Cooperative Forestry Research Unit

2012 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: "Mixedwood forest near Orono, Maine – August 18th, 2012

Photo courtesy of Daniela M. Roth

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RESEARCH HIGHLIGHTS

SILVICULTURE

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

MODELING

- **REFINEMENT of the FVS:** Forest managers rely on growth and yield models to assess whether their short-term plans will meet long-term sustainability goals. Forest growth and yield models currently in use in Maine, such as the Forest Vegetation Simulator (FVS), were initially built on data from the 1970s and 1980s and often use older statistical techniques. Subsequent tests have shown that these models may not produce the best predictions of how the forests of Maine will grow. As a result, this project was initiated to develop improved allometric and growth equations through the use of an extensive regional database of permanent growth and yield plots. To date, several equations and a site productivity model have been improved and are being evaluated over a range of silvicultural treatments. A beta version of the improved model has been constructed and includes a relatively simple software interface which will allow for seamless integration into existing software systems.

WILDLIFE HABITAT

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

Bill Patterson
Chair, Advisory Committee

CHAIR'S REPORT

The 2012 CFRU annual report is once again full of timely and useful research results from the Maine forest. I would like to thank the staff, scientists, and students listed below that engage the CFRU and do the hard work to advance the research agenda each year. I also extend my thanks to the CFRU member companies, agencies and conservation organizations that year after year provide financial support for this research and also donate the professional staff time that is critical to the operation of the Advisory Committee. It is the ongoing engagement of these professional foresters and land managers that makes the CFRU so effective in its ability to address the most important research questions today.

I trust that forest managers will continue to benefit from the application of this information to better understand and manage the forest resource in Maine. The continuity and longevity of certain CFRU studies is remarkable including the Austin Pond Study established in 1977 as well as the snowshoe hare study which has extended over the last decade. This commitment to long term research is somewhat rare in science and further demonstrates the value of the end-user driven model of research prioritization that exists within CFRU. At the same time, it is gratifying to see the CFRU cooperators and scientists work together to tackle emerging research questions quickly and efficiently as they have recently with the development of the Spruce Budworm decision support tool.

There are too many contributors to the work of the CFRU to thank them each by name but I must point out the highly effective and well organized staff at the CFRU who made my work as Chair so enjoyable and always position the Advisory Committee to be effective in its work. It has been a pleasure to work with such an earnest yet cooperative group of professionals and to observe the critical questions that are asked in the shaping of the CFRU research agenda each year.

Robert Wagner
Director, CFRU

DIRECTOR'S REPORT

Thanks again go to our CFRU members, staff, Cooperating Scientists, Project Scientists, and graduate students who make the unit a success. The CFRU remains strong after 37 years of industry / university collaboration to solve Maine's most pressing forest management challenges. We are one of the oldest forest research cooperatives in the country and continue to provide critical leadership on key issues facing Maine's forestland managers in the region and country.

Special thanks go to the CFRU Executive Committee (**Bill Patterson, Greg Adams, Mark Doty,** and **Kevin McCarthy**) for their continued leadership and hard work in keeping the CFRU functioning smoothly for its members and the University. **Brian Roth** continued to do a great job as CFRU's Associate Director by installing a fantastic new experiment at Austin Pond, maintaining our Commercial Thinning Research Network (CTRN) sites, and managing 20 summer students on a variety of other CFRU projects. **Mohammad Bataineh** developed some excellent research findings on the 40-year results from the Austin Pond Study (APS) and increased our understanding about natural regeneration in the region. CFRU Cooperating Scientists (**Jeff Benjamin, Dan Harrison, Bob Seymour,** and **Aaron Weiskittel**) continued to provide us with strong research leadership in the areas of forest operations, wildlife habitat, silviculture, and forest modeling.

After a dynamic year of changes in temporary staffing in the CFRU office, we welcomed **Cindy Smith** as the new CFRU Administrative Assistant. We especially want to thank **Kae Cooney,** Center for Research on Sustainable Forests (CRSF), for stepping in to train our string of temporary assistants and keeping the program moving forward.

As is evident in the following 2012 CFRU Annual Report, the unit continues to deliver a wide array of relevant research finding that are contributing to the sustainable management of Maine's working forests.

MEMBERSHIP

Major Cooperators

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

Other Cooperators

Field Timberlands
Finestkind Tree Farms
LandVest

Advisory Committee

William Patterson, Chair
The Nature Conservancy

Greg Adams, Vice -Chair
JD Irving, Ltd.

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

Kevin McCarthy, Member-at-large
SAPPI Fine Paper

Members

John Brissette, USFS Northern Research Station

John Bryant, American Forest Management, Inc.

Jason Castonguay, Canopy Timberlands Maine, LLC

Tom Charles, Maine Division of Parks & Public Lands

Brian Condon, The Forestland Group, LLC

Dave Daut, Timbervest, LLC

Everett Deschenes, Old Town Fuel & Fiber

David Dow, Prentiss & Carlisle Company, Inc.

Kenny Fergusson, Huber Resources Corporation

Ian Prior, Seven Islands Land Company

Gordon Gamble, Wagner Forest Management

Brian Higgs, Baskahegan Company

Eugene Mahar, Landvest

Marcia McKeague, Katahdin Forest Management, LLC

Jake Metzler, Forest Society of Maine

Rick Morrill, Baxter State Park, SFMA

David Publicover, Appalachian Mountain Club

Tim Richards, UPM Madison

Jim Robbins, Robbins Lumber Company

Dan Russell, Huber Engineered Woods, LLC

RESEARCH TEAM

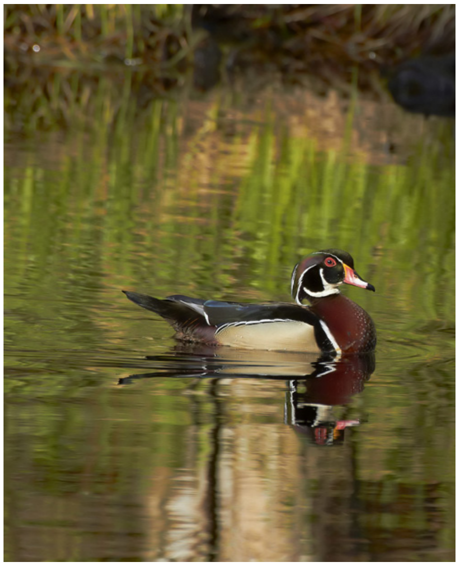
Staff

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

Brian Roth, Ph.D., Associate, Director

Mohammad Bataineh, Ph.D., Research Scientist

Cynthia Smith, Administrative Assistant



Wood Duck *photo by Pamela Wells*

Cooperating Scientists

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

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

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

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

Project Scientists

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

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

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

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

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

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

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

Matthew Olson, Ph.D., Missouri Department of Conservation

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

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

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

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

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

Upper Togue Pond, Baxter State Park (August 3rd, 2012) - photo by Daniela M. Roth

FINANCIAL REPORT

Thirty-two members representing 8.27 million acres of Maine's forestland contributed $500,107 to support CFRU this year (table 1-1). The amount of acreage remained stable despite some changes in ownership: **Huber Resources Corporation** sold land and **Snowshoe Timberlands, LLC** became a member of the CFRU. We thank all of our members for their continued support as the economy continues to recover.

In addition to member dues, CFRU Cooperating and Project Scientists were successful at leveraging an additional $169,764 in grants and in-kind support from extramural sources to support approved CFRU projects. Of these funds, $70,000 came from the **National Science Foundation** as part of CFRU's membership in the national **Center for Advanced Forestry Systems** (CAFS), which is supporting our growth & yield modeling efforts. Thus, 19% of total CFRU funding came from outside sources to support our research program (figure 1-1). UMaine in-kind contributions from reduced overhead was $227,232 or 25% of total CFRU funding. Total CFRU funding including these leveraged sources was $897,103.

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**), $7.11 was received from other CFRU member dues, $2.75 in external grants through CFRU scientists, and $3.68 in in-kind contributions from UMaine; for a total of $13.54. CFRU research expenses by category included 62% on silviculture & productivity, 25% on wildlife habitat, and 12% on improving forest growth & yield models (figure 1-2).

Continued sound fiscal management by CFRU project scientists and staff resulted in spending $8,137 (1.5%) less than the $551,217 that was approved by the Advisory Committee including $10,200 that was carried-over for a project from the previous fiscal year. All projects came in under or on budget. Unfortunately, due to a small accounting oversight at the University Systems office, there was a long delay in charging overhead for facilities and administration for the months of July, August, and September. This oversight resulted in a late charge of $14,434 from the UMaine System well after the fiscal year ended. By using the unspent funds from CFRU projects, however, we were able to reduce the overage to $6,297 (or ~1% of the total budget) (table 1-2). To make up for this shortfall, this overage was removed from the Austin Pond and CTRN projects for the 2012/13 fiscal year. Thus, we were able to avoid requesting any additional funds from the Advisory Committee to balance the budget.

CFRU Funds by Source (FY11-12)

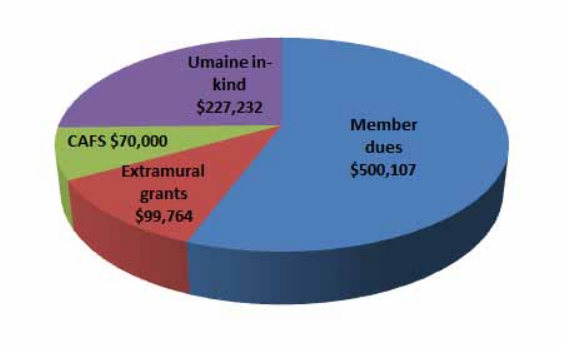


Figure 1-1. CFRU funds by source during FY11-12 (October 1, 2011 to September 30, 2012).

Program Expenses by Research Area (FY11-12)

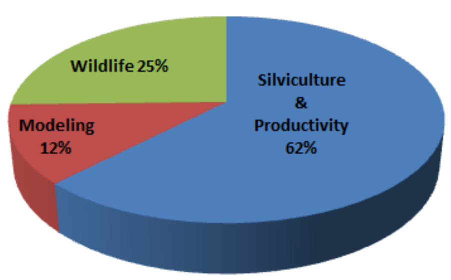


Figure 1-2. CFRU research expenditures by category during FY11-12 (October 1, 2011 to September 30, 2012).

Table 1-1. CFRU dues received during FY 11-12 (October 1, 2011 to September 30, 2012).

LANDOWNERS / MANAGERS	2012 Acres	Amount Requested	Amount Received
Irving Woodlands, LLC	1,255,000	$68,804	$68,804
Wagner Forest Management	1,120,200	$61,956	$61,956
BBC Land, LLC	971,538	$54,333	$54,333
Plum Creek Timber Company, Inc.	884,000	$49,667	$49,667
Prentiss and Carlisle Company, Inc.	807,882	$45,610	$45,610
Seven Islands Land Company	721,261	$40,993	$40,993
Clayton Lake Woodlands Holding, LLC	425,281	$24,836	$24,836
Maine Division of Parks and Public Lands	400,000	$23,360	$23,360
Katahdin Forest Management, LLC	299,000	$17,462	$17,462
Canopy Timberlands Maine, LLC	294,298	$17,187	$17,187
The Nature Conservancy	175,863	$10,270	$10,270
The Forestland Group, LLC	147,467	$8,612	$8,612
Snowshoe Timberlands, LLC	137,720	$8,043	$8,043
Timbervest, LLC	110,000	$6,424	$6,424
Baskahegan Corporation	99,487	$5,810	$5,810
Sylvan Timberlands, LLC	99,177	$5,792	$5,792
North Woods ME Timerlands, LLC	84,236	$4,919	$4,919
Appalachian Mountain Club	65,445	$3,822	$3,822
Frontier Forest, LLC	53,338	$3,115	$3,115
Baxter State Park, SFMA	29,537	$1,725	$1,725
Robbins Lumber Company	27,224	$1,590	$1,590
St. John Timber, LLC	24,845	$1,451	$1,451
EMC Holdings, LLC	23,526	$1,374	$1,374
Mosquito, LLC	16,222	$947	$947
LANDOWNERS / MANAGERS TOTAL	**8,272,547**	**$468,103**	**$468,103**
WOOD PROCESSORS	**2012 Tons**		
Sappi Fine Paper	1,800,797	$22,870	$22,870
Madison Paper Industries	334,150	$4,244	$4,244
Old Town Fuel & Fiber	196,070	$2,490	$2,490
WOOD PROCESSORS TOTAL	2,331,017	29,604	29,604
OTHER COOPERATORS:			
Huber Engineered Woods, LLC		$1,000	$1,000
Landvest		$200	$200
Forest Society of Maine		$1,000	$1,000
Field Timberlands		$100	$100
Finestkind Tree Farms		$100	$100
OTHER COOPERATORS TOTAL		**$2,400**	**$2,400**
	GRAND TOTAL	**$500,107**	**$500,107**

Table 1-2. CFRU expenses by source during FY11-12 (October 1, 2011 to September 30, 2012).

PROJECT	Principal Investigator	Approved	Amount Spent As of 10/31/12	Balance Remaining	% Balance
ADMINISTRATION		**$193,843**	**$189,069**	**$4,774**	**2%**
Administration		$171,491	$166,717	$4,774	3%
Silviculture Post-Doc		$12,152	$12,152	$0	0%
Carry-Over for S.W. Cole contract *		$10,200	$10,200	$0	0%
RESEARCH PROJECTS					
Silviculture & Productivity:		**$265,977**	**$274,935**	**($8,958)**	**-3%**
Commercial Thinning Research Network	Wagner et al.	$62,822	$60,133	$2,689	4%
Early Commercial Thinning	Benjamin et al.	$11,275	$10,313	$962	9%
Machine Productivity and Cost	Benjamin et al.	$55,036	$55,675	($639)	-1%
Austin Pond: Third Wave	Wagner et al.	$55,826	$64,106	($8,280)	-15%
Young Hardwood Stand Responses	Wagner et al.	$21,958	$24,794	($2,836)	-13%
Partial Harvesting	Weiskittel et al.	$14,162	$14,600	($438)	-3%
Growth & Yield Modeling:					
Modeling Natural Regeneration	Weiskittel et al.	$18,798	$19,386	($588)	-3%
Spruce Budworm DSS	MacLean	$25,000	$25,000	$0	0%
CTRN Mortality	Weiskittel et al.	$1,100	$927	$173	16%
Wildlife Habitat:		**$91,397**	**$93,511**	**($2,114)**	**-2%**
Spruce Grouse Habitat	Harrison	$38,500	$39,197	($697)	-2%
Long-term Monitoring of Snowshoe Hare	Harrison	$52,897	$54,313	($1,416)	-3%
TOTAL		$551,217	$557,514	($6,297)	-1%

ACTIVITIES

Advisory Committee

The CFRU is guided by our member organizations through an Advisory Committee. The CFRU Advisory Committee elects officers for the Executive Committee for two-year terms in the positions of Chairperson, Vice Chairperson, Member-at-Large, and Financial Officer. The Vice Chairperson serves as Chairperson after one term, and the past Chairperson moves to the position of Financial Officer for one term. This year **Bill Patterson** of **The Nature Conservancy** (figure 1-3) assumed the position of Chair while **Mark Doty** of **Plum Creek** moved to the Financial Officer position previously held by **John Bryant** of **American Forest Management/BBC Land, LLC**. We thank John for his four years of service on the Executive committee. **Greg Adams** of **JD Irving, Ltd.** was elected as Vice Chair and, **Kevin McCarthy** of **SAPPI Fine Paper** was elected as Member-at-Large. Kevin replaced **Kip Nichols** of **Seven Islands Land Company** who served two consecutive terms. We thank Kip for his four years of service.

