079	0.063
Scarlet Tanager	0.007	0.004		0.007	0.016	
Sora		0.004				
Song Sparrow	0.014	0.014		0.003	0.010	
Spruce Grouse				0.007	0.005	
Spotted Sandpiper		0.002				
Sharp-Shinned Hawk	0.003	0.010		0.003	0.003	
Swamp Sparrow		0.016		0.003	0.008	0.063
Swainson's Thrush	0.625	0.328	0.400	0.562	0.398	0.479
Tennessee Warbler	0.003	0.006		0.013	0.005	
Tree Swallow	0.005	0.002				
Turkey Vulture	0.002					
Veery	0.031	0.046		0.042	0.113	0.188
Virginia Rail						0.021
White-Breasted Nuthatch		0.010		0.003		
Willow Flycatcher				0.003		
Wilson's Snipe	0.002	0.002				

Table 4-4 Continued	Conifer Regen	Mature	Overstory Removal	PCT	Selection	Shelterwood
Wild Turkey		0.008			0.008	
Wilson's Warbler	0.016			0.007	0.005	
Winter Wren	0.469	0.722	0.333	0.513	0.618	0.604
Wood Duck	0.002	0.002				
Wood Thrush	0.002			0.003		
White-Throated Sparrow	1.071	0.577	0.467	0.592	0.505	1.125
Yellow-Bellied Flycatcher	0.240	0.105		0.245	0.131	0.146
Yellow-Bellied Sapsucker	0.068	0.085		0.092	0.178	0.063
Yellow Warbler	0.003	0.002			0.005	
Yellow Palm Warbler	0.198	0.018		0.141	0.042	0.146
Yellow-Shafted Flicker	0.127	0.036	0.067	0.118	0.097	0.083
Yellow-Throated Vireo		0.002				

Appendix

Outreach

OUTREACH

Journal Publications

Bataineh, M.M., L. Kenefic, A.R.Weiskittel, R.G. Wagner, and J. Brissette. 2013. Influence of partial harvesting and site factors on the abundance and composition of natural regeneration in the Acadian Forest of Maine, USA. *Forest Ecology & Management* 306: 96–106.

Bataineh, M.M., R.G. Wagner, M.G. Olson, E.K. Olson. 2013. Midrotation response of ground vegetation to herbicide and precommercial thinning in the Acadian Forest of Maine, USA. *Forest Ecology & Management* 313: 132–143.

Bataineh, M.M., R.G. Wagner, A.R. Weiskittel. 2013. Long-term response of spruce-fir stands to herbicide and precommercial thinning: Observed and projected growth, yield, and financial returns in central Maine, USA. *Canadian Journal of Forest Research* 43(4): 385-395.

Fuller, A. K,. and D. J. Harrison. 2013. Modeling the influence of forest structure on microsite habitat use by snowshoe hares. International Journal of Forestry Research: Volume 2013, Article ID 892327, 7 pages.

Hiesl, P. and J.G. Benjamin. 2013. Harvesting Equipment Cycle Time and Productivity Guide for Logging Operations in Maine. University of Maine, Maine Agriculture and Forest Experiment Station. Orono, ME. Miscellaneous Publication 762. 60p.

Hiesl, P. and J.G. Benjamin. 2013. A Multi-Stem Feller-Buncher Cycle Time Model for Partial Harvest of Small Diameter Wood Stands. International Journal of Forest Engineering 24(2):101-108.Nelson, A.S., R.G. Wagner, M.R. Saunders, and A.R. Weiskittel. 2013. Influence of management intensity on the productivity of young early successional Acadian stands in eastern Maine. *Forestry* 86 (1): 79-89.

Russell, M.B., Weiskittel, A.R., and Kershaw, J.A. 2013. Benchmarking and calibration of Forest Vegetation Simulator individual tree attribute predictions across the northeastern US. Northern Journal of Applied Forest Research 30: 75-84.

Simons-Legaard, E. M., D. J. Harrison, W. B. Krohn, and J. H. Vashon. 2013. Canada lynx occurrence and forest management in the Acadian forest. Journal of Wildlife Management 77:567-578.

