Cooperative Forestry Research Unit

2011 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 32 member organizations including private and public forest landowners, wood processors, conservation organizations, and other private contributors. Research by the CFRU seeks to solve the most important problems facing the managers of Maine's forests.

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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: "Million Dollar View" from Morrison Ridge Road, Hancock County, Maine
Photo courtesy of Pamela Wells

Center for Research on Sustainable Forests

1865 THE UNIVERSITY OF MAINE

Swamp on Studmill Road, Milford, Maine photo courtesy of Pamela Wells

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RESEARCH HIGHLIGHTS

SILVICULTURE

- The final reporting phase of the composition project is underway. Key findings indicate that understory beech can be controlled with an optimized combination of herbicide and surfactant. Additionally, we have demonstrated that early silvicultural prescriptions designed to maintain species compositions in Maine (i.e. hardwood, mixedwood, or conifer) can be effective. (… more)

- The CTRN has marked another milestone during the winter of 2011/12: the final thinning entries were completed on the first experiment in PCT'd stands envisioned twelve years earlier. The growth and yield data that has been gathered and used in computer modeling will assist forest managers when deciding when to thin and how much to remove in spruce-fir stands. (… more)

MODELING

- The Spruce Budworm Decision Support System (SBWDSS) and USDA Forest Inventory and Analysis (FIA) data was used to assess potential spruce-fir losses in Maine. Spruce-fir volume impacts under alternative management and outbreak scenarios were examined over the next 10 years in Maine. Using this information, localized maps of stand volume impact by various outbreak scenarios were created where GIS data and stand yields were available. (… more)

- The shortfalls of the current NE variant of the FVS growth and yield model are being addressed. To date many improved equations have been developed using data which adequately represent the various growth patterns for many species in the Acadian forest. A beta model is being tested, validated, and assessed for performance. (… more)

WILDLIFE HABITAT

- Relationships among commercial forest harvesting, snowshoe hares and Canada lynx are being quantified. Snowshoe hares are a keystone species affecting many species and processes in northern forest ecosystems. This project monitors hare densities in benchmark harvested stands and examines the seasonal shifts in habitat use, as a means of understanding the relationships between hare and lynx population dynamics. (… more)

Mark Doty
Chair, Advisory Committee

CHAIR'S REPORT

We had another productive year building a stronger CFRU. Special thanks go to **John Bryant, Kip Nichols** and **Bill Patterson** for their insightful counsel in working through the issues faced by the Executive Committee. We also welcome for 2012 a fresh Executive Committee with Chair **Bill Patterson**, Vice-Chair **Greg Adams**, and Member-at-Large, **Kevin McCarthy**.

The advisory committee took action to maintain the long term viability of the CFRU through maintaining a target base funding level that provides a strong platform on which to attract good scientists and leverage significant external funding. Thanks to all that worked on the CFRU Finance sub-committees over the two years, and to **John Bryant**, **Bill Paterson**, **Kevin McCarthy**, **Bob Wagner**, and **Brian Roth** for their work on the final product presented to the advisory committee.

I wish to welcome **Brian Roth** as Associate Director. Brian proved himself to be an excellent choice for the position, providing professional support for the CFRU through organizing the workshops and tours, executing field work well and producing high quality publications and presentations. Thank you to the review committee **Wagner**, **Meyer**, **Seymour**, **Harrison**, **Leahy**, **Bryant, Gamble** and **Doty** for your work to bring an excellent associate director on board.

Thanks to **Bob Wagner**, Director of the CFRU, Director of the School of Forest Resources, and Director of the CRFS, who remains the constant that continues to keep the past in focus so we do not need to learn old lessons again while he ably leads the CFRU on to fulfill our mission.

The Fall Field Tour "Managing the Spruce Budworm Era 'Sea of Wood' " proved to be a big draw. Around 90 forestry professionals representing approximately 8.5 million acres of Maine's managed working forests participated in the field tour which was centered around the Austin Pond CFRU study site on Plum Creek that was established in 1977. I would like to thank the CFRU Advisory Committee members for their insight and cooperative spirit as we work together toward our shared goal of research and technology transfer. I look forward to a healthy future for the CFRU.

We note with sorrow the tremendous loss that CFRU had suffered in 2011 with the deaths of two of our very active members. **Hugh Violette** of Orion Timberlands and **Stephen Coleman** of LandVest contributed greatly to the on-going vitality of CFRU and will be greatly missed by everyone. Steve Coleman was an important mentor for me through the years.

Robert Wagner
Director, CFRU

DIRECTOR'S REPORT

Thanks again go to our steadfast CFRU members that continue to work closely with UMaine to improve the management of Maine's incredible forest resource. The CFRU effort is as strong today as it has ever been in its 36-year history. CFRU membership represents 8.3 million acres (nearly half of Maine's forestland).

We welcomed **UPM Madison** and **Old Town Fuel & Fiber** as new members of the CFRU this year. We greatly appreciate the confidence that their membership represents. Their addition to the CFRU roster also substantially increased the representation of wood processors in the cooperative; a trend we would like to see continue.

Special thanks go to the CFRU Executive Committee (**Mark Doty, Bill Patterson, John Bryant,** and **Kip Nichols**) for their continued leadership and hard work in keeping the CFRU functioning smoothly for its members and the university. We especially thank **Mark Doty** for his excellent work as Chair over the past two years. Under his leadership, the members successfully developed a long-term policy to ensure that CFRU funding is sustained into the future. We also welcome our incoming 2012-14 Executive Committee **- Bill Patterson** (Chair), **Greg Adams** (Vice-Chair), and **Kevin McCarthy** (Member-at-Large). We look forward to working with each of you in this new capacity.

We also thank **Will Mercier** and **Andrew Nelson** who stepped in to provide crucial leadership for the CFRU Annual Report and many research functions early last year while we were in transition from one Associate Director to another. They both did an excellent job keeping CFRU fully functional during this period. This annual report also marks nearly one year since the addition of **Brian Roth** as CFRU's new Associate Director. Brian quickly got on the learning curve for this key position and has done a great job doing most of the heavy lifting for CFRU over the past year. We also saw the departure of **Matt Olson** and arrival of **Mohammad Bataineh** as post-doctoral fellows working jointly with the USFS Northern Research Station and the CFRU. We wish Matt the best in his new position and welcome Mohammad in this collaborative research effort. CFRU Cooperating Scientists (**Jeff Benjamin, Dan Harrison, Bob Seymour,** and **Aaron Weiskittel**) continued to provide us with strong research leadership, and **Rosanna Libby** continued to do a wonderful job providing administrative support for CFRU.

Despite the many positive things that happened in CFRU during 2011, we were all devastated by the very untimely deaths of two highly valued members of the Advisory Committee. **Stephen Coleman** (LandVest) and **Hugh Violette** (Orion Timberlands) left us much too soon, but provided a passionate professional voice for the work of CFRU that is badly missed. Over many years as a member of the Advisory Committee, Steve Coleman became the sage that we all looked to for what was practical and what was not. I will sorely miss looking across the table for his approval on some project that was being proposed.

As is evident in the following 2011 annual report, CFRU continues to support a wide array of research projects that are contributing to the sustainable management of Maine's forest.

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
Huber Resources Corporation
Irving Woodlands, LLC
Katahdin Forest Management, LLC
Maine Bureau of Parks and Lands
The Nature Conservancy
UPM Madison
North Woods Maine, LLC
Old Town Fuel & Fiber
Plum Creek Timber Company, Inc.
Prentiss & Carlisle Company, Inc.
Robbins Lumber Company
Sappi Fine Paper
Seven Islands Land Company
St. John Timber, LLC
Sylvan Timberlands, LLC
Timbervest, LLC
Wagner Forest Management

Other Cooperators

Field Timberlands
Finestkind Tree Farms
LandVest
Mosquito, LLC

Advisory Committee

Mark Doty, Chair
Plum Creek Timber Company, Inc.

William Patterson, Vice Chair
The Nature Conservancy

John Bryant, Financial Officer
American Forest Management

Kip Nichols, Member-at-Large
Seven Islands Land Company

Members

Greg Adams, JD Irving, Ltd.

John Brissette, USFS Northern Research Station

Jason Castonguay, Canopy Timberlands Maine, LLC

Tom Charles, Maine Bureau of Parks and Lands

Brian Condon, The Forestland Group, LLC

Dave Daut, Timbervest, LLC

Everett Deschenes, Old Town Fuel & Fiber

David Dow, Prentiss & Carlisle Company, Inc.

Kenny Fergusson, Huber Resources Corporation

Gordon Gamble, Wagner Forest Management

Brian Higgs, Baskahegan Company

Eugene Mahar, Landvest

Kevin McCarthy, Sappi Fine Paper

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

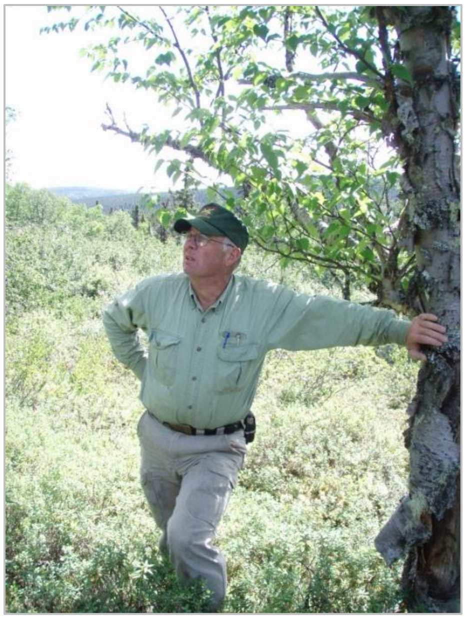
HUGH VIOLETTE

Hugh Violette will be sorely missed as an emerging leader in Maine's forestry community. Hugh died unexpectedly in April 2011 after a very brief illness. Hugh was a 2005 graduate of the University of Maine, School of Forest Resources earning his B.S. in Forest Operations Science. He was a licensed Maine forester, was certified by the Society of American Foresters, and worked in Aroostook County for Orion Timberlands LLC.

Hugh maintained an ongoing and deep commitment to the world of professional forestry. At the time of his death, he was chairman of New England Regional Council on Forest Engineering. He was actively involved in the Society of American Foresters, Forest Resource Association, Maine GIS Users Group, UMaine Cooperative Forestry Research Unit and Eastern Canada-USA Forest Science Conference. Hugh lived his life to the fullest and would want to be remembered for his commitment to his profession, his deep love for family and friends, and for the joy he brought to others rather than be mourned for the brevity of his life.

A special tree-planting ceremony was held by Hugh's family, friends, colleagues, and professors in the Nutting Hall courtyard last October. A chestnut tree and granite marker now honors Hugh's memory as a UMaine forestry student and professional forester.

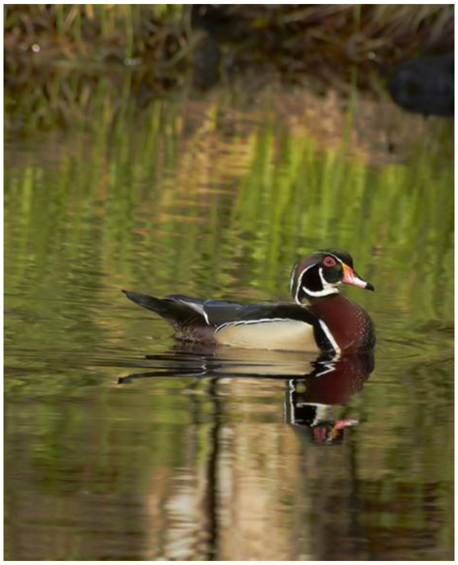
STEVE COLEMAN



There are few in Maine's forestry community that did not know Steve Coleman and his outstanding dedication to the profession of forestry. He was a 1977 graduate of our BS forestry program. Steve also was a true woodsman whose skills in the woods, on the water, steering a snow sled or in the cabin of his 185 Cessna float plane allowed him to bring a unique, practical and always efficient approach to practicing forestry on the ground. Steve's deep grasp of forestry and forest operations, as well as his ability to develop sensible, cost effective and strategies for cutting edge forestry is what made him so successful and widely respected. His integrity as a person and professional was of the highest order.

When the UMaine's Cooperative Forestry Research Unit's Advisory Committee needed a practical and no nonsense view about a new research project they were considering, Steve was the one they looked to for an honest assessment. In addition, to his position at Landvest, Steve was deeply dedicated to public and community service. At the time of passing, he was the President of the North Maine Woods Board, an active and valuable member of the Maine Forest Products Council Board, Society of American Foresters, Small Woodland Owners Association of Maine, and was running for Somerset County Board of Commissioners. During his career, he also served on the Maine Board of Forester's Licensing and many other committees. UMaine's SFR and Maine's forestry community will be forever indebted to Steve for his example, leadership, and service to Maine forestry.

RESEARCH TEAM



Wood Duck photo by Pamela Wells

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

Matthew Russell, M.S., Forest Data Manager

Rosanna Libby, Administrative Assistant

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

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

Matthew Olson, Ph.D., Paul Smith's College, The College of the Adirondacks

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 (M.S. student - Benjamin) - Logging Productivity and Cost

Emily Meachum (M.F. student - Benjamin) - Early Commercial Thinning

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

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

Joseph Pekol (M.S. student - Weiskittel) - Mortality Following Thinning

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

Baburam Rijal (M.S. student - Weiskittel) Improving the NE Variant of the FVS

Matthew Russell (Ph.D. candidate - Weiskittel) Improving the NE Variant of the FVS

Dog Violet - photo by Pamela Wells

FINANCIAL REPORT

Thirty-two members representing 8.29 million acres of Maine's forestland contributed $492,791 in dues to support CFRU this year (table 1-1). While the amount of acreage declined slightly this year from 8.38 million acres in 2010, the CFRU added to its membership base with wood processors including **Old Town Fuel & Fiber** and **UPM Madison**. We thank all of our members for their continued support during these tough economic times.

In addition to member dues, CFRU Cooperating and Project Scientists were successful at leveraging an additional $449,351 in grants from extramural sources to support approved CFRU projects. Of these funds, $70,000 came from the **National Science Foundation (NSF)** as part of CFRU's membership in the national **Center for Advanced Forestry Systems (CAFS)** (see CAFS section), which is supporting our growth & yield modeling efforts. Thus, 34% of total CFRU funding came from outside sources to support our research program (figure 1-1). **UMaine's** in-kind contributions from reduced overhead was $131, 675 or 14% of total CFRU funding. Total CFRU funding including these leveraged sources was $942,142.

Total leveraging of external funds this year meant that for every $1 in dues contributed by our three largest members (**JD Irving, Wagner Forest Management,** and **BBC Land**), $7.09 was received from other CFRU member dues, $7.38 in external grants through CFRU scientists, and $2.16 in in-kind contributions from **UMaine**; for a total of $16.63.

Continuing sound fiscal management by CFRU project scientists and staff resulted in spending $13,690 (3.0%) less than $463,334 that was approved by the Advisory Committee (table 1-2). Of this surplus, $10,200 was approved as carry-over to the FY11-12 Administration budget by the CFRU executive Committee. All projects came in under or on budget. CFRU research expenses by category included 45% on silviculture, 33% on improving forest growth & yield models, and 22% on wildlife habitat (figure 1-2).

CFRU Funds by Source FY10-11

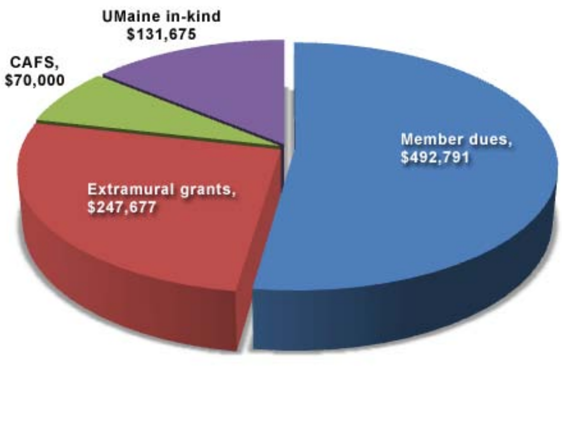


Figure 1-1. CFRU funds by source during FY10-11 (October 1, 2010 to September 30, 2011).

Program Expenses by Research Area FY10-11

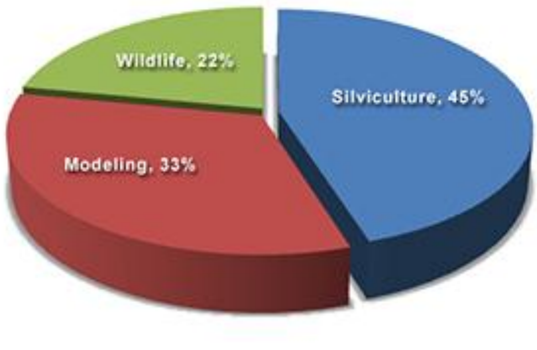


Figure 1-2. CFRU research expenditures by category during FY10-11 (October 1, 2010 to September 30, 2011).

Table 1-1. CFRU dues received during FY10-11 (October 1, 2010 to September 30, 2011).

LANDOWNERS / MANAGERS:	2011 Acres	Amount Invoiced	Amount Paid
Irving Woodlands, LLC	1,255,000	$67,750.00	$67,750.00
Wagner Forest Management	1,132,754	$61,637.70	$61,637.70
BBC Land, LLC	968,649	$53,354.07	$53,354.07
Plum Creek Timber Company, Inc.	884,000	$48,910.00	$48,910.00
Prentiss and Carlisle Company, Inc.	807,171	$44,876.48	$44,876.48
Seven Islands Land Company	721,261	$40,366.20	$40,366.20
Clayton Lake Woodlands Holding, LLC	409,356	$23,537.97	$23,537.97
Maine Bureau of Parks and Lands	400,000	$23,000.00	$23,000.00
Katahdin Forest Management, LLC	299,000	$17,192.50	$17,192.50
Canopy Timberlands Maine, LLC	293,170	$16,857.28	$16,857.28
The Nature Conservancy	177,464	$10,204.18	$10,204.18
The Forestland Group, LLC	147,467	$8,479.35	$8,479.35
Huber Timber	143,962	$8,277.82	$8,277.82
Timbervest, LLC	121,039	$6,959.74	$6,959.74
Baskahegan Corporation	101,709	$5,848.27	$5,848.27
Sylvan Timberlands, LLC	99,394	$5,715.16	$5,715.16
North Woods ME Timberlands, LLC	84,236	$4,843.57	$4,843.57
Appalachian Mountain Club	65,224	$3,750.38	$3,750.38
Frontier Forest, LLC	53,338	$3,066.94	$3,066.94
Baxter State Park, SFMA	29,537	$1,698.38	$1,698.38
Robbins Lumber Company	27,224	$1,565.38	$1,565.38
St. John Timber, LLC	24,845	$1,428.59	$1,428.59
EMC Holdings, LLC	23,526	$1,352.75	$1,352.75
Mosquito, LLC	16,222	$932.77	$932.77
LANDOWNERS / MANAGERS TOTAL	**8,285,548**	**$461,605.45**	**$461,605.45**
WOOD PROCESSORS:	**2011 Tons**		
Sappi Fine Paper	1,794,151	$22,426.89	$22,426.99
UPM Madison	313,650	$3,920.63	$3,920.63
Old Town Fuel & Fiber	195,000	$2,437.50	$2,437.50
WOOD PROCESSORS TOTAL	**2,302,801**	**$28,785.01**	**$28,785.01**
OTHER COOPERATORS:			
Huber Engineered Woods, LLC		$1,000.00	$1,000.00
Forest Society of Maine		$1,000.00	$1,000.00
Landvest		$200.00	$200.00
Field Timberlands		$100.00	$100.00
Finestkind Tree Farms		$100.00	$100.00
OTHER COOPERATORS TOTAL		**$2,400.00**	**$2,400.00**
	GRAND TOTAL	**$492,790.46**	**$492,790.46**

Table 1-2. CFRU expenses by source during FY10-11 (October 1, 2010 to September 30, 2011).

PROJECT	Principal Investigator	Approved	Amount Spent as of 10-24-11	Balance	% Balance
Administration[1]		**$176,186**	**$164,684**	**$11,503**	**7 %**
Administration	Wagner	$164,460	$156,630	$7,830	**5 %**
Silviculture Post-Doc	Wagner	$11,726	$8,053	$3,673	**31 %**
Research Projects:					
Silviculture and Productivity:		**$130,523**	**$128,469**	**$2,053**	**2 %**
Commercial Thinning Research Network	Wagner *et al.*	$52,407	$52,407	$0	**0 %**
Improving the Species Composition of Hardwood Regeneration	Wagner	$13,557	$13,557	$0	**0 %**
CTRN Regeneration	Olson *et al.*	$11,044	$11,044	$0	**0 %**
Early Commercial Thinning	Benjamin *et al.*	$28,050	$27,558	$492	**2 %**
Partial Harvesting	Weiskittel *et al.*	$25,465	$23,904	$1,561	**6 %**
Growth & Yield Modeling:		**$93,942**	**$93,936**	**$6**	**0 %**
Refinement of FVS-NE Individual Tree Model	Weiskittel	$28,685	$28,685	$0	**0 %**
Development of Regional Taper Equations	Weiskittel *et al.*	$17,609	$17,608	$1	**0 %**
Modeling Natural Regeneration	Weiskittel *et al.*	$18,798	$18,797	$1	**0 %**
CTRN Mortality	Weiskittel *et al.*	$ 3,850	$ 3,846	$4	**0 %**
Spruce Budworm DSS	Hennigar	$25,000	$25,000	$ 0	**0 %**
Wildlife Habitat:		**$62,693**	**$62,565**	**$128**	**0 %**
Spruce Grouse Habitat	Harrison	$30,800	$30,672	$128	**0 %**
Long-term Monitoring of Snowshoe Hare Populations	Harrison	$31,893	$31,893	$0	**0 %**
TOTAL		**$463,344**	**$449,654**	**$13,690**	**3 %**

[1] $10,200 of FY10-11 Administration budget was approved as carry-over to the FY11-12 Administration budget by the Executive Committee.

ACTIVITIES

Advisory Committee

The CFRU is guided by a group of forest managers who represent our cooperators forming the CFRU Advisory Committee. They are led by the Executive Committee, which this year consisted of **Mark Doty** of **Plum Creek** (chair), **Bill Patterson** of **The Nature Conservancy** (Vice-Chair), **John Bryant** of **American Forest Management/BBC Land, LLC** (Financial Officer), and **Kip Nichols** of **Seven Islands Land Company** (Member-at-Large).

The Advisory Committee meets three times a year for business meetings. The first business meeting of the fiscal year was held on October 6, 2010 at the **University of Maine (UMaine)** where the dues structure sub-committee presented their final report on the long-term viability and financial sustainability of the CFRU. At the second meeting, held on January 26, 2011 at **UMaine**, eight pre-proposals were presented to the Advisory Committee. Of these, all eight were approved to advance to the full proposal stage and were presented at the April 13, 2011 business meeting. Five projects were approved for funding beginning on October 1, 2011. Look for updates on these projects in future CFRU functions and annual reports.

Cooperators

This year the CFRU is happy to welcome two new cooperators: **UPM Madison** (represented by **Tim Richards**) and **Old Town Fuel & Fiber** (represented by **Everett Deschenes**). These additional members greatly expand the wood processing class of CFRU membership and we are thrilled that they find value in what the CFRU has to offer.

Personnel

It was a busy year for personnel changes at the CFRU. Following the transition of Associate Director, **Spencer Meyer** to the **Center for Research on Sustainable Forests (CRSF)**, **Wilfred Mercier** joined the CFRU team as the **Interim Research and Communications**

Early Commercial Thinning Crew on Ponsse Fox (left to right: Brian Roth, Jeff Benjamin, Emily Meacham, Mallory Bussell).

Coordinator prior to taking a position with **J.W. Sewall Company** in Old Town. We would like to thank Wilfred for his service and hard work for the CFRU and we wish him the best of luck in his future endeavors. In order to permanently fill the Associate Director Position, a national search was conducted by a committee made up of University personnel and CFRU cooperator representatives. Early in 2011, we were pleased to recruit **Dr. Brian Roth** as the new **Associate Director** of the CFRU who comes with a wealth of University and Industrial forestry experience. Welcome to the CFRU Brian.

2011 Fall Field Tour

On October 27th, 2011 the CFRU held its annual **Fall Field Tour**. This year's tour entitled **"Managing Maine's Future Forest: The Spruce Budworm 'Sea of Wood'"** was hosted on **Plum Creek Timber Company** lands and featured the **Austin Pond Study** site that was established by the CFRU in 1977. The tour explored key management issues facing CFRU members with the 'Sea of Wood' that is coming from spruce budworm era stands established in the 1970's and 80's across northern Maine. Participants saw first-hand the results of 1970's herbicide application and 1980's pre-commercial thinning on 40-year stand development. The stands that were created at Austin Pond represent the wide range of conditions facing CFRU members in northern Maine.

Discussions centered on options for future commercial thinning and timber stand improvement operations in these stands as well as associated wildlife habitat issues. The tour included stops at two of **Plum Creek Timber's** operational plantations established in the area during the last budworm outbreak and included a presentation by current **Maine State Forester**, **Doug Denico**.


Yellow warbler - Photo by Pamela Wells

Students

There currently are ten Graduate Students working on CFRU projects. This year, **Joseph Pekol** has completed his Master's degree under the advisement of **Dr. Aaron Weiskittel** on predicting mortality following thinning in Spruce fir stands in Maine. We wish Joe the best in his career.

The CFRU welcomed one new student this year, **Patrick Hiesl**. Patrick came to Maine in 2011as the crew leader for the 2011 CTRN summer crew and is working on a CFRU project examining the productivity and costs for logging equipment in Maine's forest industry with **Dr. Jeff Benjamin**. Patrick originally is from Germany with a background in forest management.

CENTER FOR ADVANCED FORESTRY SYSTEMS (CAFS)

By Bob Wagner and Aaron Weiskittel

Drs. Bob Wagner and Aaron Weiskittel completed the second 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.

Led by North Carolina State University, CAFS is a consortium of university/industry forest research cooperatives at University of Maine, Oregon State University, Purdue University, Virginia Polytechnic Institute, University of Georgia, University of Washington, University of Idaho, and University of Florida.

CAFS provides $70,000 per year to the University of Maine and CFRU members to advance growth & yield models for natural forest stands in the Northeast. This funding is supporting a PhD student (Matt Russell) and MS student (Patrick Clune). Matt is developing growth and yield equations for the northern forest (see modeling section) and Patrick is analyzing the 10-year results from the CFRU Commercial Thinning Research Network (see CTRN update).

Silviculture

Commercial Thinning Research Network

Regeneration Response to Thinning

Species Composition of Regeneration

Early Commercial Thinning

Partial Harvesting Inventory Methods

White throated sparrow.
Photo by Pamela Wells

COMMERCIAL THINNING RESEARCH NETWORK: 2011 UPDATE

Authors:

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Introduction

2011 marks a milestone for the CFRU Commercial Thinning Research Network (CTRN) as it has been 11 years since the installation of the first thinning treatments and the final thinning treatments, as laid out in the experimental design, were conducted in the fall of 2011. As outlined in previous CFRU Annual Reports, the network now consists of three experimentally controlled studies which examine commercial thinning responses in Maine spruce-fir stands. A dozen study sites were established on CFRU cooperator lands across the state beginning in 2000.

The first study was established in mature balsam fir stands on six sites that had previously received pre-commercial thinning (PCT) and 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). The third experiment expanded the network by including PCT stands on intermediate and low quality sites and follows an experimental design similar to that of the first study. This study is replicated across three locations and encompasses the lands of three cooperators. See previous Annual Reports for more thorough description of the experimental design and implementation.

Field Season

This year's measurement crew consisted of five members and was aptly lead by **Patrick Hiesl** who has gone on to pursue a MS degree with **Dr. Jeff Benjamin**. The rest of the crew included **Vance Brown** and **Danny Hayes** (figure 2-1). A two person sub-team staffed by **Andrew Picarillo** and **Josh Kohn** worked closely with the CTRN crew on a related study investigating regeneration patterns following thinning (see Regeneration Response to Thinning in this report for preliminary study results).

Figure 2-1. The 2011 CTRN measurement crew: from left to right - Danny Hayes, Vance Brown, and Patrick Hiesl at the Alder Stream location (June 20th, 2011).

Final Treatments on PCT Study

The last of the thinning treatments scheduled for the PCT study (final five year interval) were implemented in the fall of 2011. Following the summer measurements, one plot each was marked to thin to 33 and 50% relative density reduction on each of the six PCT study locations. At the time of writing this report five of the six locations have been treated, with the sixth scheduled for the spring of 2012 (table 2.1). One contractor implemented the treatments on the first five installations with the last location, Weeks Brook, yet to be completed at the time of writing this report.

Figure 2-2. Avery & Son Logging at the Ronco Cove location: from left to right – Roger Avery, Leo Cyr, Ernest Leveille, and Bill Theriault (December 5th, 2011).

Roger Avery of **Avery and Son Logging** in **Milford, ME** utilized a three person crew and a cable skidder to harvest the plots (figure 2-2). Due to access issues and the small numbers of trees to be removed, not all timber was salvaged. With the exception of the PEF 23a and Lake Macwahoc installations; trees were hand felled, limbed, bucked to short lengths and left onsite. On the installations where the skidder was used to remove logs, care was taken to avoid damage to the residual trees and roots (figure 2-2).

Roger and his crew did an exceptional job. A special thanks to **David Cole** and **Scott Olson** (**American Forest Management**), **Mike Rundell** (**Plum Creek Timber Company**), and **Ked Coffin** (**Irving Woodlands, LLC**) for arranging and coordinating the thinning operations. A study of this magnitude would not be possible without the in-kind contributions of our member organizations.

Figure 2-3. Avery & Sons cable skidder at PEF 23a location on December 16th, 2011.

Summary

The CTRN database now contains over 129,000 unique measurements on 16,043 trees on 15 sites across the state of Maine. This world class database continues to provide valuable growth and yield data which is actively being used in multiple modeling projects (see Refining the FVS NE Variant section in this report). **Patrick Clune**, under the direction of **Dr. Bob Wagner**, continues to synthesize the first 10 years of data for his MS project on a CAFS assistantship.

Table 2-1. Summary of PCT Study Installations scheduled for treatment in 2011/2012.

Location	Landowner/Manager	Plots	Harvest dates	Contractor
Alder Stream	AFM	5 & 7	Nov. 21 – 22, 2011	Avery & Son
Ronco Cove	Plum Creek	2 & 6	Dec. 1 – 5, 2011	Avery & Son
Lazy Tom	Plum Creek	5 & 8	Dec. 2, 2011	Avery & Son
PEF 23a	USFS/UMaine	4 & 5	Dec. 21 – 22, 2011	Avery & Son
Lake Macwahoc	AFM	5 & 6	Dec. 26 – 27, 2011	Avery & Son
Weeks Brook	Irving	2 & 5	TBD	TBD

RESPONSE OF TREE REGENERATION TO COMMERCIAL THINNING IN SPRUCE-FIR STANDS OF MAINE: FIRST DECADE RESULTS FROM THE COMMERCIAL THINNING RESEARCH NETWORK

Authors: Matt Olson, Spencer Meyer, Bob Wagner, and Bob Seymour

Introduction

Traditional silvicultural thinning is implemented to boost growth and final yield of crop trees with no specific intention of triggering a regeneration response. However, there is some reason to anticipate that thinning will initiate some tree regeneration. After all, thinning is still a form of canopy disturbance that temporarily increases resource availability and some tree species have evolved their regeneration strategies to take advantage of such opportunities.

The CFRU initiated a project evaluating the effect of commercial thinning on regeneration in spruce-fir stands using the **Commercial Thinning Research Network (CTRN)** from 2002-2004 (Greenwood and McConville, 2004).

Matt Olson examines vegetation at a sample grid point on the Penobscot Experimental Forest CTRN location (June 27th, 2011).

A major focus of this investigation was testing for thinning effects on germination and early seedling survival of red spruce and balsam fir. Unfortunately, as is common with assessments of forest regeneration, the data were too variable from one year to the next and few notable trends with implications for management were detected. It is likely that the focus on germinants and early timing of this study relative to the thinning treatments (only three years post thinning) limited the scope of this investigation to capturing short-term regeneration responses, such as inter-annual variability in germinant abundance, which may not have much bearing on the development of viable regeneration (i.e., established regeneration with a higher probability of recruiting into the canopy).