The Advisory Committee meets three times a year for business meetings. The first business meeting of the fiscal year was held on October 26, 2011 at the **University of Maine (UMaine)** where the committee approved a change to the membership contribution structure in order to maintain the long-term viability and financial sustainability of the CFRU. At the second meeting, held on January 25, 2012 at **UMaine**, eight pre-proposals were presented to the Advisory Committee. Of these, six were approved to advance to the full proposal stage and were presented at the April 11, 2012 business meeting. Four projects were approved for funding beginning on October 1, 2012. Look for updates on these projects in future CFRU functions and annual reports.

Cooperators

There were some land transactions and resulting changes to CFRU membership this year. **Huber Resources Corporation** sold 143,962 acres of forestland in Maine and has left the CFRU as a member in the landowner category. It is significant that Huber Corporation was a founding member of the CFRU in 1977.

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

Personnel

As always, there were personnel changes at the CFRU this year. **Dr. Mohammad Bataineh** was hired as the CFRU/USFS **Postdoctoral Research Fellow**. Mohammad earned his Ph.D. from **Stephen F. Austin State University** in **Texas**. Mohammad has been very active since joining the CFRU, conducting numerous analyses and contributing a number of excellent publications on CFRU projects. **Rosanna Libby** retired from CFRU after four years as Administrative Assistant. We will miss Rosanna and her dedication and attention to detail on CFRU affairs. **Kae Cooney**, Administrative Assist with the **Center for Research on Sustainable Forestry**, has done tremendous work in filling in for Rosanna while we searched for a replacement. A special thank-you to Kae for going above and beyond to keep the CFRU running smoothly. During this time, **Blane Shaw**, **Paula Portalatin,** and **Paula Hamlin-LeVasseur** temporarily assisted in the CFRU Administrative Assistant position.

2012 Fall Field Tour

On October 18th, 2012 the CFRU held its annual **Fall Field Tour**. This year's tour entitled **"Moose Density and Forest Regeneration"** was hosted on **Plum Creek Timber Company** lands and included the **Maine Chapter of the Wildlife Society**. Moose are an iconic species in Maine and are both economically and ecologically important to the North Woods. However, where moose density is high, browsing can negatively impact forest regeneration. There were presentations from biologists, scientists and land managers including: **Lee Kantar**, State deer and moose specialist; **Henning Stabins**, Plum Creek wildlife biologist; **Fred Servello**, UMaine Associate Dean/Director College of Natural Sciences, Forestry & Agriculture, and **Pete Pekins**, University of New Hampshire Wildlife Ecology Professor (figure 1-4).

Students

There currently are eight graduate students working on CFRU projects. This year, **Matt Russell** completed his Ph.D. under **Dr. Aaron Weiskittel**. Matt's research focused on modeling individual tree and snag dynamics in the mixed-species Acadian Forest as well as improving the Acadian Variant of the FVS model. We congratulate Matt on his completion and wish him the best in his new position as a post-doctoral fellow with the University of Minnesota.

Figure 1-4. Plum Creek Community Affairs Manager, Mark Doty leads a tour stop op the "Moose Density and Forest Regeneration" joint field tour with the CFRU and the Maine Chapter of the Wildlife Society on Ocotber 18th, 2012 near Little Spencer Mountain.

CENTER FOR ADVANCED FORESTRY SYSTEMS (CAFS)

By Bob Wagner and Aaron Weiskittel

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

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

CAFS provides $70,000 per year to the University of Maine and CFRU members to advance growth and yield models for natural forest stands in the Northeast. This funding supported Matt Russell (Ph.D. student) and Patrick Clune (M.S. student). Matt recently completed his Ph.D. dissertation entitled, “Modeling Individual Tree and Snag Dynamics in the Mixed-species Acadian Forest.” We congratulate Matt on his completion and wish him the best in his new position as a post-doctoral fellow with the University of Minnesota. Patrick is completing his last year analyzing the 10-year results from the CFRU Commercial Thinning Research Network.

In June 2012, the Center hosted the CAFS Annual Meeting in Bangor, ME. Over 65 scientists, graduate students, and forest industry representatives met to review and approve all CAFS projects nationwide. The meeting included a tour of UMaine and U.S. Forest Service research on the Penobscot Experimental Forest (figure 1-5).

Figure 1-5. Bob Wagner leads a presentation of a CAFS tour stop at the Penobscot Experimental Forest on June 28th, 2012.

Silviculture

Commercial Thinning Research Network

Regeneration Response to Thinning

Early Commercial Thinning

Harvest Productivity

Austin Pond Study

Young Hardwood Stands

Partial Harvesting

COMMERCIAL THINNING RESEARCH NETWORK: 2012 UPDATE

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

Introduction

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

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

Field Season

The 2012 CTRN measurement crew consisted of **Vance Brown**, **Justin Libby** and **Scott Austin** (figure 2-1). This measurement season was less intense than last, given the alternating measurement periods between the various experiments in the network. Generally, annual re-measurements alternate between an extensive measurement (EM) and an intensive measurement (IM) for a period of time following treatment. The extensive measurement consists of DBH and condition which captures information about mortality in a cost effective manner.

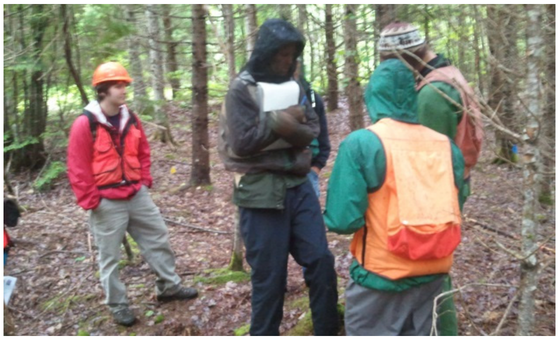


Figure 2-1. CTRN measurement crew working amongst the biting insects on the Penobscot Experimental Forest on June 5th, 2013.

In 2012, a total of 9 out of 15 installations were re-measured, all consisting of an IM. An IM always immediately follows a thinning treatment. The PCT experiment was thinned in the fall of 2011. In addition, we also began a one-time stem mapping of each individual tree in the CTRN which will conclude in 2013. Including mapped locations of each tree in the database will be required for future distance-dependent G&Y modeling efforts as well as remote sensing projects such as LiDAR (see Proposal).

Final Thinning at Weeks Brook

The last thinning treatment at Weeks Brook which was delayed from the Fall of 2011 due to operational constraints, was implemented the third week in November of 2012. This was the final thinning, with two plots (plots 2 and 5) marked to thin to 33 and 50% relative density reduction. The same contractor (**Roger Avery of Avery and Son Logging** in Milford, ME) who thinned the previous five installations, treated Weeks Brook (figure 2-2). Due to access issues and the small numbers of trees to be removed, the thinned trees were not salvaged, and were hand felled, limbed, bucked to short lengths (figure 2-3). Roger and his crew did an exceptional job assisted by Brian Roth and Adam Bland.

Figure 2-2. Avery & Son Logging at the Weeks Brook location: from left to right – Roger Avery and Ernest Leveille (November 21st, 2012).

Figure 2-3. Thinning crew working on Weeks Brook 33% removal CTRN plot on November 21st, 2012.

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 Bob Wagner, continues to synthesize the first 10 years of data for his MS project on a CAFS assistantship. These results will be reported in Patrick's MS thesis and presented in next year's CFRU Annual Report.

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

Matt Olson, Spencer Meyer, Robert Wagner, and Robert Seymour

Introduction

Silvicultural practices are typically prescribed to meet one or more specific goals. However, the ecological effects of silvicultural practices are often not limited to desired outcomes. A good example of this is commercial thinning (CT). A primary goal of CT is to concentrate site resources and growth on fewer overstory trees (Smith et al., 1997). Although not typically a stated goal, CT can trigger a regeneration response similar to partial-overstory removal regeneration methods (e.g., shelterwood and selection). Since there is usually a time lag between the thinning operation and subsequent canopy closure by residual crowns, CT can also redistribute resources to the understory, which, in turn, can stimulate tree regeneration.

Results from CT studies have shown a variety of understory regeneration responses. Inconsistencies among understory regeneration responses to thinning is likely related to differences among published studies in site conditions, stand history, species composition, thinning treatments, and time since thinning. Regeneration establishment and growth after thinning typically declines as overstory tree crowns expand to fill thinning gaps (Nyland 2002), but the reduction in understory development depends on thinning intensity. It is generally assumed that regeneration density increases with thinning intensity (Smith et al., 1997; Nyland, 2002). Most thinning studies in mesic forests directly attribute the positive relationship between thinning intensity and regeneration density to increasing availability of site resources, particularly light (Otto *et al.*, 2008), to the understory. However, other studies have shown that reduction in litter depth (Seiwa *et al.*, 2009) and increased seed production from the residual stand (Otto *et al.*, 2008) can also boost regeneration establishment after thinning.

A common forest management objective for eastern spruce-fir is to get high yields of commodity products, which is often accomplished through silvicultural systems emphasizing full stocking and shorter rotations than those used in other forest types of the region (Seymour, 1995). Therefore, standard silvicultural guidelines for eastern spruce-fir recommend managing for uniform, even-aged stand structures (Frank and Bjorkbom 1973; Blum et al., 1983; Seymour, 1995). Even-aged, spruce-fir stands are established mainly by natural regeneration and uniform shelterwood methods are recommended to achieve desired regeneration stocking when well-distributed, advance regeneration is lacking (Frank and Bjorkbom 1973; Seymour, 1995). Mid-rotation treatments, such as precommercial and commercial thinning, are recommended in eastern spruce-fir forests to space dense, naturally-regenerated stands, adjust species composition, boost residual tree growth, and reduce rotation length (Seymour 1995). Due to the shade-tolerance of the spruces and balsam fir, CT stands in stem exclusion likely stimulates the establishment of advance regeneration prior to initiation of regeneration methods.

The goal of this study was to enhance our understanding of the influence of CT on the development of tree regeneration in spruce-fir forests of Maine during the first decade after treatment. We evaluated regeneration responses using the CFRU Commercial Thinning Research Network (CTRN). We tested the general hypothesis that CT increases the density of tree regeneration in the understory of spruce-fir stands. Additionally, we tested the hypothesis that regeneration responds positively to increasing CT intensity (i.e., unthinned<light thinning<heavy thinning). Finally, we tested for effect of stand type on the composition and

density of softwood regeneration, which was based on our expectation of greater densities of softwood regeneration in older than younger spruce-fir stands, owing to advanced stand age and greater post-thinning mortality in older stands.

Methods

To test our hypotheses, we sampled forest regeneration at six sites of the CTRN, three each with (thin-now only) and without PCT (crown-thin only), to assess regeneration development under two levels of thinning intensity (33% and 50% relative density reductions) and an unthinned control. Counts 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 trees 0.1-1.4 m tall and >1.4m tall, respectively. For this investigation, data for tree species were classified according to size strata as follows: 1) small regeneration = 0.1-0.6m tall, 2) medium regeneration = 0.6-1.4m tall, and 3) large regeneration = 1.4m tall to 8.9cm DBH. Regeneration responses were assessed for softwoods (mainly the spruces and balsam fir) and hardwoods.

Analysis of variance (ANOVA) was used to test for an effect of CT treatment and stand type on the density of tree regeneration. Additionally, specific treatment comparisons were made using contrasts (e.g., 50% vs. 33%, thinned vs. unthinned, etc.). Analyses were conducted using SAS 9.2. Statistical significance was assessed at alpha = 0.10.

Results

Effect of Thinning

Thinning was a significant factor explaining regeneration density in ANOVA models for small and medium softwood regeneration, and small hardwood regeneration ($p<0.10$). Densities of all sizes classes of both softwood and hardwood regeneration were higher in thinned than unthinned stands (table 2-1 and figures 2-4 and 2-5). All size classes of softwoods and hardwoods were more abundant in the 50% thinning treatment than unthinned stands. Densities of small and medium softwoods were higher in 33% thinning than the unthinned stands, while only small hardwoods were more abundant in the 33% treatment. Although no differences were detected between 33% and 50% treatments, densities of small softwoods were nominally greater in 33% than 50% treatments. Conversely, the abundance of medium and large softwoods was nominally greater in the 50% than 33%. All size classes of hardwood regeneration were nominally greater in the 50%.

Effect of Stand Type

There was a significant effect of stand type on the density of medium softwood regeneration, but not for other size classes of softwoods or any size classes of hardwood regeneration. The density of medium softwood regeneration was higher in thinned spruce than thinned fir stands (8,285 vs. 347 trees per hectare (TPH), respectively). Small softwood regeneration was nominally greater in thinned spruce stands compared to thinned fir stands (83,506 vs. 47,777 TPH, respectively), while the same was observed for large softwood regeneration (3,879 vs. 492 TPH).

Density and stocking (percentage of plots supporting regeneration) of total softwood regeneration (all size classes combined) were nominally greater in spruce stands than fir stands (table 2-2). Despite these differences, mean densities and stockings of total softwood regeneration exceeded 38,000 TPH and 83 %, respectively in all thinned treatments. In unthinned stands, mean densities and stockings exceeded 3,500 TPH and 36%.

Table 2-1. P-values from contrasts comparing thinned (T), unthinned (UT), 50% (50), and 33% (33) treatments of the CTRN in Maine. Bold p-values are statistically significant at p<0.10.

Comparison	Softwood	Hardwood
Large		
T v. UT	**0.082**	**0.091**
50 v. UT	**0.086**	**0.096**
33 v. UT	0.175	0.187
50 v. 33	0.651	0.668
Medium		
T v. UT	**0.031**	**0.045**
50 v. UT	**0.041**	**0.047**
33 v. UT	**0.068**	0.117
50 v. 33	0.762	0.569
Small		
T v. UT	**<0.001**	**0.003**
50 v. UT	**0.002**	**0.006**
33 v. UT	**<0.001**	**0.008**
50 v. 33	0.225	0.849

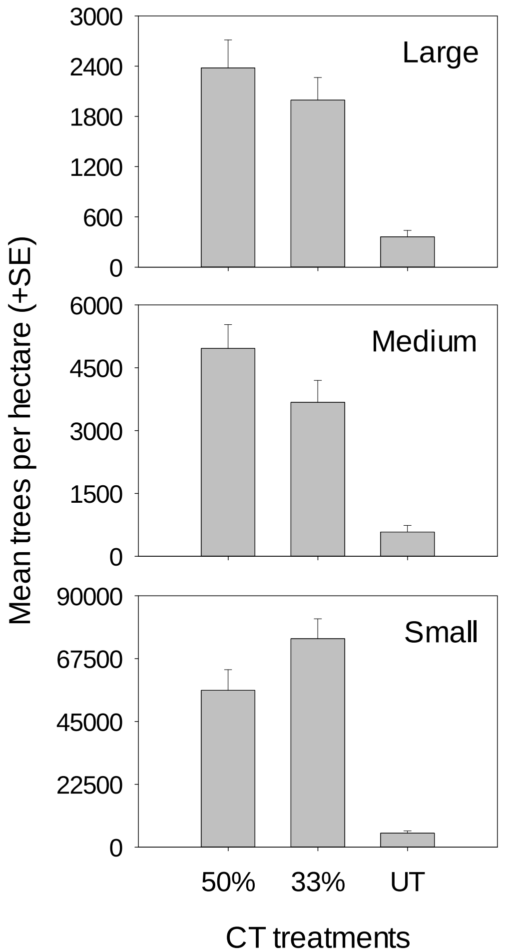


Figure 2-4. 2011 mean density of small, medium, and large *softwood* regeneration observed within 50% relative density reduction (RDR), 33% RDR, and unthinned (UT) treatments of the CTRN in Maine.