Articles in Periodicals

Benjamin, J.G. 2013. No free lunch in the woods: An economic reality check for proponents of biomass harvesting. Atlantic Forestry Review. 20(1): 20-21. September 2013.

Research Reports

Harrison, D., E. Simons-Legaard, K. Legaard, and S. Sader. 2013. Effectiveness of zoning to protect deer wintering habitats in Maine: Did the designation of LURC-zoned deeryards achieve desired objectives during the period 1975-2007? Final Report to Northeastern States Research Cooperative and USDA Forest Service. http://www.nsrc.org.

Meyer, S.R. (Ed.) 2013. Center for Research on Sustainable Forests Annual Report – 2013. University of Maine. Orono, Maine. 145 p.

Roth, B.E. (Ed.). 2013. Cooperative Forestry Research Unit Annual Report - 2012. The University of Maine, Orono, ME. 95 p.

Theses

Clune, P.M. 2013. Growth and development of Maine spruce-fir forests following commercial thinning. M.S. thesis, University of Maine, Orono. 132 p.

Hiesl, P.A. 2013. Productivity standards for whole-tree and cut-to-length harvesting systems in Maine. M.S. thesis, University of Maine, Orono. 150 p.

Conference Proceedings

Bataineh, M.M., L. Kenefic, A.R.Weiskittel, R.G. Wagner, J. Brissette, and R.S. Seymour. 2012. The relative importance of harvesting and local site factors in structuring regeneration abundance and composition in partially harvested stands in central Maine. Eastern CANUSA Forest Science Conference, Durham, New Hampshire, November 2-3, 2012.

Bataineh, M., A. Nelson, R. Wagner, B. Roth, and A. Weiskittel. 2013. Individual-tree response to commercial thinning in northern Maine: Influence of including competition, site, and treatment regime in growth and yield models. Center for Advanced Forestry Systems (CAFS) Annual Meeting, April 9-11, 2013, St. Simmons, GA.

Clune, P., R. Wagner, A. Weiskittel, and R. Seymour. 2013. Growth and development of Maine spruce-fir stands following commercial thinning. Center for Advanced Forestry Systems (CAFS) Annual Meeting, April 9-11, 2013, St. Simmons, GA.

Hiesl, P. and J.G. Benjamin. 2013. Assessment of Feller Buncher and Harvester Caused Stand Damage in Partial Harvests in Maine. Paper presented at the 36th Council on Forest Engineering: Forest Operations for a Changing Landscape. Missoula, MT. July 7-10, 2013.

Nelson, A.S., Weiskittel, A.R., Wagner, R.G., and Saunders, M.R. 2012. Verification of the Jenkins and FIA Sapling biomass equations for hardwood species in Maine. *In* Moving from Status to Trends: Forest Inventory and Analysis (FIA) Symposium 2012. Edited by R.S. Morin, and G.C. Liknes. USDA Northern Research Station Gen. Tech. Rep. NRS-P-105, Baltimore, MD. pp. 373-377.

Nelson, A.S., Weiskittel, A.R., Wagner, R.G., and Saunders, M.R. 2012. Vertical distribution and total tree leaf area equations of juvenile trees in eastern Maine. Southern Mensurationist 2012 Annual Meeting, October 7-9, 2012, Jacksonville, FL.

Nelson, A.S. A.R. Weiskittel, R.G. Wagner, and M.R. Saunders. 2012. Development and verification of aboveground sapling biomass equations for tree species in eastern Maine. 16th Annual Northeastern Mensurationist Organization (NEMO) Annual Meeting, October 1-2, 2012, State College, PA.

Nelson, A.S., Weiskittel, A.R., Wagner, R.G., and Saunders, M.R. 2012. Verification of the Jenkins and FIA Sapling biomass equations for hardwood species in Maine. In Moving from Status to Trends: Forest Inventory and Analysis (FIA) Symposium 2012. Edited by R.S. Morin, and G.C. Liknes. USDA Northern Research Station Gen. Tech. Rep. NRS-P-105, Baltimore, MD. pp. 373-377.