The goal of this project is to increase our understanding about the influence of commercial thinning on the development of viable regeneration in Maine spruce-fir stands during the first decade after treatment. Toward this goal, we started to re-evaluate understory regeneration in both PCT and no-PCT experiments within the CTRN study. We are testing the hypothesis that commercial thinning increases the density of softwood regeneration in spruce-fir stands of Maine (i.e., the de facto shelterwood effect). Additionally, we are comparing regeneration between PCT and no-PCT softwood stands to test the hypothesis that softwood regeneration density is greater in no-PCT stands than the PCT stands. Presented here are the preliminary findings of this investigation.

Methods

To test our hypotheses, we sampled forest regeneration at six sites of the CTRN. Of these, three stands had previously been PCT'd and then commercially thinned and three were only commercially thinned. Generally, the PCT sites are dominated by balsam fir, originated in the late 1970s to early 1980s, and have relatively high site indices. Conversely, the no-PCT sites are generally dominated by red spruce with a significant balsam fir component, are considerably older, and are typically of lower site quality. Within each of the sites we tested two levels of thinning intensity (33% and 50% relative density reductions) and an unthinned control. Counts of stems by species were recorded in summer 2011 using two overlapping grids of 4-m^2 plots (2 x 2m) and 16-m^2 plots (4 x 4m) to capture small (0.1-1.4 m tall) and sapling (dbh < 6.6 cm) regeneration, respectively. Data on overstory trees, regeneration substrate, and hardwood sprout clumps were also recorded.

Preliminary Results

We expected to find higher densities of softwood regeneration in stands treated with commercial thinning compared to the control. Our preliminary results clearly support this hypothesis. Mean density of softwood regeneration was 10-fold greater in thinned stands than controls for both PCT and no-PCT types (table 2-2). Similarly, mean percent stocking of softwoods was substantially greater in thinned stands. Interestingly, mean softwood regeneration density was greater in the lighter 33% removal treatment than the 50% treatment for both PCT and no-PCT sites and, in the case of the PCT sites, softwood mean percent stocking was higher in the 33% treatment.

Early findings of this investigation also support the hypothesis that softwood regeneration was more abundant in the no-PCT experiment. This hypothesis was based on our expectation of greater softwood advance regeneration development in the older, no-PCT stands prior to commercial thinning and under a higher rate of canopy mortality due to blowdown since thinning (Meyer *et al.* 2007). In fact, mean density of softwood regeneration in the 33% treatment was nearly two-fold more abundant in the no-PCT, while mean softwood regeneration density in the 50% treatment of the no-PCT experiment was more than double that of the PCT (table 2-2).

Balsam fir dominated the regeneration pool of the thinned stands with a history of PCT, while red spruce dominated thinned stands of the no-PCT half of the study. Mean density of balsam fir regeneration ranged from 40,000 to 60,000 stems per hectare in PCT stands treated with commercial thinning compared to less than 4,000 in controls (figure 2-4). A similar, but magnified, trend was observed for red spruce regeneration in the no-PCT thinning treatments with 75,000 to 90,000 stems per hectare compared to less than 4,000 recorded in the controls. Pothier and Prevost (2008) also observed high red spruce regeneration densities (> 88,000 stems per ha) 10 years after light shelterwood cutting (~15% of merchantable BA removed) in red spruce dominated softwood stands. Mean percent stocking of balsam fir and red spruce regeneration followed a similar trend with greater than two-fold higher stocking in thinned stands compared to the controls of the PCT and no-PCT, respectively. This shift in understory dominance by balsam fir and red spruce regeneration between halves of the CTRN study is partly an artifact of local seed source differences, since balsam fir dominates the younger canopy of the PCT stands and red spruce dominates the canopy of the older, no-PCT stands.

Table 2-2. 2011 mean density and percent stocking of softwood regeneration (small and sapling combined) recorded in the PCT (thin-now only) and no PCT (crown-thin only) experiments of the CTRN study. The controls represent the no-thin option.

Treatment History	Density (stems/ha)	Percent Stocking
PCT		
Control	3,591	36
33%	57,421	94
50%	38,829	83
No PCT		
Control	7,571	58
33%	99,190	99
50%	83,393	99

Other species also appear to have benefited from commercial thinning. In PCT sites, red maple and intolerant hardwoods had higher mean regeneration densities and percent stocking in thinned stands than the controls (figure 2-4). For the no-PCT half of the study, white pine and intolerant hardwoods were more abundant and well-distributed in the thinned stands. The higher abundance and stocking of hardwoods in thinned stands was partly due to sprouting initiated by the removal of hardwoods during thinning.

Figure 2-5 shows the mean density of hardwood sprout clumps initiated by thinning treatments (i.e., control treatment excluded). Thinned stands on the PCT sites had substantially higher densities of sprout clumps than those of the no-PCT. Hardwood clump densities were comparable between thinning treatments of the no-PCT sites and composed mainly of species other than red maple (primarily the birches). The PCT sites, on the other hand, were dominated by red maple sprout clumps which were more abundant in the 50% than the 33% treatments suggesting that clump density increased with thinning intensity in the PCT half of the study.

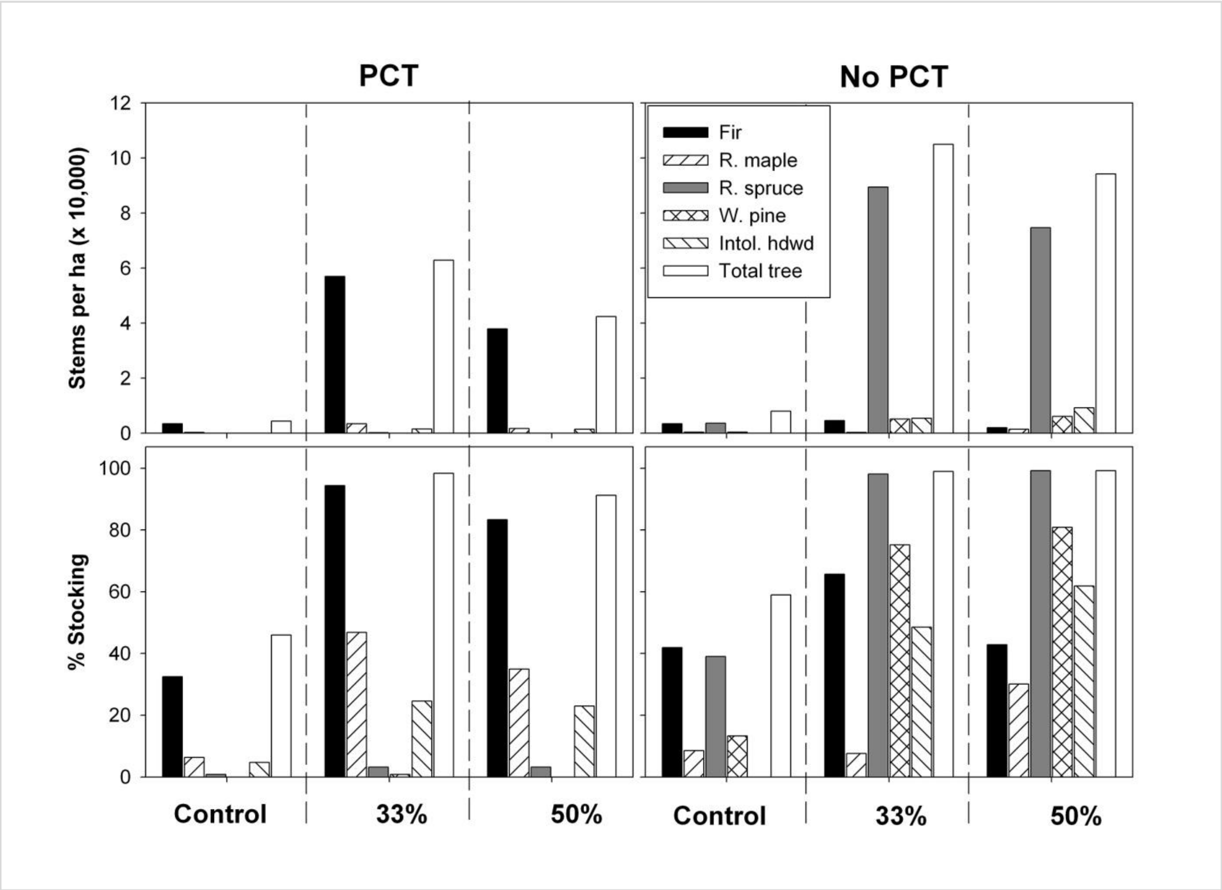

Figure 2-4. 2011 mean density and percent stocking of regeneration (small and sapling combined) recorded in the PCT (thin-now only) and no PCT (crown-thin only) experiments of the CTRN study. The controls represent the no-thin option.

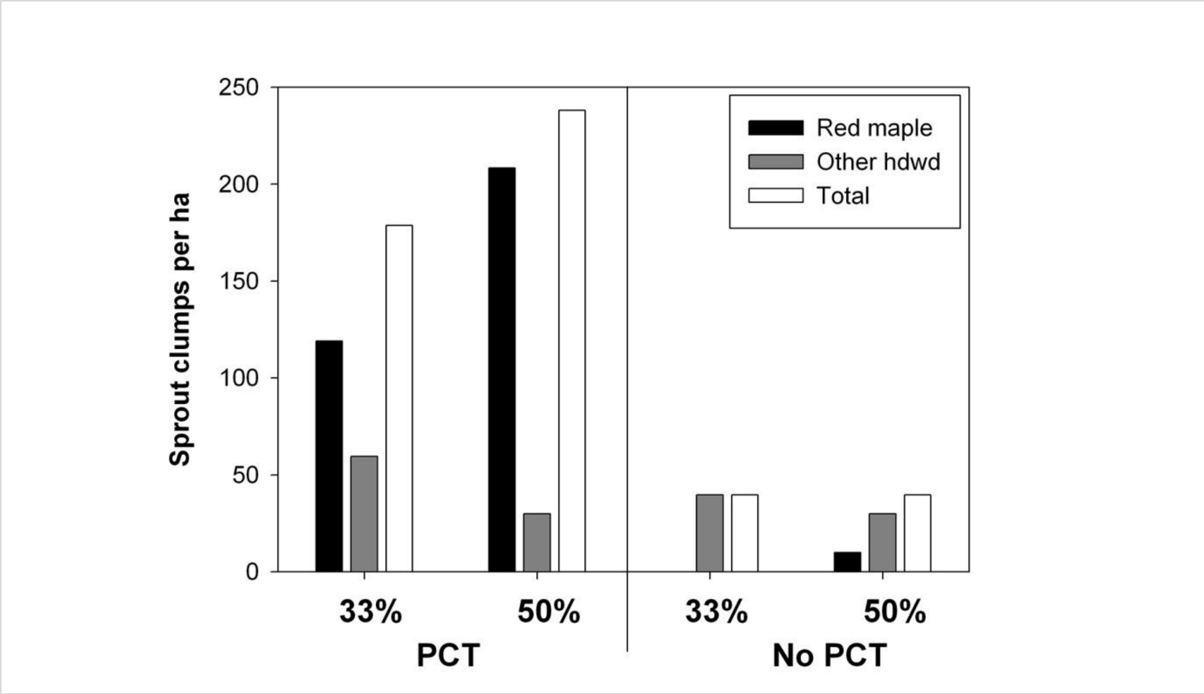

Figure 2-5. 2011 mean density of hardwood sprout clumps initiated by thinning treatments in the PCT (thin-now only) and no PCT (crown-thin only) experiments of the CTRN study.

Early Conclusions

Our early findings indicate that commercial thinning has stimulated the development of natural softwood regeneration within the first decade following treatment in a manner similar to a shelterwood establishment cut. Therefore, commercial thinning has the potential to serve as a "de facto shelterwood" entry in similar spruce-fir stands while still providing the benefit of concentrating growth on fewer crop trees.

Commercial thinning in older, spruce-dominated stands without a history of management, similar to the no-PCT sites used in this study, could produce abundant red spruce advance regeneration available for release within 10 years of treatment. These sites also experienced high overstory mortality (i.e. blowdown) over the same period. Re-entering these stands to capture anticipated mortality could perpetuate spruce dominance if large advance regeneration is protected during subsequent entries.

Higher densities of hardwood sprout clumps initiated by thinning in PCT sites suggests that sprout clumps could have a stronger, negative effect on the development of softwood regeneration in younger PCT stands following commercial thinning. If this scenario is true, then additional cultural treatments may be needed to control hardwood sprout clumps in favor of desirable softwood regeneration.

What's Next

In the next phase of this investigation, we will formally test our hypotheses using advanced statistical procedures. After that is finished, we will address smaller scale within-stand factors correlated with density and spatial dispersion of tree regeneration in the CTRN.

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INFLUENCE OF SILVICULTURAL INTENSITY AND SPECIES COMPOSITION ON THE PRODUCTIVITY OF EARLY-SUCCESSIONAL STANDS IN MAINE

White Spruce Leader Photo by Andrew Nelson

Authors: Andrew Nelson & Robert Wagner

Hardwood Regeneration Improvement Update

This was the final year of funding for the hardwood regeneration improvement (i.e., beech control) project, and our progress is on track with the anticipated timeline proposed to the CFRU. Funding for this project allowed us to implement the various herbicide-surfactant treatments, and collect four field seasons worth of data to document the response of beech-dominated understories to various herbicide treatment combinations. CFRU funding covered 40% of the assistantship of Andrew Nelson throughout the tenure of his M.S. and resulted in a M.S. thesis and a peer-reviewed publication. The publication, *"Improving the composition of beech-dominated northern hardwood understories in northern Maine"* was recently published in the Northern Journal of Applied Forestry (Nelson and Wagner 2011). Andrew Nelson completed his M.S. in 2009 and the CFRU funding has been used to support his Ph.D. studies in hardwood silviculture. Last year, we reported preliminary results from a project on the Penobscot Experimental Forest (PEF) investigating the performance of four clones of hybrid poplar in mixture with naturally regenerated stands and in plantations with intensive vegetation control. The analysis was extended to include the performance of white spruce plantations and the results are being published in the journal New Forests (Nelson *et al. in press*).

Response of Early-Successional Stands Managed to Different Intensities of Silviculture and Species Composition

Introduction

In Maine, 936,760 ha (13%) of forestlands are dominated by early-successional hardwood species and 1.7 million ha (24%) are dominated by saplings (McWilliams et al. 2005). Trees species diversity can often be high in these young stands which are typically mixedwood composition (conifer and hardwood), yet the response of these young stands to silvicultural intensity is poorly understood. For instance, on some sites, species composition can be shifted to shade-intolerant hardwood composition and growth rates can be increased with thinning. Additionally, conifer dominance is often desired on many sites, and vegetation management treatments (such as herbicide release) can be applied to reduce or eliminate hardwood composition from the stands to promote conifer dominance. Other stands can be managed to maintain mixedwood composition and provide the benefits of multiple species. Therefore, the overall goal of this study (the SI-Comp experiment) is to document the response of early-successional stands to different intensities of silviculture and species composition objectives.

Experimental Design

During 2003-04, the SI-Comp experiment was established at a 9.2 ha clearcut site on the PEF. The site was harvested in 1995 and regenerated to a mixedwood composition of aspen, birch, red maple, and scattered patches of conifers (balsam fir, red and white spruce, eastern hemlock and eastern white pine). Across the site, we installed a 3 x 3 +1 factorial experiment that included three species compositional objectives (Hardwood, Mixedwood, Conifer) and three silvicultural intensities (Low, Medium, and High), plus an untreated control. The treatment combinations include: Low Conifer (LC), Low Mixedwood (LM), Low Hardwood (LH), Medium Conifer (MC), Medium Mixedwood (MM), Medium Hardwood (MH), High Conifer

(HC), High Mixedwood (HM), High Hardwood (HH), and Untreated Control (UC).

Each treatment is replicated four times for a total of 40 treatment plots. Treatment plots are 30 m x 30 m with a 20 m x 20 m nested measurement plot in the center. Each treatment plot is subdivided into 2 m x 2 m growing space cells where each crop-tree was assigned and silvicultural prescriptions were implemented. Figure 2-6 shows the actual crop-tree locations and species identification for each of the 40 treatment plots at the start of the experiment. Additionally, five 16 m^2 composition sample plots were established in each treatment plot. Four composition plots are located at the corner of each measurement plot and the fifth in the center of the treatment plot.

Implementation of the treatments began in 2003 with the removal of all woody and herbaceous vegetation in the High intensity plots. Combinations of triclopyr basal applications, brushsaw cutting, and broadcast glyphosate applications were used to remove all woody and herbaceous vegetation. In 2004, the plantations were planted on a 2 m x 2 m spacing (2,500 trees per hectare [tph]) and the silvicultural prescriptions for the natural treatments were implemented. In the Low-intensity treatments, vigorous trees with minimal defect in each 2 m x 2 m growing space were identified as crop-trees, and all competitors in a 1-m radius around each crop-tree were removed to promote survival and eventual dominance. If crop-trees were conifer species, hardwood competitors were controlled with triclopyr bark applications while conifer competitors were removed with brushsaws. If the crop-trees were hardwood species, only brushsaws were used to remove competing woody vegetation as we wanted to avoid herbicide flashback on aspen root-suckers. Planted improved white spruce and hybrid poplar clones accounted for 50% of the crop-trees in the Medium-intensity treatments, and similar techniques to the Low-intensity treatments were used to ensure crop-tree survival and dominance.

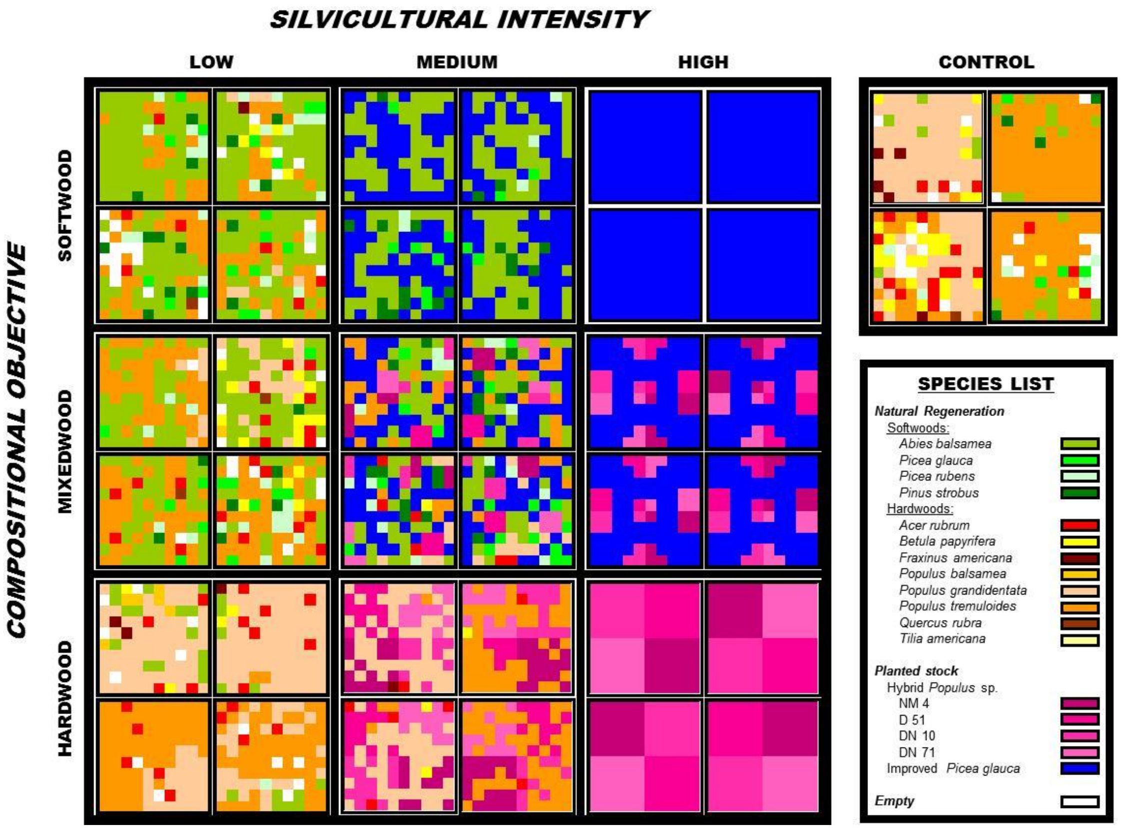

Figure 2-6. Experimental Design of the SIComp experiment installed in 2003 in a previously clearcut stand on the PEF. Each "pixel" represents a 2 x 2 m growing space that was assigned to each crop-tree species being monitored in the study. Actual assignments are shown for each of the four replicated (20 x 20 m) measurement plots for each treatment.

In the Hardwood treatments, nearly all of the selected crop-trees were hardwoods including aspen, birch, and maple. In the Conifer treatments, most of the crop-trees were either balsam fir, white spruce, red spruce, or white pine. Mixedwood treatments were designed to have a 67:33 proportion of conifers to hardwoods.

Measurements

Crop-trees in the measurement plots have been measured annually (with the exception of the 2008 growing season). For each crop-tree, their status (dead or alive) is recorded and DBH, basal diameter, height, and length of live crown are measured. Periodically, crown width is measured for each crop-tree. The composition plots have been measured in five inventories (pre-treatment (0), 1, 2, 6, and 7 years after treatment). In the composition plots, DBH is measured for all trees ≥ 1.37 m in height and their species is recorded.

Results

To date, only the data for the composition plots have been analyzed. The goal of the composition plot analysis was to document the changes in species composition, and growth and yield for the various treatments. Table 2-3 shows the species composition six years after treatment for all ten treatment combinations. Paper birch, gray birch, trembling aspen and bigtooth aspen, and red maple dominated the UC, LH, and MH treatments. Balsam fir was the dominant species in the LC, LM, MC, and MM treatments, while the other conifer species were much less common. Interestingly, hardwoods comprised 44.1% and 34.4% of the composition in the LC and MC treatments, respectively. Hardwood basal area was likely high in the Conifer treatments because they established in the open growing space created by the treatment All woody (tree and shrub) stems less than 1.37 m in height are tallied by species.

Planted White Spruce saplings *Photo by Andrew Nelson*

Table 2-3. Species composition (calculated as a proportion of total basal area) six years after the start of the SIComp experiment by treatment. Treatment abbreviations are: UC - Untreated Control, LC - Low Conifer, LM - Low Mixedwood, LH - Low Hardwood, MC - Medium Conifer, MM - Medium Mixedwood, MH - Medium Hardwood, HC - High Conifer, HM - High Mixedwood, and HH - High Hardwood.

	Percent of all stems (%)									
	UC	LC	LM	LH	MC	MM	MH	HC	HM	HH
Paper birch	22.4	2.0	4.4	6.6	8.6	10.2	12.2	0.0	0.0	0.0
Gray birch	4.6	2.8	2.4	35.2	1.6	13.9	9.1	0.0	0.0	0.0
Bigtooth aspen	20.0	10.9	10.4	9.4	2.0	4.1	16.1	0.0	0.0	0.0
Trembling aspen	13.0	2.0	2.0	7.3	1.2	2.5	7.7	0.0	0.0	0.0
Red maple	17.4	14.2	8.4	20.7	5.9	11.5	33.6	0.0	0.0	0.0
Other hardwood	10.3	12.1	8.8	14.1	15.2	11.1	15.7	0.0	0.0	0.0
Balsam fir	9.0	49.8	54.2	6.1	44.9	31.6	1.4	0.0	0.0	0.0
Red spruce	1.3	3.2	2.8	0.2	0.4	2.5	0.0	0.0	0.0	0.0
Natural white spruce	0.2	1.2	2.0	0.0	0.4	0.0	0.7	0.0	0.0	0.0
White pine	1.7	1.6	1.6	0.5	4.3	6.1	2.1	0.0	0.0	0.0
Hemlock	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Improved white spruce	0.0	0.0	0.0	0.0	15.6	6.1	0.0	100.0	81.0	0.0
Hybrid poplar	0.0	0.0	0.0	0.0	0.0	0.4	1.4	0.0	19.0	100.0
Total hardwood	87.7	44.1	36.3	93.2	34.4	53.7	95.8	0.0	19.0	100.0
Total conifer	12.3	55.9	60.6	6.8	65.6	46.3	4.2	100.0	81.0	0.0

Overall, results suggest that the silvicultural prescriptions have been effective in shifting or maintaining their target species composition (hardwood, conifer or mixedwood). Figure 2-7 shows the change in stand biomass (Mg ha^{-1}) in relation to stem density (tph) over the seven years of development. All of the natural treatments (UC, LH, MH, LM, MM, LC, and MC) had similar starting densities of 14,000 to 18,000 tph, and biomass yields between 8 and 10 Mg ha^{-1}. The UC treatment maintained relatively high densities but the yield increased substantially. Densities and biomass of all the naturally-regenerated treatments were initially reduced by the silvicultural prescriptions. After treatment, the rate of biomass increase tended to be much greater than the rate of increasing densities in all of the naturally-regenerated treatments. The MH and LH treatments had the greatest yields after seven years, and the yield of the LH treatment was the same as the UC treatment, but with lower densities. This result suggests a thinning response of the hardwood crop-trees in the LH and MH treatments. The densities were initially reduced, but the growing space was shifted to the residual crop-trees. The plantation treatments (HC, HM and HH) had starting densities of 2,500 tph. The densities in these treatments have not changed substantially, but the yields have increased. For instance, seven years post-treatment the HH treatment had a yield of nearly 30 Mg ha^{-1}.

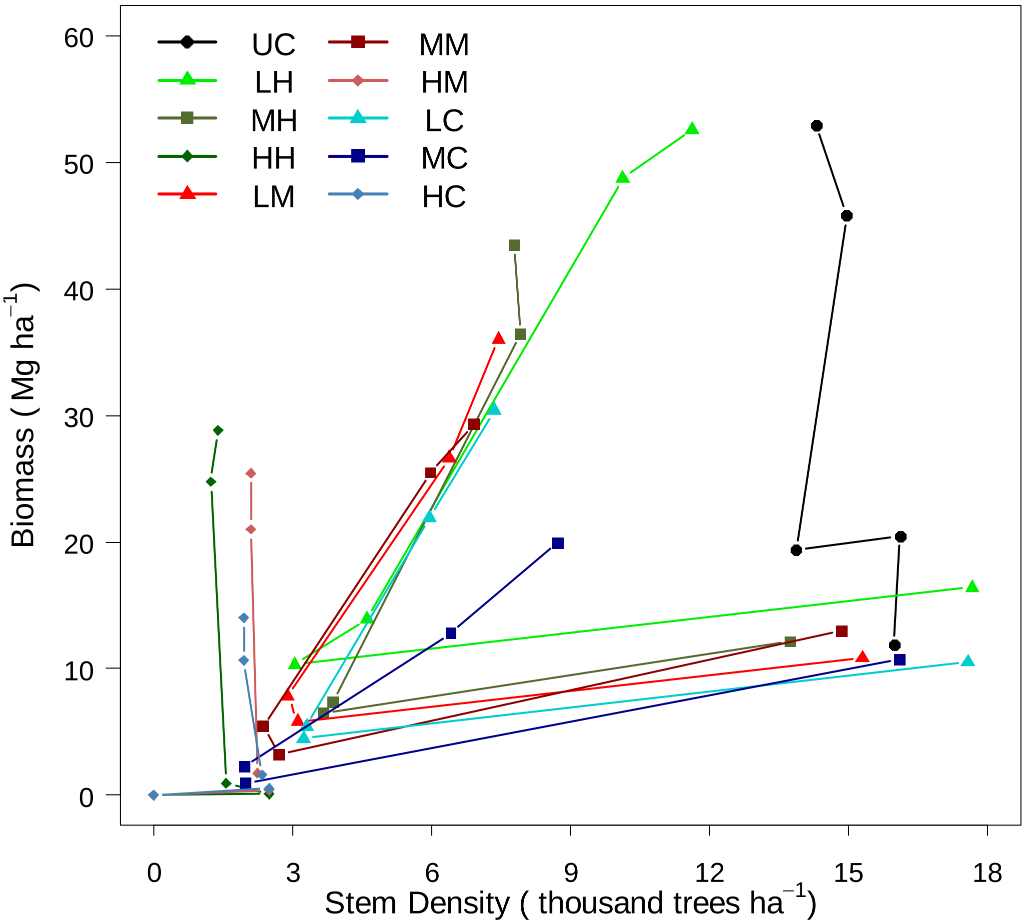

Figure 2 – 7. Change in stand biomass (Mg ha^{-1}) and stem density (thousand trees ha-1) prior to the start of the experiment (lower right corner), initially following treatment application (lower left corner) and seven years after treatment (upper left and right).

Future Directions

The CFRU recently funded the continuation of the hardwood assistantship cost-share with the H.W. Saunder's Chair at the University of Maine. This cost-share supports the Ph.D. research of Andrew Nelson. During the coming year, we will focus our analysis on 1) comparing stand dynamics among treatments, 2) developing small tree biomass and leaf area equations among species and treatments, and 3) modeling future stand development.

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EARLY COMMERCIAL THINNING HARVEST SYSTEMS: A SILVICULTURAL AND OPERATIONAL ASSESSMENT

Authors:

Jeff Benjamin, Emily Meacham, Bob Seymour and Jeremy Wilson

Early Commercial Thinning Crew on Ponsse Fox (left to right: Brian Roth, Jeff Benjamin, Emily Meacham, Mallory Bussell).

Introduction

Many of Maine's regenerating clearcuts from the budworm era and are dominated by dense spruce and fir saplings (< 6 in. dbh) with a small component of hardwood. Some of these stands were pre-commercially thinned; others, however, have grown beyond the stage where brush-saw treatment is feasible. Such stands are overstocked and would benefit from thinning, but they are decades away from being operable with traditional harvesting systems and there is no consensus within the industry as to how these young stands should be treated. This study allowed three sectors of the forest industry (landowners, contractors, and equipment dealers & manufacturers) to develop silviculturally effective, operational solutions for implementing early commercial thinning treatment.

Project Objectives

The objectives of this study are to determine the effectiveness of early commercial thinning treatments using cut-to-length (CTL) and whole-tree (WT) harvest methods with respect to 1) silvicultural implementation measured in terms of final tree spacing, residual stem damage, and area in trails; and 2) operational performance measured in terms of productivity, unit cost of production, and product utilization. This report summarizes pre-harvest measurements, data collection techniques during active operations, as well as post-harvest measurements from the first year of the study. Preliminary results for objective 1 are also included.

Study Site Description

The research site is 24 acres of forest in Summit Township, Maine, managed by American Forest Management (AFM). The site is most likely the result of budworm salvage and consists of stands that have been both pre-commercially thinned (PCT) and left untouched (non-PCT). During the summer of 2011, a thinning prescription was completed on the majority of the 24 acres with several research goals in mind. The PCT stand was 20 acres and the non-PCT stand was 4 acres. Before the harvest, both stands consisted mostly of balsam fir (~60%); but the PCT stand had a larger proportion of eastern white pine (24%) and a smaller proportion of red spruce (12%), than the non-PCT stand, which had proportions of these two species at 12% and 24% respectively. Other species in the two stands that were present, but consisted of less than 5% of the species composition included: red maple, eastern hemlock, American beech, quaking aspen, pin cherry, and paper-, grey-, and yellow-birch.

There were two predominant soil types on site. Roughly half of the soil on site consisted of Plaisted, a very stony loam, and the other half of the soil on site consisted of Monarda and Burnham, a very stony silt loam. Soil pits were dug within each soil type in order to confirm classification using Briggs Site Classification Field Guide (Briggs 1994). The soil pits dug in the Plaisted soil type were classified as having a class 2 soil profile. This class is moderately well drained with a mottling depth between 12 to 24 inches. The soil pits dug in Monarda and Burnham soil type were classified as having a class 3 soil profile. This class is somewhat poorly drained with a mottling depth between 8 to 16 inches. According to the Briggs classifications, the Plaisted site has a site balsam fir index of 57 and the Monarda site has a balsam fir site index of 52.

Harvest Plan

The research site was harvested during the summer of 2011 with two harvest methods: cut-to-length (CTL) and whole-tree (WT). University of Maine faculty and students established 32 research plots (0.2 acre) and each harvest method was performed for two trail spacings (50 feet and 80 feet, trail center to trail center) within PCT and Non-PCT stands. Based on the pre-harvest inventory data (see below) and the methods used by the Commercial Thinning Research Network, the target basal area removal was 40% plus trails. The execution of the prescription was expected to shift species composition to red spruce and white pine as well as favor higher quality stems. The prescription was to remove:

1. all trees within machine trails;
2. all balsam fir less than or equal to 3.5 inches dbh;
3. all balsam fir greater than or equal to 8.5 inches dbh; and
4. remaining balsam fir and intolerant hardwoods as necessary to achieve 40% removal.