Discussion

Our hypothesis that CT increases the density of tree regeneration in spruce-fir stands within the first decade after treatment was confirmed for all regeneration types. In some instances, softwood regeneration density was 10-times higher in thinned stands compared to unthinned stands. Pothier and Prevost (2008) also observed substantially higher densities of softwood regeneration (0.3-4.0m tall) in stands treated with shelterwood establishment cutting compared to unharvested stands ten years after treatment in eastern spruce-fir forests of Canada. In our study, hardwoods also benefited from CT.

We hypothesized a positive response in regeneration density with increasing thinning intensity (i.e., unthinned<light thinning<heavy thinning). Statistically, this expectation was not supported by our study. There were no instances in which regeneration densities were significantly greater in the heavier 50% thinning than the lighter 33% thinning. A positive response in regeneration abundance to overstory removal intensity has not been consistently observed in past research.

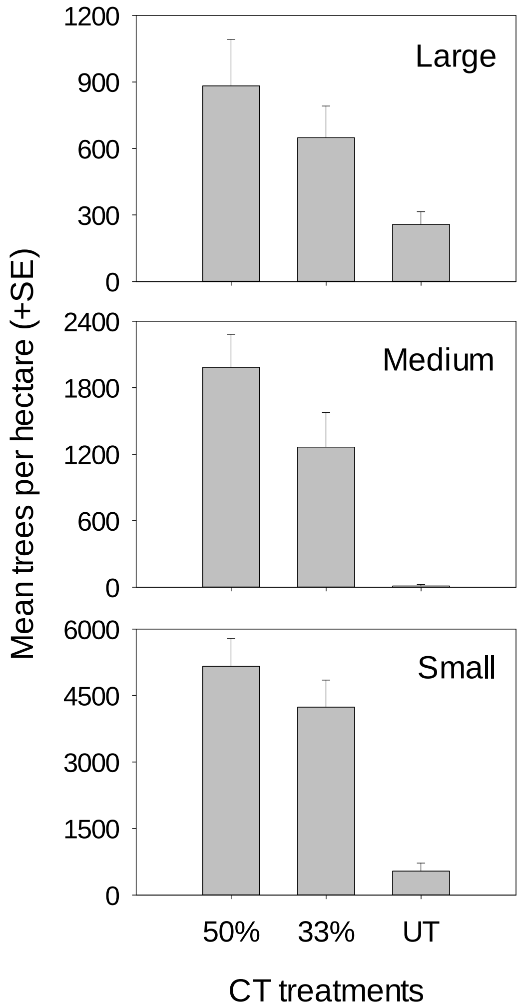


Figure 2-5. 2011 mean density of small, medium, and large *hardwood* regeneration observed within 50% relative density reduction (RDR), 33% RDR, and unthinned (UT) treatments of the CTRN in Maine.

Interestingly, densities of small softwood species and groups in this study often were nominally greater in 33% thinning than the 50%, while the reverse was observed for medium and large classes. Although results of statistical analyses did not support our hypothesis of a positive response in regeneration abundance to thinning intensity, absolute differences between treatments suggested that the regeneration densities of medium and large softwood species and groups and all size classes of hardwoods increased with thinning intensity.

Table 2-2. 2011 mean density and percent stocking of softwood regeneration (all size classes combined) recorded in fir and spruce-dominated stands of the CTRN in Maine.

Stand type & Treatment	Trees per hectare	Percent stocking
Fir stands		
Unthinned	3,591	36
33%	57,421	94
50%	38,829	83
Spruce stands		
Unthinned	7,571	58
33%	99,190	99
50%	83,393	99

For small and total softwood regeneration, lower densities in 50% thinning than 33% thinning treatments appeared to be linked to higher densities of medium and large regeneration in heavier 50% than lighter 33% thinning. Similar trends among regeneration classes were observed by Pothier and Prevost (2008). This pattern between thinning treatments and among sizes classes was likely due to treatment differences in the rate of softwood recruitment into larger regeneration size classes over the last decade; specifically, a higher rate of softwood recruitment beneath the more open residual stand of the 50% thinning treatment compared to that of the greater overstory density of 33%-thinned stands.

We expected higher densities of softwood regeneration in older, spruce-dominated stands owing to advanced stand age and greater post-thinning mortality. This hypothesis was confirmed statistically for medium softwood regeneration, but not for other size classes. Specifically, medium softwoods were more abundant in thinned spruce stands than thinned fir stands. Older, spruce stands in this study occur on poorly drained sites and, coupled with shallow-rooting habit of spruce and fir (Frank and Bjorkbom, 1973; Blum *et al.*, 1983), likely were predisposed to higher levels of post-thinning windthrow.

There are two commonly cited standards of acceptable stocking for eastern spruce-fir forests. According to Frank and Bjorkbom (1973), a stocking of 50% or more of sample plots with one or two spruce or fir, depending on size, is considered acceptable. Frisque *et al.* (1978) recommended a density of 2,500 TPH and 60% of plots with desirable spruce or fir regeneration as minimum acceptable stocking. These standards for acceptable stocking can be applied to assess the efficacy of CT treatments used in this experiment in developing desirable spruce and fir regeneration within the first decade. Both criteria were met for total softwoods in all CT treatments included in this study. Interestingly, these criteria were nearly met in unthinned stands, which corroborates the widely held notion of prolific advance regeneration in mature spruce-fir forests.

Conclusions

The main conclusion of this research is that in addition to the expected boost in individual-tree growth and yield, CT in eastern spruce-fir also increases regeneration density over unthinned stands, as well as increasing rate of recruitment as thinning intensity increases. This shelterwood effect of CT has implications for the management of eastern spruce-fir using even-aged systems (i.e., those that integrate intermediate treatments). Traditional shelterwood methods may not be necessary in intensively managed even-aged spruce-fir since CT can be used to simultaneously boost residual tree growth and accumulation of softwood advance regeneration to an acceptable stocking level, which in turn could reduce rotation length by eliminating the regeneration period needed to develop acceptable stocking under a shelterwood. However, if softwood advance growth gets too large by the end of the rotation, a final overstory removal can kill or severely damage a significant portion of acceptable softwood stocking, potentially compromising long-term sustainability. Therefore, careful logging to protect larger advance regeneration may be necessary in stands treated with commercial thinning to avoid losses of future spruce and fir growing stock.

Acknowledgments

This research was jointly funded by the CFRU and the U.S. Forest Service, Northeastern States Research Cooperative. We thank the landowners of the CFRU for access to CTRN study sites and assistance with the harvesting on their properties. We also thank Brian Roth with the CFRU for assistance throughout the duration of this study. Finally, we thank Joshua Kohn and Andrew Piccirillo for data collection.

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EARLY COMMERCIAL THINNING HARVEST SYSTEMS: A SILVICULTURAL AND OPERATIONAL ASSESSMENT

Jeffrey Benjamin, Robert Seymour and Jeremy Wilson

Introduction

Many of Maine's regenerating clearcuts from the spruce budworm era are dominated by dense spruce and fir saplings (<6 in. dbh) with a small component of hardwood. Some of these stands were precommercially thinned, while others have grown beyond the stage where a brushsaw treatment is feasible. Such stands are overstocked and would benefit from thinning, but they are decades away from being operable with traditional harvesting systems. Unfortunately, there is no consensus as to how these young stands should be treated.

Many landowners believe that stand growth will be improved with early commercial thinning and that the economic value of the harvested material should be adequate to cover harvest costs. Local equipment dealers/manufacturers are eager to test specialized equipment that is commercially available for both harvesting and transporting small-diameter material to roadside. Contractors, however, are unsure if they can economically harvest these stands since their current mix of equipment was not designed to handle and process small-diameter stems. Further, given current market realities, contractors are reluctant to invest heavily in specialized equipment. Given the presence of an active regional energy wood market, and because over 80 percent of the volume harvested in Maine is by whole-tree systems, it is important to consider such commercial thinning treatments from a different perspective.

In 2010, the CFRU funded a project that allowed three sectors of the forest industry (landowners, contractors, and equipment dealers/ manufacturers) to assess silviculturally effective operational solutions for implementing early commercial thinning (ECT) treatments. Results from this study focused on a comparison of whole-tree and cut-to-length systems in terms of residual stand damage, product utilization, and unit cost of production.

Methods

Study Site Description

The 24 ac research site is located in central Maine, approximately 25 miles from the University of Maine, on forestland managed by American Forest Management. The site regenerated from a clearcut in the early 1970s and approximately 20 ac was precommercially thinned around 1985[1]. Species composition of the site consisted of balsam fir (*Abies balsamea*) (59%), eastern white pine (*Pinus strobus*) (24%), red spruce (*Picea rubens*) (12%) and a variety of other species (5%) including *Acer rubrum* (red maple), *Tsuga canadensis* (eastern hemlock), *Fagus grandilifolia* (American beech), *Populus tremuloides* (quaking aspen), *Prunus pensylvanica* (pin cherry), and *Betula papyrifera*, -*populifolia*-, and *allegheniensis* (paper-, grey-, and yellow- birch respectivly). Roughly half of the site was on moderately well drained soil that consisted of a very stony loam, and the other half was on somewhat poorly drained soil that consisted of a very stony silt loam.

Equipment Selection and Harvest Plan

Twenty-two research plots were established along trails spaced either 50 ft or 80 ft from trail-center to trail-center. All plots were 0.2 ac in size, but plot length varied by trail spacing. Equipment was selected for this study in consultation and cooperation with local equipment dealers and one of the land manager's preferred logging contractors. As indicated in Table 2-3, two new CTL processors and a new tracked feller buncher were compared to a larger feller buncher common to the industry. The primary focus of this study was the performance of harvesting equipment in a thinning context, but productivity and cost of the full operation was also considered, so primary transportation and roadside processing were included. Forwarding was conducted using a Ponsse Wisent and a Valmet 644. All skidding

[1]This paper will only present results from the PCT portion of the study. Demonstration harvests were conducted in the non-PCT stand (four acres), but ground conditions prevented replication of harvest activity.

and roadside processing was conducted using a JD 648GII grapple skidder and a JD 200LC stroke delimber.

The machine operators had varying degrees of experience with the harvesting equipment. The CTL operators each had over 20 years of experience; one was an operator trainer for John Deere and the other had operated several Ponsse processors for local logging companies. The operator for the CAT 501 was retired from the logging industry, but he had over 30 years of experience operating whole-tree harvesting equipment. The operator for the second feller buncher (753J) only had five years of experience, but he operated that machine for over 11,000 hours and was considered proficient for the study. The operators for the skidding and roadside processing equipment each had over 30 years of experience and thousands of operating hours on the machines used in this study. Prior to the research harvest, each operator was given the opportunity to harvest in a practice area near the research site to ensure familiarity with specific machine functions.

Based on a pre-harvest inventory and results from the CTRN, target basal area removal was 50% plus trails. The harvest was expected to shift species composition to eastern white pine and red spruce as well as favor higher quality stems by removing:

- all old residual stems greater than 30 cm dbh (12 in) from previous harvest
- all hardwoods
- all poorly formed eastern white pine
- all trees within machine trails;
- all balsam fir greater than or equal to 21.6 cm dbh (8.5 in); and
- remaining balsam fir and intolerant hardwoods as necessary to achieve 50% removal.

Operationally, the prescription favored eastern white pine spaced at 15-20 ft and red spruce at 10-12 ft. Trees were painted for removal in the research plots only, so that machine operators harvested the remainder of each trail with no further guidance.

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-inch 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. Round wood and biomass volume was estimated at roadside and cross referenced with mill scale records provided by the logging contractor. Fuel consumption rates for each machine were calculated based on overall fuel usage for each machine during the operations. Standard machine rate assumptions and calculations, as outlined in Brinker *et al.* (2002), were used to develop hourly machine rates for each piece of logging equipment (table 2-4). Data were obtained through personal communication with equipment dealers and logging contractors participating in this study[2].

Post-Harvest Measurements

A 100% tally in each plot was completed post-harvest for all standing residual trees greater than or equal to 2.0 in dbh. Data recorded included dbh, height of every 10th tree and species. Each residual tree was thoroughly inspected for damage related to the recent harvesting activities.

[2] Quotes for purchase price on each piece of equipment were obtained from equipment dealers to develop machine rates, but cannot be shared in this publication.

Table 2-3. General specifications of harvesting equipment used in this study.

Harvest Method	Machine	Specifications				
		Width *m (ft)*	**Weight** *tonne (lbs)*	**Reach** *m (ft)*	**Clearance** *m (in)*	**Gross Power** *@ 2,000 kw (hp)*
CTL	John Deere 1070E	2.6 (8.5)	14.7 (32,400)	10.7 (35)	0.56 (22)	136 (182)
CTL	Ponsse Fox	2.7 (9.0)	17.7 (39,000)	10.0 (33)	0.61 (26)	147 (197)
WT	CAT 501	2.6 (8.5)	15.9 (35,000)	7.0 (23)	0.66 (24)	157 (157)
WT	John Deere 753J	3.2 (10.5)	23.6 (52,000)	8.2 (27)	0.74 (29)	164 (220)

Table 2-4. Data and assumptions used to develop machine rates.

Item	Value or Range	Units
Machine Life	5	years
Scheduled Machine Hours	2200-2400	hours
Utilization Rate	75-85	%
Salvage Value	20	%
Interest Rate	4-5	%
Fuel Price	4	$/gal
Fuel Consumption Rate	0.015-0.044	gal hp^{-1} hr^{-1}
Operator Wage	11-18	$/hr
Operator Benefit Rate	40	%

Causes of damage were not differentiated between harvesting and skidding activities. Stems that were completely bent over or uprooted were not included in the final residual stem count. Damage was assessed using the Ostrofsky *et al.* (1986) method where wounds were recorded as injured or uninjured and classified by severity.

For each wound, width perpendicular to stem and length parallel to them stem at the widest and longest points were recorded as well as wound location in terms of height from the ground. Severity was categorized within 3 classes: 1) Low; bark scuff, 2) Moderate; cambium broken with uninjured sapwood, 3) High; cambium broken with injured sapwood. When combinational wounds were found, severity class was assigned by the highest severity present. If wounds were low and discontinuous, they were classified as low and assigned an approximated percentage of wound cover. Each wound on a tree was assessed and recorded separately unless it could be assumed that the damaged area would eventually converge and were then measured as one continuous wound. Crown and root damage were noted when present.