Nelson, A.S., R.G. Wagner, M.R. Saunders, and A.R. Weiskittel. 2012. Influence of Management Intensity on The Productivity of Early Successional Acadian Stands in Eastern Maine. Eastern CANUSA Forest Science Conference, Durham, New Hampshire, November 2-3, 2012.

Olson, M., S. Meyer, R. Wagner, and R. Seymour. 2012. Response of Softwood Regeneration to Commercial Thinning in Two Northeastern Spruce-Fir Stand Types: 1st Decade Results From the Commercial Thinning Research Network in Maine. Eastern CANUSA Forest

Science Conference, Durham, New Hampshire, November 2-3, 2012.

Rice, B., R.G. Wagner, and A.R, Weiskittel. 2012. Nonselective Partial Harvesting in Maine. Eastern CANUSA Forest Science Conference, Durham, New Hampshire, November 2-3, 2012.

Rice, B., A. Weiskittel, and R. Wagner. 2012. Forest inventory methods in Maine's partially harvested stands. 16th Annual Northeastern Mensurationist Organization (NEMO) Annual Meeting, October 1-2, 2012, State College, PA.

Weiskittel, A. and R. Wagner. 2013. Extending the Acadian Variant of the Forest Vegetation Simulator (FVS) to managed stands in the Northeast US. Center for Advanced Forestry Systems (CAFS) Annual Meeting, April 9-11, 2013, St. Simmons, GA.

Presentations

Bataineh, M., Kenefic, L., Weiskittel, A., Wagner, R., Brissette, J., and Seymour, R. 2012. The relative importance of harvesting and local site factors in structuring regeneration abundance and composition in partially harvested stands in central Maine. Eastern CANUSA Forest Science Conference, Durham, New Hampshire, November 2-3, 2012.

Bataineh, M., Kenefic, L., Weiskittel, A., Wagner, R., Brissette, J. 2013. Influence of partial harvesting and site factors on the abundance and composition of natural regeneration in the Acadian Forest of Maine, USA. Silviculture Matters, Society of American Foresters National Convention, North Charleston, South Carolina, October 23-27, 2013.

Bataineh, M., Nelson, A., Wagner, R., Roth, B., and Weiskittel, A. 2013. Individual-tree response to commercial thinning in northern Maine: influence of including competition, site, and treatment regime in growth and yield models. National Science Foundation, Center for Advanced Forestry Systems (CAFS) 2013 Annual Meeting, St. Simons Island, Georgia, April 9-11, 2013.

Bataineh, M., Wagner, R., and Weiskittel, A. 2013. Long-term response of spruce-fir stands to herbicide and precommercial thinning: observed and projected growth, yield, and financial returns in central Maine, USA. Northeastern Mensurationists Annual Meeting, York, Maine, November 4-5, 2013.

Bataineh, M., Wagner, R., and Weiskittel, A. 2013. Long-term response of spruce-fir stands to herbicide and precommercial thinning: observed and projected growth, yield, and financial returns in central Maine. Silviculture Matters, Society of American Foresters National Convention, North Charleston, South Carolina, October 23-27, 2013.

Bataineh, M., Wagner, R., and Weiskittel, A. 2013. Long-term response of spruce-fir stands to herbicide and precommercial thinning: observed and projected growth, yield, and financial returns in central Maine, USA. 2nd IUFRO Conference Complex Forest Ecosystems: From Tree to Landscape, Southern Mensurationists Annual Meeting, New Orleans, Louisiana, October 7-9, 2013.

Bataineh, M., Wagner, R., and Weiskittel, A. 2013. Long-term response of spruce-fir stands to herbicide and precommercial thinning: observed and projected growth, yield, and financial returns in central Maine, USA. National Science Foundation, Center for Advanced Forestry Systems (CAFS) Annual Meeting, St. Simons Island, Georgia, April 9-11, 2013.

Benjamin, J.G. 2013. The University of Maine’s iFOR Program: Innovative Forest Operations Research. Northeastern Loggers’ Association Equipment Expo and Logger Workshops. Bangor, ME. May 17.