Operationally, the prescription favored white pine at 15' spacing and red spruce at 8-10' spacing. It was also acceptable to leave balsam fir (4-8" dbh) at 8-10' spacing to fill in between higher value crop trees. Trees were painted for removal in the research plots only, so that machine operators harvested the remainder of each trail with no further guidance. Equipment was selected for this study in consultation and cooperation with local equipment dealers (Chadwick Ba-Ross, Nortrax, and Milton CAT) and one of AFM's preferred logging contractors (A.W. Madden). Two new CTL processors (Ponsse Fox and John Deere 1170E) and a new tracked feller buncher (CAT 501) were compared to a conventional feller buncher common to the industry (John Deere 753J). Table 2-4 provides detailed specifications for each machine.

The primary focus of this study is the performance of harvesting equipment in a thinning context, but it is important to consider productivity of the full operation, so primary transportation and roadside processing was also included. Forwarding was conducted using a Ponsse Wisent provided by Chadwick Ba-Ross and a Valmet 644 under subcontract with Richard Adams Logging. All skidding and roadside processing was conducted by A.W. Madden using a JD 648 GII grapple skidder and a JD 200LC stroke delimber. Figure 2-8 identifies the specific trails and plots assigned to each harvest system.

Table 2-4. General specifications of harvesting equipment used in this study.

Machine	Specifications				
	Width (ft)	Weight (lbs)	Reach (ft)	Clearance (in)	Gross Power @ 2000 (hp)
John Deere 1070E	8.5	32,400	32-35	22	182
Ponsse Fox	9.0	39,000	33	26	197
CAT 501	8.5	35,000	23	24	157
John Deere 753J	10.5	52,000	27	29	220

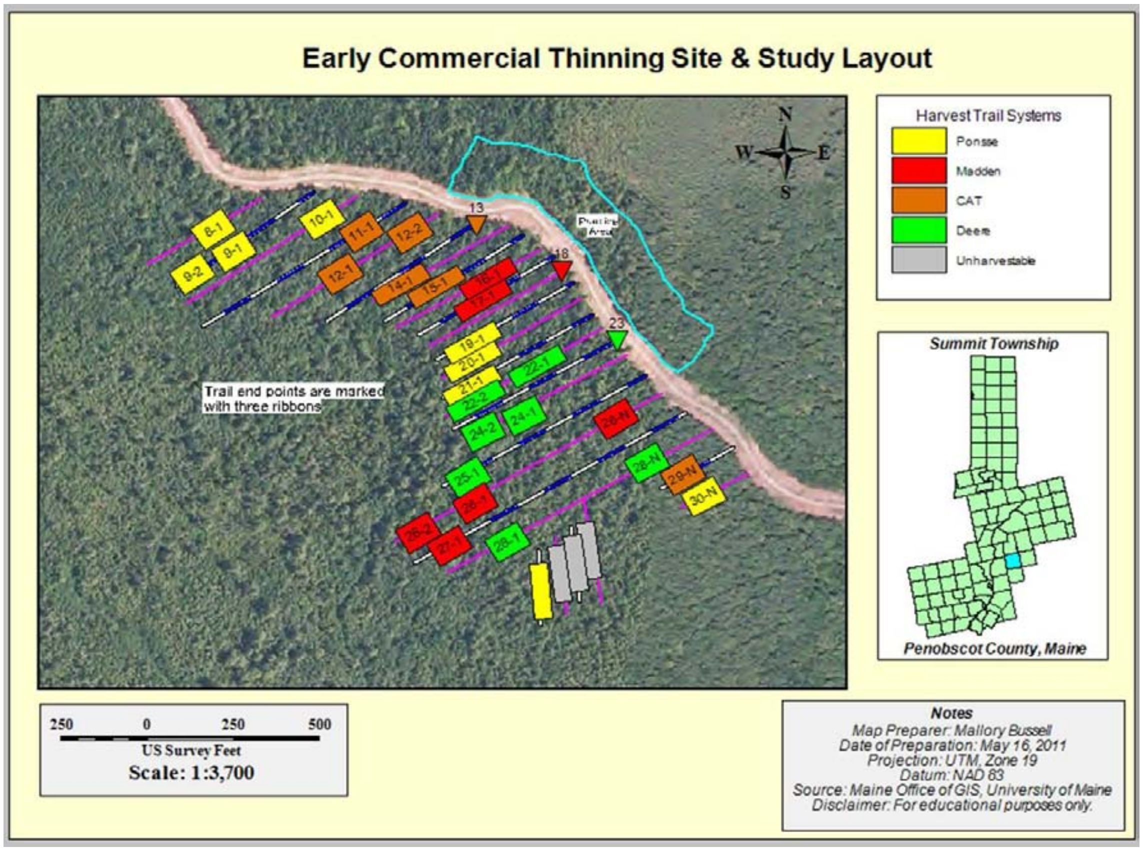

Figure 2-8. Research site overview map depicting plot and trail assignments by harvest method and system.

Active Harvest Measurements

Plot-level and trail-level production data were collected during active operations. At the plot-level, individual machine cycle times were recorded with respect to dbh (2" classes corresponding to colors of marked stems) and species using a time study program (LAUBRASS inc., UMT plus V. 16.7.14) installed on a PDA handheld device (Palm Tungsten E2). A feller buncher cycle began and ended with empty accumulators at the bunch and included the time to harvest, accumulate, and place a bunch in a twitch. Time within each cycle was also noted for trail work, removal of snags or non-merchantable stems, re-piling a twitch, and excessive travel. A processor cycle began and ended with a saw cut and included the time to fell, delimb, top, process, and select the next stem. If multi-stem processing occurred, the cycle ended after all stems were processed and a new stem was selected with empty accumulators. Time within each cycle was also noted for any trail work, removal of snags or non-merchantable stems, processing rot, excessive work to delimb forks, and excessive travel.

At the trail-level, total productive machine hours were recorded for each machine using a combination of manual stopwatches and the PDA system described above. Roundwood and biomass volume was estimated at roadside and cross referenced with mill scale records provided by A.W. Madden. Fuel consumption rates for each machine were calculated based on overall usage for each machine during the operations.

Overstory Inventory

A pre-harvest inventory was conducted on all plots that included diameter dbh, stock grade and species. A 100% cruise was implemented for each PCT plot, whereas only one quarter of each non-PCT plot was sampled in this manner. All residual post-harvest trees within each plot were inventoried with 100% tally regardless of stand and included dbh, every 10^{th} height, and species. Each residual within a plot was labeled with a unique number and unique x,y coordinates in relation to an origin collected with a GPS.

Stand Damage Measurements

Damage was recorded in terms of severity where low severity was bark scuff, moderate severity was cambium broken with uninjured sapwood, and high severity was cambium broken with injured sapwood. Each residual tree was thoroughly inspected for any and all damage. For each wound, diameter and length at the widest points were recorded as well as wound location in terms of height. Crown and root damage were noted when present.

Downed Woody Material

Additionally, a sample of pre- and post-harvest downed coarse woody material (CWM) and fine woody material (FWM) was measured using the line intersect method (Van Wagner 1968). The transect layout was modified from that of Briedis (2009) and consisted of one transect for each plot instead of two. This alteration was made due to the uniformity of the site and the high number of plots in comparison. Transects were 100 feet long and taken from each plot center. The azimuth of each transect was determined randomly and the same was used in both pre- and post-harvest measurements.

CWM was measured if its longitudinal midpoint crossed the transect line and had a small end diameter ≥ 3 inches and a length ≥ 3 feet. The large and small end diameter, mid-point diameter, intersecting diameter, and length were all recorded for each piece of CWM. The species was recorded where identification was possible, otherwise it was recorded as hardwood, softwood, or unknown. Decay class was recorded to indicate the stage of decay using Waddell's (2002) five decay stage classification scheme.

The volume for each recorded piece of downed CWM was calculated using Fraver et al.'s (2007) conic-paraboloid equation; this equation assumes the piece of CWM to be between the shape of a cone and a second-order paraboloid. Waddell's (2002) equations after DeVries' (1973) formula were used to estimate a per-unit-area value for cubic feet per acre (Waddell, 2002).

Results

Pre-and post-harvest inventory analyses were made for both stands. Error was assessed using a 95% confidence interval. The results for the PCT stand are shown in table 2-5 and table 2-6. Volume was approximated using Honer's volume equation which relied on heights estimated from a regression line of observed vs. predicted heights. Approximately 105 ft^2/ac of basal area was removed, including machine trails. Total basal area removal was just over 60%. Close to 500 trees per acre were removed in the harvest. The plots were marked with no bias towards machine trails. Regardless of trail area, the removal was heavier than expected. This may be due to operational effects or because of the low number of quality residuals to choose from when marking the pre-harvest stand. The post-harvest results in table 2-6 include machine trail area.

The results for the non-PCT stand are shown in table 2-7 and table 2-8. Approximately 140ft^2/ac of basal area was removed, including machine trails. Total basal area removal came out to be just under 70%. Close to 3000 trees per acre were removed in the harvest. The large difference in density removal between the two stands is likely due to the large number of small diameter stems. The quadratic mean diameter is ~1.5 inches higher in the post-harvest conditions which in line with the objective to shift the non-PCT stands to larger diameter species. The post-harvest results in table 2-8 include machine trail area. Total basal area removal came out to be closer to the target. Total basal area removal in the PCT stand was 53% and for the non-PCT stand was 64%.

Table 2-5. Pre-harvest assessment of PCT stand.

Statistic	Volume (ft^3/ac)	BA (ft^2/ac)	TPA	QMD (in)
Mean	3871.3	168.8	729	6.6
SD	588.7	22.0	113	0.5
CV	15%	13%	16%	8%
SE	131.6	4.9	25.3	0.1
%SE	3%	3%	3%	2%
95% Lower	3608.0	159.0	678	6.3
95% Upper	4134.5	178.7	779	6.8

Table 2-6. Post-harvest assessment of PCT stand.

Statistic	Volume (ft^3/ac)	BA (ft^2/ac)	TPA	QMD (in)
Mean	1566.6	66.5	242	7.1
SD	362.2	13.9	37	0.6
CV	23%	21%	15%	9%
SE	81.0	3.1	8.2	0.1
%SE	5%	5%	3%	2%
95% Lower	1404.6	60.3	226	6.8
95% Upper	1728.6	72.8	259	7.4

Table 2-7. Pre-harvest assessment of non-PCT stand.

Statistic	Volume (ft^3/ac)	BA (ft^2/ac)	TPA	QMD (in)
Mean	4`001.3	202.3	3425	3.5
SD	394.7	22.7	1244	0.8
CV	10%	11%	36%	22%
SE	197.3	11.3	622.1	0.4
%SE	5%	6%	18%	11%
95% Lower	3606.7	179.7	2181	2.7
95% Upper	4396.0	225.0	4669	4.3

Table 2-8. Post-harvest assessment of non-PCT stand.

Statistic	Volume (ft^3/ac)	BA (ft^2/ac)	TPA	QMD (in)
Mean	1329.9	61.9	405	5.3
SD	199.9	9.5	64	0.1
CV	15%	15%	16%	2%
SE	99.9	4.8	32.1	0.1
%SE	8%	8%	8%	1%
95% Lower	1130.0	52.4	341	5.2
95% Upper	1529.8	71.5	469	5.4

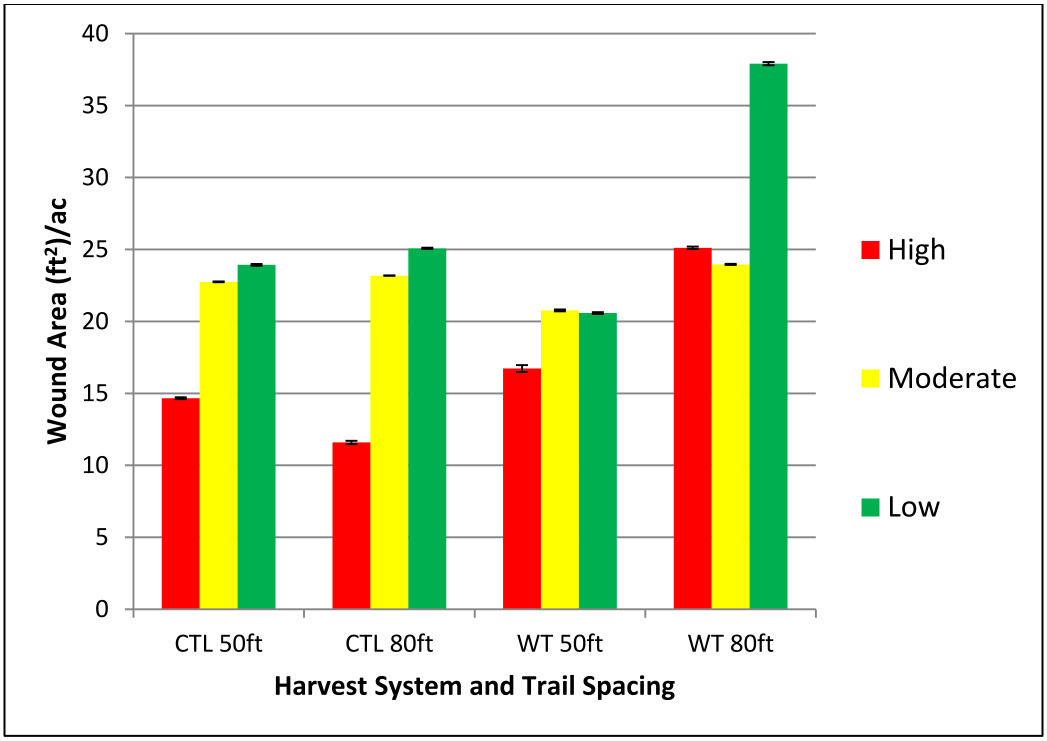

Figure 2-9. Damage in area by harvest system and trail spacing. Error bars depict standard error.

Stand Damage Assessment

The results of the stand damage measurements are shown in figure 2-9 and table 2-9. As can be seen in figure 2.9, there is clearly more area in damage at the severe and moderate levels for the whole tree harvest method. However, in table 8 it is evident that there are fewer trees per acre injured for the whole tree harvest method. Therefore, despite higher overall area in wound, the damage is more concentrated in the whole tree method.

Downed Woody Material

The results of the coarse woody material are shown in figure 2-10 and of the fine woody material in figure 2-11. Both figures show that in all cases, more material was left post-harvest compared to what was present in the pre-harvest stands. However, for both coarse and fine woody material in each trail spacing, there was always a higher amount of material left post-harvest in the cut-to-length harvest method.

Table 2-9. Percentage of trees with significant damage, including moderate and high severity.

Severity	Cut-to-Length		Whole-Tree	
Rating	50 ft	80 ft	50 ft	80 ft
High	8%	5%	5%	7%
Moderate	25%	24%	16%	16%
Total	33%	30%	21%	24%

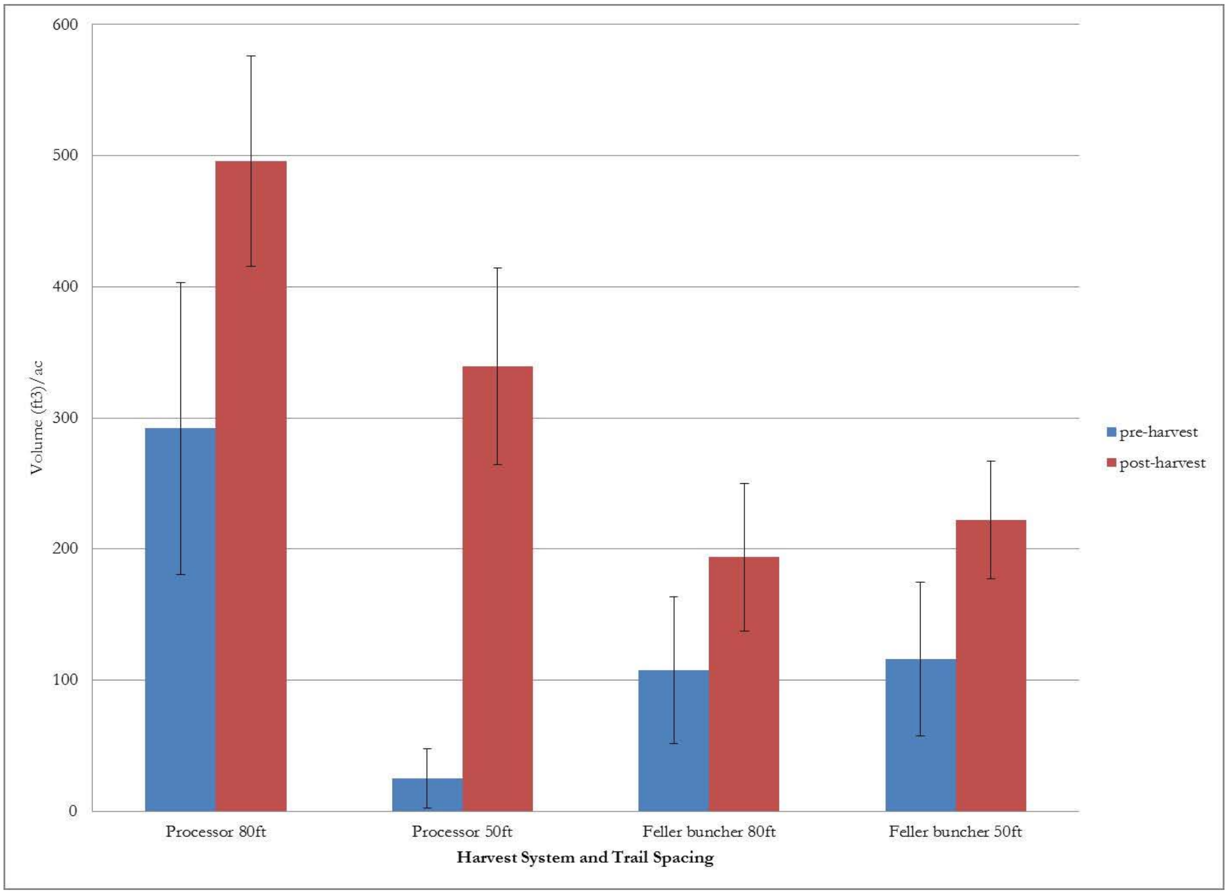

Figure 2-10. Coarse woody material by harvest system and trail spacing with standard error bars.

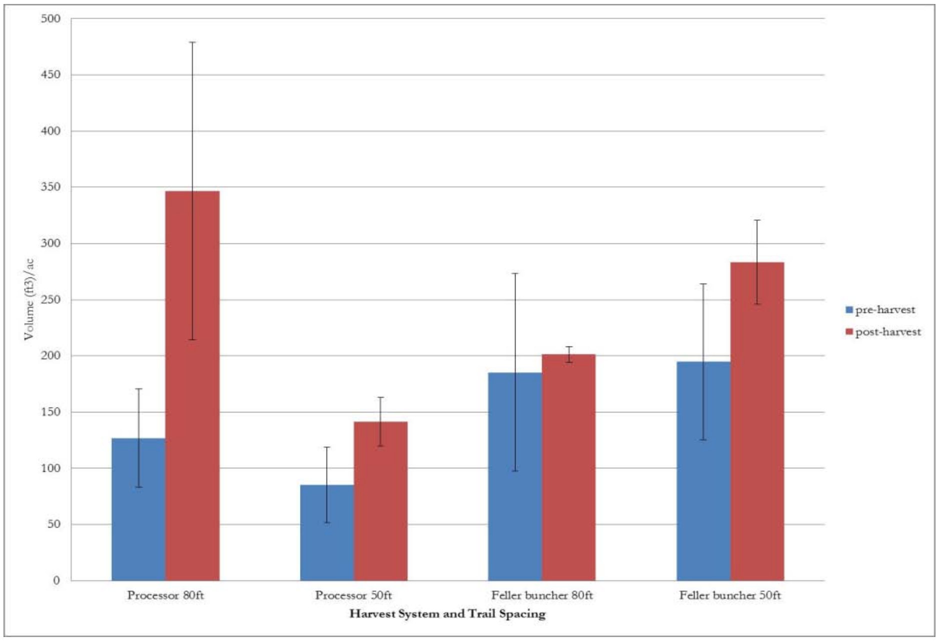

Figure 2-11. Fine woody material by harvest system and trail spacing with standard error bars.

Future Work for 2012

After a successful field season and active harvest operations, the focus in 2012 will be to complete the production analysis (including development of unit production costs for each harvest system) and conduct a machine level cycle time analysis for the processors and feller bunchers. Cooperators can expect to learn of preliminary results in this regard during upcoming CFRU meetings and workshops.

Collaboration / Acknowledgements

In addition to the funding provided by the CFRU, this project would not have been possible without the commitment of many others including: American Forest Management, local equipment dealers and their respective manufacturers (Chadwick Ba-Ross & Ponsse, Nortrax & John Deere, Milton CAT & Caterpillar), local logging contractors (A.W. Madden, Randall Madden Trucking, Richard Adams Logging), and UMaine forestry students (Emily Meacham, Mallory Bussell, Molly Lizotte, Jacob Hicks, Jack Kelly).

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IMPROVED SAMPLING METHODS AND GROWTH & YIELD MODELS FOR PARTIALLY HARVESTED STANDS

Photo by Adam Komar

Authors:

Aaron Weiskittel, Ben Rice, Jeremey Wilson and Robert Wagner

Introduction

Much of Maine's forestland has been managed using partial harvesting methods over the past two decades. The most recent Maine Forest Service data available shows that over the past 5 years (2005-2009) 5,972,676 cords (13,530,188 m^3) were harvested from 478,821 acres (193,854 ha; Maine Forest Service 2009, 2010a, b). In contrast, throughout the 1980s <300,000 acres (<121,457ha) were harvested annually to obtain about the same amount of wood (5.5 to 6 million cords; 12.5 to 13.6 million m^3). These partial harvesting methods generally produce highly heterogeneous stand structures and composition, and it is currently unclear which inventory methods are best given these heterogeneous conditions. Work began on this project in 2010 to compare the efficiency and precision of variable-radius and fixed-area sample plots in stands that have been partially harvested.

Methods

A list of 250 partially harvested stands within the study area (figure 2-12) was obtained from the Maine Image and Analysis Laboratory (MIAL). Through analysis of Landsat satellite images these stands were determined to have been partially harvested between 1988 and 2007 with <70% canopy removal. The information provided by the MIAL includes the location, approximate harvest boundaries, and the period of harvest (generally within a three-year period). Twenty-five stands were randomly selected from the larger list provided by the MIAL and a total of 16 stands were sampled for this objective.

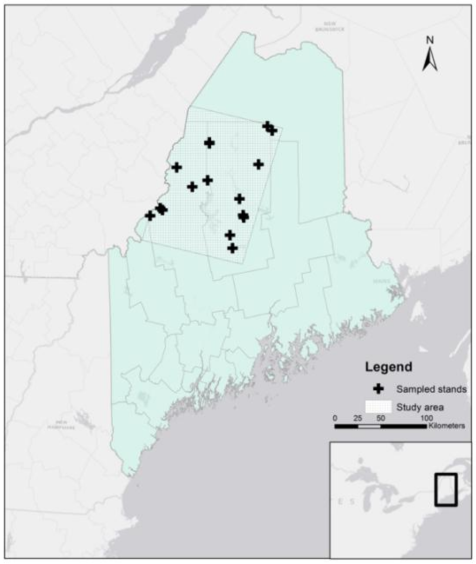

Figure 2-12. Map of study area in northern in central Maine, USA. Study area denoted in dotted portion.

We used six inventory methods (table 2-10): horizontal point (four BAFs), fixed area, and horizontal line sampling measurement methods. Overall, a total of 437 plots in 16 stands were measured and used in our analysis.

For each "in" tree > 4.5 feet height and > 2 inches diameter at breast height (DBH), we recorded species and measured DBH to the nearest 1/10 inch. For height trees (VBAR trees), height to the nearest foot and height to crown base to the nearest foot were measured using a Haglof ultrasonic hypsometer (Haglof Inc., Madison, MS). Height to crown base was determined using the "uncompacted crown method" wherein the height to the lowest live foliage is measured.

Table 2-10. Overview of methods evaluated in this analysis. The methods include fixed area and variable radius, horizontal point sampling (HPS) and horizontal line sampling (HLS), with varying basal area factors (BAF) as well as volume to basal area ratio (VBAR) selection criteria.

Method	Description	VBAR tree selection	Sampling frequency
10 BAF_e	HPS using 10BAF (2.29 BAF metric)	Every 5th tree	Each sampling point
20 BAF_e	HPS using 20 BAF (4.59 BAF metric)	Every 5th tree	Each sampling point
80 BAF_e	HPS using 80 BAF (18.43 BAF metric)	Every tree	Each sampling point
Big BAF	HPS using 20 BAF (4.59 BAF metric)	Selected with 80 BAF (18.43 BAF metric)	Each sampling point
Fixed	Circular 0.04 ha (0.1 acre) plot	Every 5th tree	1/5 of sampling points
Line	HLS using 28 BAF (6.38 BAF metric) on 70 foot (21.34 m) line	Every 5th tree	1/3 of sampling points

We calculated stand level values for each method, including basal area, VBAR, density (trees per hectare) total stand volume per acre, diameter distribution, quadratic mean diameter (QMD) and efficiency, calculated as volume percent standard error times the total time to inventory the stand under a given method.

Results

Efficiency, defined as a combination of precision of volume estimates and measurement time, varied among measurement methods at lower basal areas but with the exception of the fixed area method, was similar at higher basal areas (figure 2-13). Volume percent standard error was higher in the 80 BAF, horizontal line sampling, and fixed area methods compared to all other methods. There was also an interaction between method and basal area for all methods, resulting in an inverse relationship between basal area and volume standard error for all methods tested. Similarly for measurement time, there was difference between methods and there was an interaction between method and basal area. Although, both the 80 BAF horizontal point sampling and horizontal line sampling methods were relatively unaffected by basal area.

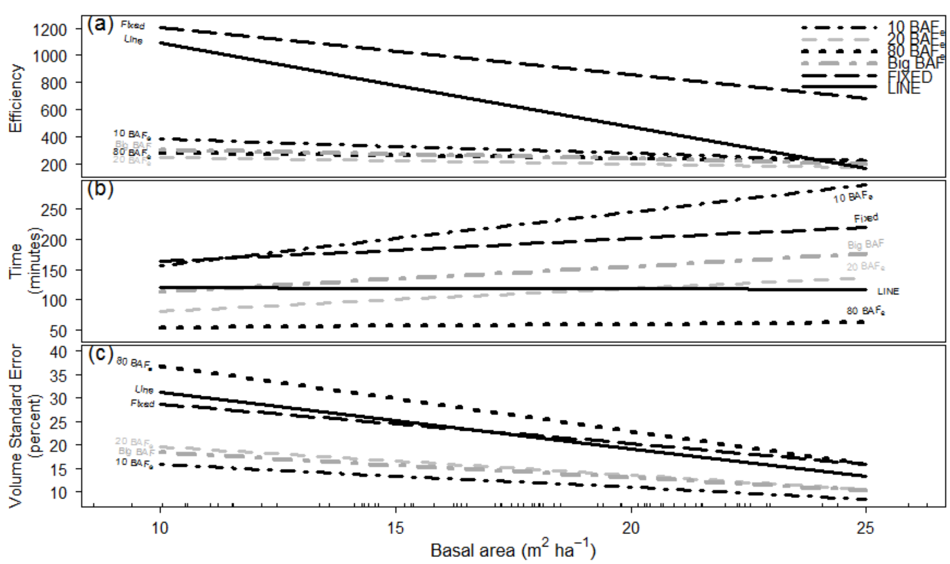

Figure 2-13. Fitted regression lines displaying the interaction of method and basal area with (a) efficiency, (b) stand measurement time and (c) volume standard error. The horizontal lines at the bottom of the x-axis represent observed values.

Estimates of some stand variables (e.g., volume, QMD and small stem density and basal area) varied by method (Table 2-11), while others varied little (e.g., overall basal area and stem density) under rather heterogeneous forest conditions present after partial harvesting.

Discussion

Forest inventories need to be designed and conducted to optimize a balance of the relevant quality data, while minimizing costs. In the case of partially harvested stands in Maine, there may be several advantages to horizontal line sampling compared to horizontal point sampling. Primarily, horizontal line sampling allows the forest inventory crews to sample a wider range of the within stand variability, while visiting a fewer number of points. With horizontal point sampling and fixed area sampling, there is potential for under- or overestimates of stand values based solely on the chance that a majority of plots fall within harvested or unharvested portions of a stand. This possibility may be particularly problematic when sampling intensity is low. Secondly, bias in plot center location is significantly reduced, particularly when using a randomly oriented line. Finally, the horizontal line method allows estimation of the percent area in different stand conditions, which may be important for scaling the plot-level estimates to the stand level.

Due to the inherent variability in forested systems and the subjective nature of balancing competing values, there is no single approach that predictably serves both purposes across a range of stand conditions. Our results illustrate the tradeoffs between precision and time involved in several measurement methods under a range of heterogeneous stand conditions. .

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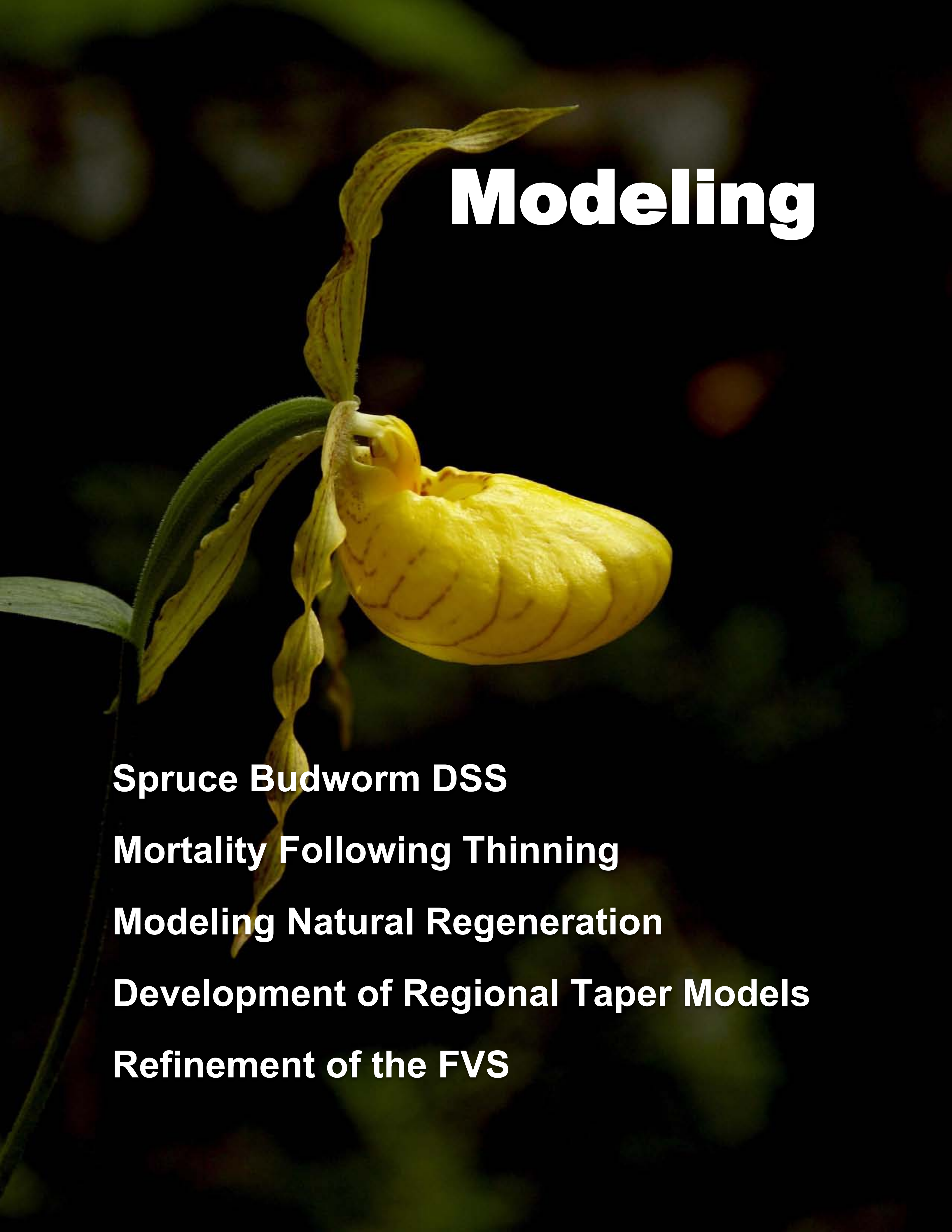
Table 2.11. Stand level least square estimates (mean ± SE) by measurement method for 16 partially harvested stands in northern and central Maine. Different letters among methods indicate statistically significant differences at p=0.05.