Results

Stand Inventory

Descriptive statistics for pre- and post-harvest inventory can be found in tables 2-5 and 2-6 respectively. Error was assessed using a 95% confidence interval. Volume was approximated using Honer's volume equation which relies on heights estimated from a regression line of observed vs. predicted heights.

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

Statistic	Volume m^3/ha (ft^3/ac)	BA m^2/ha (ft^2/ac)	Trees per Area *ha (ac)*	QMD *cm (in)*
Mean	271.0 (3871.3)	38.8 (168.8)	1801 (729)	16.8 (6.6)
SD	41.2 (588.7)	5.1 (22.0)	279 (113)	1.27 (0.5)
CV	15%	13%	16%	8%
SE	9.2 (131.6)	1.1 (4.9)	62.5 (25.3)	0.25 (0.1)
%SE	3%	3%	3%	2%

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

Statistic	Volume *m^3/ha (ft^3/ac)*	BA *m^2/ha (ft^2/ac)*	Trees per Area *ha (ac)*	QMD *cm (in)*
Mean	109.7 (1566.6)	15.3 (66.5)	598 (242)	18.0 (7.1)
SD	25.4 (362.2)	3.2 (13.9)	91 (37)	1.5 (0.6)
CV	23%	21%	15%	9%
SE	5.7 (81.0)	0.7 (3.1)	20.2 (8.2)	0.25 (0.1)
%SE	5%	5%	3%	2%

Table 2-7. Average percentage of trees per plot with significant damage, including moderate and high severity.

Severity Rating	Cut-to-Length		Whole-Tree	
	15.2 m (50 ft)	*24.4 m (80 ft)*	*15.2 m (50 ft)*	*24.4 m (80 ft)*
High	6%	5%	5%	5%
Moderate	28%	25%	16%	14%
Total	34%	30%	21%	19%

Approximately 105 ft^2/ac of basal area was removed, including machine trails. Total basal area removal came out to be just over 60% and around 500 trees/ac 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.

Residual Stand Damage

Ostrofsky and Dirkman (1991) considered moderate and high severity wounds on residual stems to be the most likely to cause volume and value loss over time. Table 2-7 summarizes the average percentage of individual stems per plot damaged with either high or moderate severity by harvest method and trail spacing. There was significantly more stems wounded in total by the CTL method (31%) compared to the WT method (20%) (p=0.006), but there was no difference in the number of stems with high severity wounds (p=0.808). There were no differences in number of stems wounded between harvest method and trail spacing.

Total wound area by severity level can be found in figure 2-6 for each harvest method and trail spacing. There was no statistical difference in moderate and high wound area at the plot level between CTL and WT methods (p=0.637). The WT method, however, did have more wound area (3.2 ft^2) per plot in the high severity class than the CTL method (1.5 ft^2) (p=0.011). Wound area per tree was also greater for the WT method (0.43 ft^2) compared to the CTL method (0.24 ft^2) (p<0.001). There were no differences in wound area at the plot- or tree-level with respect to trail spacing.

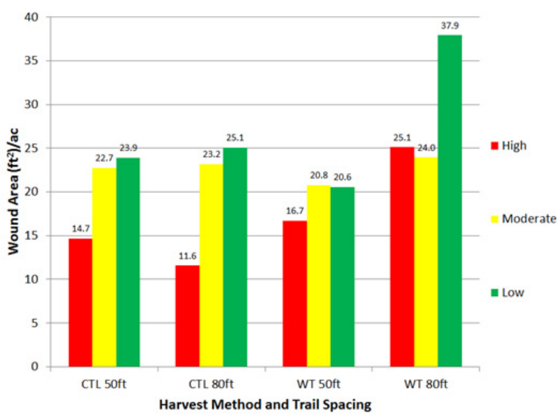

Figure 2-6. Wound area (ft^2/ac) separated by severity class and shown by harvest method and trail spacing.

Arguably the most important form of stand damage is that of crop tree loss by trail access or machines reaching into treatment zones. As shown in figure 2-7 crop tree loss by both harvest methods was substantial regardless of trail spacing. With the exception of CTL at 80 ft, crop tree loss was between 17% and 25%. There was significantly more crop tree loss from WT systems (22%) compared to CTL systems (12%) (p=0.023) and on trails spaced 50 ft apart (21%) compared to 80 ft apart (14%) (p=0.098).

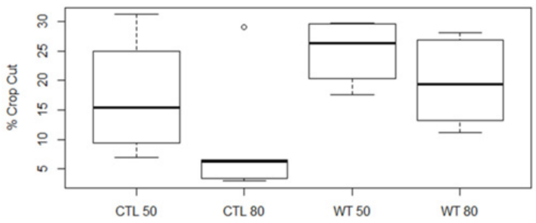

Figure 2-7. Percent of crop tree loss, with respect to basal area, by harvest method and trail spacing.

Product Utilization

Another objective of this study was to determine the amount of woody biomass that could be harvested from the stand with each harvest system. Operators were instructed to leave tops, limbs, and other logging residue in the trails as necessary to reduce compaction and erosion, but all other woody biomass was to be harvested and transported to roadside. As the same harvest prescription was applied across the site, it is not surprising that both CTL and WT systems produced the same amount of round wood at 31.9 ton/ac and 28.1 ton/ac respectively. With respect to woody biomass, the WT systems produced four times more than the CTL systems (16.8 ton/ac and 4.2 ton/ac). This resulted in a total production of 44.9 ton/ac and 36.1 ton/ac for WT and CTL systems respectively as shown in figure 2-8.

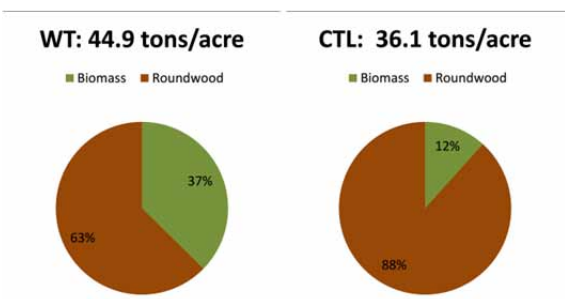

Figure 2-8. Product utilization in percent round wood and biomass by harvest method.

Unit Cost of Production

Feller bunchers are expected to harvest significantly more stems per hour than processors given that processors complete more work functions in a cycle. As shown on figure 2-9, the feller bunchers from this study more than doubled the production (18.7 tons/pmh to 7.61 tons/pmh) of the processors (p=0.005). In order to compare production costs, however, the entire system must be considered. Time and motion studies conducted on transportation and roadside processing equipment were used to scale production estimates to typical operating conditions. For example, the maximum skidding distance on the site was approximately 500 ft, but it was scaled to an industry average of 1000 ft[3].

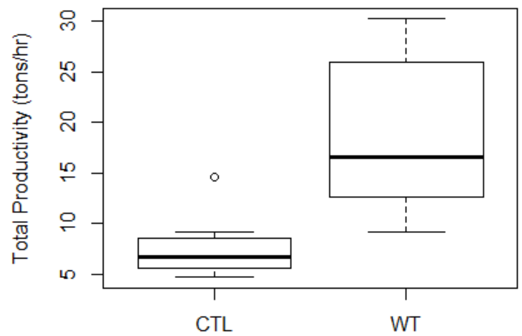

Figure 2-9. Variation in machine-level productivity (tons/hr) for feller bunchers (WT) and processors (CTL). Bold lines represent median productivity.

Productivity estimates per machine were combined with machine rates to develop system level cost estimates. As shown on figure 2-10, there is no statistical difference in production costs between WT (32 $/ton) and CTL (32 $/ton) systems (p=0.990), but there is a high degree of variability within the CTL system costs, which is evident on figure 2-11.

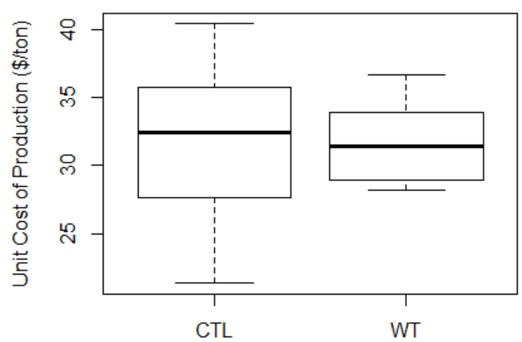

Figure 2-10. Variation in unit cost of production ($/ton) for WT and CTL systems. Bold lines represent median unit costs.

[3] Personal communication with several local contractors indicated that skidding distances greater than 2,000 ft. would result in negotiated rate increases with landowners. Although contractors routinely transport wood up to 1,500 ft., it was assumed for this study to use 1,000 ft. as an industry average.

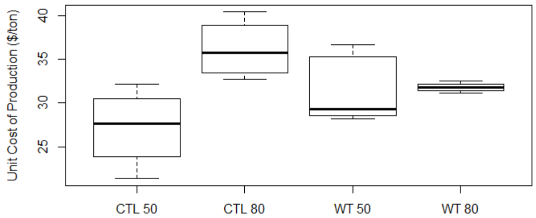

Figure 2-11. Variation in unit cost of production ($/ton) for WT and CTL systems by trail spacing. Bold lines represent median unit costs.

Discussion and Conclusions

This study allowed landowners, contractors, and equipment dealers and manufacturers to assess silviculturally effective operational solutions for implementing ECT treatments. From a silvicultural perspective it is clear that we have commercially available equipment that can conduct such treatments. The CTL system at 80 ft. spacing (figure 2-7) was able to achieve less than 10% crop tree loss on average. Unfortunately, there are still high amounts of residual stand damage across all systems and trail spacings and more importantly the best system silviculturally was also the most expensive (figure 2-11). Given the additional reach and maneuverability of the dangle head processors (table 2-3), it is surprising that the amount of wound area in the moderate and high severity classes is the same between harvest systems. There was more high severity damage from the WT system – presumably resulting from the skidding operations - but the overall damage is concentrated on fewer stems compared to the CTL system. Although some variability in stand damage was expected because of multiple equipment operators, the results clearly indicate systems harvest selection is a trade-off for the forester when designing a harvest plan and assessing post-harvest results.

It is encouraging to know that existing technology can conduct such treatments, but that optimism must be tempered with the realization that it takes skilled operators to ensure success. It is also important to note that even under optimistic scenarios, the unit costs to deliver this material roadside are still prohibitive under current market conditions. There is a need to continue efforts in development of harvesting machines that can cost effectively treat such stands. The logging contractors in this region are highly innovative and they will continue to find ways to increase productivity and reduce operating costs to ensure such treatments will be feasible in the future.

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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HARVEST PRODUCTIVITY STUDY: 2012 UPDATE

Patrick Hiesl and Jeffrey Benjamin

Introduction

There are approximately 11 million acres of forestland in Maine with stems smaller than 12 inches in dbh (McCaskill *et al.* 2011). Therefore, it is important to understand harvest system productivity in these stands. Although existing software is available from the USFS to estimate harvest productivity and cost (Fight *et al.* 1999, 2003, 2006), none of these models use machine productivity data from Maine. In fact, a literature review conducted by the authors resulted in no productivity information for Maine within the last 30 years. Feller-buncher data from eastern Canada is mostly from the 1980's and 1990's (Légère and Gingras 1998; Gingras and Favreau 1996; Gingras 1988, 1989, 1994), while more recent publications are from the western US (Bolding *et al.* 2009; Adebayo 2007; Han *et al.* 2004). Therefore, in 2011 the CFRU initiated this project to develop machine productivity functions for whole-tree and cut-to-length systems used in Maine.

Methods

Machine-level productivity data were collected from twelve different harvesting sites throughout Maine from May until August 2012. Table 2-8 shows the site conditions as well as operator and equipment information. Individual contractors and land managers, willing to participate in this study, gave permission to observe and measure the productivity of some of their ongoing harvesting operations. The sites represent harvesting conditions common to Maine in regards of species mixture, ground conditions and prescription. Table 2-9 shows the description of the individual work cycles measured for each machine.

Table 2-8. Site and equipment information for twelve harvest sites throughout Maine.

FELLER-BUNCHER

Density *(trees ha⁻¹)*	**Basal Area** *(m^2 ha^{-1})*	**Slope**	**Basal Area** *Removed*	**DBH rem.** *(cm)*	**Power** *(hp)*	**Work** *Hours*	**Operator** *Experience* [a]	**Productivity** *(m^3 PMH^{-1})* [b]	**Twitch Size** *(m^3)*
1,756	26.8	3%	67%	10 - 48	241	8,800	7 years	42	3.3
1,015	32.8	11% - 14%	48%	10 - 43	167	10,000	13 years	22.8	2
2,536	29.4	3%	76%	10 - 38	241	8,800	15 years	31.2	2.5
2,104	54.6	5% - 7%	15%	10 - 53	300	196	8 years	62.3	8.6
1,934	27.3	7%	66%	10 - 63	284	11,800	4 years	48.9	3.5
1,469	34.4	2%	54%	10 - 58	241	9,000	7 years	66.1	2.9
1,062	25	7% 12%	33%	10 - 58	228	10,000	1 year	59.2	3.3

PROCESSOR

Density *(trees ha⁻¹)*	**Basal Area** *(m^2 ha^{-1})*	**Slope**	**Basal Area** *Removed*	**DBH Removed** *(cm)*	**Power** *(hp)*	**Work** *Hours*	**Operator Experience** [a]	**Productivity** *(m^3 PMH^{-1})* [b]
1403	37.3	17% - 35%	57%	10 - 56	300	2800	4 years	30.7
1326	36.1	3%	90%	10 - 58	275	7500	15 years	18.6
2596	47.9	1%	25%	10 - 38	215	14650	12 years	15.2
1630	27.4	2%	45%	10 - 30	228	5000	<1 year	12.6
4812	41.3	2% - 5%	45%	10 - 33	197	1200	<1 year	10.1

[a] Operator experience in feller-buncher or processor.
[b] Productive Machine Hours including breaks less than 15 minutes

Table 2-9. Description of work cycles for each machine studied.

Machine Type	Work Cycle Description
Feller-Buncher	Begins and ends at empty accumulators at the bunch and includes the time to harvest, accumulate, and place a bunch in a twitch. Time within each cycle will also be noted for trail work, removal of snags or non-merchantable stems, re-piling a twitch, and excessive travel.
Processor (Fixed- or Dangle-Head)	Begins and ends at saw cut and includes the time to fell, delimb, top, process, and select the next stem. If multi-stem processing occurs, the cycle will end after all stems have been processed and a new stem is selected with empty accumulators. Time within each cycle will also be noted for any trail work, removal of snags or non-merchantable stems, processing rot, excessive work to delimb forks, and excessive travel.
Forwarder	Begins and ends when the machine leaves the yard empty and includes the time to travel, load, unload and sort. Time within each cycle will also be noted for any trail work, wait at yard, re-piling, and excessive travel.
Grapple Skidder	Begins and ends when the machine leaves the yard empty and includes the time to travel, load, and unload. Time within each cycle will also be noted for any trail work, wait at yard, brush clean-up at yard, and excessive travel.
Delimber	Begins and ends with grabbing a tree and includes the times to delimb and pile. Extra time will be noted for brush clean-up.