Benjamin, J.G. 2013. Forest Business Planning Workshop – NE Logging Industry Overview and Process Improvement. Vermont Forest Parks and Recreation Department. Essex Junction, VT. May 10.

Benjamin, J.G. 2013. What is the Value of Your Time? Productivity Improvement Workshop for Treeline Inc. Lincoln, ME. May 3.

Benjamin, J.G. 2013. Effect of Stem Size on Harvesting Costs from Early Commercial Thinnings. Association of Consulting Foresters Meeting. Brewer, ME. April 25.

Benjamin, J.G. 2013. iFOR – The University of Maine's Innovative Forest Operations Research Program. Northern Hardwood Research Institute Seminar Series. Edmundston, NB. April 10.

Benjamin, J.G. and P. Hiesl. 2013. Influence of Stem Size and Cycle Time on Harvest Cost. New England Council on Forest Engineering Annual Meeting. Legal Issues in Forestry & Foresters….Knowing Your Costs. University of Maine, Orono, ME. March 11-12, 2013.

Benjamin, J.G. and P. Hiesl. 2013. Influence of Stem Size on Cycle Time on Harvest Productivity and Cost. LP Supplier Workshop. Houlton, ME. August 21, 2013.

Harrison, D.J. Conserving sustainable landscapes: using Canada lynx and American martens as umbrella species to enhance landscape planning. Invited presentation at 2013 Kennebec Land Trust Lyceum, Wayne, Maine. March 21, 2013.

Harrison, D., D. Mallett, A. K. Fuller, and J. H. Vashon. Snowshoe hares, forests, and Canada lynx: a dynamic interaction between populations, forestry and habitat. Presentation at Meeting of Maine Cooperative Forestry Research Unit, Orono, Maine, April 24, 2013.

Kenefic, L.S. and Weiskittel, A.R. 2013. U.S. Forest Service Research in Northern Conifers: Historical Perspective, Management Implications, and Modeling Applications. Invited webinar. Northeastern States Research Cooperative. March 21.

Wagner, R.G. Spruce Budworm – Human Response Life Cycle: How it shaped everything in Maine forestry for the past 40 years. Forestry Noontime Seminar, School of Forest Resources, University of Maine, Orono. (Oct)

Wagner, R.G. Maine Spruce Budworm Strategy Plan. 2013 Maine Forest Products Council, 53rd Annual Meeting, Sugarloaf, ME. September 9, 2013.

Wagner, R.G. Spruce Budworm – Human Response Life Cycle: How it shaped everything in Maine forestry for the past 40 years. 2013 Maine Forest Products Council, 53rd Annual Meeting, Sugarloaf, ME. September 9, 2013.

Wagner, R.G. Importance of Wood & Future Long-term Drivers for Forest Industry. 2013 Maine Forest Products Council, 53rd Annual Meeting, Sugarloaf, ME. September 9, 2013.

Wagner, R.G., M. Bataineh, M. Olson, A. Nelson, and B. Rice. Influence of Partial Harvesting on Hardwood Regeneration. Financially Feasible Hardwood Silviculture: Sustaining a Competitive Hardwood Value Chain, Edmundston, NB. October 1-2, 2013.

Rolek, B., C.S. Loftin, D. Harrison, and P. B. Wood. Softwood forest birds and forest management in New England, USGS-Maine Cooperative Fish and Wildlife Research Unit Annual Coordinating Committee Meeting, Wells Conference Center, Orono, ME. March 21, 2013.

Simons-Legaard, E. and D. Harrison. Habitat trends in Maine's LURC-zoned deer wintering areas. Seminar, Department of

Wildlife Ecology, The University of Maine. October 15, 2012.

Weiskittel, A.R. 2013. Development of a regional growth and yield model for complex, managed stands of the Acadian Forest. IUFRO Meeting on Complex Forest Ecososytems. New Orleans, LA. October 7 – 9.

Weiskittel, A.R. 2013. Linking growth and wood quality models: Past, present, and future. MeMoWood Conference. Invited keynote. Nancy,France. October 1-4.

Cooperative Forestry Research Unit

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