	10 BAF_e	20 BAF_e	80 BAF_e	Big BAF	Fixed	Line
Basal area *(m^2 ha^{-1})*	17.33[a] (1.48)	18.64[a] (1.50)	18.86[a] (1.48)	*	17.97[a] (1.48)	17.44[a] (1.48)
Basal area <12.7cm *(percent of total)*	20.15[ab] (2.52)	20.81[ab] (2.54)	15.82[a] (2.52)	*	20.94[b] (2.52)	20.39[ab] (2.52)
QMD *(cm)*	15.15[a] (0.86)	15.10[a] (0.88)	17.97[b] (0.86)	*	15.23[a] (0.86)	15.39[a] (0.86)
Basal area CV *(percent)*	57.21[a] (7.23)	63.47[a] (7.41)	115.67[b] (7.23)	*	48.25[a] (7.23)	59.61[a] (7.23)
Stems *(number ha^{-1})*	990.44[a] (96.37)	1071.22[a] (97.37)	943.20[a] (96.37)	*	1037.01[a] (96.37)	987.63[a] (96.37)
Stems <12.7 cm *(percent of total)*	64.81[a] (4.03)	65.93[a] (4.10)	49.15[b] (4.03)	*	65.35[a] (4.03)	64.10[a] (4.03)
Volume *(m^3 ha^{-1})*	112.41[ab] (10.69)	119.72[ab] (10.80)	125.97[b] (10.69)	125.73[b] (10.80)	86.32[c] (10.69)	98.83[ac] (10.69)
Weibull scale parameter	14.25[a] (0.90)	14.22[a] (0.92)	17.83[b] (0.90)	*	14.38[a] (0.90)	14.59[a] (0.90)
Weibull shape parameter	1.71[a] (0.12)	1.70[a] (0.12)	2.15[b] (0.12)	*	1.74[a] (0.12)	1.73[a] (0.12)

Note: * Values derived from 20 BAF_e



Modeling

Spruce Budworm DSS

Mortality Following Thinning

Modeling Natural Regeneration

Development of Regional Taper Models

Refinement of the FVS

SPRUCE BUDWORM DECISION SUPPORT AND STRATEGIES TO REDUCE IMPACTS IN MAINE: 2011 UPDATE

Authors:

Chris Hennigar, David MacLean and Thom Erdle

Spruce Budworms, photo: CFRU Archives

Background

Both theory and past experience suggest that another eastern spruce budworm (SBW) outbreak is due across the Northern forest region. Management of this threat by Maine landowners can be improved by (a) quantifying the potential magnitude of consequences of the next SBW outbreak on wood supplies, land values, and management plans; (b) implementing appropriate harvesting and silviculture in advance of that outbreak to mitigate consequences when it occurs; and (c) having in place a sound decision support system to allocate harvest and protection activities once the outbreak begins.

Under a CFRU pilot project in 2006-2008, the Spruce Budworm Decision Support System (SBW DSS), originally developed for New Brunswick (MacLean et al. 2001), was implemented on two small townships in Maine (Hennigar et al. 2011) to gauge compatibility with Maine forests and available datasets. This two year project extends that effort throughout Maine.

Objectives

1) Calibrate the SBW DSS for Maine forests:

    a) build SBW defoliation scenarios representative of levels observed in New Brunswick and Maine from available historical data;

    b) provide means to simulate SBW defoliation impacts on tree growth and survival in FVS with New Brunswick tree-level defoliation-damage relationships;

    c) project stand development for available Forest Inventory and Analysis (FIA) sample plots in Maine using Forest Vegetation Simulator (FVS; northeast variant, ver. 08-10-2011; Crookston and Dixon 2005; Dixon 2008) with and without SBW defoliation and foliage protection.

2) Produce from the Maine-calibrated SBW DSS, maps of stand merchantable volume impact by outbreak scenario for all participating CFRU members' forestlands.

3) Develop a non-spatial wood supply model for Maine using FIA inventory data, typical silviculture regimes, and FVS volume forecasts with and without outbreak impact estimates to quantify potential benefits of alternative silviculture portfolios for a wide range of outbreak start dates (2015, 2025, 2035, 2045) and severities.

Customizing the SBW DSS for Maine

Defoliation Patterns

We defined four plausible outbreak patterns in terms of severity and duration: two theoretically based (MacLean et al. 2001; moderate and severe), one based on SBW L_2 (second instar larvae) and egg mass counts recorded in New Brunswick since the 1950s, and one new pattern re-constructed from aerial defoliation sketch mapping, egg mass surveys, and vulnerability maps compiled from annual Maine Forest Service reports from 1972 to 1989 (figure 3-1). UNB undergraduate student Taisa Brown is analyzing these data for her Honors BScF Thesis, supervised by Dr. David MacLean. Methods to isolate spatiotemporal defoliation patterns follow those of Gray and MacKinnon (1996), using cluster analysis to group areas with similar temporal defoliation patterns, and a recent reanalysis of SBW defoliation scenarios in New Brunswick. This will be complete by March 2012.

Collectively, the four SBW outbreak patterns define a broad and plausible range of severity and duration of defoliation. Given that most trees sampled for monitoring SBW populations were balsam fir, outbreak scenarios primarily represent defoliation trends on fir. Based on Hennigar et al. (2008), we recalculated defoliation on white, red, and black spruce as 72%, 41%, and 28% of that on balsam fir. For cases where annual defoliation exceeded 95% (indication of high-extreme populations), spruce was assumed to be defoliated at similar levels to balsam fir.

Foliage Protection Scenarios

Foliage protection was applied if annual defoliation was projected to exceed 40%. The Régnière and Cooke (1998) *Bacillus thuringiensis* (Bt) efficacy model was used to

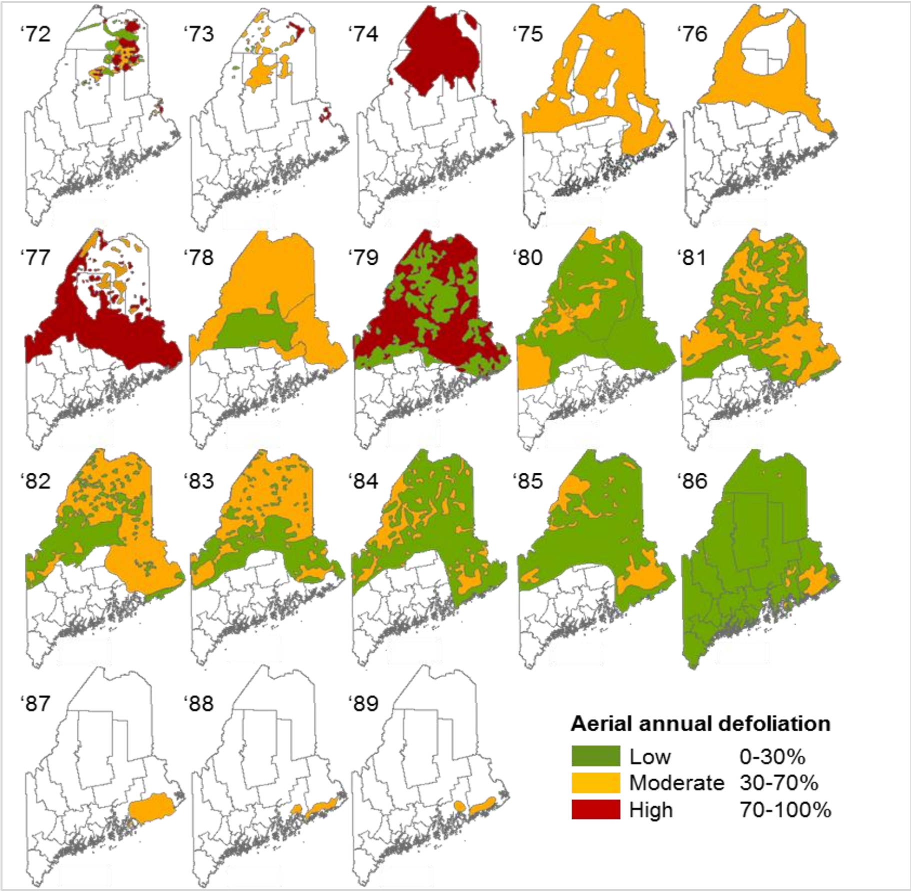


Figure 3-1. Aerial defoliation sketch maps of annual spruce budworm defoliation compiled from the Maine Forest Service for 1972-1989 (Maine Forest Service 1972-1989).

predict defoliation reduction resulting from protection as a function of SBW density, where SBW density was inferred from unprotected defoliation levels in their model. Because defoliation scenarios lack SBW density estimates, and because severely defoliated stands may have between one and two L_2/bud, direct application of the Bt efficacy model is problematic for years where defoliation is severe (>95%). For extremely high SBW densities (two L_2/bud), typical levels of Bt application may not be able to reduce defoliation below 100% (Régnière and Cooke 1998). To quantify foliage protection efficacy for a range of possible SBW density levels when annual defoliation is severe (>95%), we included two alternate scenarios: 1) a high density scenario – one L_2/bud and 2) an extreme density scenario – two L_2/bud.

Modelling SBW Stand Impacts in FVS

STAMAN, New Brunswick's current stand growth model, has been previously calibrated for predicting effects of SBW defoliation (a function of cumulative annual defoliation; MacLean et al. 2001) on spruce and balsam fir tree periodic (5-yr) growth loss and mortality from permanent sample plots measured annually from 1984-1993 throughout New Brunswick (MacLean 1996; Erdle and MacLean 1999). FVS has a comprehensive set of command keywords (Dixon 2002) to control the internal application of growth and mortality multipliers during runtime. Tree-level growth and survival multiplier commands used in STAMAN to simulate SBW defoliation effects were translated for use with FVS. The FVS command keywords and respective arguments listed in table 3-1 provide means to emulate the implementation of STAMAN multipliers in FVS.

A systematic model sensitivity analysis was performed to 1) test whether multipliers applied in FVS would result in the same relative level of stand impact as would be projected by STAMAN over the short term (5-10 years), and 2) better understand salient differences in long-term stand dynamics when modeling SBW impacts in FVS compared to STAMAN. For this sensitivity analysis, FIA spruce-fir (≥75% BA) sub-plots measured in 2006 and classed by FVS as ≥ moderate stocked and not seedling or sapling were selected (*n*=85). Periodic (5-year) survival and/or growth multipliers were applied for all spruce-fir trees for the first two growth periods (2006-2010, 2011-15). The FIXDG and FIXMORT keywords were used to modify growth and mortality in FVS, respectively (Table 3-1). Survival and growth multipliers were increased from 0 to 1 in increments of 0.2 resulting in 6,120 simulations (all combinations of multipliers [6^2] X 85 stand samples X two models). Stand BA (stems ≥4cm DBH) was calculated for all simulation iterations.

Table 3-1. FVS multiplier command keywords and arguments generated by the spruce budworm keyword file builder tool. See Van Dyck (2011) for a more thorough description of arguments for each command. TOPKILL is not currently used, however, it is included here to identify that top kill damage could be easily introduced in later versions if a SBW top kill model is calibrated.

Keyword*	Arguments						
FIXDG	Cycle or year	Species	Multiplier	Min DBH	Max DBH	--	--
FIXHTG	Cycle or year	Species	Multiplier	Min DBH	Max DBH	--	--
FIXMORT	Cycle or year	Species	Multiplier	Min DBH	Max DBH	Effective mortality†	Mortality distribution‡
TOPKILL	Cycle or year	Species	Min Height	Max Height	Probability	Proportion of total tree height killed	Standard deviation of the distribution of the proportion of total tree height killed

* Excerpts from Dixon (2002 p. 149): The FIXDG and FIXHTG keywords adjust diameter growth and height growth, respectively. FIXMORT adjusts mortality, while TOPKILL is used to kill a portion of the trees' crown. TOPKILL operates on randomly selected tree records that fall within the user-specified species or species group, and height class parameters. Top-killed trees will continue to grow in height, from the point of top-kill, in subsequent years.

† Option to control how the mortality multiplier is used in model calculations. See Van Dyck (2011) for a list of options. Option = 1 (add multiplier value to mortality rate) was identified as the closest approximation of STAMAN morality multiplier implementation.

‡ Option to control the distribution of the mortality caused by this command. Uniform distribution was assumed here (option argument = 0) to align with distribution assumptions in STAMAN.

Despite extreme differences in stand BA yield predicted by FVS and STAMAN (figure 3-2; multipliers = 1; base growth scenario), similar levels of total stand BA reduction from the base growth scenario were apparent between models for the first 10 years when survival and growth multipliers values were reduced from 1 (figure 3-2 and figure 3-3; multipliers = 0.8 - 0.2). Surprisingly, relative BA changes caused by survival multipliers after the first period (2006-2011) matched almost perfectly (1-2% difference; figure 3-3a). On the other hand, growth multipliers caused inconsistent levels of relative BA reduction when compared between models (figure 3-3b). In some cases (e.g., growth multiplier = 0.2) relative growth reductions were exactly the same for the first period, but in most cases, relative growth reduction in FVS was nearly 30-35% of levels reported by STAMAN (e.g., growth multiplier = 0.6). Beyond the first period, direct effect of multipliers on BA development is diluted and less comparable between models as a result of underlying differences in growth and mortality mechanics among STAMAN and FVS.

Overall, relative BA change between models, as multipliers were adjusted, remained very similar over the first 5 to 10 years at ≤2 and 4% difference, respectively (figure 3-4; 2011, 2016). However, due to underlying model regeneration response, self-thinning, growth rates, and other core model predictions, this congruency of relative BA difference measured between models was greatly reduced over time (figure 3-4; 2022-2036). By 2036, STAMAN predicted between 10% less and 18% more stand BA recovery compared to the base scenario than FVS for all combinations of multipliers (figure 3-4).

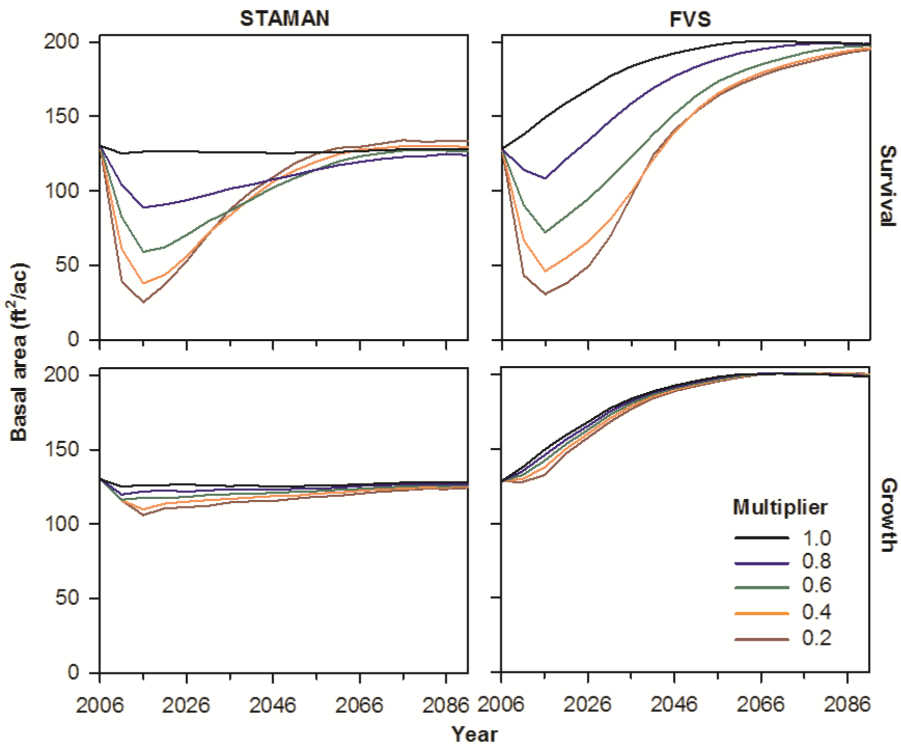


Figure 3-2. Survival and growth multiplier effects on mean stand basal area predictions in STAMAN and FVS for 85 spruce-fir inventory plots in Maine measured in 2006. The multiplier value was applied to the first two 5-yr periods (2006-2010, 2011-2015) and only to spruce-fir trees.

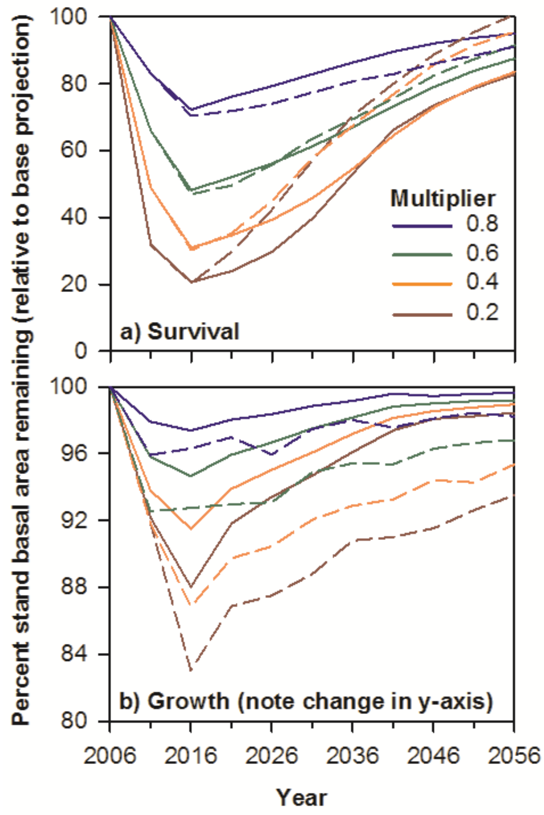


Figure 3-3. Average relative survival and growth multiplier effects on mean stand basal area predictions in FVS (solid line) and STAMAN (dotted line) for 85 spruce-fir inventory plots measured in 2006 in Maine. The multiplier value was applied to the first two 5-yr growth periods (2006-2010, 2011-2015) and only to spruce-fir trees.

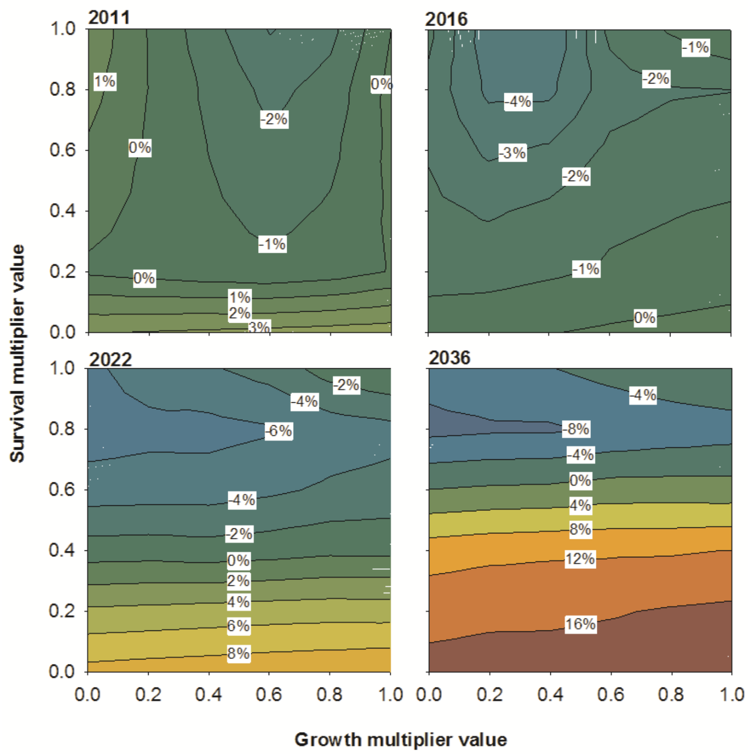


Figure 3-4. Difference (contours) between FVS and STAMAN percentage stand basal area change from base forecast for all combinations of growth and survival multipliers. A value of 10% indicates that 10% more basal area reduction was predicted in FVS compared to STAMAN.

It appears that if methods described here for modifying FVS growth and survival are used, multipliers calibrated by Erdle and MacLean (1999) for adjusting growth and survival in STAMAN to emulate SBW damage can be used 'as is' in FVS. Overall there was excellent agreement among models when predicting relative BA impacts caused by multipliers in the first 5 years regardless of multiplier values used. This is a good indication that multipliers are being used in similar ways in each model. This also suggests that a SBW DSS calibrated from STAMAN simulations may be applicable for predicting short-term impacts on stand yields generated from other models. On the other hand, over the long-term (10+ years), use of relative stand impact estimates from one stand growth model are probably invalid for use in predicting absolute impacts on stand yield predicted from other models. This latter point is dependent on the degree of underlying differences in growth and survival equations and calculations between models. Therefore defoliation-caused stand growth impacts for Maine can be based on NB-derived growth and survival multipliers, but should be calculated from FVS simulations.

SBW-FVS Keyword Builder for Simulating Defoliation Impacts

Between May and June 2011, a .NET application was developed to translate temporal scenarios of SBW annual defoliation by host tree species into commands and parameters to adjust tree survival and growth in the FVS model at runtime.

The first step in forecasting defoliated stand growth is to define probable or possible annual defoliation scenarios (figure 3-1). The application converts these user-defined estimates of annual percent defoliation by species (input text file) into 5-year mean periodic estimates by scenario.[2] Within the same routine, using periodic defoliation-damage relationships (Erdle and MacLean 1999), the application will write tree growth and survival multiplier values, using FVS keyword syntax (table 3-1), for each host species and simulation period to an FVS

[2] In the SBW DSS annual defoliation is weighted by the proportion of total foliage mass by age-class on a healthy balsam fir crown in order to calculate 'cumulative defoliation' described by MacLean et al. (2001). This calculation also weights the contribution of foliage remaining, on an annual basis, by the relative photosynthetic capacity of each age-class. This calculation is required in order to apply SBW defoliation-damage relationships developed by Erdle and MacLean (1999).

'keyword' text file. One text file, containing temporal FVS multiplier keywords by species, is written for each defoliation scenario specified in the annual defoliation scenario input file.

The application and documentation will be released to the CFRU in September 2012. It is currently being used for all SBW-FVS modeling in this project.

Application of the Maine SBW DSS on CFRU Members' Lands

Participating Landowners

In January 2010, all CFRU landowners were solicited to provide a number of key information sources (forest classification schemes, stand inventory in GIS format, and optionally their forest estate model) to apply the SBW DSS on each landbase. By May 2011, six of 32 landowners provided the requested GIS data in shapefile format with forest classification information and two provided their forest estate model. Data confidentiality agreements were signed between all parties before data was transferred. For those who did not contribute, reasons included confidentiality concerns, lack of inventory data, or lack of staff to compile inventory data. Those who did participate were relatively large landowners, so despite low participation numbers, a relatively large proportion (22% or 3.8 million acres; figure 3-5.) of Maine's forest land was assessed.

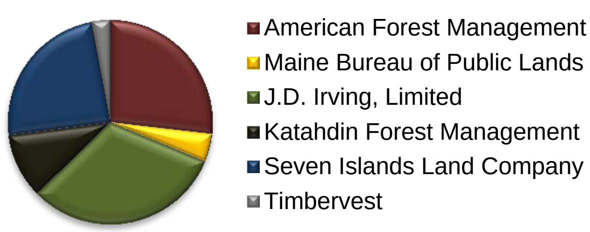


Figure 3-5. Total forest area (3.8 million acres) with potential SBW impacts estimated in Maine by participating landowner.

To forecast SBW volume impacts, spruce and fir species abundance of each stand in the inventory and projections of spruce-fir growth and volume yield over time are required. All GIS data received had information on abundance of spruce and fir by stand type either qualitatively in categorical stand type codes or explicitly quantified in separate species columns within the GIS. Only one landowner had spruce broken down by white, red, and black species. While, forest classification schemes differed among landowners, all incorporated some classification of stand species composition, size (dominant height or mean tree diameter measures), and stocking (crown closure, density, or stocking measures). Given the importance of spruce host species breakdown when quantifying vulnerability of stands to SBW, and because only two landowners were able to provide host volume projections (from forest estate models), we were required to make some rather large assumptions in order to quantify potential volume losses across landowners' stands in a consistent and repeatable way.

To estimate merchantable volume yields by species and stand type, plots from the Maine FIA-PSP database (2006-2010) were compiled and projected with FVS-NE.[3] Each FIA plot was projected as an independent stand sample (n = 3,140). A number of stand attributes such as % species composition, size class, stocking, crown closure, age, and height were considered when grouping plots into stand types.

Stand size class (sapling-seedling, pole, timber) and stocking class (poor, moderate, and fully to overstocked) were found to be the most important predictors of stand volume development.[4]

Stocking class was not an important factor when predicting volume for sapling-seedling size stands and was therefore removed for those cases. Plots were further categorized into 19 species classes (excluding non-stocked or non-commercial), with emphasis on host species resolution (table 3-2). This resulted in a total of 135 potential stand-type combinations.[5]

In most cases there was sufficient information in each GIS layer to match landowner stand types to our stand type classes and associated species-level volume predictions. In other cases,

[3] FIA-PSPs were downloaded using the FIA DataMart and converted to FVS format using the FIA FIA2FVS conversion tool. The FORUS Simulation Framework (FORUS 2011) was used to submit plot tree lists and simulation logic to FVS, and to summarize all stand-level performance measures over time from FVS tree list projections.

[4] See Appendix B in Dixon (2002) for quantitative descriptions of each size and stocking class and Arner et al. (2001) for stocking calculations.

[5] 19 stand classes * 2 size classes (pole, timber) * 3 stocking classes + 19 stand classes for seedling-sapling size class + non-stocked forestland + non-commercial forestland.

landowners were consulted regarding these matching assumptions; e.g., stand height or height class was used as a surrogate for stand size class, and crown closure or density class as a surrogate for stocking class.

SBW Volume Impact Mapping

Using the same set of FIA plots used to estimate current and future stand type volumes, plots were re-forecast in the FVS for each defoliation-protection scenario by submitting growth and mortality multipliers derived from the FVS-SBW Keyword File Builder application.[6] Mean absolute and relative volume change from non-defoliated projections for each species, stand type, future time period, and outbreak/protection scenario were compiled into a large SBW impact lookup table. Periodic dead volume resulting from SBW defoliation was also included in this table in order to estimate available salvageable volume.

This impact table was joined to each landowner's GIS layer by way of our generic forest classification scheme. On October 26th, 2011, participating landowners were provided with a DVD containing their GIS layer with the addition of absolute and relative merchantable volume impact estimates for each GIS polygon 20 years post-outbreak (the period of maximum impact) for moderate, severe, and historical outbreaks with and without foliage protection (figure 3-6).

The stand impact lookup table was also provided in this package to allow landowners to estimate volume reductions for other time periods. Because the stand impact table contains relative impacts, landowners are encouraged to more accurately calculate future volume reductions by multiplying these relative impacts against their own merchantable volume yield forecasts for each time period. If time of harvest is known, then impact estimates should be reported for that period. These additional steps should substantially improve the accuracy of these impact estimates because: 1) landowner volume estimates ought to be more precise, and 2) absolute impact estimates will explicitly consider the timing of harvest operations.

[6] The Maine historic pattern will be completed by March 2012 and run through this process. All outbreak scenarios were assumed to begin in 2010.

Table 3-2. Species composition classification rules used to group Maine Forest Inventory and Analysis 2006-2010 plots with productive forestland (n= 3,140). Plots having <50% commercial species were classed as non-commercial (n=8), and those having <4.35ft²/ac for stems >1.6" DBH, or <10% stocking were classed as non-stocked (n=42). Classification rules were applied in the order they appear.

Stand species composition class		Plot	Classification rules	Top five species by
Code	Name*	count	(basal area based)*	% net merchantable volume (in brackets)*
F	Balsam fir	87	≥70% balsam fir	BF(78), RBS(8), WS(3), Poplar(3), RM(2)
S	Spruce	147	≥70% spruce spp.	RBS(76), WS(10), BF(4), WP(3), OSW(2)
C	Cedar	71	≥70% cedar spp.	Cedar (79), RBS(7), BF(4), OSW(2), RM(2)
P	White pine	52	≥70% white pine	WP(89), RM(3), Oak(2), Poplar(1), WS(1)
H	Eastern hemlock	22	≥70% eastern hemlock	EH(76), RM(7), OHW(4), RBS(4), WP(2)
HQHW†	High quality HW	177	≥70% high quality HW	SM(58), YB(17), Oak(8), OQHW(4), OHW(3)
LQHW†	Low quality HW	250	≥70% low quality HW	RM(35), Poplar(21), OHW(16), PB(11), BF(4)
FS	Fir-spruce mix	205	≥70% SP or BF	RBS(38), BF(35), WS(8), Cedar(4), PB(4)
FSW	Fir SW mix	118	≥40% BF & ≥ 60% SW	BF(45), Cedar(10), RM(9), WP(8), Poplar(6)
SSW	Spruce SW mix	121	≥40% SP & ≥ 60% SW	RBS(50), Cedar(11), WP(10), RM(6), BF(6)
FHW	Fir HW mix	47	≥40% BF & <60% SW	BF(43), RM(17), Poplar(13), PB(10), YB(4)
SHW	Spruce HW mix	49	≥40% SP & <60% SW	RBS(46), RM(15), YB(11), PB(7), BF(5)
FSSW	Fir-spruce SW mix	171	≥40% SP or BF & ≥ 60% SW	RBS(24), BF(23), Cedar(15), WP(7), RM(7)
FSHW	Fir-spruce HW mix	97	≥40% SP or BF & <60% SW	BF(21), RBS(19), RM(14), YB(12), Poplar(11)
SW	Softwood	277	≥75% SW	Cedar(25), WP(22), EH(14), RBS(12), OSW(6)
HLQHW†	High-low quality HW	189	≥75% HW & low ≤ high quality HW	SM(25), YB(15), Oak(14), RM(14), OHW(9)
LHQHW†	Low-high quality HW	179	≥75% HW & low > high quality HW	RM(29), OHW(12), YB(10), SM(10), Oak(8)
HWMX	Hardwood mix	474	HW ≥ SW	RM(19), YB(9), WP(9), EH(8), BF(8)
SWMX	Softwood mix	357	HW < SW	WP(23), EH(17), RM(15), Cedar(8), BF(6)

* BF – balsam fir, RBS – red or black spruce, WS – white spruce, WP – white pine, EH – eastern hemlock, YB – yellow birch, SM – sugar maple, RM – red maple, PB – paper birch, OQHW – other high quality hardwood (ash spp., walnut spp., black cherry, black maple), OHW – other commercial hardwood, SW – softwood, HW – hardwood.

† High quality hardwoods include: SM, YB, oak spp., ash spp., walnut spp., black cherry, and black maple. Low quality hardwoods include all other commercial hardwoods.

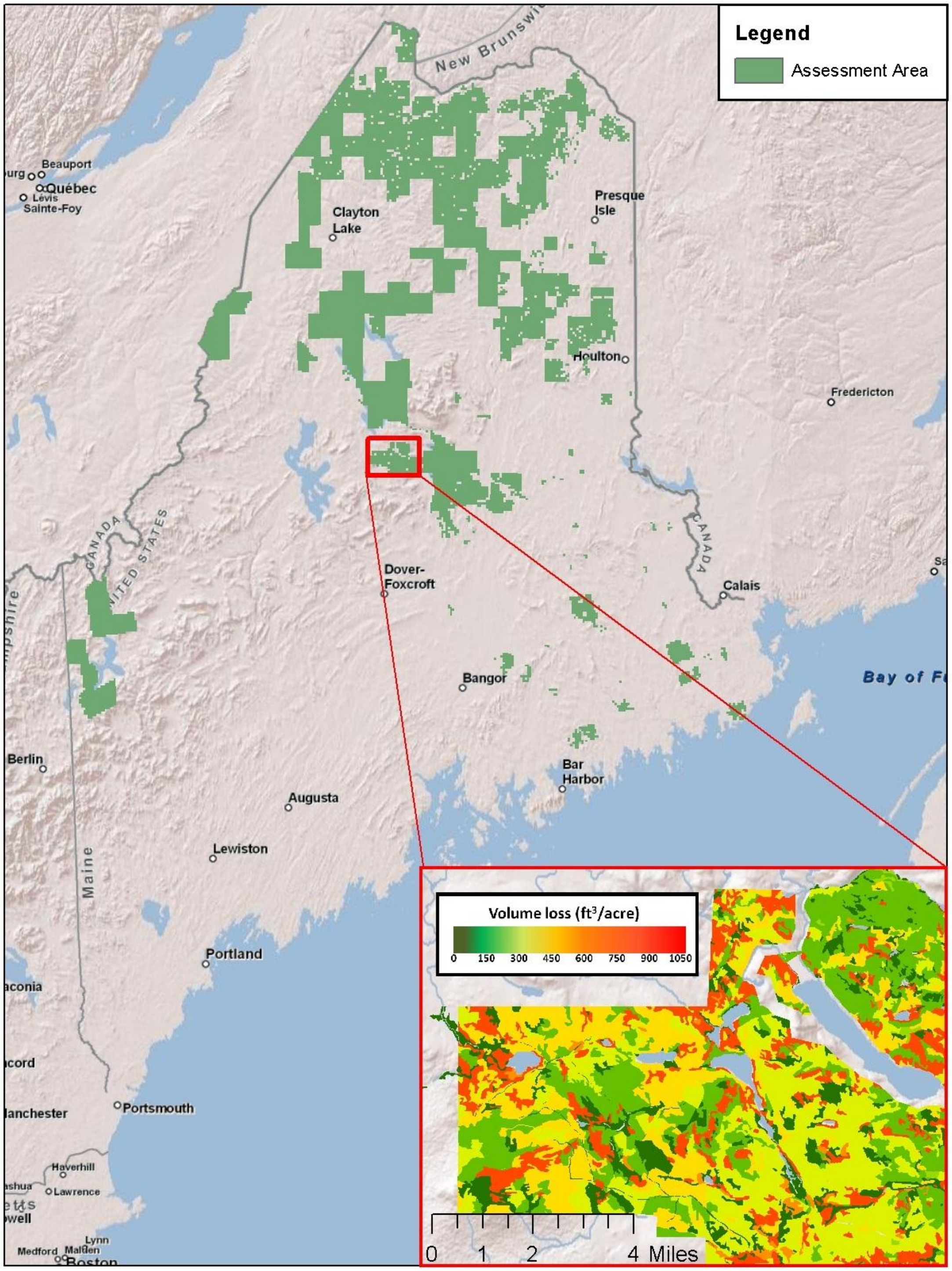


Figure 3-6. Landowner locations (3.8 million acres) where spruce budworm impact assessments occurred. Zoomed inset shows projected spruce-fir merchantable volume reduction 20 years post severe outbreak (initiation in 2010) for a portion of the Maine Bureau of Public Lands' forest.