Feller-Buncher and Processor

On each site a study area between one and three acres was laid out. One to two horizontal line samples with lengths between 100 and 300 feet (30 – 91 m) were conducted to establish initial tree density and basal area. These sample lines were marked with flags and trunks adjacent to the sample lines were painted orange for easier retrieve of these lines after the harvest. For the feller-buncher all trees within the study area were painted in four different colors (blue, green, orange, yellow) based on 2 in (5.1 cm) dbh classes. Trees larger than 20 in (50.8 cm) had the dbh painted as a number on the bole. All four colors were used two times, in the same order, for trees smaller than 12 in. (30.5 cm) and greater or equal to 12 in. (30.5 cm) (table 2-10). For the processor all trees within the study area were painted in in the same colors based on 1 in (2.5 cm) dbh classes. Trees larger than 11.4 in (29.1 cm) had the dbh painted as a number on the bole. The threshold for small and large trees in terms of color recycling was at 8 in. (20.3 cm) (table 2-10).

The data collected within each sample area was the cycle time it takes to cut and/or process each individual tree as well as the cycle time for each feller-buncher head accumulation in combination with the dbh class and species. During the data collection process the operator and the researcher were communicating via a two-way radio with a headset with each other. Each time the operator moved to cut a new tree he would call out the color on the tree, species and a visual estimate if the tree belongs into the lower or upper range of the color coding (see table 2-10). The researcher entered the data into a Palm Tungsten E2 with the time study software UMT Plus (Laubrass, Inc.). The tree volume was estimated using Honer's equations (Honer 1967) and estimated tree heights from linear regression models based on samples of tree heights within each sample area.

Grapple Skidder and Forwarder

A high accuracy GPS unit was used to track the path of the machine during the observation time and was synchronized with the data collectors to provide information about the distance travelled for each cycle. A researcher followed behind the machine at a safe distance and recorded the number of logs in each grapple and the time it took to load, unload and transport the wood to the landing. For the grapple skidder the average twitch size was calculated based on ten sample measurements of twitches in the harvest block. For the forwarder 100 logs in the harvest block were measured and the average multiplied with the number of logs in the bunk for each cycle.

Table 2-10. DBH class and color codes used during the time and motion study for feller-buncher and processor.

Feller-Buncher

DBH Class	DBH Range *(inches)*	DBH Range *(cm)*	Color
5" (12.7 cm)	4.0 - 5.9	10.2 - 15.0	blue
7" (17.8 cm)	6.0 - 7.9	15.1 - 20.1	green
9" (22.9 cm)	8.0 - 9.9	20.2 - 25.2	orange
11" (28.0 cm)	10.0 - 11.9	25.3 - 30.2	yellow
13" (33.0 cm)	12.0 - 13.9	30.3 - 35.3	blue
15" (38.1 cm)	14.0 - 15.9	35.4 - 40.4	green
17" (43.2 cm)	16.0 - 17.9	40.5 - 45.5	orange
19" (48.3 cm)	18.0 - 19.9	45.6 - 50.7	yellow
>20" (50.8 cm)	DBH painted on bole		

Processor

DBH Class	DBH Range *(inches)*	DBH Range *(cm)*	Color
4" (10.1 cm)	3.5 - 4.4	8.9 - 11.0	blue
5" (12.7 cm)	4.5 - 5.4	11.1 - 13.7	green
6" (15.2 cm)	5.5 - 6.4	13.8 - 16.3	orange
7" (17.8 cm)	6.5 - 7.4	16.4 - 18.8	yellow
8" (20.3 cm)	7.5 - 8.4	18.9 - 21.3	blue
9" (22.9 cm)	8.5 - 9.4	21.4 - 23.9	green
10" (25.4 cm)	9.5 - 10.4	24.0 - 26.4	orange
11" (27.9 cm)	10.5 - 11.4	26.5 - 29.0	yellow
>11.5" (29.1 cm)	DBH painted on bole		

Stroke Delimber

Time to process individual stems was recorded and associated with a species and an estimated dbh. The number of twitches processed was also recorded to estimate average productivity. Time to sort biomass was recorded separately.

Preliminary Results

Feller-Buncher

The data was analyzed using the statistical software package R (R Core Team 2012). Due to the fact that the cycle time for cutting the last tree in a feller-buncher head accumulation (bunch) is higher (because of the extra time it takes to place the bunch in a twitch along a trail) the data was aggregated by the individual bunch. While aggregating the data three new variables were created, namely stem count, sum of dbh and average dbh in each bunch. Figure 2-12 shows the frequency of stem counts in bunches throughout the study.

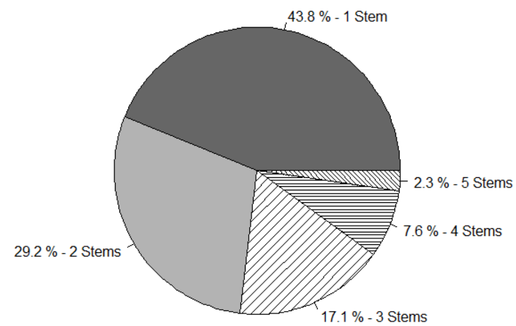

Figure 2-12. Frequency of stem count in feller-buncher head accumulations (bunches) in the observed sample of 486 bunches.

The analysis shows that most of the feller-buncher head accumulations consist of only one stem (43.8%), followed by two stems with 29.2% and three stems with 17.1%. Only 7.6% and 2.3% of bunches consist of four and five stems, respectively. Figure 2-13 illustrates the frequency of occurrence of individual dbh classes being accumulated in one of the five stem count classes. Over 50% of the trees in the 13 inch to 17 inch dbh classes and 100% of trees greater than 19 inches in dbh are harvested as single trees. Small diameter trees are most likely to be cut in bunches of two and three stems with a few being cut in four and five stem counts. The larger the diameter gets the more likely it is that trees will be cut in bunches of two and three trees per bunch.

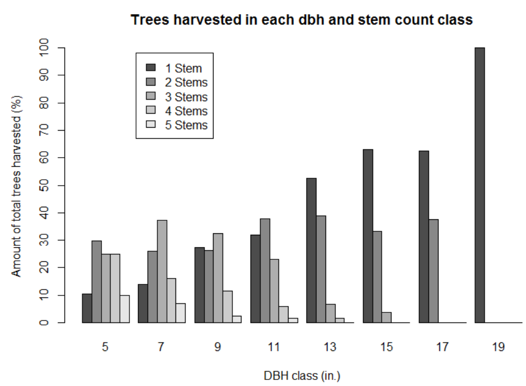

Figure 2-13. Percentage of trees harvested in each dbh class for all five stem count classes in feller-buncher head accumulations (n=949).

Next Steps

The next step for the feller-buncher is to develop a productivity function that includes the information described. The first draft of such a function has been developed and is currently under review for statistical soundness and to eliminate bugs in the code. For the processor, grapple skidder, forwarder and stroke delimber cycle time and productivity function drafts have been developed but need to be refined before publishing. A paper on the feller-buncher productivity function will be submitted for publication by the beginning of 2013. By the end of the first quarter of 2013, the productivity functions for the other machines will be submitted for publication and presented to the CFRU.

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AUSTIN POND STUDY: THIRD WAVE UPDATE

Brian Roth, Robert Wagner, Robert Seymour, Aaron Weiskittel, Derek Brockmann, and Jeffrey Benjamin

Introduction

The Austin Pond Study, located on land currently owned by Plum Creek Timber Company, was established in 1977 by the CFRU to test the efficacy of seven aerially applied herbicides on conifer release in a regenerating clearcut harvested in 1970. In 1986, each of the original treatment plots was divided in half with one-half receiving PCT. Today, there is an opportunity to extend this study to final rotation by overlaying a series of Commercial Thinning (CT) treatments overtop of the existing design in a "Third Wave" of silvicultural treatments. Rotation-length measurements from this study on the effects of a wide range of silvicultural options will be invaluable to managers working in Maine's diverse northern forest.

Experimental Design

The previous herbicide and PCT treatments have driven stand development along many different pathways and there now exists a wide variety of stand conditions which are representative of much of the forested region of Maine. Using these existing stand conditions, we have identified five broad types of thinning treatments in addition to a "start over" clearcut option. The first three thinning treatments are assigned to the conifer-dominated plots and follow the CTRN protocol of a 33 and 50% relative density reduction with an additional treatment of 66% reduction. The fourth, treatment, "red spruce release", is assigned to plots with a significantly higher spruce component in which all fir will be removed with the remaining spruce and hardwoods to be thinned to minimum 8-foot spacing. The last treatment is a type of late conifer release and is assigned to plots with a hardwood overstory and conifer understory. This treatment will remove the hardwood overstory and thin the residual understory softwoods to minimum 8-foot spacing. There are enough plots in each initial condition class to allow for three to four replicates of each treatment at least one acre in size. Additionally, there were two locations, approximately 10 acres in size each, within the study buffer area that had not received treatment of any kind. These two "blocks" offer an opportunity to examine a "start over" option that will contrast two types of management: short rotation coppice versus high intensity plantation.

Implementation

In the summer and fall of 2012, preparations began for the final wave of treatments. The field crews were led by **Derek Brockmann** and included several crew members: **Brandon Learnard, Adam Bland, Vance Brown, Justin Libby, Scott Austin, Karl Buckley,** and **Chris Chase**. All treatment block boundaries were located and flagged and 28 CTRN plots were established, tagged and inventoried (adding over 6,800 trees to the CTRN database). Using this pre-thinning data, plot level prescriptions were generated and 38 acres were marked with tree paint. Additionally, over 8 miles of forwarder trails were laid out on a 50-foot spacing and all boundaries, corners and trails were monumented with GPS and entered into a GIS system (figure 2-14).

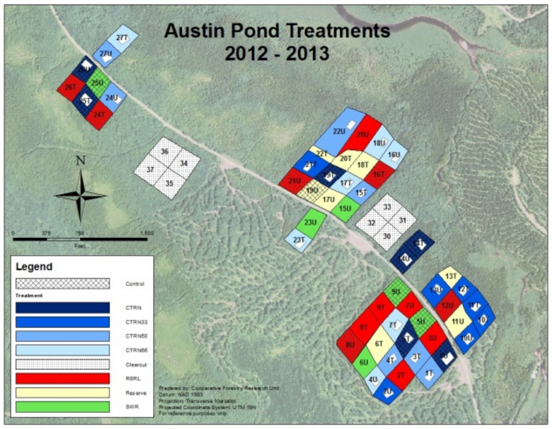

Figure 2-14. Experimental design of the third wave of treatments at the Austin Pond Study.

Implementation of the third wave began in January of 2013 with the previously PCT treated experimental units. These plots were harvested using a Ponsee Ergo processor and a Timberjack 1110 forwarder owned and operated by **Sam Andrews of Andrews Timber Company in Addison, ME** (figure 2-15). Andrews and his forwarder operator Tony did a fantastic job of following the prescriptions while sorting the wood by plot and product so that removals could be measured at the landing. **Patrick Hiesl** and **Derek Brockmann** helped guide the operators around the site and recorded the volume of wood removed by treatment unit. A week after the cut-to-length system arrived, **Michael Gould** and **Adam Cates** of **Dirigo Timberlands** in **North Anson, ME**, brought in their specialized feller-buncher (a small Link-Belt excavator mounted with a small felling head) to begin work on the clearcuts and non-PCT'd plots. Wood was extracted using a Timberjack 1010 forwarder and piled at roadside to be chipped. This unique whole-tree system was termed "nipper-chipper" by John Ackley (Plum Creek). Unfortunately, after two plots were thinned it became clear that this system was not meeting the silvicultural goals of the experiment. Consequently, work was halted. The non-PCT thinning treatment will be thinned in the winter of 2013/14 with a set of equipment that can meet the silvicultural objectives. The clearcut treatments were completed by **Melcher & Sons of Bingham, Maine** in March of 20123 using a John Deere 653 feller-buncher, a CAT 545C skidder, a CAT 320 de-limber, and a Trelam chipper. Melcher's operation did a fantastic job of removing nearly all the woody biomass, leaving a clean site for our future experiments, with a minimum of soil disturbance.

Figure 2-15. Timberjack 1110 forwarder working in 50% relative density reduction PCT plot at Austin Pond.

Acknowledgements

Many thanks go out to **John Ackley** and **Erik Charles** of Plum Creek, and to **Plum Creek Timber Company** for financially supporting the operations and coordinating logistics with the contractors.

VERIFICATION OF REGIONAL AND NATIONAL ABOVEGROUND SAPLING BIOMASS EQUATIONS IN MAINE

Andrew Nelson, Robert Wagner, and Aaron Weiskittel

Project Update: Responses of Young Hardwood Stands to Various Levels of Silviculture and Stand Composition

The overall goal of this project is to refine the prediction of hardwood growth and yield, while incorporating the influence of various intensities of silviculture and species composition. Over the last year, we developed a new set of biomass equations and tested the fit of published biomass equations for common hardwood species in Maine. A manuscript detailing the results was prepared and submitted for publication (Nelson *et al. in press*). Below, we present part of the analysis comparing the fit of the published equations. In addition, funds for this project were used to analyze the growth and yield of young stands subjected to various intensities of silviculture and species compositional objectives, using the Silviculture and Composition (SIComp) experiment on the Penobscot Experimental Forest. Preliminary results from this analysis were presented in the 2011 CFRU Annual Report (Nelson and Wagner 2011), and the final peer-reviewed manuscript was recently published (Nelson *et al.* 2013). Over the next year, we will continue to refine the growth and yield predictions of young hardwood stands by developing growth equations and integrating these equations into current growth and yield efforts currently underway by Dr. Weiskittel.

Introduction

Estimation of aboveground biomass in Maine has relied on a handful of equations, including those developed by Harold Young at the University of Maine (Young *et al.* 1980) and equations from New York (Monteith 1979). More recently, nationally-consistent equations have been developed that encompass all trees species in the US (Jenkins *et al.* 2003). Although it is desirable to have consistent biomass estimates across the nation, these equations were not developed from field data and their predictions have not been verified for tree species in Maine. In addition, many of the biomass equations available for Maine tree species were developed for trees > 5 inches in diameter at breast height (DBH), while smaller sapling and seedlings have received less attention.

In 2009, the United States Forest Service, Forest Inventory and Analysis (FIA) program switched their biomass estimation protocols from an approach using regional equations to the new component ratio method (CRM). The CRM predicts biomass using conversions from volume estimates and sums the biomass of branches, bole, and stump to obtain estimates of total aboveground biomass (Heath *et al.* 2009). The CRM is only applicable for trees > 5 inches in DBH, since below this threshold, tree volume is considered zero. To estimate sapling biomass, the FIA developed a set of equations that predict aboveground woody biomass with the Jenkins *et al.* (2003) equations multiplied by a species-specific adjustment factors based on the ratio of the Jenkins *et al.* (2003) estimates and CRM estimates for all trees 5 inches in DBH (Heath *et al.* 2009). In Maine, the change in biomass estimation techniques resulted in a loss of 31% of aboveground biomass across the state, while stem densities increased by 7% between 2003 and 2008 (McCaskill *et al.* 2011; McWilliams *et al.* 2005). In particular, during this period sapling biomass decreased by 35% and sapling density increased by 9%. The inconsistences in state-wide biomass estimation makes it difficult to predict forest carbon storage in the region and accurately assess growth and yield, especially since ~32% of forestlands in Maine are dominated by small diameter trees (McCaskill *et al.* 2011).