State-wide Impact and Management Analysis

A state-wide wood supply model is being developed using the Remsoft Spatial Planning System to address three higher-level SBW management questions:

1. How much volume is at risk under various outbreak and protection scenarios?
2. What can be done in advance of the outbreak to mitigate impacts?
3. What can be done during the outbreak to mitigate impacts?

Model progress

During the summer of 2011, we surveyed participating landowners regarding silviculture regimes implemented on their lands. For those who responded, most conduct some form of shelterwood, clearcut, and patch cut harvesting; not surprising given that these treatments comprise roughly 30%, 5%, and 65% of all harvest operations, respectively, in Maine (USDA 2005). However, specifics on exact operability constraints, target removals, timing and sequence of harvest entries, eligible stand types, and species removal preference varied considerably between landowners. While some conduct commercial and pre-commercial thinning, herbicide, and planting, these treatments are generally uncommon (<6% combined) from a state-wide perspective (USDA 2005).

Given that the aim of this modeling effort is to better understand potential forest-level SBW impacts and mitigation opportunities, we limited silviculture regimes to the most common: clearcut, shelterwood, and patch cut (table 3-3) In addition, two thinning treatments that we termed 'timber-improvement' and 'SBW resistance' were added to explore at the stand and forest level what can be done in advance of the outbreak to mitigate impacts. These two treatments (table 3-3), which specifically target balsam fir and white spruce removal, are based upon those currently being implemented at Austin Pond in a separate CFRU field study led by Dr. Brian Roth.

Stands were required to yield ≥1500 ft^3/ac and ≥100 ft^2/ac to be considered for harvest; however, other pre- and post-treatment criteria such as residual basal area and/or species composition were also enforced for patch cut and other thinning treatments (table 3-3). In the case of shelterwood (SHEL) and timber improvement cut (TIC), ≥50% of stand basal area must be composed of 'preferred species'; i.e., species that will add future value to the stand if retained. Preferred species include: red spruce, white pine, white cedar, eastern hemlock, yellow birch, sugar maple, oak, ash spp., walnut spp., black cherry, and black maple. Percent of fully stocked plots by pole and timber size class having ≥50% preferred species basal area is shown by stand type species class in table 3-4. The SBW resistance cut (SBWR) was designed to promote non-susceptible species over susceptible species (fir and spruce). It can also be thought of as a pre-emptive salvage with aim toward increasing future stand value of the residual non-susceptible component. SBWR was therefore restricted to stands with appreciable amounts of pre-treatment susceptible (≥40 ft^2/ac) and non-susceptible (≥40 ft^2/ac) basal area. At the stand-type level, candidates for these three thinning treatments (SHEL, TIC, SBWR) were restricted to species-types with ≥50% of plots meeting all operability criteria (table 3-3) in a fully stocked timber size stand condition.[7]

Forest landscape classification and area inventory was based on Maine's current timberland area (17.15 million acres) allocated on a weighted stockable area basis to the 135 stand types described above and by FIA eco-sub-region and FIA site class. Eco-sub-region will be used to spatially limit SBW outbreak extents to areas having ≤ one year of historical defoliation (figure 3-1). Stand type yields reported in the model include potential net merchantable volume (veneer log, saw log, stud wood, and pulp log) and tonnes of available oven-dry biomass (logs, tops, and branches). These areas and associated mean stand type yields have been compiled into the base wood-supply model. Work is now underway to develop stand-type succession rules and yield responses following

[7] A candidate in this context refers to a stand type that is considered by the wood supply model for treatment. The candidate must still meet all operability constraints at the stand-type level in Table 3-3 before it can be treated, which vary temporally as a function of stand-type yields. Because up to 49.9% of stands within the stand type may be inoperable, we implicitly assume that <50% of area within the stand type will be treated over time. This assumption will be re-evaluated if shown to be false once forest-level simulations commence.

each treatment, which is expected to be complete by mid-February.

Once the base wood-supply model is fully compiled, time-dependent volume impact multipliers by stand type, derived from SBW outbreak and protection simulations in FVS will be introduced into the wood-supply model following methods described by Hennigar et al. (2007). Between March and July 2012, this model will be used to help identify: 1) what silviculture regimes and schedules consistently reduce SBW outbreak impact on long-term harvest given uncertain timing of outbreak initiation and defoliation severity; and 2) how much harvest impact resulting from SBW can be avoided by implementing various levels of salvage and foliage protection?

Spruce Budworm – *Photo courtesy of J.D. Lafontaine*

Table 3-3. Treatment regimes and respective operability constraints used for stand-level treatment modeling in FVS and forest-level treatment scheduling in the Maine wood-supply model.

Silviculture regime	**Basal area of preferred species (%)***	**Pre-entry stand yield†**	**Basal area removal (%)**	**Residual basal area target (ft^2/ac)**	**Return interval (yrs)**	**Residual species preference‡**
Clearcut	-	≥1500 ft^3/ac; ≥100 ft^2/ac	100	-	-	-
Partial cut	-	≥1500 ft^3/ac; ≥100 ft^2/ac	≥30	≥70	≥30	-
Shelterwood (SHEL)						
i) 1st entry thin from below	≥50	≥1500 ft^3/ac; ≥100 ft^2/ac	>40	>40	≥10	WP>RS>BS>WS>YB>SM>RO>EC>EH>BF>WA>RM>PB>QA
ii) 2nd entry thin from above		-	100% of overstory	-	10-yrs post 1st entry	-
Timber improvement and spruce budworm resistance inspired treatments						
Timber improvement cut (TIC) *individual tree selection method*	≥50	≥70 ft^2/ac of hardwood; ≥1500 ft^3/ac; ≥100 ft^2/ac	≥30	≥70	≥30	YB>SM>WP>WC>RS>BS>RO>WA>RM>PB>QA>WS>BF
SBW resistance cut (SBWR) *remove/salvage fir and spruce*	-	≥40 ft^2/ac of spruce or fir ≥100 ft^2/ac	33-66	≥40 excluding white spruce and fir	≥30	WP>YB>SM>RO>WC>EH>BS>RS>WA>RM>PB>QA>WS>BF

* Preferred tree species include: RS, WP, WC, EH, YB, SM, RO, ash spp., walnut spp., black cherry, and black maple.
† Volumes are expressed as net merchantable.
‡ BF – balsam fir, RS – red spruce, WS – white spruce, BS – black spruce, WP – white pine, WC – eastern white cedar, EH – eastern hemlock, YB – yellow birch, SM – sugar maple, RO – red oak, WA – white ash, RM – red maple, PB – paper birch, QA – quaking aspen.

***Table 3-4.** Percentage of full and over stocked plots by pole and timber size class and by species composition class having ≥50% basal area of preferred species (Table 3-3 footnotes), and percentage of respective plots operable for shelterwood (SHEL), timber improvement cut (TIC), and spruce budworm resistance cut (SBWR) inspired thinning treatments according to operability limits in Table 3-3. Percentages are weighted by plot stockable area. Cells shaded light grey indicate values ≥50%.*

	Percentage of full and over stocked plots by size class							
	Pole size class				Timber size class			
		Treatment regime				Treatment regime		
Species class (Table 2)	Preferred species*	SHEL	TIC	SBWR	Preferred species	SHEL	TIC	SBWR
F	0	0	0	25	-	-	-	-
S	63	63	0	90	80	69	0	75
C	100	93	0	0	100	96	0	38
P	100	100	0	0	100	94	0	0
H	100	80	0	0	100	81	0	0
HQHW	100	32	28	0	100	66	66	2
LQHW	0	0	0	3	0	0	0	0
FS	33	26	0	73	50	50	0	93
FSW	0	0	0	59	9	9	0	85
SSW	40	35	0	86	89	89	0	100
FHW	0	0	0	76	0	0	0	100
SHW	58	54	0	82	74	65	0	77
FSSW	30	24	0	74	48	45	0	90
FSHW	12	12	0	77	41	35	6	89
SW	80	69	0	36	94	84	0	41
HLQHW	76	34	33	0	87	62	58	0
LHQHW	8	5	5	5	11	0	0	0
HWMX	35	24	12	17	66	53	32	13
SWMX	53	40	2	30	85	75	9	10

* See Appendix B in Dixon (2002) for quantitative descriptions of each size and stocking class and Arner et al. (2001) for stocking calculations.
† Percentage of plots having >50 basal area of preferred species (see table 3 footnotes).

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INFLUENCE OF COMMERCIAL THINNING ON STAND & TREE-LEVEL MORTALITY PATTERNS OF BALSAM FIR AND RED SPRUCE FORESTS IN MAINE WITH & WITHOUT PRECOMMERCIAL THINNING

Authors:

Joseph Pekol, Aaron Weiskittel, Robert Seymour and Robert Wagner

Introduction

The Commercial Thinning Research Network (CTRN) has been a longstanding project developed by researchers and shareholders in the Cooperative Forestry Research Unit. The purpose of the CTRN is to further the knowledge on how commercial thinning affects the stand development of balsam fir and red spruce stands. A recent M.S. thesis by Joseph Pekol utilized the CTRN database to assess mortality and damage patterns in the two CTRN experiments.

Non-catastrophic mortality is due to the interaction between individual trees and is a key driver of stand dynamics. Competition for resources (light, nutrients, and growing space) and site quality (moist/dry or rich/poor nutrient availability) are considered two of the major factors controlling regular mortality (Franklin et al. 1987; Peet 1987). Silvicultural practices such as pre-commercial (PCT) and commercial thinning (CT) can be applied to decrease the probability of mortality and increase the growth of select trees.

One method of mortality prediction within silvicultural confines is through the use of density management diagrams. In Maine, the stand density management diagram (SDMD) of Wilson et al. (1999) has been used to develop PCT and CT regimes for red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*) dominated stands. Mortality can be inferred through the diagram as a stand reaches its maximum density. However, mortality patterns due to the method, timing or relative density removal cannot be predicted with the diagram and have been largely unknown.

Methods

This study utilized the two experiments (PCT and NoPCT) from the CTRN to examine the mortality patterns of spruce – fir forests in Maine. At the stand level, analysis of variance (ANOVA) on 10 – year cumulative mortality rates (as a percentage of basal area lost) was conducted for each experiment. Data for the 10 – year treatment, which had not been applied at the time of this study, was considered a control where appropriate.

At the individual tree level, a generalized linear mixed model (GLMM) was developed predict the annual probability of mortality. This method has been used successfully (Yao et al. 2001) with size, site, and competition indices as explanatory variables. The GLMM model takes the form (equation 3-1):

Equation 3-1: $logit(p_{ij}) = \alpha + \beta x_{ij} + a_{ij}$

where p_{ij} = the probability a tree will die at plot j within site i, $\alpha + \beta x_{ij}$ = a linear function of estimators and metrics, and $a_{ij} \sim N(0,\sigma^2)$ describes the random effects of sites i and plots j.

This approach simplifies the model in two ways: (1) by removing the need to incorporate site and plot as fixed effects and (2) ensuring the random effect of site and plot within site are properly partitioned, allowing for a better assessment of correlation between variables.

Results and discussion

PCT

Mean annual mortality for the PCT sites never exceeded 5%, with exceptions figure 3-7 shows the 10-year cumulative mortality trends by BA for the PCT sites. Lake Macwahoc (LM) and Lazy Tom (LT) were the only two PCT sites to show appreciable mortality. Plotting these sites on the SDMD (figure 3-8) reveals clean developmental patterns, regardless of treatment.

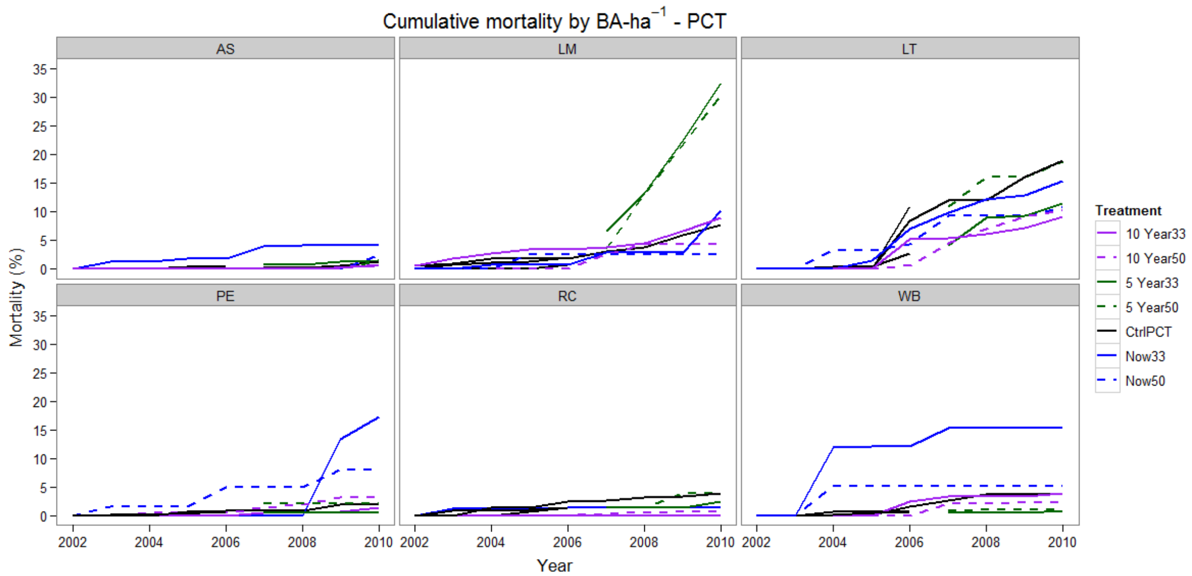

Figure 3-7. Cumulative mortality (calculated as a ratio between dead basal area and live basal area and expressed as a %) through time for sites receiving PCT.

The overall mean 10-year cumulative mortality rate was 6.7 ± 7.8 (mean ± SD). Table 3-5 shows the 10-year mortality rate statistics for each treatment. The Least Squares (LS) mean estimates for cumulative 10 – year mortality for the PCT sites ranged from 4.5 ± 4.8 on the ctrlPCT sites to 10.6 ± 6.6 on the Now33 sites (figure 3-9). ANOVA revealed no significant differences between treatment or removal factors. However, the ctrlPCT showed the least amount of variability (SD = 4.8), while the 5-Year treatments showed the most (SD = 12.6 and 12.1 for the 33 and 50% removals, respectively).

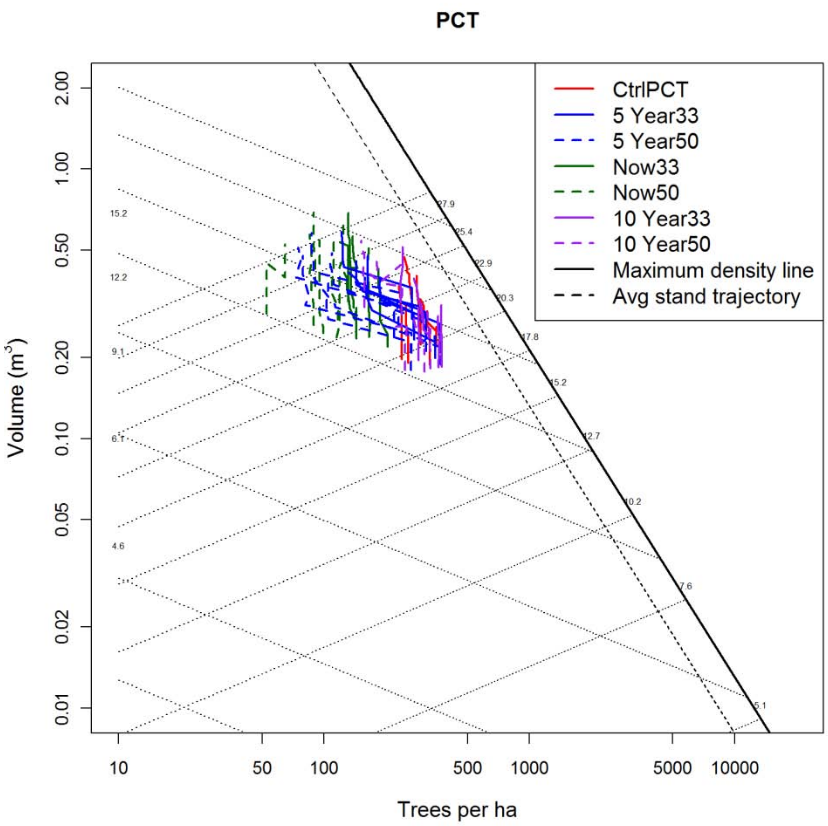

Figure 3-8. PCT treatments plotted on a stand density management diagram for northeastern red spruce and balsam fir forests. The maximum density line (Wilson et al. 1999) is represented by the thick black line, the dashed line represents the average stand trajectory at relative density (RD) of 0.67, and the dominant height (m) and QMD (cm) relationship lines are represented by the thin black lines.

Table 3-5. 10-year mortality rate (calculated as a ratio between dead basal area and live basal area and expressed as a %) statistics for PCT experiment.

	PCT			
Treatment	Mean	Min	Max	SD
5 Year33	8.2	0.4	32.4	12.6
5 Year50	9.6	1.0	30.4	12.2
CtrlPCT	4.5	0.0	18.8	4.8
Now33	10.6	1.3	17.2	6.6
Now50	4.7	0.0	10.6	4.0
Overall	6.7	0.0	32.4	7.8

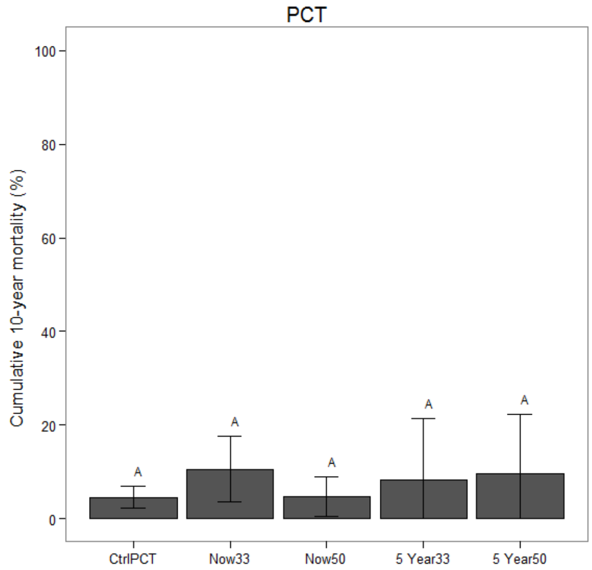

Figure 3-9. Least squares mean estimates of cumulative 10-year mortality rates (calculated as a ratio between dead basal area and live basal area and expressed as a % lost) for PCT experiment with standard error bars.

The timing or RD reduction of a CT treatment on PCT sites did not significantly alter the cumulative mortality. Give that the earliest CT application was about 15 years since PCT, it is likely that this was enough time to create tree with sufficient HDR (Weiskittel et al. 2009) to sustain stands after a CT treatment between 15 and 20 years following a PCT. Furthermore, the ctrlPCT sites have only just reached the average stand trajectory line for spruce-fir stands (Wilson et al. 1999), implying the 5-year CT was early enough to reset the trajectory of these stands without losses due to natural thinning.

The 10-year treatment will reset the stand trajectory, but potentially at a loss of current timber and future volume as the stand begins to self thin. Waiting any longer to CT after a PCT may result in loss of timber; however, more time is needed to adequately observe the effects of the 10-year treatment as well as the continued development of the ctrlPCT plots.

NoPCT

The NoPCT sites generally experienced higher annual mortality rates and more variability (figure 3-10). The overall mean 10 – year cumulative mortality rate for the NoPCT sites was 32.3 ± 25.9. The dominant and crown thinnings received the highest cumulative mortality rates (28.5 – 94.3% and 11.4 – 72.1%, respectively). The Low50 treatment had comparable mortality rates (16.8 ± 11.5) to the ctrlNoPCT (16.8 ± 9.6). Only the Low33 treatment resulted in less than 10% cumulative mortality (7.0 ± 2.0) within the NoPCT experiment (table 3-6). Plotting these sites on the SDMD (figure 3-11) shows sporadic development patterns within the crown and dominant treatments. The low treatments developed relatively evenly and the untreated controls fall within the average stand trajectory.

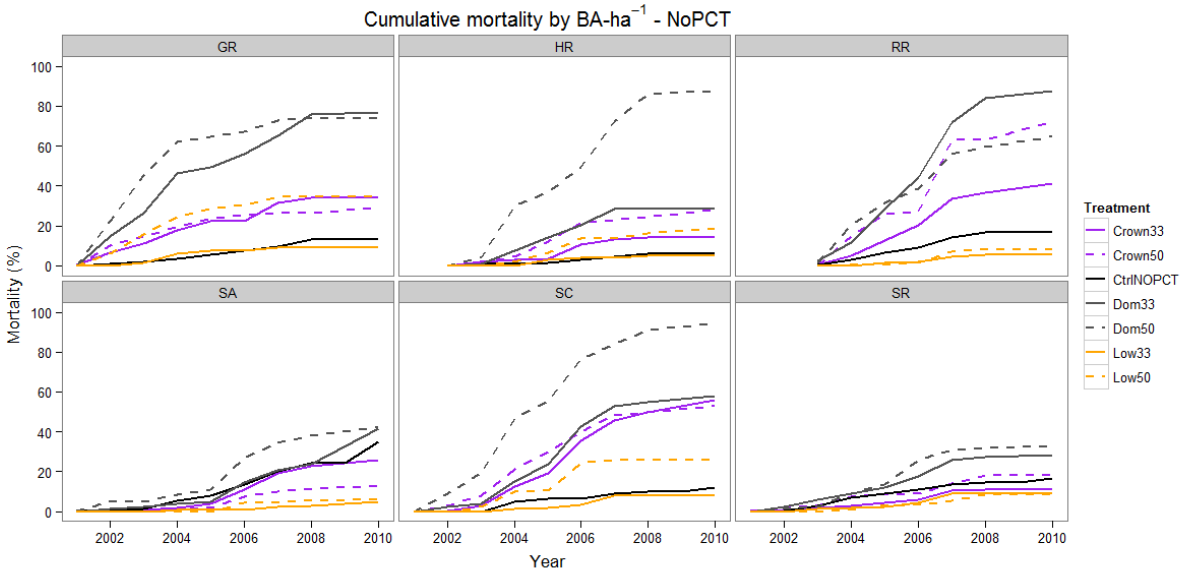

Figure 3-10. Cumulative mortality (calculated as a ratio between dead basal area and live basal area and expressed as a %) through time for sites not receiving PCT.

Table 3-6. 10-year mortality rate (calculated as a ratio between dead basal area and live basal area and expressed as a %) statistics for NoPCT experiment

Treatment	Mean	Min	Max	SD
Crown33	30.6	11.4	55.9	16.9
Crown50	35.4	12.9	72.1	22.6
CtrlNoPCT	16.8	6.6	34.9	9.6
Dom33	53.6	28.5	87.5	24.9
Dom50	65.8	32.5	94.3	24.6
Low33	7.0	5.1	9.2	2.0
Low50	16.8	5.9	34.7	11.5
Overall	32.3	5.1	94.3	25.9

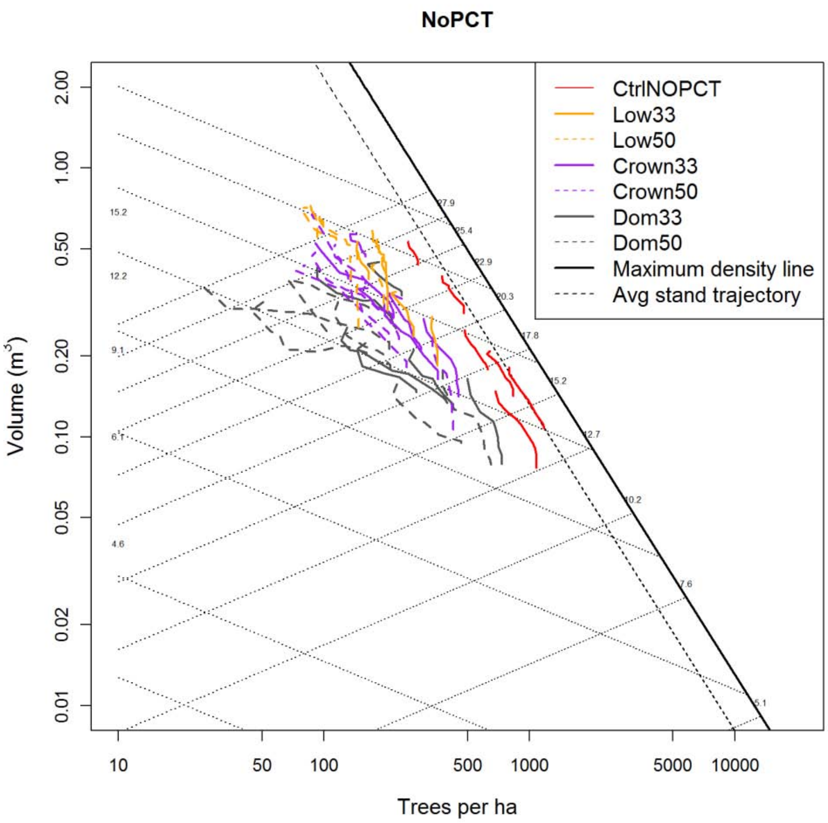

Figure 3-11. NoPCT treatments plotted on a stand density management diagram for northeastern red spruce and balsam fir forests. The maximum density line (Wilson et al. 1999) is represented by the thick black line, the dashed line represents the average stand trajectory at relative density (RD) of 0.67, and the dominant height (m) and QMD (cm) relationship lines are represented by the thin black lines.

Results of ANOVA on the NoPCT experiment revealed several significant differences between the LS mean estimates of 10-year mortality rates (figure 3-12). The dominant CT method causes significantly higher mortality rates than the low CT ($p < 0.0001$). The crown method did not differ significantly from either the ctrlNoPCT, the low, nor dominant treatments. Likewise, the low CT did not differ significantly from the ctrlNoPCT. No removal factors were significantly different for a given treatment.

It is not surprising that the dominant thinnings had the highest mortality rates given that smaller, less vigorous trees remained after thinning. Likewise, crown and low thinnings, which retained more trees in the dominant and co-dominant classes, saw less mortality. Our results imply that when applying CT to dense, mature spruce-fir stands, mortality rates will be higher if dominant and/or co-dominant trees are not retained.

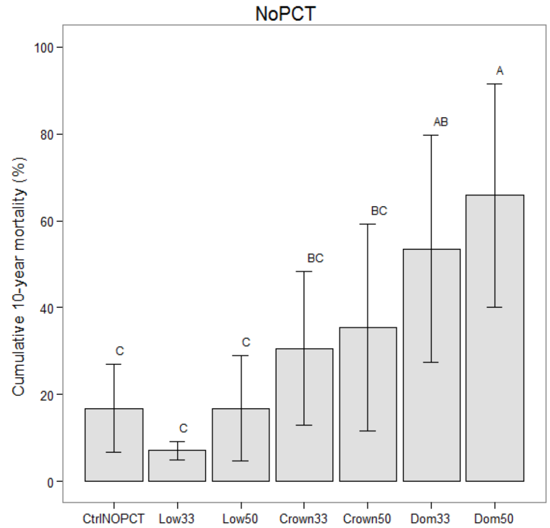

Figure 3-12. Least squares mean estimates of cumulative 10-year mortality rates (calculated as a ratio between dead basal area and live basal area and expressed as a % lost) for NoPCT experiment with standard error bars.

Model application

The final model for predicting the annual rate of mortality for individual trees took the following form:

Equation 3-2: $\text{logit}(p_{ij}) = \alpha + \beta_i \cdot \text{DBH}_{ij} + \beta_i \cdot (\text{HDR})_{ij} + \beta_i \cdot \text{CR}_{ij} + \beta_i \cdot \text{d/D}_{ij} + \beta_i \cdot \text{DBH}_{ij}^2 + \beta_i \cdot \text{BA}_{ij} + \beta_i \cdot \text{Spp}_{ij} + \beta_i \cdot \text{actrm}_{ij} + \beta_i \cdot \text{Trt}_{ij} + \beta_i \cdot \text{YrSinceTrt}_{ij} + \beta_i \cdot \text{DBH}_{ij}{*}\text{Spp}_{ij} + \beta_i \cdot \text{Spp}_{ij}{*}(\text{HDR})_{ij} + \beta_i \cdot \text{Spp}_{ij}{*}\text{CR}_{ij} + \beta_i \cdot \text{Spp}_{ij}{*}\text{Trt}_{ij} + \beta_i \cdot \text{Spp}_{ij}{*}\text{YrSinceTrt}_{ij} + a_{ij} + \varepsilon_{ij}$

where * indicates an interaction, (1 – p) is the probability of mortality occurring assuming a binomial distribution, and all other variables are described in table 3-7.

The final model had high discrimination as the area under the curve (AUC) was 0.86 with random effects and 0.83 without. The model had a chi-square (X^2) value of 8.8, minimized at a probability cut point of 0.74 (Hein and Weiskittel 2010). Parameter statistics can be seen in table 3-8.

Table 3-7. Independent variables used to described tree size, competition, and treatments.

Variable	Description
DBH (cm)	Diameter at breast height
DBH^2	Quadratic transformation of DBH
HDR	Height-diameter ratio (cm/cm)
CR	Live crown ratio
BA	Tree basal area
d/D	Mean DBH pre treatment over mean DBH post treatment
SPP	Species indicator
Trt	Treatment factor
Actrm	Actual percent BA removal
YrSinceTrt	Year since treatment was applied
SiteID	Random effect for site location
PlotID	Random effect for plot location

Table 3-8. Parameter estimates for tree-level mortality occurrence (Eq.3-2).

Effect	Estimate	StdError	DF	p_value	
Intercept	8.0145	1.5031	80	<.0001	*
DBHcm	0.3309	0.02456	89035	<.0001	*
BF	0.5885	0.8739	89035	0.5007	
DBHcm*BF	-0.09729	0.01783	89035	<.0001	*
actRM	-4.5685	1.1505	89035	<.0001	*
HDR	-0.01212	0.002533	89035	<.0001	*
HDR*BF	-0.00129	0.003302	89035	0.6969	
CR	-1.5998	0.5489	89035	0.0036	*
CR*BF	0.8774	0.6527	89035	0.1789	
dD	-3.3727	1.3347	89035	0.0115	*
DBHsq	-0.00475	0.000805	89035	<.0001	*
BA	0.01428	0.007269	89035	0.0495	*
5 Yrs	-0.02911	0.9837	89035	0.9764	
Crown	-1.4006	0.7086	89035	0.0481	*
CtrlNOPCT	-3.0349	0.9044	89035	0.0008	*
CtrlPCT	-0.8734	0.86	89035	0.3098	
Dom	-1.2642	0.7224	89035	0.0801	
Low	-2.0743	0.7696	89035	0.007	*
BF*5Yrs	-1.0822	0.9643	89035	0.2617	
BF*Crown	-0.219	0.6515	89035	0.7368	
BF*ctrlNOPCT	-0.3544	0.6505	89035	0.5858	
BF*ctrlPCT	-0.3289	0.6612	89035	0.6189	
BF*Dom	-0.3853	0.6449	89035	0.5503	
BF*Low	-0.06935	0.6876	89035	0.9197	
Year0	3.1466	0.7028	89035	<.0001	*
Year1	0.8905	0.2189	89035	<.0001	*
Year2	0.1003	0.2099	89035	0.6327	
Year3	0.0223	0.2122	89035	0.9163	
Year4	-0.2864	0.2119	89035	0.1765	
Year5	-0.5346	0.2105	89035	0.0111	*
Year6	0.1547	0.2231	89035	0.4881	
Year7	0.194	0.2352	89035	0.4094	
Year8	0.6791	0.2666	89035	0.0109	*
Year9	0.519	0.2914	89035	0.0749	*
BF*Year0	-0.6085	0.7529	89035	0.419	
BF*Year1	0.3305	0.3418	89035	0.3336	
BF*Year2	0.1633	0.326	89035	0.6165	
BF*Year3	-0.08167	0.3264	89035	0.8024	
BF*Year4	0.1304	0.3273	89035	0.6903	
BF*Year5	-0.3881	0.3228	89035	0.2293	
BF*Year6	-0.5569	0.3353	89035	0.0967	
BF*Year7	-0.2743	0.355	89035	0.4396	
BF*Year8	-0.4528	0.3817	89035	0.2355	
BF*Year9	-1.2939	0.398	89035	0.0012	*

* indicates estimate significance at alpha = 0.05; references levels are Spp:RS, Trt:Now, and YrSinceTrt:10

The species:treatment interaction exhibited several statistically significant differences amongst species and treatment (figure 3-13). Balsam fir (BF) exhibited the highest annual probability of mortality across the treatments. Amongst the NoPCT treatments, BF mortality was significantly higher for all treatments and the controls. Within the NoPCT sites, this may be due to the low percent composition of BF and the fact that the stands are of an age correspondent to the age when balsam fir typically reaches senescence.

Statistically different LS mean estimates were also observed amongst the species:YrSinceTrt interactions (figure 3-14). BF again exhibited the highest annual probability of mortality, with a significant increase at 5 YrSinceTrt. Red spruce (RS) also saw a significant increase at 5 YrSinceTrt, although to a significantly less extent than BF. Annual probability of mortality began to decrease for RS after 5 YrSinceTrt, but not for BF.

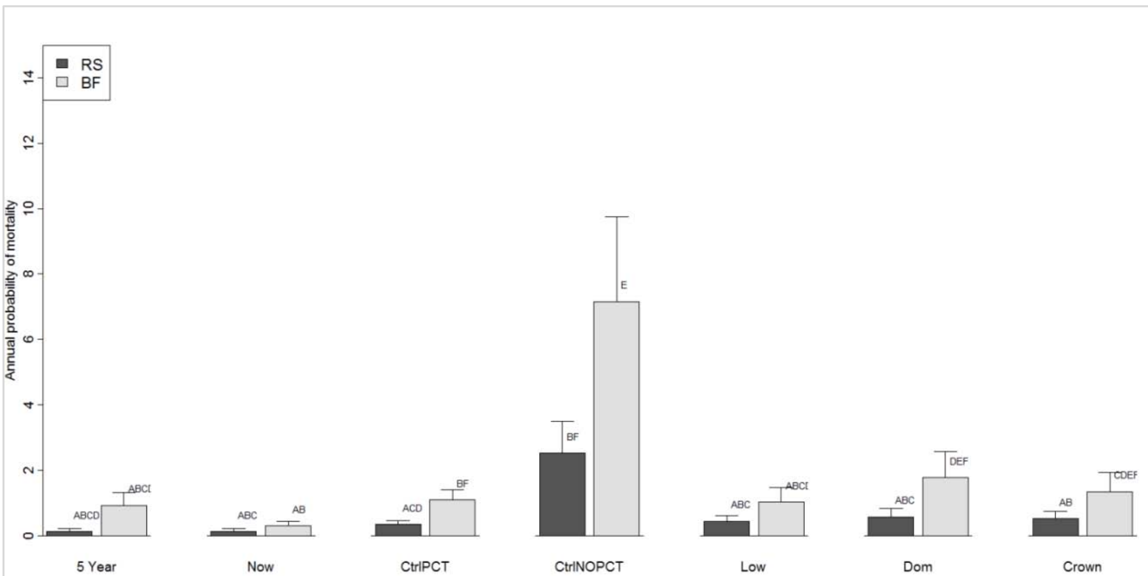

Figure 3-13. Least squares mean estimates of annual probability of mortality at the individual tree - level due to treatment by species with standard error bar.

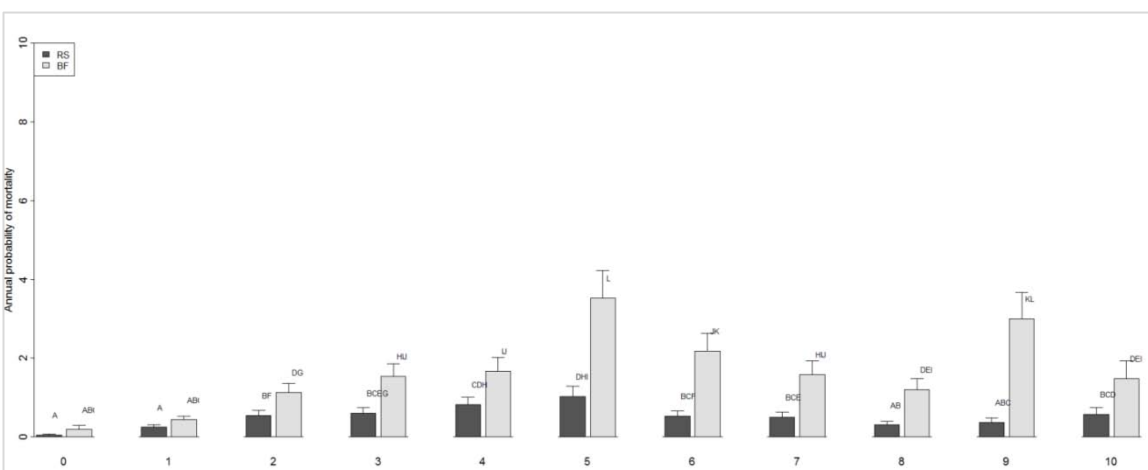

Figure 3-14. Least squares mean estimates of the temporal effect on annual probability of mortality of individual trees by species.

Overall, our results indicate that BF trees are more likely to experience mortality after a CT in either experiment. Decreases in mortality can be significant if a site has received PCT, but the timing of CT is less influential. Thinning from below may significantly reduce mortality by removing less vigorous trees from an even-aged setting while the opposite is true for dominant thinning.

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MODELING NATURAL REGENERATION INGROWTH IN THE ACADIAN FOREST

Authors:

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Introduction

Ingrowth is defined as trees in a sample plot that have grown into a required threshold size (usually measured by tree height or diameter at breast height) over a certain period. Modeling tree ingrowth is of great importance for forest growth simulations, particularly long-term projections, since it represents one of four key components of forest development: survivor growth, ingrowth, mortality, and harvest.

A number of studies have developed one single linear or nonlinear equation (e.g. Adams and Ek, 1974; Hann, 1980; Shifley *et al.*, 1993) to predict amount of recruitment at the end of each simulation cycle. However, these models will always predict ingrowth to occur, even if it has not. Consequently, two-stage models were proposed and demonstrated as a better approach in many studies (e.g. Vanclay, 1992; Fortin and DeBlois, 2007; Adame *et al.*, 2010). In a two-stage model, the first equation estimates probability of ingrowth occurrence based on a set of covariates and a second equation estimates amount of ingrowth based on the same or different set of covariates, given that ingrowth has occurred.

The goal of this project was to develop the best modeling approach for estimating annualized ingrowth occurrence and frequency for stands in the Acadian Region. In addition, models for ingrowth species composition were also developed

Methods

Data

Data used in this study came from an extensive regional database of fixed-area permanent plots compiled from a variety of data sources (Weiskittel *et al.*, 2010). Some important sources of data were the US Forest Service (USFS) Forest Inventory and Analysis (FIA), the USFS Penobscot Experimental Forest, and permanent sample plot (PSP) data from several Canadian provinces. Sample plots covered the majority of Maine and southeastern Canada, including Québec, Nova Scotia, and New Brunswick. The primary conifer species included: balsam fir [*Abies balsamea* (L.) Mill], red spruce [*Picea rubens* (Sarg.)], white spruce [*Picea glauca* (Moench) Voss.], white pine [*Pinus strobus* L.], eastern hemlock [*Tsuga canadensis* (L.) Carr.], and northern white-cedar [*Thuja occidentalis* L.]. Hardwoods commonly found in the region include: red maple [*Acer rubrum* L.], paper birch [*Betula papyrifera* Marsh.], yellow birch [*Betula alleghaniensis* Britt.], and aspen [*Populus* Michx.].

Multiple measurements were obtained from each sample plot, which included plot size, total basal area, and number of trees. The time interval between two measurements varied among plots, with most having 5-year remeasurement intervals (61%). The number of observed ingrowth trees in a sample plot was divided by measurement length to obtain annualized ingrowth counts (rounded to the nearest integer and standardized on a per ha basis). Since site index was rarely measured on these plots and detailed soil maps do not exist for much of the region, a site quality index variable was derived based on geographical location of sample plots. This index is based on 1 km^2 climate normals from 1960-1991 and an empirically derived relationships with observed site index (Weiskittel *et al.*, 2011) (figure 3-9).

Table 3-9. Ingrowth data attributes by data source.

source	# of plots	Avg. plot size (ha)	Avg. measurement interval (yr)	Avg. total basal area (m^2 ha^{-1})*	Avg. stem density (# ha^{-1})*	Climate site index (m)	Avg. # of ingrowth observations (trees/ha/yr)	Range of # of ingrowth observations (trees/ha/yr)	Minimum dbh (cm)
AFERP	175	0.050	5	39.8	1294	16.3	27	(0, 212)	2.3
CFRU GIS	365	0.020	1	30.5	959	13.4	7	(0, 250)	11.9
CTRN	85	0.081	1	25.9	1837	14.2	5	(0, 278)	4.1
FIA	438	0.075	11	16.4	305	14.6	10	(0, 67)	12.8
FIA	4457	0.014	5	27.0	898	14.4	24	(0, 297)	6.0
New Brunswick	1999	0.027	4	25.4	2156	11.9	27	(0, 299)	4.3
Nova Scotia	2754	0.040	5	18.9	826	10.7	22	(0, 270)	9.2
Maine PEF	198	0.074	4	17.4	920	16.0	52	(0, 298)	1.6
Maine PEF	275	0.081	5	27.0	2045	16.0	50	(0, 239)	1.5
Maine PEF	32	0.076	4	0.1	275	15.9	27	(0, 204)	0.5
Quebec BAS1	1523	0.040	10	19.5	884	12.4	24	(0, 192)	4.4
Quebec BAS2	498	0.032	11	15.8	833	11.6	33	(0, 225)	4.0
Quebec FEDE	116	0.037	9	16.8	887	13.0	42	(0, 175)	4.5
Quebec PACA	15	0.040	10	24.5	950	12.6	19	(0, 48)	4.1
Quebec SCOF	115	0.037	10	7.7	303	13.0	60	(0, 190)	4.0
Quebec SPIM	339	0.034	10	21.4	965	12.7	29	(0, 157)	4.4
Quebec UNLA	162	0.040	5	20.8	1264	11.8	44	(0, 220)	3.9

*: measured at the time when the plots were initially established.

In addition to the stochastic nature of ingrowth, another difficulty in this analysis was the use of different threshold diameters for determining ingrowth. In this analysis, the threshold diameter varied from 0.1 to 11.4 cm according to different data sources. Although Shifley et al. (1993) attempted to develop a method for estimating forest ingrowth at multiple threshold diameters, the precision was quite low and other factors were likely more influential. In our study, we included the threshold diameter (minimum dbh for each plot) as a predictor variable to enhance model performance. However, it is worth noting that the majority of the data had a threshold diameter of <11.7 cm (90% of observations) with a median of 9 cm.

Data Analysis

Key factors that influence the annualized number of ingrowth trees are related to a variety of stand and site conditions. Understocked stands have potential growing space for ingrowth trees (Shifley et al. 1993) so stand density should be a good indicator for the number of future ingrowth trees. Shifley et al. (1993) also pointed out that tree size, species composition, stand shading conditions, and other stochastic events (such as weather, disturbance) may all contribute to the probability of occurrence of ingrowth trees and number of ingrowth trees in a certain area. Based on the data availability and desired use in future projections, four explanatory variables for predicting number of ingrowth trees per ha were selected: (1) total basal area (m^2 ha^{-1}), (2) hardwood basal area percentage, (3) number of trees per ha, (4) the site quality index described above, and (5) minimum measured dbh of each plot.

To fit the equation, a zero-inflated negative binomial modeling approach was used. This approach consists of two models, namely one to predict the probability of ingrowth occurrence and the second predicts the amount of ingrowth given that it has occurred (equation 3-3).

To predict ingrowth species composition, a system of equations was developed that used percentage of ingrowth tree basal area for each species as the dependent variable. The independent variables were stand total basal area, percentage of basal area for each species, and the site quality index variable. A logistic model was used, but was constrained to force additivity. The original ingrowth data contained over 50 different individual species. However, balsam fir and spruce accounted for over 50% of the observations. Consequently, the species in this analysis were grouped into the following categories: birch (8.9%), red maple (8.8%), balsam fir (26.1%), spruce (24.5%), white pine (1.4%), other hardwood (21.7%), and other softwood (8.6%) (equation 3-4).

For the parameter estimation of the annualized total number of ingrowth trees through maximum likelihood process, we used the SAS/STATNLMIXED procedure (SAS Institute 2008). For the ingrowth species composition estimation, the system of equations was simultaneously fit by the SAS/STATMODEL procedure (SAS Institute 2008).

Equation 3-3.

$$\pi = \left[\frac{1}{\left(1+\exp(-(\gamma_0+\gamma_1\cdot \text{BA}+\gamma_2\cdot \text{PHW}+\gamma_3\cdot (\text{TPH}/1000)+\gamma_4\cdot \text{CSI}+\gamma_5\cdot \text{MinDBH}\right)}\right]$$

$$(\text{ING}\mid\pi)=\exp(\beta_0+\beta_1\cdot \text{BA}+\beta_2\cdot \text{PHW}+\beta_3\cdot (\text{TPH}/1000)+\beta_4\cdot \text{CSI}+\beta_5\cdot \text{MinDBH}$$

where π is the probability that annual ingrowth occurs, ING is that the number of ingrowth per year, BA is stand basal area (m^2 ha^{-1}), PHW is the proportion of basal area in hardwood species, TPH is the number of stems per ha, CSI is climate site index, and MinDBH is the plot threshold diameter.

Equation 3-4.

$$y_i=1/(1+\exp(-(b_{i0}+b_{i1}*\text{BA}+b_{i2}*\text{PBA}_i+b_{i3}*\text{CSI}+b_{i4}*\text{MinDBH})),\qquad i=1,\ldots,7$$

where y_i is the percentage of ingrowth trees for the i^{th} species; b_{i0}, b_{i1}, b_{i2}, and b_{i3} are parameters for i^{th} species; and PBA_i is the proportion of basal area for the i^{th} species. Species index i corresponds to the above 7 species groups defined above.

Results

Ingrowth Occurrence and Frequency

Of the 33,054 observations available for analysis, 30.6% of them were zeros. When it did occur, the average ingrowth was 32.2 ± 37.1 counts ha^{-1} yr^{-1} (mean ± SD) with a range between 1 and 298 counts ha^{-1} yr^{-1}. Overall, the ZINB with random effects was shown to be the best model tested ($p<0.0001$) and all parameter estimates were statistically significant (table 3-10). Stand basal area, hardwood basal area percentage and threshold diameter had a negative effect on the number of non-zero ingrowth tree counts, while number of trees per ha and site quality index had a positive influence. The effect of stand basal area on ingrowth was much more pronounced compared to the other factors (figures 3-15 and 3-16).

Table 3-10. The estimated parameters for zero-inflated negative binomial model (ZINB) with and without random effects for predicting annual ingrowth occurrence and frequency (equation 3-1).

	No random effects			With random effects		
Parameter	*Estimate*	*Std. err.*	*P-value*	*Estimate*	*Std. err.*	*P-value*
γ_0	-0.2116	0.0659	0.0013	-0.1596	0.0626	.0108
γ_1	0.0255	0.0008	<.0001	0.0253	0.0008	<.0001
γ_2	-0.1396	0.0274	<.0001	-0.1241	0.0261	<.0001
γ_3	-0.0054	0.0011	<.0001	-0.0583	0.0107	<.0001
γ_4	0.0433	0.0044	<.0001	0.0419	0.0043	<.0001
γ_5	0.0409	0.0028	<.0001	0.0393	0.0027	<.0001
β_0	3.8982	0.0414	<.0001	4.0303	0.0491	<.0001
β_1	-0.0257	0.0005	<.0001	-0.0277	0.0005	<.0001
β_2	-0.3668	0.0166	<.0001	-0.3654	0.0200	<.0001
β_3	0.0238	0.0007	<.0001	0.1787	0.0069	<.0001
β_4	0.0216	0.0028	<.0001	0.0159	0.0034	<.0001
β_5	-0.0514	0.0019	<.0001	-0.0642	0.0023	<.0001

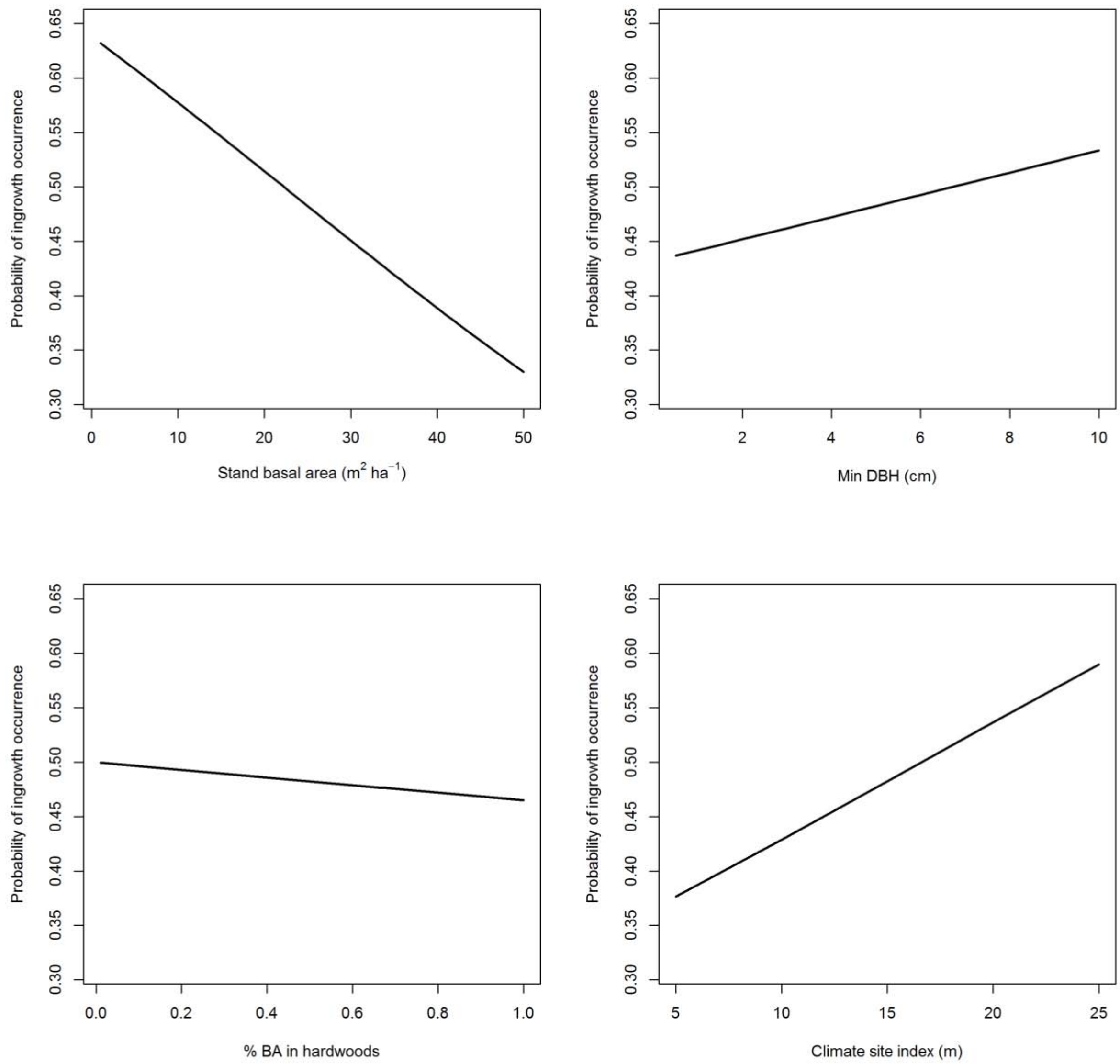

Figure 3-15 . Predicted probability of annual ingrowth occurrence over stand basal area, minimum DBH, percent basal area in hardwoods, and climate site index using equation 3-3.

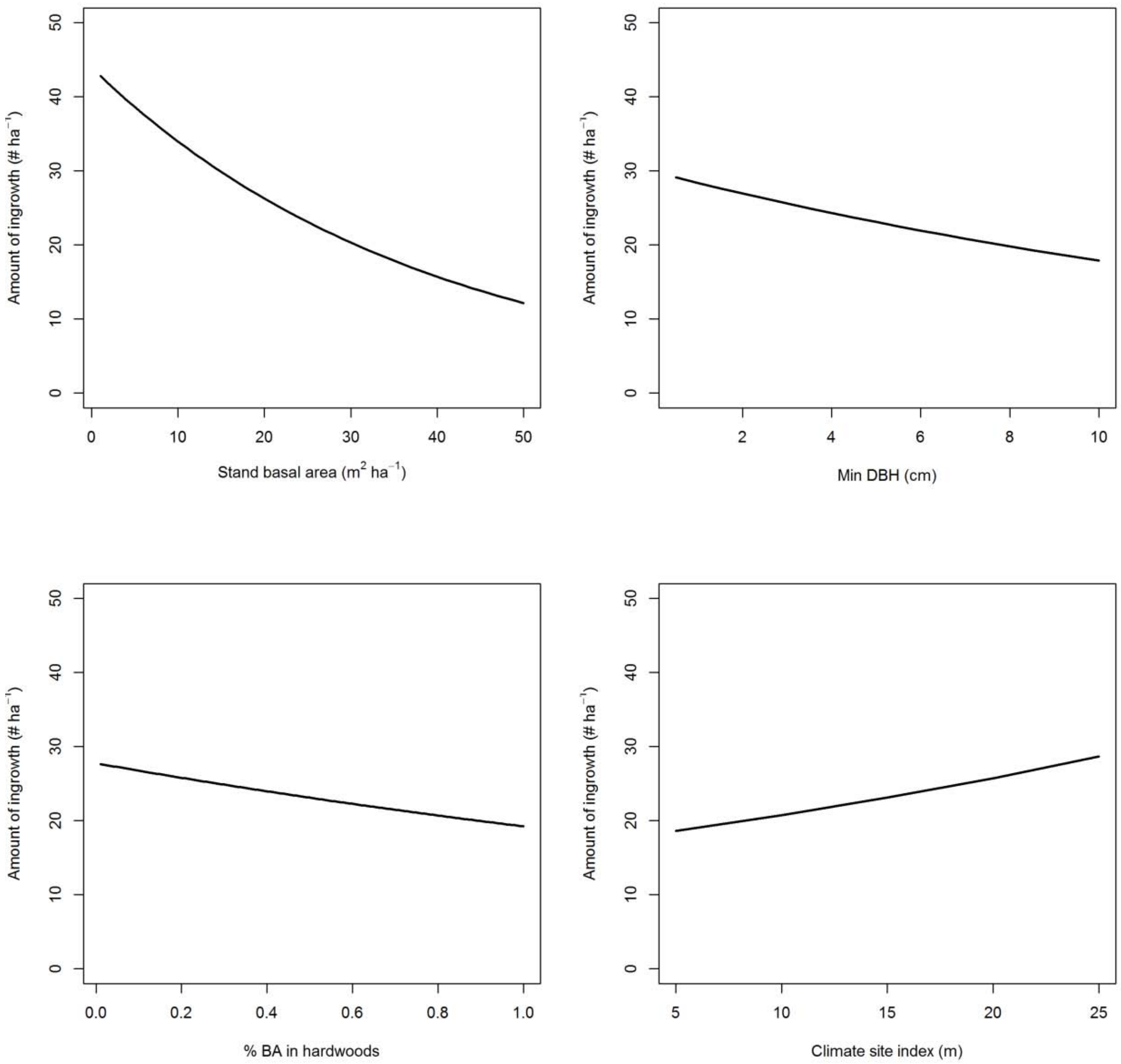

Figure 3-16. Predicted annual ingrowth frequency (# ha^{-1}) over stand basal area, minimum DBH, percent basal area in hardwoods, and climate site index using equation 3-3.

Ingrowth Composition

Except for the birch species group, all parameters in the species composition model were statistically significant at 0.05 level (table 3-11). The models fit well with mean square errors ranging from <0.01 to 0.1. In general, balsam fir and spruce had a significantly higher probability to generate ingrowth trees across a range of stand densities and site indices (figure 3-17). White pine and red maple had the lowest probabilities of the species groups examined. Some species like balsam fir and red maple showed a positive relationship with stand total basal area, while others like spruce and white pine had a negative relationship.

Table 3-11. The parameter estimates, standard deviation and p-values for the fitted ingrowth species composition model (equation 3-2).

Species group	Parameter	Estimate	Standard error	p-value
birch	b10	-2.5645	0.0917	<.0001
	b11	0.0020	0.0011	0.0554
	b12	2.6624	0.0333	<.0001
	b13	-0.0010	0.0062	0.8704
	b14	-0.0127	0.0042	0.0024
balsam fir	b20	-3.0291	0.0846	<.0001
	b21	0.0027	0.0010	0.0091
	b22	2.7779	0.0342	<.0001
	b23	0.0211	0.0053	<.0001
	b24	0.0221	0.0040	<.0001
red maple	b30	-0.6566	0.0661	<.0001
	b31	0.0123	0.0007	<.0001
	b32	1.7669	0.0174	<.0001
	b33	-0.0421	0.0045	<.0001
	b34	-0.0283	0.0030	<.0001
spruce	b40	-1.2500	0.0679	<.0001
	b41	-0.0132	0.0007	<.0001
	b42	2.0470	0.0193	<.0001
	b43	-0.0514	0.0048	<.0001
	b44	0.0351	0.0030	<.0001
white pine	b50	-5.1074	0.0909	<.0001
	b51	-0.0117	0.0014	<.0001
	b52	3.8817	0.0562	<.0001
	b53	0.0501	0.0061	<.0001
	b54	0.0726	0.0057	<.0001
other hardwood	b60	-2.9832	0.0681	<.0001
	b61	-0.0020	0.0008	0.017
	b62	2.4837	0.0227	<.0001
	b63	0.0673	0.0045	<.0001
	b64	-0.0167	0.0031	<.0001
other softwood	b70	-4.7182	0.0776	<.0001
	b71	0.0070	0.0008	<.0001
	b72	3.2269	0.0340	<.0001
	b73	0.1000	0.0049	<.0001
	b74	0.0188	0.0031	<.0001

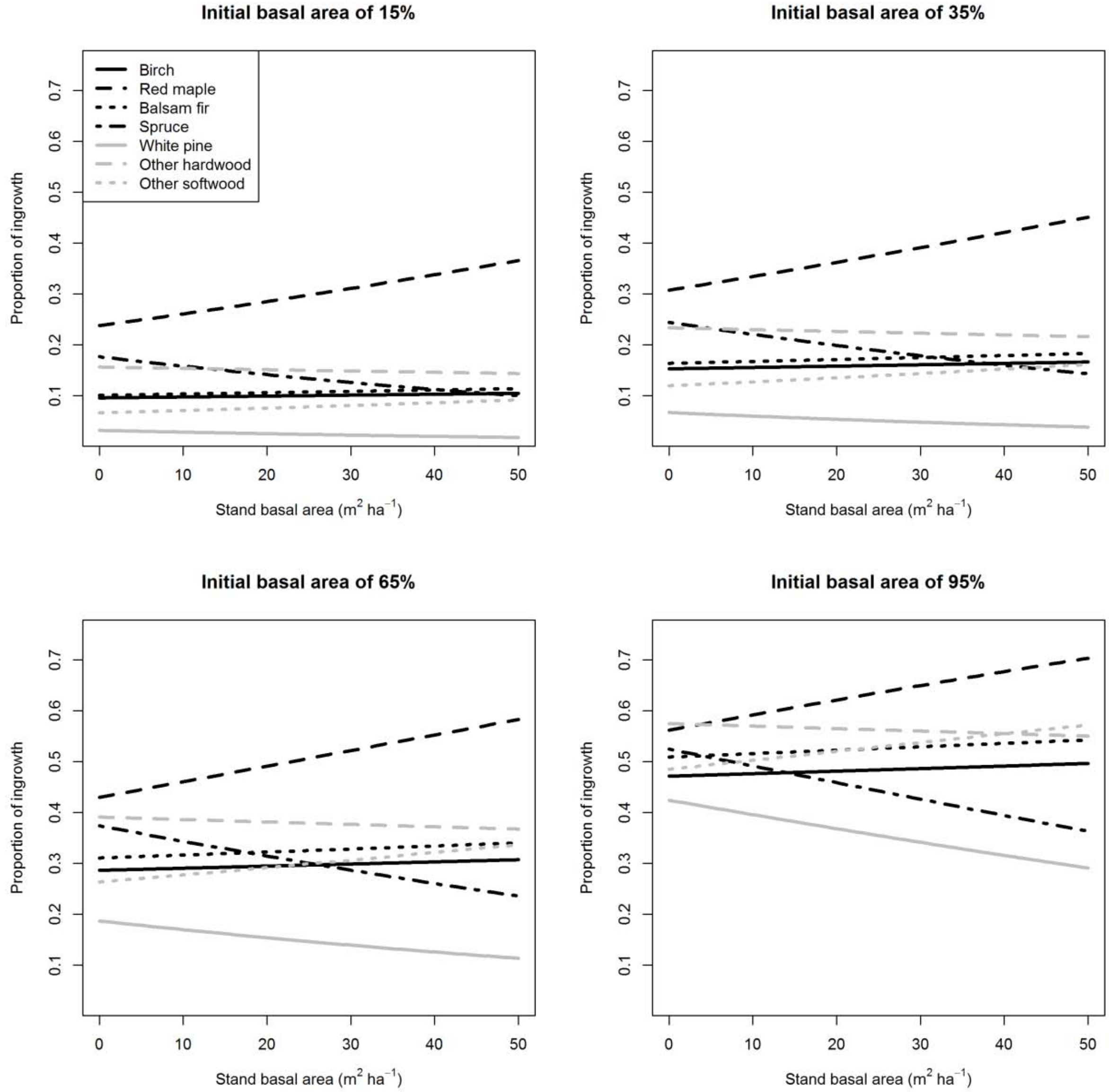

Figure 3-17. Predicted proportion of ingrowth by species and varying species proportion of initial basal area over stand total basal area using equation 3-4. A climate site index of 15 m and a minimum DBH of 5 cm were assumed on all graphs.

Discussion

The results of this analysis indicated high plot-to-plot variability, which was unable to be fully explained. Graphical assessment of the plot-level random effects and residuals over various factors like threshold diameter, plot size, soil drainage, and elevation did not show any obvious trends. In this analysis, the number of ingrowth trees decreased with greater stand density when expressed in terms of total basal area. As in this analysis, most other recruitment studies have found basal area to be the strongest predictor. Rather than basal area, crown competition factor (CCF) was initially assessed as a potential covariate, given its prior use in other studies. However, CCF did not drastically improve model performance and basal area was used instead for simplicity. Although stem density also is an indicator of stand density, the results showed it to have a positive effect on the number of ingrowth trees, unlike total basal area. This result also has been reported in several previous studies and most likely represents stage of stand development rather than competition as young dense stands are likely to have larger numbers of ingrowth trees, especially if the threshold diameter is large.