The only way to determine whether the regional-equation approach produced more accurate biomass estimates than the new nationally-consistent approach is to compare the fit of the equations to field data. Therefore, in this investigation, we used data collected from an experiment on the Penobscot Experimental Forest (PEF) for five naturally regenerated hardwood species (red maple, paper birch, gray birch, bigtooth aspen, and trembling aspen) and compared the fit of regional and national sapling aboveground biomass equations to the data.

Methods

Hardwood trees were destructively sampled in the summer of 2011 from the Silvicultural Intensity and Composition (SIComp) experiment on the PEF (Nelson and Wagner 2011; Nelson *et al.* 2013). Trees were cut at the root collar during peak leaf out to ensure accurate estimates of hardwood foliage biomass. Between 12 and 17 trees per species were sampled, across a range of DBH sizes. Trees ranged in size from 0.1 in to 5.2 in DBH, where the aspen species were larger than the birch species and red maple. The entire tree was separated into components, dried at 150 °F for a minimum of 2 weeks for foliage and branches, and 4 weeks for stem sections.

Total oven-dry aboveground biomass was predicted with 4 sets of equations for all species across the range of DBH sampled. The equations included: (a) Additive (Nelson *et al. submitted for publication*), Young (Young *et al.* 1980), Jenkins (Jenkins *et al.* 2003), and TMK (Ter-Mikaelian and Korzukhin 1997) equations. The Additive equations were fit to the trees collected for this investigation, while the Young equations were developed from field data in Maine by Harold Young of the University of Maine. The Jenkins and TMK equations encompass common tree species in North America, and were developed from other published equations. Woody aboveground biomass (total – foliage) was predicted with the Jenkins and FIA sapling (FAS) (Heath *et al.* 2009) equations.
Biomass predictions were verified with root mean square error (RMSE), mean absolute bias (MAB), and the minimum detectable negligible difference (MDND) equivalence test, where the null hypothesis is that the observed and predicted mean biomass are not the same (Radtke and Robinson 2006). For this investigation, if the prediction relative to the observed (PRO) value (i.e. negative or positive percent deviation of predictions from the observed values) was within the bounds of observed mean ± MDND, the null hypothesis of the equivalence test was rejected and the predicted values were considered similar to the observed values. RMSE and MAB were defined as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \hat{y}_i\right)^2}{n}}$$

$$MAB = \frac{\sum_{i=1}^{n}\left|y_i - \hat{y}_i\right|}{n}$$

Where: y_i are the observed values, $\hat{y}_i$ are predicted values from the equations, and n is the number of observations.

Results

Among the 4 equations investigated, the Jenkins and Young equations overestimated total aboveground biomass of red maple, paper birch, and gray birch, while biomass of these 3 species was underestimated by the TMK equation (figure 2-16). For red maple, RMSE and MAB of the Young equations were 44% and 77% lower than the TMK equation. The Young and Jenkins equations produced similar total aboveground biomass estimates for both aspen species, overestimating bigtooth aspen total aboveground biomass by 12% and 13%, respectively, and underestimated trembling aspen biomass by 11% and 8%, respectively. The RMSE and MAB of the TMK bigtooth equation were 2.16 lbs and 1.32 lbs, respectively, while the RMSE and MAB of the Jenkins equations were 4.74 lbs and 3.06 lbs, respectively. The null hypothesis of the equivalence test was not rejected for the TMK equations for red maple, paper birch, gray birch, and trembling aspen, while the null hypothesis of the Young equations was only not rejected for trembling aspen.

Paper birch and gray birch were combined for verification of the woody biomass equations because of the small sample size for both species within the valid DBH range of the FAS equations (1.0 in and 4.9 in DBH), and since woody biomass was estimated with the same Jenkins equation and FAS adjustment factor. The FAS equations substantially underestimated aboveground woody biomass relative to the observed data for all four naturally regenerated hardwood species (figure 2-17), from 37% for trembling aspen to 19% for the birch species. Similarly, the equivalence test of the FAS equation was not rejected for any of the species.

Comparatively, the Jenkins equations overestimated woody biomass by 8%, 11%, and 17% for red maple, birch species, and bigtooth aspen, respectively, and underestimated trembling aspen woody biomass by 3%. The Jenkins equation equivalence test was rejected for all species.

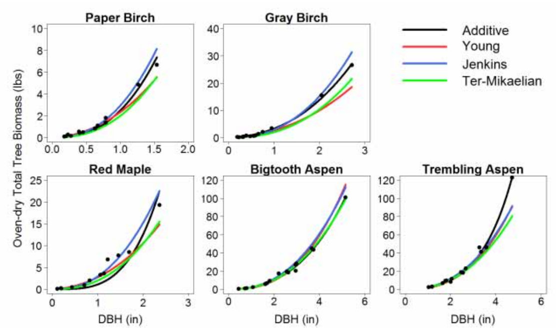

Figure 2-16. Total aboveground oven-dry biomass (lbs) versus DBH (in) for the five naturally regenerated hardwood species. Observed data are shown as solid circles, while each of the four lines represents a different biomass equation. The equations are: Additive, Young, Jenkins, and Ter-Mikaelian (TM). Note the difference in the X- and Y-axis values.

Discussion

Performance of Total Biomass Equations

The Jenkins and Young total aboveground biomass equations both had good agreement with the observed data of the naturally regenerated species. It was hypothesized that of all the compared equations, the Young equations would have the best fit to the data since they were fit with data collected in Maine. The results showed that the Jenkins equations produced similar or better estimates than the Young equations, as RMSE was lower for paper birch, gray birch, and bigtooth aspen.

The equivalence test null hypothesis of the TMK equations was not rejected for all species except bigtooth aspen, suggesting the predicted values were not within an acceptable range to be considered similar to the observed values. In particular, the TMK equations underestimated total aboveground biomass by more than 25% for red maple, paper birch, and gray birch. Data used to fit the equations in TMK for these species were collected from Nova Scotia and New Brunswick, Canada, and included trees with DBH < 1 inch (Ker 1980, 1984). The poor fit of these models were unexpected because of the close geographic proximity, number of observations (44, 196, and 197 for gray birch, paper birch, and trembling aspen, respectively) and similar DBH ranges to the trees in the current investigation. It is possible that the number of saplings used to fit the TMK equations were small relative to the total sample size.

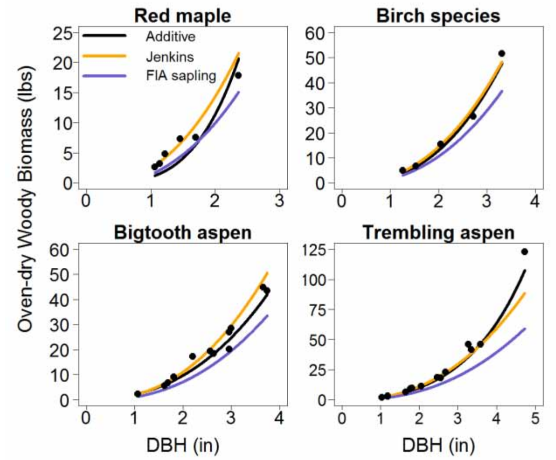

Figure 2-17. Woody aboveground oven-dry biomass (lbs) versus DBH (in) for the five naturally regenerated hardwood species (paper birch and gray birch combined). The observed data are shown as solid circles, while the three lines represent predictions of the different equations. The equations were: Additive – this investigation, Jenkins and FIA aboveground sapling (FAS). Note the difference in the X- and Y-axis values.

The Jenkins equations were developed to encompass all tree species across the United States and are currently part of the CRM methods used by the FIA program to estimate woody biomass on all forestlands, yet the equations were fit using generalized regression of pseudo-data and have not been well verified with actual field data. In this investigation, null hypotheses of the equivalence tests were rejected for the Jenkins total aboveground biomass predictions for all species. Although further validation of the Jenkins equations is warranted across a wider range of tree size and geographic location, the results from this investigation suggest the Jenkins equations provided adequate estimates of total aboveground biomass of the species investigated at this particular site.

Performance of Woody Biomass Equations

The FAS equations reduced Jenkins woody biomass estimates for all species, resulting in the underestimation of mean biomass between 19% and 37% for the hardwood species. Similar to the Jenkins equations, the FAS equations lack verification with field data in northeastern North

America. In stands dominated by saplings, such as 32% of the forested area in Maine, our results suggest aboveground woody biomass may be substantially underestimated.

The underestimation of sapling biomass with the FAS is likely a cause for the estimated 35% reduction in sapling biomass in the state of Maine when FIA switched from regional equations to the current methods. Since nearly one-quarter of forestlands in Maine are dominated by saplings, the switch to the FAS equations has also influenced aboveground biomass predictions of all living trees in the state. For instance, aboveground biomass of all living trees > 1 in DBH decreased by 31% between 2003 and 2008 (McCaskill *et al.* 2011; McWilliams *et al.* 2005), likely due to a combination of biomass removal, the change to the CRM for estimating biomass of tree ≥ 5 inches DBH, and the switch to the FAS equations for sapling biomass. The inability of the FAS equations to accurately estimate biomass of saplings may pose problems for producing landscape biomass estimates by the FIA program across the nation for stands dominated by trees < 5 inches DBH, and warrants further verification with field data.

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RESIDUAL CONDITIONS OF 50 PARTIALLY HARVESTED STANDS IN NORTHERN MAINE

Ben Rice, Robert Wagner, and Aaron Weiskittel

Introduction

During the spruce budworm outbreak of the 1970s and 1980s in eastern Canada and northern New England forestry management was focused on protection of forests from the budworm defoliation and salvage of merchantable volume following severe budworm defoliation. In Maine clearcut harvesting was a prevalent silvicultural tool in the salvage phase, reaching 44% of the annual harvested area in Maine in 1989 (Maine Forest Service 1995; Rowland *et al.* 2005). Ultimately, social and political concern over the use of clearcut harvesting and the coinciding end of the spruce budworm outbreak resulted in the Maine Forest Practices Act, which was followed by sharp reductions of clearcut harvesting.

Consequently, clearcutting has fallen from 145,357 acres in 1989 to 19,292 acres, or 4.4% of the total annual harvested acres, in 2010 (Maine Forest Service 1995, 2010). This dramatic shift in harvesting patterns has resulted in a steep increase in the number of acres harvested annually to obtain about the same wood volume over the past 30 years or more (Maine Forest Service 2011a; McWilliams *et al.* 2005). Recent data from the Maine Forest Service indicate that 5,337,191 cords were harvested from 439,601 acres in 2010 (Maine Forest Service 2011a, b). In contrast, throughout the 1980s <300,000 acres were harvested annually to obtain about the same amount of wood (5.5 to 6 million cords). In particular, partial harvesting, including both the partial harvest and shelterwood categories from Maine Forest Service reports, has accounted for 96.8% of the harvested area and clearcutting 3.2% of the annual harvested acreage over the past 5 years. This is in contrast to the period between 1988 and 1992, when 71.7% of the acreage was partially harvested and 28.3% clearcut (Maine Forest Service 1995).

With the continued prevalence of partial harvesting practices, there is a strong need to better understand post-harvest stand dynamics. In order to begin developing an understanding of the silvicultural outcomes associated with partial harvesting in Maine, we are examining post-harvest conditions. Specific objectives were to evaluate the influence of partial harvesting in northern and central Maine timberlands on stand attributes, such as residual stand density, basal area, volume, and tree damage (table 2-13).

Methods

The Maine Image and Analysis Laboratory (MIAL) provided a list of stands that had been partially harvested between 1988 and 2007 with <70% canopy removal. Fifty of these stands were randomly selected from this list and subsequently inventoried (figure 2-16).

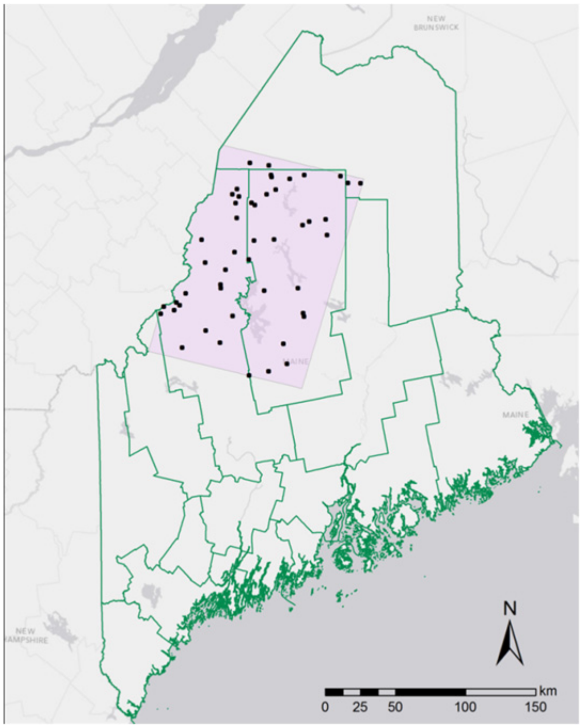

Figure 2-16. Map of study area denoted in shaded portion and points representing inventoried stands.

Table 2-13. Variables of interest including the units utilized and variable description.

Attribute	Units	Description
Stand attributes		
Commercial basal area	ft^2 ac^{-1}	Basal area of commercial tree species
Commercial density	stems ac^{-1}	Trees per acre of commercial species
Gross commercial volume	ft^3 ac^{-1}	Unadjusted volume of stems ≥5 in. of all commercial species
Quadratic mean diameter	in.	Quadratic mean of commercial species
Percent noncommercial basal area	%	Percent of total basal area (commercial + noncommercial) of noncommercial species
Percent noncommercial density	%	Percent of total density of noncommercial species
Live crown ratio	%	Height of crown/ total tree height
Damaged basal area	%	Percent of basal area commercial species with damage
Damaged density	%	Percent of stems of commercial species with damage
Deadwood basal area	ft^2 ac^{-1}	Basal area of all standing dead stems
Deadwood density	stems ac^{-1}	Standing dead stems per acre
Importance value	---	Relative frequency, density, and dominance
Harvest attributes		
Percent complete removal	%	Percent of stand area with complete overstory removal
Percent partial removal	%	Percent of stand area with partial overstory removal
Stand size	ha	Size of stand determined by remote sensing and in some case revised by on the ground conditions
Harvest interval	year	Midpoint of harvest timing as determined through remote sensing
Reharvested	Y/N	Variable to denote whether stand was harvested again after harvest interval

For each stand, we noted whether the stand had evidence of being re-harvested since the harvest interval provided by the MIAL. Inventory plots were placed on a systematic grid in each stand. The number of plots in each stand ranged from 4 to 19 with an average of 11 plots, varying based on stand size and shape. At each sampling point, we collected overstory tree and harvest data. In sampling the overstory trees, we used horizontal line sampling, implementing the basic methods of Beers and Miller (1976). A previous analysis indicated that this method worked quite well in stands of this nature (Weiskittel *et al.* 2012).