There is no consensus on whether site quality influences number of ingrowth trees. For example, Fortin and DeBlois (2007) did not include a measure of site quality in their recruitment model, while Ek (1974) found it to be non-significant. In contrast, Hann (1980) concluded ingrowth was higher on better sites. The results of the present analysis agree with Hann (1980) as we found higher sites have more ingrowth occurrence. This is logical since better sites generally have better soil conditions or more available resources to support growth and development of regeneration. However, this ingrowth rate increase on better sites is highly dependent on ingrowth occurrence. That is, when ingrowth is highly likely to occur in a plot, the site quality for this plot imposes a positive influence on producing the number of ingrowth trees. In this analysis, ingrowth rates were dependent on species composition where stands dominated by hardwood species had a reduced annual ingrowth rates. This result may be caused by several factors including the predominance of intolerant hardwood species in the Acadian Forest Region, the past site disturbance history, and the increased presence of balsam fir in the overstory.

In general, white pine and red maple had much lower ingrowth rates compared to balsam fir and spruce. The predominance of balsam fir ingrowth agrees with recent findings of Olson and Wagner (2010) where they found it has dominated the understory in the last 5 decades across a wide range of silvicultural regimes. This is because balsam fir is relatively shade-tolerant, a prolific producer of seed, can grow on a range of habitats, and responds well to release. In contrast, white pine is more shade intolerant, seeding more periodic, early growth is slow, and has certain seedbed conditions. These species characteristics are clearly evident in the model predictions, particularly the response to changes in total stand basal area. For example, our model predicts percentage of balsam fir to increase as stand basal area increases, while the opposite is true for white pine. Likely, this is depicting changes in understory light conditions and balsam fir would be favored in low light conditions.

In summary, this work represents a significant improvement in modeling tree recruitment. The results are binge incorporated into the Acadian Variant of the Forest Vegetation Simulator (FVS). A kcp file (written by Dr. Hennigar of University of New Brunswick) to implement these equations in the Northeastern Variant of FVS is available.

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The Realty Road in northern Maine, January 2012 *Photo by Brian Roth*

DEVELOPMENT OF REGIONAL TAPER AND VOLUME EQUATIONS: HARDWOOD SPECIES

Authors: Aaron Weiskittel and Rongxia Li

Introduction

Last year, taper equations for the primary softwood species in the region were presented (Li *et al.*, 2011). The primary goal of this analysis was to compare and evaluate two taper equations for the major hardwood species in the region. One equations was from the work of Li et al. (2011), while the other was recently developed for the majority of hardwood species in the Northeastern United States (Westfall and Scott, 2010). We aimed to find out whether the two well-performed taper equations can be directly applied to the hardwood species in the Acadian Region. In addition, the taper equations were compared to the widely used Honer (1965) regional volume equations and bark thickness equations are presented for species with sufficient data.

Methods

Data

Stem analysis data were gathered mainly from four sources: (1) 683 trees used in the Honer (1965) study, (2) 38 trees collected by Georgia Pacific in New Brunswick, (3) 2429 trees collected by the Quebec Ministry of Natural Resources; and (4) 795 trees used by Westfall and Scott (2010) (table 3-12). The majority of the data was obtained from the stem analysis of felled trees, while the Westfall and Scott (2010) was collected on standing trees. Preliminary analysis indicated relatively little influence of the different data sources. Sample plots were primarily located in eastern and central Maine, New Brunswick, and Quebec. The Westfall and Scott (2010) data did also include data from other northeastern states like New York, Ohio, Pennsylvania, and West Virginia. Again, preliminary analysis indicated relatively little influence of geographic region on the results.

On each sampled tree, measurements of diameter outside bark (dob) were taken at stump height, breast height, and approximately every 1 m or 2 m after breast height until the top of the main stem (where branches spited the main stem). In a few of the datasets, measurements of diameter inside bark were also obtained.

Analysis

Give then results of Li et al. (2011) on softwood species, the Kozak (2004) model form was selected for use in this analysis (equation 3-3). The other taper equation was originally formulated by Valentine and Gregoire (2001) and then revised by Westfall and Scott (2010).

We used nonlinear mixed-effects modeling (nlme) techniques to estimate parameters in equation 3-5 (table 3-13). The parameters α_0 and β_3 were chosen to include random effects since the models with these two as mixed parameters gave the minimum AIC among all other models with two random-effects. The parameter estimation procedure was implemented by the nlme function in the nlme library in R (Pinheiro and Bates, 2009). The estimated parameter values for the Westfall and Scott (2010) equation are found in table 3-14. For each sample tree, Smalian's formula was used to calculate both estimated volume outside bark (VOB) based on estimated dob and observed volume based on measured dob.

Since volume inside bark (VIB) is usually of greater interest, bark thickness equations for the different hardwood species were developed when sufficient data was available. Although Li and Weiskittel (2011) found that bark thickness equations dependent on the ratio of inside bark DBH to outside bark DBH were superior to other equations, bark thickness is generally not measured and using an equation was more effective than assuming a fixed ratio between dob and diameter inside bark (dib).

Consequently, the following equation was estimated

$$\text{dib}= {}_{1}\text{dob}^{\ 2}$$

where the β_i's are parameters to be estimated and all other variables have been defined above.

For evaluation, mean absolute bias (MAB), root mean square error (RMSE), and mean bias (MB) were used to evaluate model performance for both diameter and volume prediction.

Results

The number of sample trees ranged from 6 (green ash) to 1327 (yellow birch) (table 3-12). The taper equation using the Kozak (2004) model form fit well as the RMSE ranged from 0.88 cm (gray birch) to 3.45 cm (yellow birch) (tables 3-13 and 3-14). The Kozak (2004) equation performed slightly better than the Westfall and Scott (2010) equation. Overall, the Kozak (2004) equation resulted in 71.3, 7.4, and 12.2% reduction in MB, MAB, and RMSE, respectively. The improvements were most noticeable in balsam poplar, green ash, and sugar maple.

Overall, the three approaches for predicting total stem volume were quite similar (table 3-15). Generally, the Kozak (2004) taper equations show the lowest bias, while the Westfall and Scott (2010) had the highest bias. For some species, the Honer (1965) volume equation outperformed the taper equations, particularly red oak and yellow birch. Volume prediction differences were most notably in trees larger than 25 cm (10 inches) (figure 3-18).

The bark thickness equations fit well with RMSEs between 0.28 cm (sugar maple) to 0.69 cm (yellow birch) (table 3-16). Across the different species tested, quaking aspen was predicted to have the thickest bark for a given dob, while sugar maple was predicted to have the thinnest.

Equation 3-5: $$d = \alpha_0 D^{\alpha_1} H^{\alpha_2} X^{\beta_1 z^4 + \beta_2 (1/e^{D/H}) + \beta_3 X^{0.1} + \beta_4 (1/D) + \beta_5 H^Q + \beta_6 X}$$

where $X = \dfrac{1-(h/H)^{1/3}}{1-p^{1/3}}$, $Q = 1 - z^{1/3}$, p=1.3/H, *h* is the stem section height, *d* is the diameter outside bark at height *h*, H and D refers total tree height and dob at breast height, and α_0 - α_2, β_1 - β_6 represent parameters to be estimated.

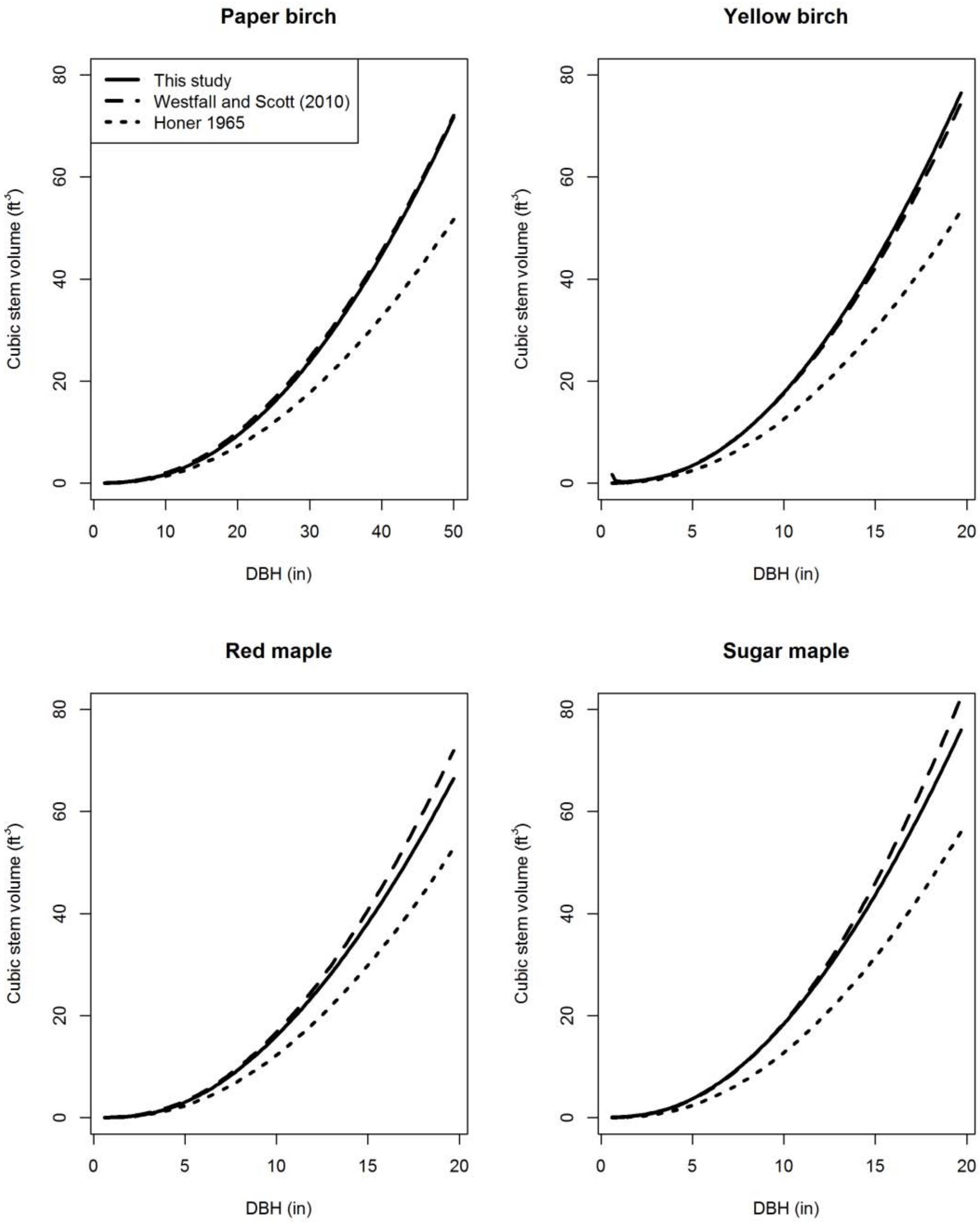

Figure 3-18. Estimated total stem volume (ft³) for paper birch, yellow birch, red maple, and sugar maple using the taper equations in this study as well as Westfall and Scott (2010) and the volume equations of Honer (1965) across a range of DBH classes (in).

Table 3-12. Attributes (mean ± SD; minimum and maximum in parentheses) of the sample trees by species.

Species	# of Sample Trees	# of dob (dib) measurements	DBH (cm)	HT (m)	dob (cm)	dib (cm)
American beech	142	2285	32.4 ± 17.4 (7.1, 89.7)	18.93 ± 6.12 (7.89, 33.77)	22.8 ± 18.2 (0.1, 107.7)	-
Black cherry	115	1808	28.6 ± 14.2 (7.6, 81.8)	19.66 ± 5.51 (5.85, 32.49)	19.8 ± 15.0 (0.1, 95.3)	-
Balsam poplar	9	123	23.3 ± 8.4 (9.6, 34.79)	16.42 ± 3.97 (9.72, 21.61)	16.5 ± 10.1 (0.1, 38.6)	-
Bigtooth aspen	26	382	26.0 ± 9.8 (9.1, 42.7)	20.49 ± 5.35 (10.82, 31.58)	18.1 ± 11.7 (0.1, 52.6)	-
Green ash	6	76	20.3 ± 11.7 (8.9, 38.6)	16.23 ± 7.19 (10.24, 26.42)	15.5 ± 12.3 (0.1, 54.6)	-
Gray birch	13	141	15.2 ± 5.3 (8.1, 24.4)	12.27 ± 2.83 (7.58, 16.86)	11.4 ± 7.1 (0.1, 29.5)	
Paper birch	991	12961 (3271)	26.9 ± 9.63 (5.6, 70.8)	16.57 ± 3.22 (6.5, 26.8)	25.1 ± 10.9 (0.1, 86.7)	15.1 ± 7.5 (0.7, 50.3)
Quaking aspen	41	643 (161)	24.8 ± 9.5 (8.4, 39.1)	18.28 ± 4.34 (7.80, 24.57)	18.1 ± 11.1 (0.1, 49.5)	21.1 ± 9.6 (2.3, 46.7)
Red maple	162	2580 (145)	32.3 ± 13.5 (7.6, 75.9)	19.18 ± 4.83 (6.83, 32.00)	24.9 ± 15.2 (0.1, 104.4)	19.1 ± 9.7 (1.7, 46.1)
Red oak	46	768	35.1 ± 19.8 (13.2, 112.5)	21.62 ± 5.55 (12.25, 32.83)	24.6 ± 21.3 (0.1. 164.3)	-
Sweet birch	41	587	24.3 ± 14.3 (8.1, 69.3)	17.15 ± 4.76 (8.96, 29.02)	17.9 ± 15.1 (0.1, 100.6)	-
Sugar maple	975	15999 (105)	37.4 ± 11.2 (7.8, 79.7)	20.32 ± 3.46 (7.68, 31.91)	33.1 ± 13.1 (0.1, 94.7)	19.1 ± 11.3 (2.4, 50.1)
White ash	46	787 (159)	28.4 ± 15.6 (9.1, 76.4)	21.02 ± 5.93 (8.22, 38.19)	20.7 ± 16.3 (0.1, 105.9)	18.4 ± 10.6 (2.0, 59.4)
Yellow birch	1327	17077 (2913)	38.3 ± 14.5 (8.1, 89.5)	17.64 ± 3.27 (8.32, 27.14)	36.5 ± 16.3 (0.1, 170.4)	18.9 ± 10.4 (2.7, 84.6)

Table 3-13. Parameter estimates for the Kozak (2004) taper equation (equation 3-3).

Species	Parameters								
	α_0	α_1	α_2	β_1	β_2	β_3	β_4	β_5	β_6
American beech	1.0683	0.9975	-0.0128	0.3921	-1.0546	0.7702	4.1035	0.1186	-1.0807
Black cherry	0.9824	0.9901	0.0215	0.6093	-0.5463	0.5054	1.6561	0.0409	-0.3028
Balsam poplar	1.0036	0.7442	0.2876	0.6634	-2.0048	0.7508	3.9248	0.0277	-0.1309
Bigtooth aspen	1.0194	1.0055	-0.0110	0.5105	-1.3264	0.5132	7.2108	0.0711	-0.5718
Green ash	1.0852	1.1862	-0.2262	0.5199	1.4303	-0.3495	3.1953	0.1392	-0.2967
Gray birch	1.0050	0.8836	0.1308	0.6114	-0.1142	0.2521	2.6574	0.0590	-0.1751
Paper birch	0.7161	0.9811	0.1383	0.4782	0.3092	0.2643	-0.3021	0.0859	-0.2787
Quaking aspen	0.5527	0.9048	0.3075	0.7131	-0.5883	0.3620	2.8516	0.0382	-0.1343
Red maple	0.7458	1.0092	0.0891	0.5862	-0.8659	0.6414	3.0604	0.0828	-0.6486
Red oak	1.1729	1.0225	-0.0699	0.4506	-0.9029	0.5927	3.6267	0.1656	-1.1143
Sweet birch	0.8471	0.9875	0.0770	0.9323	-0.9546	0.4855	3.0295	0.0768	-0.2384
Sugar maple	1.0456	0.9613	0.0386	0.8556	-0.2497	0.3889	1.2548	0.0413	-0.1135
White ash	0.8551	0.9769	0.0770	0.7819	-0.7918	0.4767	3.5004	0.0859	-0.4880
Yellow birch	1.1017	0.9485	0.0371	0.7663	-0.0281	0.1788	4.8570	0.0753	-0.2051

Table 3-14. Mean bias (MB), mean absolute bias (MAB), and root mean square error (RMSE) for the Kozak (2004) and Westfall and Scott (2010) taper equations in predicting diameter outside bark (cm). Only the fixed effects for the Kozak (2004) equations were used.

Species	Kozak (2004)			Westfall and Scott (2010)		
	MB (cm)	MAB (cm)	RMSE (cm)	MB (cm)	MAB (cm)	RMSE (cm)
American beech	0.1476	2.0120	2.9453	-0.5514	2.0336	3.1795
Black cherry	-0.0172	1.5429	2.3098	-0.0753	1.5842	2.4577
Balsam poplar	-0.1206	0.9962	1.2720	-0.2708	1.1877	1.7751
Bigtooth aspen	-0.0809	1.2983	1.9448	0.4205	1.5271	2.2863
Green ash	0.0256	0.9683	1.3206	0.8538	1.6006	2.4422
Gray birch	-0.0522	0.6705	0.8814	0.0845	0.6745	0.9778
Paper birch	-0.0435	1.6228	2.3043	0.0326	1.7342	2.5168
Quaking aspen	0.0442	1.6019	2.1694	0.2411	1.5823	2.2554
Red maple	0.0309	1.9850	2.9151	-0.2007	2.0428	3.0321
Red oak	0.1899	2.0712	3.2869	-0.0837	2.0033	3.2795
Sweet birch	0.04257	1.4699	2.5264	-0.2710	1.4543	2.7108
Sugar maple	-0.1772	2.5088	3.3429	-1.3549	3.0848	4.5731
White ash	0.1516	1.7189	2.8149	-0.2766	1.7506	3.0723
Yellow birch	-0.7912	2.3933	3.4463	-0.8194	2.4159	3.5717
Overall	-0.0465	1.6329	2.3914	-0.1622	1.7626	2.7236

Table 3-15. Mean bias (MB), mean absolute bias (MAB), and root mean square error (RMSE) for the Kozak (2004)and Westfall and Scott (2010) taper equations as well as the Honer (1965) volume equations in predicting total tree volume. Only the fixed effects for the Kozak (2004) equations were used.

Species	Kozak (2004)			Westfall and Scott (2010)			Honer (1965)		
	MB (m^3)	MAB (m^3)	RMSE (m^3)	MB (m^3)	MAB (m^3)	RMSE (m^3)	MB (m^3)	MAB (m^3)	RMSE (m^3)
American beech	0.0265	0.0979	0.2016	-0.0457	0.0986	0.2105	-0.1221	0.1424	0.2890
Black cherry	0.0088	0.0681	0.1237	0.0005	0.0773	0.1456	-0.0614	0.1034	0.2173
Balsam poplar	-0.0048	0.0319	0.0463	-0.0248	0.0512	0.0875	-0.0189	0.0532	0.0861
Bigtooth aspen	-0.0008	0.05103	0.0815	0.0562	0.0859	0.1396	0.0564	0.0841	0.1334
Green ash	0.0063	0.0123	0.0146	0.0252	0.04458	0.0731	-	-	-
Gray birch	0.0007	0.0078	0.0120	0.0012	0.0079	0.0121	-0.0001	0.0076	0.0012
Paper birch	-0.1079	0.1275	0.2317	-0.0833	0.1091	0.1982	-0.0575	0.0973	0.1727
Quaking aspen	-0.0066	0.0516	0.0764	0.0144	0.0568	0.0793	0.0127	0.0538	0.0761
Red maple	-0.0337	0.1013	0.1639	-0.0436	0.1115	0.1732	-0.0239	0.1061	0.1712
Red oak	0.0432	0.1375	0.3611	-0.0123	0.1239	0.2423	0.0692	0.1441	0.2983
Sweet birch	0.0017	0.0567	0.1487	-0.0281	0.0583	0.1763	0.0039	0.0523	0.1206
Sugar maple	-0.1670	0.2033	0.3122	-0.2367	0.2557	0.3122	-0.1064	0.1767	0.2768
White ash	0.0052	0.0796	0.1483	-0.0267	0.0824	0.1471	-	-	-
Yellow birch	-0.3623	0.3705	0.5637	-0.3309	0.3407	0.5237	-0.2769	0.2920	0.4588
Overall	-0.0422	0.0998	0.1776	-0.0525	0.1074	0.1801	-0.0438	0.1094	0.1918

Table 3-16. Parameter estimates, mean bias and root mean square error (RMSE) for the bark thickness equation by species.

Species	$ß_1$	$ß_2$	Mean bias (cm)	RMSE (cm)
Paper birch	0.8969	1.0179	-0.0591	0.3467
Quaking aspen	0.8449	1.0332	-0.1103	0.6679
Red maple	0.9214	1.0117	-0.0161	0.5501
Sugar maple	0.9383	1.0064	-0.0026	0.2787
White ash	0.8834	1.0188	0.0036	0.4669
Yellow birch	0.8688	1.0275	-0.2223	0.6873

Discussion

Hardwood species represent a more significant challenge for modeling stem form and volume when compared to softwoods. This is because a significant portion of their total volume can be in branches rather than a main bole. For example, MacFarlane (2010) found that branches comprised between 5 to 21% of the total tree volume for common hardwood species in the Lake States. Consequently, the taper equations presented in this analysis will likely underestimate total tree volume as measurements of bole volume were only available for analysis. Unfortunately, the Westfall and Scott (2010) equation suffers from a similar shortcoming. Future efforts will be needed to better quantify the ratio between branch and bole volume.

Both the Kozak (2004) and Westfall and Scott (2010) taper equations predicted hardwood stem form quite accurately, despite the range of species and tree sizes in the data. The Kozak (2004) did predict dob slightly better, on average, than the Westfall and Scott (2010). However, this improved accuracy wasn't realized when used to estimate observed stem volume as the equations had a similar level of bias. Both taper equations did generally perform slightly better than the Honer (1965) equations, except for certain species like red oak and yellow birch. However, the taper equations will likely prove more effective for estimating merchantable stem volume.

Inside bark observations were limited for most species and nonexistent for others. This suggests the need to collect bark thickness information for additional hardwood species in the future. Additional data from the New Brunswick Department of Natural Resources is currently being entered and will be used to update the presented equations. In addition, the New Brunswick Growth and Yield Unit is planning to stem section several hardwood trees in the upcoming summer, which will also be used to update the equations. Regardless, additional measurements in Maine would be helpful

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Francis Avery instructs University of Maine workers on proper felling techniques. *Photo by Brian Roth*

REFINEMENT OF THE FOREST VEGETATION SIMULATOR NORTHEAST VARIANT GROWTH AND YIELD MODEL: PHASE III

Authors:

Aaron Weiskittel, Matthew Russell, Robert Wagner, Robert Seymour

Introduction

Over the past year, significant advances have been made with equation development in the CFRU's project refining the Northeast variant of the Forest Vegetation Simulator (FVS). Using an extensive regional database of permanent growth plots gathered across the Acadian forest, total height, height-to-crown base, and diameter and height increment equations were developed and are currently being tested. Accomplishments and further work on the models individual components can be found in table 3-17.

Specific highlights over the third year of this project were: (1) total height, height-to-crown base and crown width equations were developed, (2) stem taper and bark thickness equations were integrated with datasets to estimate total and merchantable tree volume, and (3) diameter and height increment and crown recession equations were created and are currently undergoing extensive evaluations. Future work is focused on predicting individual tree mortality and developing growth modifiers for pre-commercially and commercially thinned spruce-fir stands.

Table 3-17. Refined FVS growth and yield model components and accomplishments to date.

Component	Purpose	Accomplishments
Crown width equations	Predict crown dimensions for estimating crown competition factor and canopy closure	Complete
Total height	Impute missing height measurements in a tree list	Complete
Height-to-crown base	Impute missing height-to-crown base measurements in a tree list	Complete
Stem taper	Estimate total and merchantable tree volume	Complete
Bark thickness	Estimate bark thickness in determining tree volume	Complete
Ingrowth	Predict the occurrence, frequency, and composition of regeneration	Complete
Diameter increment	Predict annual changes in diameter	Complete, but with continual testing and updating
Height increment	Predict annual changes in total height	Complete, but with continual testing and updating
Crown recession	Predict annual changes in height-to-crown base	Complete, but with continual testing and updating
Mortality	Predict the probability of tree survival	Preliminary analysis underway
Thinning modifiers	Account for the influence of commercial thinning on growth estimates	Preliminary analysis underway

Model Developments

Growth and yield data gathered from permanent sample plots across the Acadian region showed tremendous variability in observed growth between species. Overall, nearly 3 million measurements of diameter at breast height increment (ΔDBH) measurements were used. Average annual ΔDBH ranged from about 0.13 to 0.44 cm/year, while height increment (ΔHT) ranged from 0.09 to 0.32 m/year.

These data were used in the construction allometric equations, in addition to the ΔDBH, ΔHT, and crown recession (ΔHCB) component equations.

Allometric Equations

Total height and height-to-crown base equations have undergone significant development and testing for the primary tree species in the region (Rijal 2012). These equations are estimated as a function of tree size, stand density, and a climate-derived estimate of site index. Crown width equations were developed and evaluated to perform better than existing equations used by FVS and the Forest Inventory and Analysis (FIA) program (Russell and Weiskittel 2011).

Diameter Increment

Preliminary analysis indicated that predicting ΔDBH was related to a host of tree, site, and species factors. Results indicated that forecasting tree diameter increment outperformed tree basal area increment after comparing to observed growth up to 29 years (Russell et al. 2011). An increment equation (3-6) predicted the annual change in DBH.

Height Increment

Modeling of ΔHT took a three stage approach: First, the maximum or potential height increment was estimated based on initial tree height (HT) and $SI_{CLIMATE}$ (equation 3-7).

In the second stage, modified annual height increment (ΔHT_{MOD}) was estimated. Here, the average height growth was estimated and was dependent on tree size, basal area in larger trees (m^2/ha), crown competition in higher trees (CCH) and crown competition factor (CCF): using equation 3-.8.

In the second stage, modified annual height increment (ΔHT_{MOD}) was estimated. Here, the average height growth was estimated and was dependent on tree size, basal area in larger trees (m^2/ha), crown competition in higher trees (CCH) and crown competition factor (CCF): using equation 3-8.

Preliminary analyses suggested that this maximum-modifier approach performed better for ΔHT than the unified approach that was used for ΔDBH.

In the final stage, predicted height growth was estimated by multiplying the maximum and modified components (equation 3-9).

Dr Aaron Weiskittel Photo by Brian Roth

Equation 3-6:

$$\Delta DBH = \exp\begin{bmatrix} a_0 - 3.789 + (a_1 + 0.306) * \log(DBH + 1) - 0.00088 * DBH^2 - 0.034 * BAL_{SW} - 0.031 * BAL_{HW} \\ -0.00059 * \left(\dfrac{BAL^2}{\log(DBH + 5)} \right) + 0.868 * \log(SI_{CLIMATE}) \end{bmatrix}$$

where DBH is diameter at breast height (cm), BAL_{SW}, $BAL_{HW,}$ and BAL is the basal area in larger trees (m^2/ha) of softwood species, hardwood species, and all species combined, respectively, and $SI_{CLIMATE}$ is the climate-derived site index based on latitude, longitude, and elevation. Many of the parameters are shared by all species, with the a_0 and a_1 parameters adjusting the equation to provide specificity to each species' growth pattern (table 3-17).

Equation 3-7:

$$\Delta HT_{MAX} = 0.044 * \exp(0.095 * SI_{CLIMATE}) * (HT^{b_1 + 0.510}) * \exp(-0.0081 * HT^2)$$

where ΔHT_{MAX} is annual maximum height increment. Similar to diameter increment, the b_1 parameter lends species-specificity to the equation (table 3-18).

Equation 3-8:

$$\Delta HT_{MOD} = \exp\left(-0.218 - 0.00018 * \left(\frac{BAL^2}{\log(DBH)} \right) - 0.0076 * CCH + 0.0014 * CCF \right)$$

Equation 3-9:

$$\Delta HT = \Delta HT_{MAX} \times \Delta HT_{MOD}$$

Table 3-18. Parameters for diameter (Eq. 3-6) and potential height increment (Eq. 3-7). Mean bias (MB) and root mean square error (RMSE) are from applying diameter, height, and height-to-crown base increment equations to a validation dataset.

	ΔDBH				ΔHT_{MAX}	ΔHT		ΔHCB		
Species	a_0	a_1	MB (cm/year)	RMSE (cm/year)	b_1	MB (m/year)	RMSE (m/year)	*ShTol*	MB (m/year)	RMSE (m/year)
Conifers										
Balsam fir	0.142	-0.045	0.30	1.08	0.033	0.02	0.53	5.01	0.06	0.70
Eastern hemlock	0.336	-0.021	0.00	1.27	0.098	0.04	0.20	4.83	-0.01	0.33
Eastern white pine	0.631	-0.010	0.13	1.83	0.233	0.05	0.31	3.21	0.04	0.42
Red spruce	0.411	-0.145	0.08	1.09	0.033	0.00	0.31	4.39	0.06	0.49
White spruce	0.396	-0.057	-0.03	1.16	0.123	0.05	0.26	4.15	0.01	0.45
Hardwoods										
Paper birch	0.220	-0.064	-0.01	0.99	-0.281	0.04	0.26	1.54	0.00	0.31
Red maple	0.354	0.078	0.05	1.14	-0.132	0.06	0.30	3.44	0.03	0.35
Sugar maple	0.883	0.333	0.02	1.55	-0.032	0.04	0.22	4.76	-0.03	0.36
Yellow birch	0.015	0.062	0.02	1.30	-0.153	0.04	0.25	3.17	-0.10	0.40

Crown recession

Predicting the annual change in height-to-crown base increment (ΔHCB) has proved multifaceted given the tremendous variability of HCB measurements, even within a single species (table 3-19). Successes have been made in relating ΔHCB to tree crown length (CL), predicted height increment, and crown competition factor (Equation 3-10).

Equation 3-10:

$$\Delta HCB = \frac{CL + \Delta HT}{1 + \exp\left(\begin{array}{l} 2.41 - 2.29 * \log(CR) - 0.206 * \log(\mathrm{CCF} + 1) - 0.478 * \log(1.01 - CR) \\ - 0.021 * (ShTol^2) + 0.271 * (ShTol \times CR) \end{array}\right)}$$

where ΔHT is predicted height increment from equation 3-7 and *ShTol* is species shade tolerance ranking (Niinemets and Valladares 2006; table 3-19). By incorporating shade tolerance into the equations, species accounts for much of the variation observed in crown recession.

Table 3-19. Total number of observations of growth data by species with mean, standard deviation (SD) and coefficient of variation (CV%) for diameter (ΔDBH) and height increment (ΔHT), and crown recession (ΔHCB).

Species	DBH *(# of obs.)*	ΔDBH *(cm/yr)*			ΔHT *(m/yr)*			ΔHCB *(m/yr)*		
		Mean	SD	CV%	Mean	SD	CV%	Mean	SD	CV%
Balsam fir	958,162	0.26	0.23	90%	0.17	0.50	300%	0.18	0.66	372%
Black spruce	339,278	0.16	0.15	90%	0.12	0.15	122%	0.10	0.32	319%
Red spruce	303,937	0.21	0.20	92%	0.14	0.34	240%	0.18	0.53	294%
Red maple	259,252	0.17	0.16	91%	0.13	0.27	211%	0.14	0.39	290%
Paper birch	161,343	0.14	0.13	97%	0.09	0.30	324%	0.09	0.36	411%
Sugar maple	118,852	0.15	0.14	97%	0.10	0.27	260%	0.09	0.41	487%
White spruce	102,486	0.27	0.25	93%	0.23	0.24	107%	0.16	0.42	265%
Northern white-cedar	99,653	0.13	0.17	131%	0.32	1.29	408%	0.21	1.32	634%
Yellow birch	76,806	0.18	0.17	95%	0.11	0.26	235%	0.08	0.42	529%
Eastern white pine	48,054	0.44	0.34	78%	0.23	0.31	133%	0.17	0.42	248%

Model Performance

Predictions of annual ΔDBH were made and compared to predictions made by FVS that use the equations of Teck and Hilt (1991). Results showed the FVS equation to heavily overestimate ΔDBH on average and the increment equation developed here to slightly underestimate when comparing mean bias (figure 3-19). Root mean square error (RMSE) ranged from 0.99 to 1.83 cm/year, and mean bias (MB) ranged from -0.03 to 0.30 cm/year for the most common species. Predictions of ΔDBH were robust across Maine, as model error did not appear to be correlated with site or physiographic features such as site index and latitude (figure 3-20).