For each live “in” tree ≥4.5 ft height and ≥2 in. diameter at breast height (DBH), we recorded species, condition class, and DBH; and for every fifth tree measured height and height to crown base. We assessed the characteristics of tree damage in a subset of stands (n=43), using methods similar to the current FIA protocol (USDA Forest Service 2007). We recorded the source of the damage (natural, logging, or unknown), the type of damage (open wound, crack or seam, or broken bole), the location of the damage (upper or lower bole), and the severity of damage (percent of the circumference of the bole to the nearest 10%).

Harvest attributes were assessed at the plot level. In order to develop an estimate of the percent of stand area that had been completely or partially harvested, we assigned one of three harvest status conditions (unharvested- no tree removal, complete removal- removal of all overstory trees (i.e., trials and landings), and partial removal- removal of some but not all overstory stems) along the entire length of each overstory sampling line.

Harvest attributes included the size of the stand, percent of the stand harvested, and timing of the harvest (harvest interval), which includes the initial harvest interval and whether the stand had been re-harvested. We calculated the percent of each sampling line that fell within the three harvest status categories (complete overstory removal, partial overstory removal, and unharvested). The average of these values was taken to estimate the percentage of the stand in each harvest status. Harvest interval was taken from the estimates provide by MIAL change detection efforts.

Stand level attributes were calculated for overstory tree species, including basal area, gross volume, density, quadratic mean diameter (QMD), average live crown ratio, percentage of basal area and density in noncommercial species, percent damaged basal area and density, standing deadwood basal area and density, and species importance values.

Preliminary Results

Harvest attributes

Stands ranged in size from 11 to 1,450 acres (table 2-14), with an average of 292 acres (sd: 317.3). On average, 35.0% (sd: 15.8) of the stand area had complete overstory removal with a range of 0 to 71.0% (figure 2-17). Nine of the fifty stands had been re-harvested since the initial partial harvest interval and these re-harvested stands had, on average, 11.1% (95% CI: 1.3 to 20.9%) more area of complete overstory removal compared to stands that had not been re-harvested. The percent area of partial overstory removal ranged from a low of 0% (older harvests where areas of partial overstory removal were either not present or not observable) to a high of 100% (one approximately 20 year old harvest that had apparently been a regular shelterwood harvest) and the average partial overstory removal was 45.0% (sd: 25.4).

Stand attributes

Basal area of commercial species ranged between 18.7 and 137.6 $ft^2\ ac^{-1}$ with a mean of 76.8 $ft^2\ ac^{-1}$ (sd: 28.0). The coefficient of variation for commercial species averaged 65.6% (sd: 32.6) with a range of 22.5 to 193.0%. On average, noncommercial species comprised 9.5% (sd: 11.8) of total stand basal area with a range of 0 to 54.3%. The mean QMD of all stands was 5.5 in. (sd: 1.3) with a range of 3.5 to 8.8 in. Density of commercial species ranged between 117.1 and 1524.8 stems ac^{-1} with a mean of 525.3 stems ac^{-1} (sd: 309.5).

Table 2-14. Summary of raw stand attributes for 50 sampled stands (mean, standard deviation (sd), and range).

	Mean	SD	Range
Harvest attributes			
Area (ac)	292.0	317.3	11 - 1450
Complete overstory removal (percent)	35.0	15.8	0.0 - 71.0
Partial overstory removal (percent)	45.0	25.4	0.0 - 100.0
Stand attributes			
Basal area ($ft^2\ ac^{-1}$)	76.8	28.0	18.7 -137.6
Basal area CV (percent)	65.6	32.6	22.5 - 193.0
Noncommercial basal area (percent)	9.5	11.8	0.0 - 54.3
QMD (in.)	5.5	1.3	3.5 - 8.8
Density (TPA)	525.3	309.5	117.1 - 1524.8
Noncommercial density (percent)	15.6	14.5	0.0 - 67.8
Live crown ratio (percent)	55.2	7.7	39.7 - 71.5
Volume ($ft^3\ ac^{-1}$; stems ≥5 in. DBH)	1254.1	626.4	177.9 - 3022.3
Intolerant composition (percent)	8.7	8.4	0 - 44.7
Intermediate composition (percent)	14.0	6.3	3.7 - 35.0
Tolerant composition (percent)	77.3	9.3	47.2 - 95.1
Hardwood composition (percent)	61.1	21.7	4.9 - 100.0
Damaged basal area (percent)	6.7	3.7	0.0 - 18.3
Damaged density (percent)	4.7	3.5	0.0 - 11.1
Deadwood basal area ($ft^2\ ac^{-1}$)	6.5	4.1	0.0 - 20.0
Deadwood density (stems ac^{-1})	31.3	23.3	0.0 - 112.3

Noncommercial stem density averaged 15.6% (sd: 14.5) of total stem density and had a range of 0 to 67.8%. The average live crown ratio for all commercial species ≥2 in. DBH ranged from 39.7 to 71.5% with a mean of 55.2% (sd: 7.7).

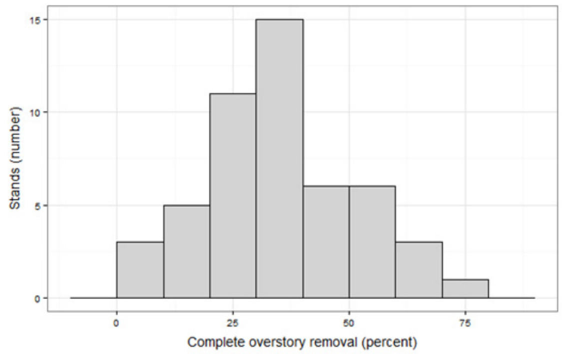

Figure 2-17. Histogram of complete overstory removal.

Gross volume of commercial species ≥5 in. DBH in 49 of the partially harvested stands sampled averaged 1254.1 ft^3 ac^{-1} (sd: 626.4) with a range of 177.9 to 3022.3. One stand was excluded from the analysis of volume because there were not enough stems ≥5 in. DBH. Composition was averaged across all stands and included both commercial and noncommercial species. Shade intolerant species comprised 8.7% (sd: 8.4; range: 0.0 to 44.7) of importance values, intermediate shade tolerant 14.0% (sd: 6.3 ; range: 3.7 to 35.0), and tolerant 77.3% (sd: 9.3 range: 47.2 to 95.1). The average percent hardwood composition was 61.1% (sd: 21.7) with a range of 4.9 to 100.0%.

Assessment of damaged stems included only stems of commercial species ≥2 in. DBH. The mean percent damaged basal area was 6.7% (sd: 3.7) with a range of 0.0 to 18.3%. Mean percent damaged density was 4.7% (sd: 3.5) with a range of 0.0 to 11.1%. The average basal area of standing deadwood was 6.5 ft^2 ac^{-1} (sd: 4.1 range: 0.0 to 20.0) and average density was 31.3 stems ac^{-1} (sd: 23.3 range: 0.0 to 112.3).

Discussion

The preliminary results of this investigation demonstrate the high level of variability in partially harvested stands, which was largely anticipated. While every landowner is different and each harvest is relatively unique, the range of variability in some harvest and stand attributes was unexpected. For example, the average of 35% complete overstory removal is equivalent to the conventional wisdom that approximately one-third of a partially harvested stand is composed of trails and landings. Yet, looking more closely at the data, 32% of stands have greater than 40% area of complete overstory removal. We would then expect harvest patterns to have a strong influence on species composition, but only 6% of stands contained more than 25% shade intolerant species. Species composition data will likely be important in assessing the silvicultural opportunities in partially harvested stands. For example, on average 9.5% of total basal area consists of noncommercial species. From a forest management perspective, it will be interesting to explore the role of noncommercial species in influencing stand development. This type of information will be vital as we move forward in the analysis of post-partial harvest growth rates and regeneration.

In addition to the preliminary results we presented here, we also established a system of long-term sample plots in partially harvested stands. We selected eight stands and established three plots in each stand. The plots consist of 1/10 acre overstory plots and regeneration subplots. All of the overstory trees within the plot have been measured, tagged, and stem mapped. This system of plots will allow us to follow post-partial harvest stand dynamics over time in terms of residual tree growth and mortality as well as regeneration establishment and growth.

Partial harvesting in Maine represents a range of harvesting practices overlaid upon on a diversity of forest stand conditions. This complicates building a picture of Maine's current forests and planning for the future. For Maine's landowners and the state as a whole it is important that we better understand the stand and landscape level effects of the suite of partial harvesting practices in term of wood supply, recreation value, wildlife habitat and overall ecological integrity. We hope that this work will lay the foundation for improved understanding of partial harvesting.

Future Direction

Currently, a peer review journal article is in preparation describing the partially harvested stands sampled for this study and examining the relationships between harvest attributes and stand attributes. Following that, we will prepare an analysis of post-harvest growth rates using data from these 50 stands, including a large number of increment cores collected.

While the outcomes of this study should be informative, there are many questions that will require further investigation. For example in terms of post-harvest mortality, Nichols et al. (1994) found approximately twice the number of stems damaged in summer harvesting compared to winter operations, and the difference was attributed to bark being more easily damaged during late spring and early summer. This magnitude of this difference could be important in managing some forest types, but remains beyond the scope of this study. We foresee our results uncovering a wide variety of further questions that are relevant to the CFRU membership in current and future management of partially harvested stands.

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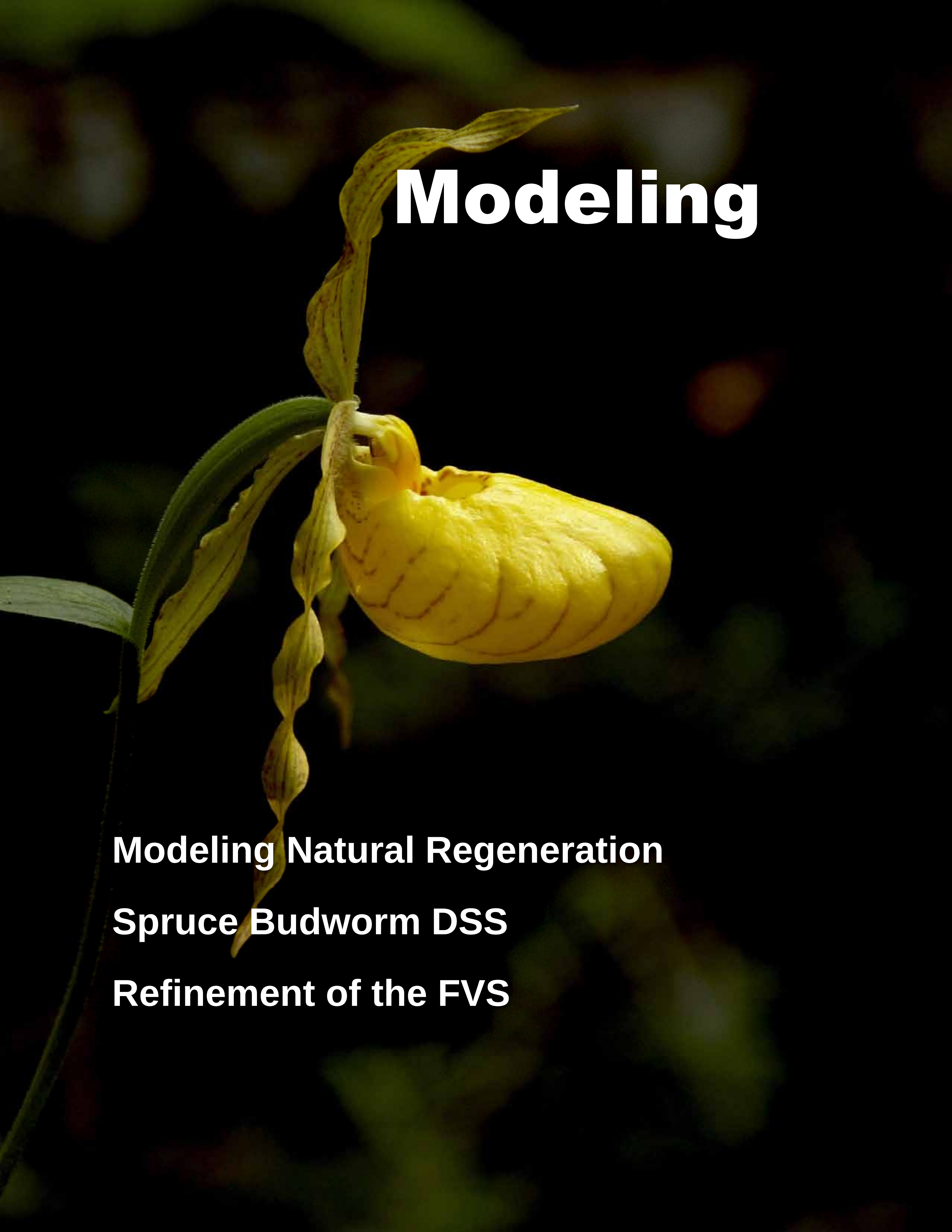

Modeling

Modeling Natural Regeneration

Spruce Budworm DSS

Refinement of the FVS

MODELING NATURAL REGENERATION INGROWTH IN THE ACADIAN FOREST

Aaron Weiskittel, Rongxia Li, and John Kershaw, Jr.

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 3-1).

Table 3-1. 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	1,294	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	1,837	14.2	5	(0, 278)	4.1
FIA	438	0.075	11	16.4	305	14.6	10	(0, 67)	12.8
FIA	4,457	0.014	5	27.0	898	14.4	24	(0, 297)	6.0
New Brunswick	1,999	0.027	4	25.4	2,156	11.9	27	(0, 299)	4.3
Nova Scotia	2,754	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	2,045	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	1,523	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	1,264	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 3-1).

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 3-2).

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 3-1.

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

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

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 3-2.

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

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 seven 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 3-2). 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 3-2 and 3-3).