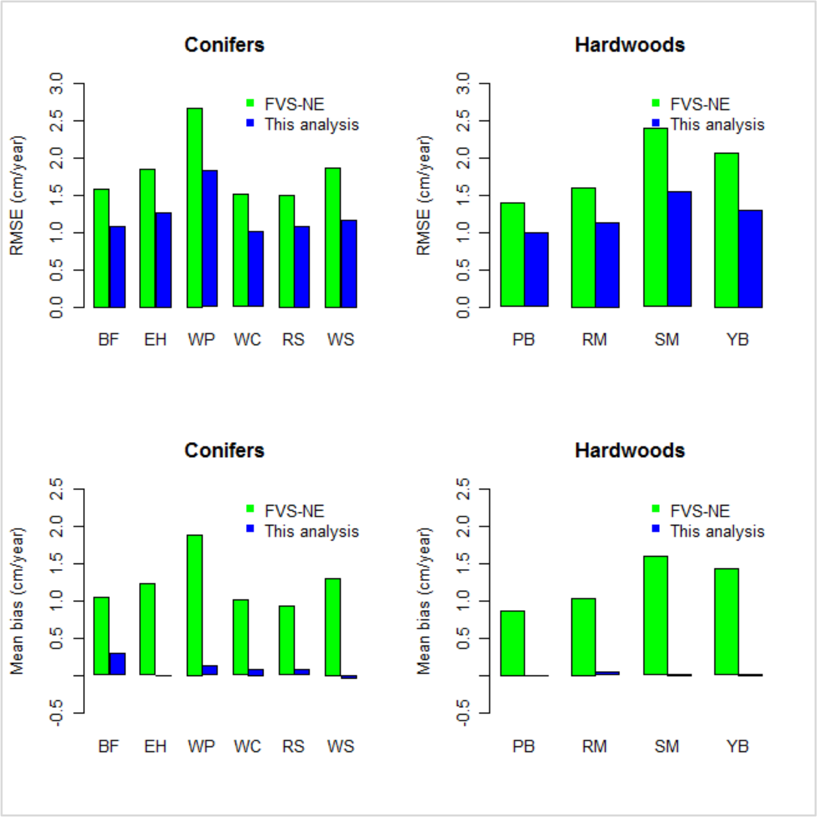

Figure 3-19. Root mean square error (RMSE) and mean bias comparing diameter increment equations in FVS-NE with those in this analysis for ten common species for trees greater than 11.5 cm in diameter.

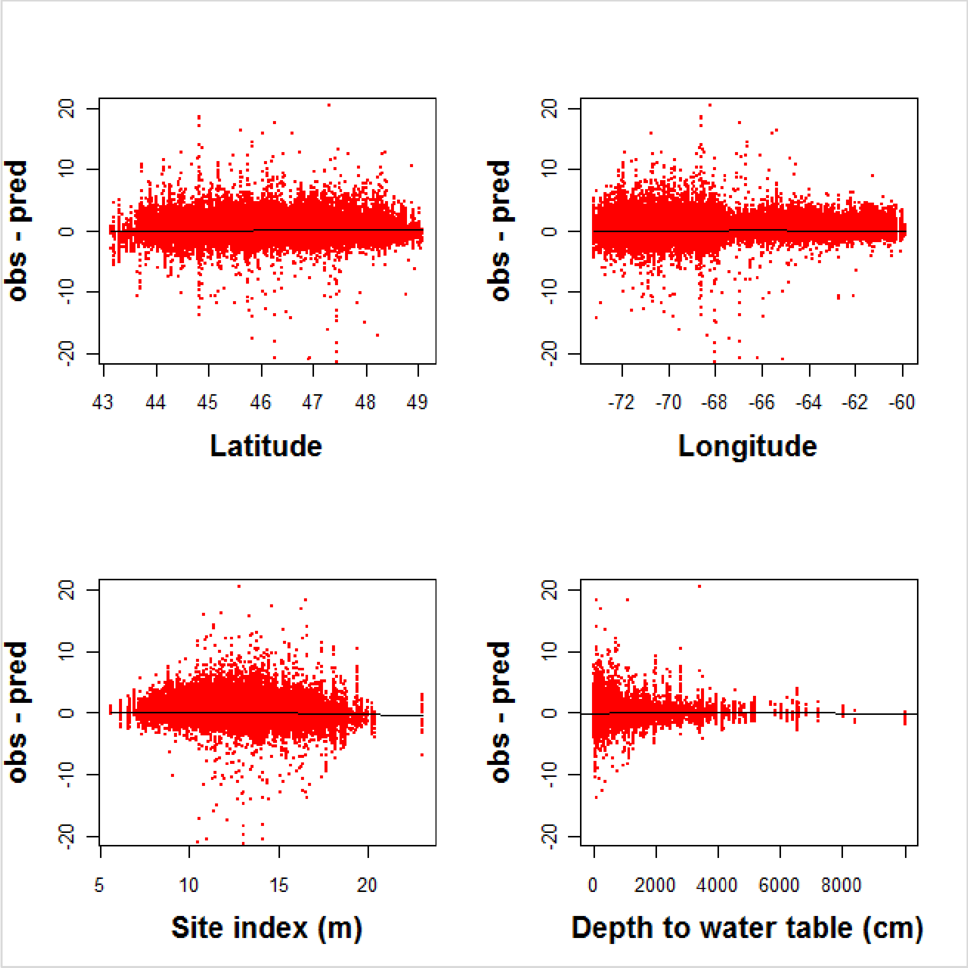

Figure 3-20. Observed annual DBH increment (obs) and predicted annual DBH increment (pred) with refined models under various site and physiographic features in Maine.

Modeling ΔHT appeared to be adequately captured using the maximum-modifier approach. RMSE ranged from 0.20 to 0.53 m/year, and MB ranged from 0.00 to 0.06 m/year for estimating ΔHT for various species. Models indicate that crown recession is strongly influenced by tree crown ratio. Models show that crowns will recede to a greater degree for shade intolerant species Figure 3-22). RMSE ranged from 0.31 to 0.70 m/year, and MB ranged from -0.10 to 0.06 m/year for predicting ΔHCB.

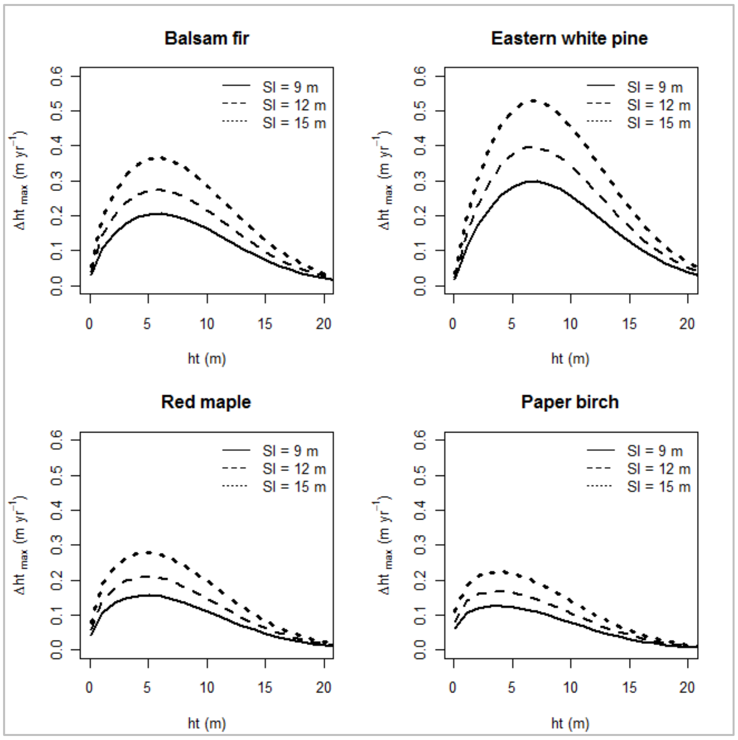

Figure 3-21. Predictions of maximum height growth at various site indices (SI) for four species with differing growth characteristics.

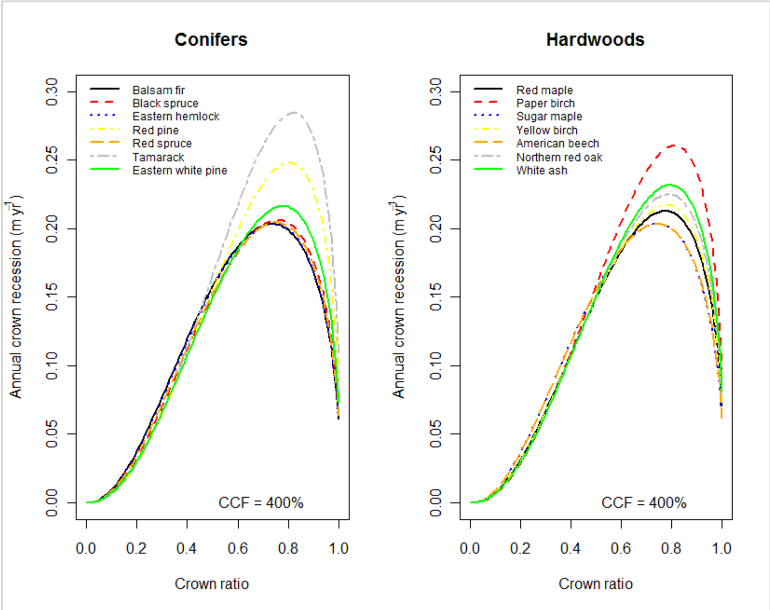

Figure 3-22. Model predictions of annual crown recession for the primary conifer species in the Acadian region and relationship with tree crown ratio.

Discussion and Future Work

The equations developed have shown significant improvement over currently-used equations and are adequately representing the various growth patterns for the many species in the Acadian forest. Models will continue to be tested, validated, and assessed for their performance. Improvements in model parameters will continue to be made as needed. A significant test of the increment equations will be in forecasting their performance with long-term data and for stands that have undergone thinning. Improvements over the current FVS are likely due to the fact that models are designed using data from the Acadian forest, contemporary statistical models are being fitted, and models are designed to provide annual output so that they provide flexible inference.

A beta version of the model has been constructed and is currently being used to test the performance of the model as each of the component equations are compiled under a single framework. This becomes essential when components such as tree volume (Li et al. 2011b) and ingrowth (Li et al. 2011a) are added to the model. Continual effort is focused on a developing a software interface the make the model widely available to users. User feedback on modeling efforts is always encouraged.

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Wildlife

Snowshoe Hare and Canada Lynx

Spruce Grouse

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

Graduate Research Assistant David Mallet conducting spring snowshoe hare pellet

Authors:

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

Background and Project Overview:

Snowshoe hares are a keystone species affecting plant succession, nutrient cycling, and populations of numerous predators (e.g., lynx, fishers, red fox, coyote, bobcat, marten, several hawks and owls), and co-existing prey species (e.g., red squirrels, small mammals, grouse, deer and mountain sheep) 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 as threatened in the lower 48 U.S. states and in New Brunswick, Canada. High densities of hares are associated with early-successional forest conditions, resulting from natural disturbances and forest harvesting. In Maine, the highest densities of hares (1.5-2.5 hares/ha) occur in regenerating clearcuts, and high densities of hares are thought to occur in these stands during the period spanning 15-35 years after cutting. In fact, regenerating clearcuts maintain hare densities that are a magnitude higher than those observed in uncut, mature stands and in selection-harvested stands, and are essential to achieving landscape densities of hares required for lynx occurrence in the Acadian forest.

High quality hare habitat (HQHH) has been defined as softwood-dominated regenerating stands supporting >0.32 hares/acre and > 27% HQHH has been recommended in potential home ranges of lynx based on observed patterns of landscape occupancy. However, most of the HQHH that currently exists in a configuration suitable for lynx originated from clearcuts in the 1970's and 1980's that were subsequently treated with herbicides (e.g., Glyphosate). Notably, many of these stands are now transitioning towards the pole stage, and, using the assumption that these stands will rapidly transition out of HQHH when stands self-thin at age 35, the supply of lynx habitat in Maine has been projected to decline substantially after about 2012. Although the age when stands transition out of hare and lynx habitat is critical for management, it is still unknown.

Graduate Research Assistant, Sheryn Olson conducting winter vegetation and visual obstruction measurements for snowshoe hares.

Thus, in this project we propose to continue to monitor 15, benchmark conifer clearcuts stands to assess their long-term trajectories in hare densities as related to their age since cutting, site quality, and structural conditions. Further we are attempting to understand seasonal shifts in habitat use of snowshoe hares and lynx as they relate to different harvesting treatments on commercial forestlands and to document the extent that lynx depend on snowshoe hares during the winter and summer seasons. Finally, to better understand the role of changing hare densities on lynx, we are collaborating with biologists at Maine Department of Inland Fisheries and Wildlife (MDIFW) to evaluate changes in spatial ecology and habitat use by lynx during periods of lynx abundance and relative scarcity.

Summary of Activities in FY 2011

Research activity during FY 2011 focused on 4 aspects of the project: 1) conducting our bi-annual pellet count surveys (May-June and September-October) to estimate changes in relative hare densities across our 28 reference stands; 2) conducting summer (July – August) vegetation surveys to index hare cover, visual obstruction, and relative food availability across our 28 stands; 3) initiation of a new lynx food habits study utilizing feces opportunistically collected during winter field work conducted by MDIFW and during previous University of Maine research, which has been coupled with additional scats collected during summer (July 2011) surveys conducted using a trained scat-locating dog from the Center for Conservation Biology at the University of Washington; and 4) continued analysis of long-term field data for lynx equipped with GPS and VHS collars during the period 2001-2010 (graduate student David Mallet's M.S. thesis project).

Hare Density Monitoring

We monitored summer and winter hare densities in 15 previously herbicide treated, non-thinned, regenerating conifer-dominated clearcut stands that range from 23-38 years post-harvest. Additionally, we monitored hare densities in 10 selection stands ranging from 8-17 years post-harvest, in 2 conifer shelterwood stands ranging from 20-26 years post harvest, and in 3 uncut mature softwood/mixed stands. Pellet densities increased 110% in regenerating stands, 165% in selection and shelterwood stands, and 350% in uncut mature stands from summers 2009 to 2010, suggesting a banner reproductive year for hares and indicating that populations may be starting to recover from the 10 year nadir observed in summer 2009 and winter 2010. Population recovery, as quantified by the over-winter densities of hares in 2010; however, was much more modest (figure 4-1). Hare densities in regenerating conifer stands increased 21% during winter 2011 relative to the 10-year low in hare densities observed during winter 2010. Similarly, densities across the selection and shelterwood stands increased 16% in 2011, whereas winter hare densities in the uncut mature stands were stable (-1%) in 2011. We will continue to monitor hare densities through winter 2013 to evaluate whether the recovery of hare populations is commensurate with levels observed (range 1.79-2.22 hares/ha) in regenerating stands during winters 2001-2006.

Summer Vegetation Surveys

We are attempting to better understand seasonal habitat shifts of hares from the summer to the winter season, and to evaluate the effects of these changes on seasonal habitat quality for Canada lynx across a range of forest management treatments. Thus, we measured the relative food availability for hares, overhead canopy closure, stem cover, and visual obstruction for hares across 20 plots within each of the 28 stands that we continue to monitor (560 plots total) during summer 2011. We will repeat those measurements in 10 plots within those 28 stands during winter 2012 (280 plots anticipated). We will model the effects of stand type, year, food, seasonal change in overhead cover, and seasonal changes in visual obstruction to a resting hare on the dependent variable of seasonal changes in hare density. Our results will allow us to make inferences about the relative value of these harvest treatments for hares and lynx during summer and winter. This sub-project is a focus of Sheryn Olson's M.S. thesis, which is scheduled for completion by 31 December 2012.

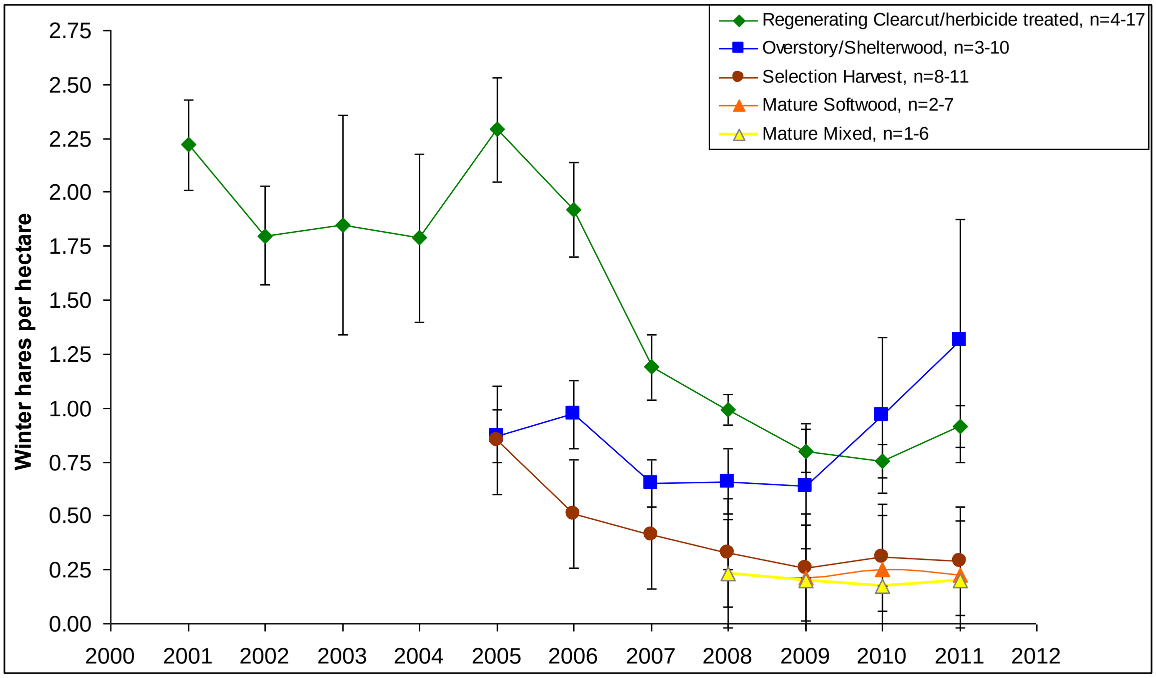

Figure 4-1. Preliminary (do not cite) snowshoe haredensities during winter across five forest stand types: regenerated conifer stands 23 to 38 years post-clearcut and herbicided three to five years post-harvest; overstory removal; shelterwood harvests; selection harvests; mature softwood stands; and mature mixed conifer-deciduous stands. Whiskers span the mean ± one standard error.

Lynx Food Habits Study

Prior to our efforts, there was no planned investigation of diets of lynx in Maine to complement the field studies of hares and lynx conducted by the University of Maine (UM) and the MDIFW. UM researchers collected 42 scats from lynx of known sex and age during winter months in 2001-2002. MDIFW also collected approximately 65 winter scats during 2001-2008 and approximately 25 scats from lynx during ecoregional surveys throughout northern Maine. Nearly all of those scats were collected during a sustained period of high hare densities spanning 2001-2006.

Graduate Research Assistant ,David Mallet fixing a GPS transmitter to a captured adult lynx.

No summer lynx scats had been collected in Maine, as they are very difficult to detect and verify as to species in the absence of tracks on snow. Thus, we utilized a trained scat detection dog as a cost-efficient and non-invasive technique for collecting lynx scats during summer. During July 2011, we contracted with a scat detection dog team from the Center for Conservation Biology at the University of Washington. During 94.6 km of ground surveys, we collected 235 "probable" lynx scats.

We have arranged for genetic analyses to verify species and gender of scats using the Conservation Genetic s Laboratory at the University of Washington. The U.S. Fish and Wildlife Service has contributed $3,000 toward the initial analyses, and approximately $6,000 in remaining funding is required to complete the genetic work. We will continue to pursue outside funding for this aspect of the project and hope to have genetic analyses and the subsequent dietary analyses completed as part of Sheryn Olson's M.S. project by December 2012.

Analysis of Long-term Lynx Telemetry Data

Graduate student David Mallet is analyzing long-term telemetry data collected under the direction of lynx biologist Jennifer Vashon, MDIFW. Those data were collected by MDIFW personnel during 2001-2010, and included $40,000 in CFRU support to MDIFW during FY's 2009 and 2010. David is co-advised by Daniel Harrison, Professor and Cooperating Scientist with CFRU and by Angela Fuller, former CFRU-funded researcher and currently the Assistant Unit Leader, NY Cooperative Fish and Wildlife Research Unit at Cornell University. Activities in 2011 included: 1) the completion of a study of habitat bias and fix success in GPS collars on lynx to provide for baseline corrections needed to compare data from lynx monitored using VHF and GPS collars; 2) completion of a satellite-derived habitat map depicting areas of high quality hare habitat during the high (2001-2006) and low (2008-2010) hare density periods; and 3) completion of analyses that compare spatial ecology of lynx between the high and low hare density periods (e.g., table 4-2).

Ongoing analyses are comparing home range- and stand-scale patterns of habitat use by lynx during periods of high and low hare density. This sub-project will be completed as an M.S. thesis and will be distributed to cooperators during FY 2012.

Graduate Research Assistant David Mallet conducting telemetry during winter on a radio-equipped lynx.

Table 4-2. Preliminary (do not cite) home range areas (km^2) for non-breeding/non-denning (NB/ND) and annual periods for lynx in northern Maine, USA during a high (2001-2006) and low (2007-2010) hare density period. Home ranges were estimated using a 90% fixed kernel with an ad hoc bandwidth selection.

Sex (Period)	NB/ND			Annual		
	n	Mean ± SE	Range	n	Mean ± SE	Range
M (High)	12	55.78 ± 5.82	27.72 – 96.72	12	56.75 ± 5.75	30.28 – 68.69
M (Low)	10	64.94 ± 12.3	23.26 – 130.38	7	54.96 ± 12.71	24.19 – 102.16
F (High)	11	39.52 ± 3.99	18.42 – 67	11	36.64 ± 4.47	16.92 – 69.73
F (Low)	7	35.7 ± 8.34	20.15 – 83.7	4	28.99 ± 4.95	22.23 – 43.35

RELATIVE DENSITIES, PATCH OCCUPANCY, AND POPULATION PERFORMANCE OF SPRUCE GROUSE IN MANAGED AND UNMANAGED FORESTS IN NORTHERN MAINE

Authors: Daniel Harrison and Stephen Dunham

Stephen Dunham using radio telemetry to locate a tagged female spruce grouse. Photo by Mitch Jackman

Background and Project Overview

Female spruce grouse with a necklace radio transmitter just after release. Photo by Mitch Jackman

Spruce grouse (*Falcipennis canadensis*) are a species of forest grouse dependent on conifer dominated forests (Boag and Schroeder 1992, Storch 2000). Although abundant across Canada and Alaska, 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 (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, and 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.

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 classic habitats that spruce grouse are often associated with may be declining as well. To the contrary, Homyack (2003) observed that spruce grouse utilized pre-commercially thinned stands (PCT), which suggests that some recently harvested areas might provide suitable habitat conditions. Thus, a better understanding of patterns of habitat occupancy and the relative quality of residual conifer and actively managed conifer stands is needed to assess the current and future status of spruce grouse in Maine's commercially managed forests.

Traditionally, it has been assumed that spruce grouse inhabit large patches of mid-late successional conifer forests and coniferous forested wetlands. Clearcutting has been shown to reduce the survival and reproductive success of spruce grouse by forcing them to move into the adjacent uncut buffer strips (Turcotte et al. 2000, Potvin and Courtois 2006). Similarly, Lycke et al. (2010) reported that male spruce grouse were less likely to occur in commercially thinned stands in Quebec. To the contrary, populations of spruce grouse in the Adirondack Forest Preserve continue to decline despite widespread prohibitions on forest management activities (Bouta and Chambers 1990). Additionally, spruce grouse have been documented to occur in plantations and PCT stands (Boag and Schroeder 1992), which implies that some forestry practices might promote stand structures required by spruce grouse.

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. The proposed objectives of this project are to:

1) Survey and compare mating season densities of spruce grouse among A) regenerating clearcuts; B) two age classes of stands that have been clearcut, herbicided, and precommercially thinned; and C) residual stands of mid- and late-successional coniferous lowland forest.

2) Evaluate and compare patterns of patch occupancy of spruce grouse among clearcut, PCT, and residual conifer stands. Calculate average patch sizes, interpatch distance, and amount of each stand type in circles centered on home ranges and at a 50 m radius around survey stations that approximate two ecological spatial scales: A) the scale of daily foraging radius, and B) the scale of the home range of grouse and their broods during summer.

3) Model vegetation, stand, and landscape attributes associated with patterns of occurrence and home range placement of spruce grouse to evaluate characteristics that might be retained in harvested areas to maintain use by spruce grouse after harvesting.

4) Evaluate and compare home range area, survival, and recruitment of spruce grouse among our three vegetation types to evaluate relative population performance.

Methods

Our first field season was focused on GIS work, visiting with landowners, identifying potential research sites, and visiting, walking and cruising 30 potential stands meeting our vegetation management criteria, harvest prescription, and harvest interval. Survey transects were established in 20 stands that met our criteria. Those stands will be systematically surveyed beginning May 2012.

During 2 consecutive years (2012-2013) spruce grouse will be surveyed in the spring (May-June) using standardized transect surveys with pre-established broadcast locations (figure 4-2). At each location a recording of a female aggressive call (cantus) will be played and all responding birds will be captured with a noose pole and banded with unique colored leg bands (Schroeder and Boag 1989, Keppie 1992). Twenty females will be selected each year across the PCT, advanced regenerating, and residual forest treatments, and will be equipped with radio transmitters to monitor their subsequent habitat use, home range area, survival, nest success, and recruitment. During July, brood surveys will be conducted using procedures similar to the cantus surveys except that a chick distress call will be utilized. Birds will again be captured and marked, but chicks will be equipped with wing tags.

Vegetation data will be systematically inventoried in each of 20 stands surveyed for spruce grouse occurrence using established protocols used during concurrent snowshoe hare studies. Height, dbh, species grouping, and density of overstory and understory stems, as well as the percent ground cover, percent canopy cover, volume of dead and down woody material, and horizontal cover will be inventoried within surveyed stands, at locations used by grouse, at positive survey stations, and at sites that are surveyed but repeatedly do not provide evidence of grouse presence. Information theoretic modeling will be used to evaluate vegetation characteristics which best discriminate among used (i,e, telemetry locations), occupied (grouse observed during call surveys), and unused (i.e., no positive survey locations or telemetry observations) sites. Home ranges will be estimated using kernel density estimators and vegetation in occupied home ranges will be compared to vegetation characteristics available in our 4 vegetation types. Further, effects of landscape and stand characteristics on home range area, survival and recruitment rates of birds will be assessed.

Male spruce grouse being removed from capture pole by field technician. Photo by Stephen Dunham

Progress During 2011

During the 2011 field season we located and established our survey sites and have explored over 30 potential sites. A third of these sites were eliminated due to a combination of factors including: past harvest activities, impending harvest, accessibility issues, and area of the site. We currently have 20 sites established (figure 4-3), including 9 that are also used as part of the snowshoe hare monitoring project. The established sites are broken into four categories: 1) five mid-late successional lowland softwood stands, 2) five non-thinned regenerating conifer stands, 3) five stands that are at least 10 years post-PCT, and 4) five stands that are at least 15 years post-PCT (table 4-2).

Initial cantus surveys and brood surveys were conducted during the late summer/early fall of 2011 to test the effectiveness of fall survey techniques. We completed 22 surveys (10 cantus and 12 brood) on 12 sites and recorded only five responses from females, and one male, during brood surveys and five responses from males during cantus surveys. However, 15 additional non-responding grouse were observed while moving among survey locations. This suggests that late summer/early fall surveys are not particularly efficient, and future survey efforts will be concentrated during the spring.

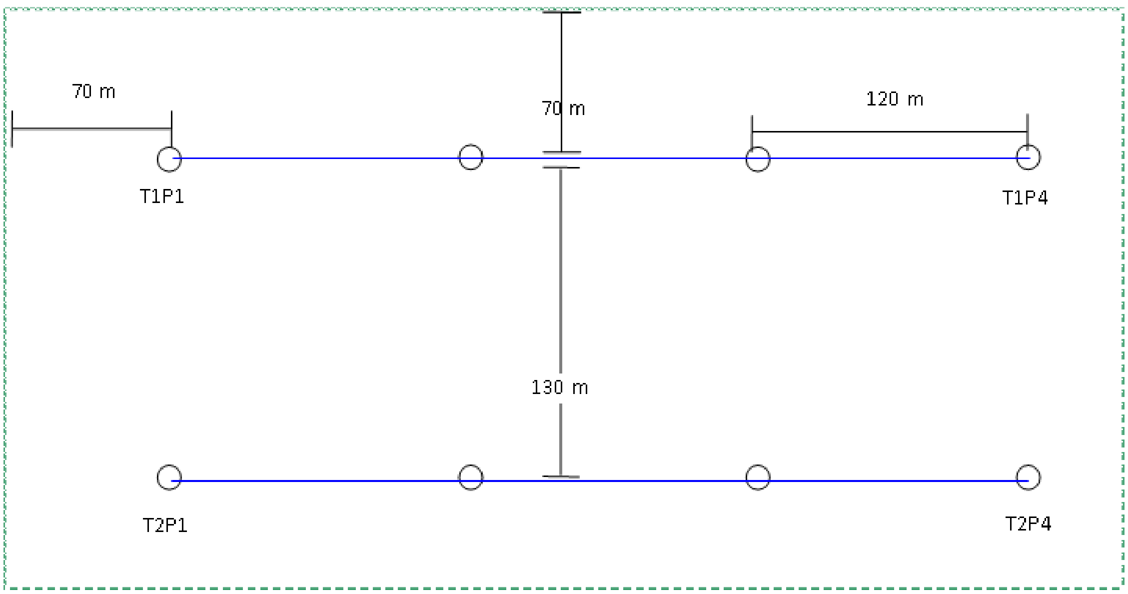

Figure 4-2. Generic survey stand map showing the spacing and location of broadcast locations. This design is uses established transects for surveying snowshoe hare density and habitat associations, which are present at most sites.

Table 4-2. Stand names, locations, and habitat types.

Stand Type	Stand Name	Township	Northing	Easting
Mature softwood	MSW2	T5R12	5105669	0480144
	MSW3	T5R12	5114593	0468528
	MSW9	T4R12	5088849	0476112
	MSW10	T6R13	5112809	0467144
	MSW11	T6R13	5116481	0468210
Advanced Regeneration	JH01C	T4R11	5096050	0487450
	JH02C	T4R11	5095454	0490399
	JH03C	T4R11	5098147	0484328
	JH04C	T5R11	5103344	0485151
	JH05C	T4R11	5097403	0492861
10y post PCT	1-1-T	T4R11	5095457	0488242
	1-2-T	T4R12	5092585	0478833
	1-3-T	T4R11	5094656	0490237
	1-4-T	T4R11	5092928	0488228
	1-5-T	T4R12	5096155	0476768
15y post PCT	15Y1	T5R11	5100288	0491362
	15Y2	T5R11	5101595	0491144
	15Y3	T6R13	5110730	0464625
	6-4-T	T5R11	5102028	0485802
	6-6-T	T5R11	5102769	0487173

Spruce Grouse *Photo by Pamela Wells*

Figure 4-3. Study area and study site locations, Piscataquis County, Maine.

Plans for 2012 and Beyond

During April and May of 2012 we will conduct three sets of cantus surveys and will attempt to capture and color band all responding or observed grouse. Radio transmitters will also be placed on 20 females. Telemetry locations will be taken at least weekly in order to establish range, and to locate nesting sites and brood ranges. Habitat will be surveyed at telemetry locations, survey locations, and at survey locations that are unsuccessful. Approximately 1-2 weeks after hatching, we will initiate brood surveys at our sites using a chick distress call. Responding grouse will be captured and banded. For telemetered hens, we will locate them throughout the summer and early fall to quantify number of chicks fledged to 1 October. Telemetry locations will continue through the fall to document movements of grouse to wintering habitats.

Data collection will be the primary activity during fiscal years 2011-12 and 2012-13, with primary efforts shifted to data analysis, report writing, and preparation of results scheduled for 2013-14. The project is scheduled for completion by December 2014.

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Appendix

Outreach

OUTREACH

Journal publications

Arseneault, J.E., M.R. Saunders, R.S. Seymour, and R.G. Wagner. 2011. First decadal response to treatment in a disturbance-based silviculture experiment in Maine. Forest Ecology and Management 262 (3): 404-412.

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