Table 3-2. 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

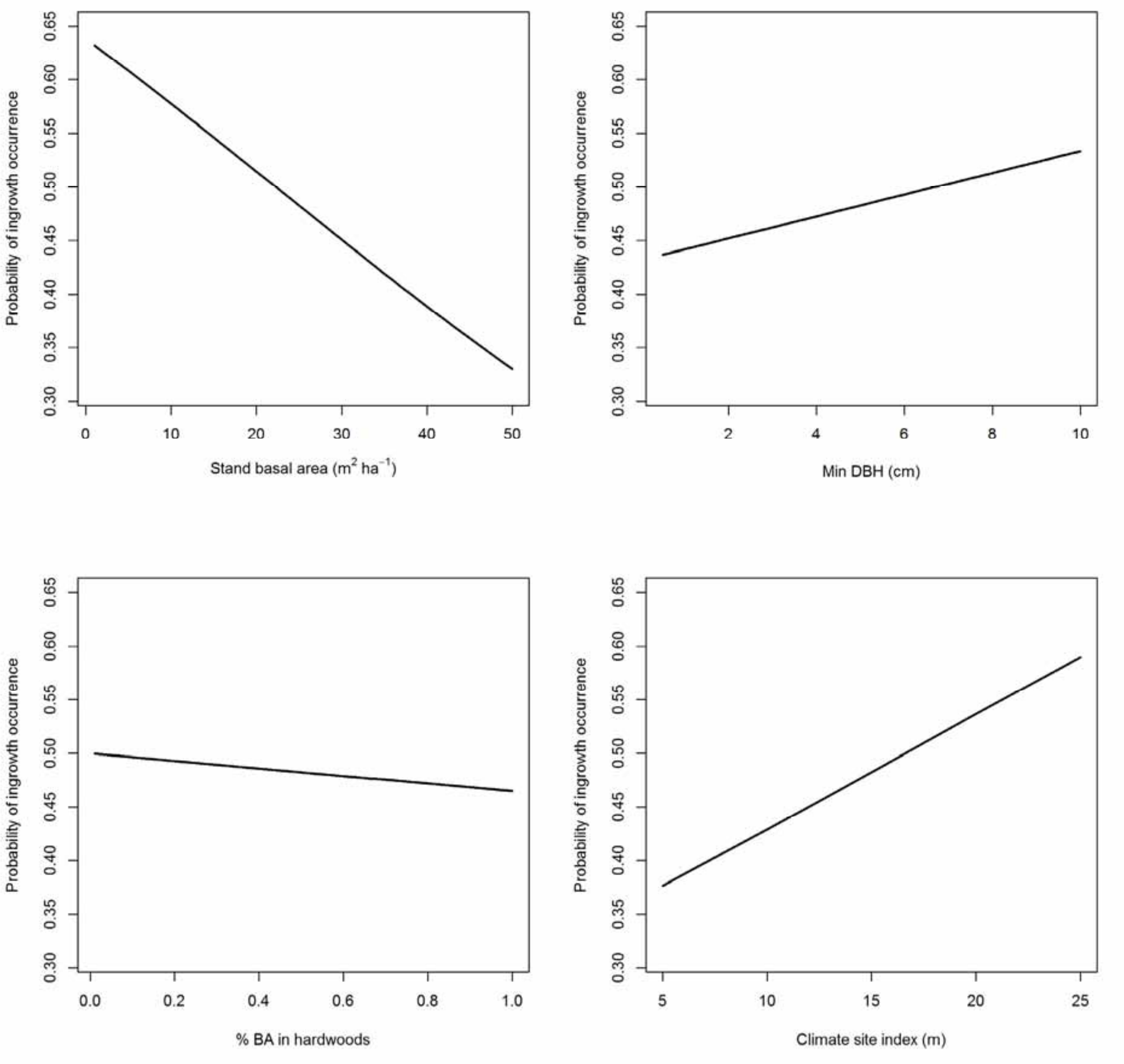

Figure 3-2 . Predicted probability of annual ingrowth occurrence over stand basal area, minimum DBH, percent basal area in hardwoods, and climate site index using equation 3-1.

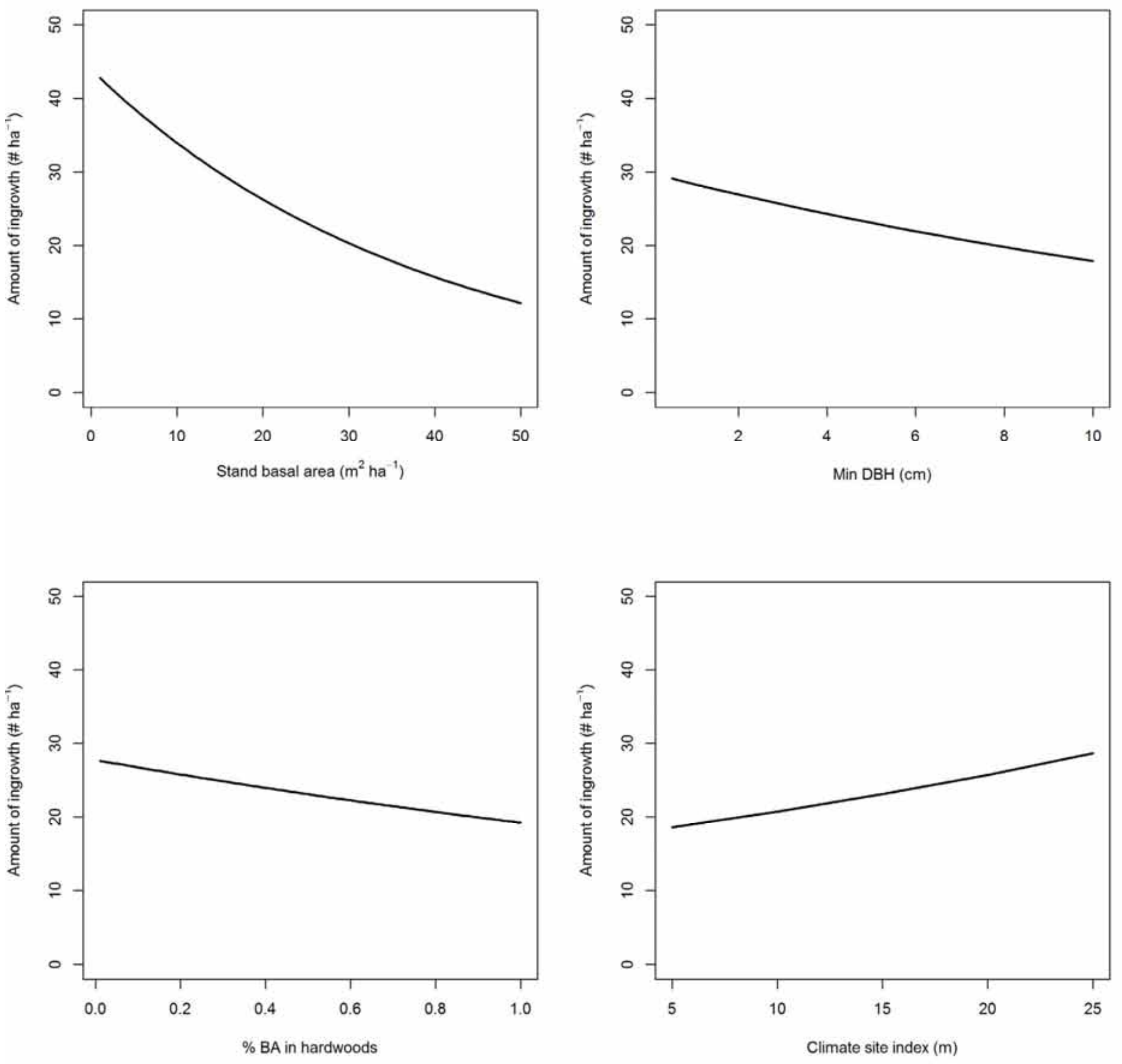

Figure 3-3. Predicted annual ingrowth frequency (# ha^{-1}) over stand basal area, minimum DBH, percent basal area in hardwoods, and climate site index using equation 3-1.

Ingrowth Composition

Except for the birch species group, all parameters in the species composition model were statistically significant at 0.05 level (table 3-3). 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 3-4). 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 3-3. 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

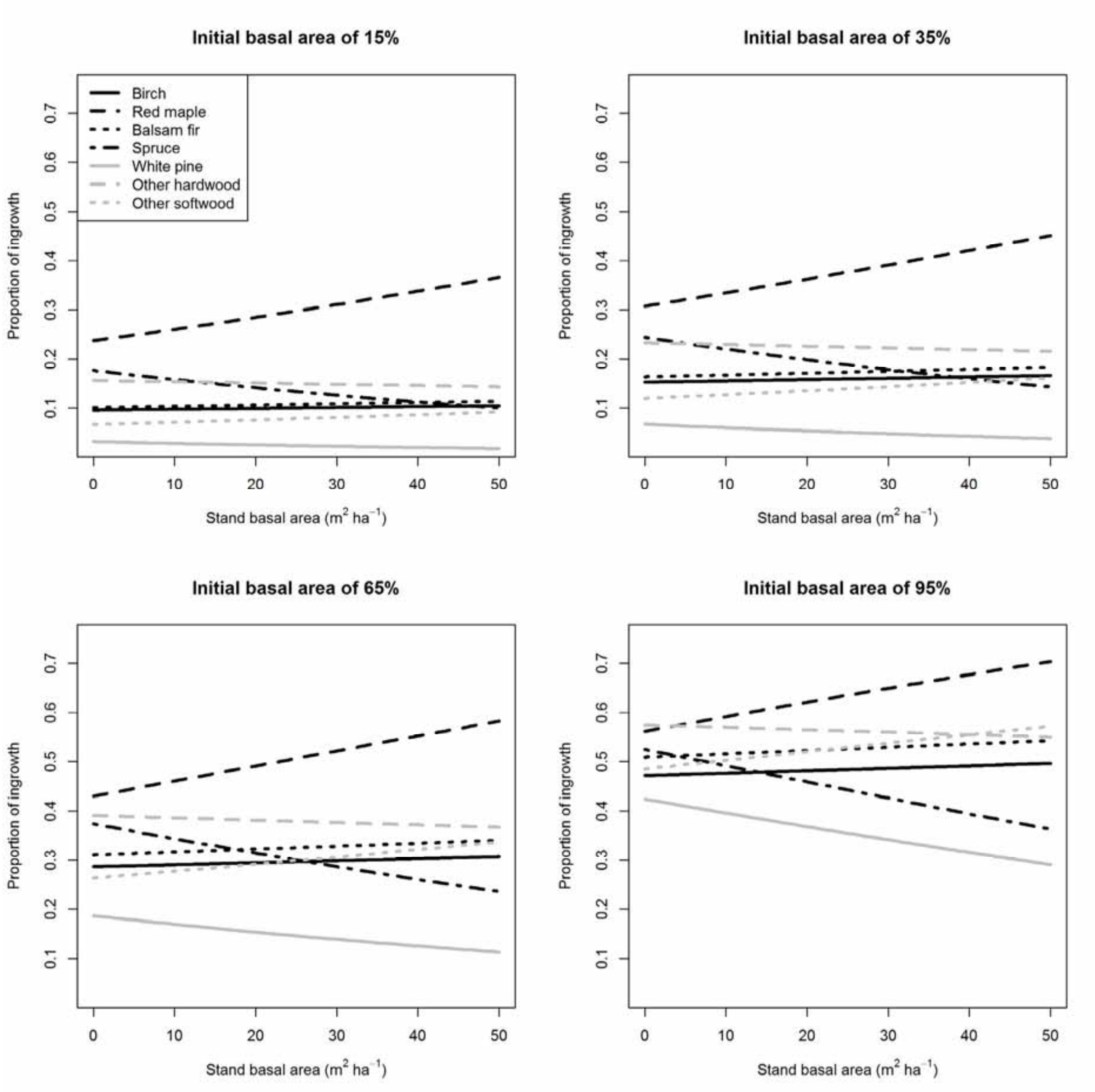

Figure 3-4. Predicted proportion of ingrowth by species and varying species proportion of initial basal area over stand total basal area using equation 3-2. A climate site index of 15 m and a minimum DBH of 5 cm were assumed on all graphs.

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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SPRUCE BUDWORM DECISION SUPPORT AND STRATEGIES TO REDUCE IMPACTS IN MAINE: 2012 UPDATE

Chris Hennigar, David MacLean, and Thom Erdle

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 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 Maine from available historical data;
    b) Provide means to simulate SBW defoliation impacts on tree growth and survival using the Forest Vegetation Simulator (FVS; Northeast variant) with New Brunswick tree-level defoliation-damage relationships;
    c) Project stand development using FVS for available Forest Inventory and Analysis (FIA) sample plots in Maine, 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 SBW outbreak impact estimates to quantify potential benefits of alternative silviculture for a wide range of outbreak start dates (2015, 2025, 2035, 2045) and severities.

Project Status

To date (February 2013), this project has fulfilled objectives 1 and 2. See the 2011 CFRU annual report for a detailed description of outcomes under objectives 1b-c and 2. This report distils results from objective 1, with emphasis on historical population and defoliation scenarios compiled and interpreted from Maine Forest Service SBW reports. These scenarios have been used, along with other plausible SBW outbreak scenarios, to assess the SBW impact potential and mitigation opportunities under objective 3.

For objective 3, all FVS projections with and without SBW are complete, the new Maine wood-supply impact model has been cross validated against FIA inventory conditions and Maine wood processing reports, and all impact scenarios have been simulated; however, these results have not yet been completely distilled into a report at this time. A full report covering all outcomes from all objectives is underway and expected by the Fall of 2013.

Customizing the SBW DSS for Maine

This project has made two main contributions to localize implementation of the SBW DSS for Maine. Firstly, all aerial defoliation sketch maps and egg mass survey points available from Maine Forest Service reports from 1972 to 1989 were digitized. This new dataset enabled characterization of historical spatial frequency and temporal severity of defoliation and population levels overtime for the last outbreak in Maine (figure 3-5). These GIS layers, including annual defoliation and population levels are available through the CFRU website. http://www.umaine.edu/cfru/Advisory_Comm/Documents/SBW_Impacts/SBW_Map.htm

Secondly, SBW tree growth and survival impact multipliers used in STAMAN (New Brunswick's current stand growth model; used to calibrate the SBW DSS) were translated for use 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.

Software was developed to extend the functionality of the FVS, via FVS commands, to permit modeling of SBW defoliation effects on growth and yield directly in FVS. These were compared to previous SBW DSS work in Maine (Hennigar *et al.* 2011) that estimated absolute stand yield impacts in Maine from impacts projected from STAMAN using New Brunswick stand conditions.

See the 2011 CFRU annual report for further details regarding SBW impact modeling methods and outcomes in FVS, as well as hyperlinks above to download documentation and software developed under this project for FVS.

Maine 1970-80s SBW outbreak

Maine Aerial Sketch Maps

Throughout the SBW outbreak in Maine, trained observers surveyed infested areas from fixed-wing aircraft and sketched areas of defoliation on 1: 62,500 topographic maps. These annual maps and associated reports were obtained from the Maine Forest Service for 1972 to 1989. The surveyors classified severity of current-year defoliation in each polygon; however, the classification scheme varied throughout the outbreak. All maps were scanned, geo-referenced, and digitized as polygon layers into a GIS. Because the classification scheme changed over time, defoliation was reclassified by class mid-points into a common scheme (figure 3-6): nil (0%), light (1%-30%), moderate (30%-70%), and high (70% +).

Figure 3-5. View from Mt. Katahdin in 1980 showing budworm damaged trees in gray. Photo by David Field.

A 2 × 2 km grid was intersected with each annual defoliation map in ArcGIS. One defoliation class was assigned to each of the 22,310 intersected cells for each year according to a majority rule developed by Gray and MacKinnon (2006):

> *if >50% of the cell area intersected a nil defoliation polygon, then defoliation equals zero; else defoliation equals the value of the non-zero defoliation polygon whose area is greater.*

This resulted in 2,765 unique temporal patterns for 1972 to 1989.

K-means clustering was used to group similar defoliation patterns, which followed closely the statistical methods used by Gray and MacKinnon (2006) to aggregate similar patterns in central and eastern Canada. Patterns were temporally shifted to align the first year of mapped defoliation > 0. Twenty-two clustered patterns were identified (figure 3-7), which explained 68.7% of the variance among the 2,765 unique patterns. When patterns were grouped according to number of years with >30% defoliation, approximately 11%, 23%, 58%, and 6% of Maine was classed as experiencing negligible (1-2 yrs), low (3-5 yrs), moderate (6-10 yrs), and severe (11+ yrs) defoliation (figure 3-7).[4]

[4] These classes were originally defined by Gray et al. (2000) and are used here to allow comparison between defoliation patterns presented by Gray *et al.* (2000) for Quebec during the last outbreak.

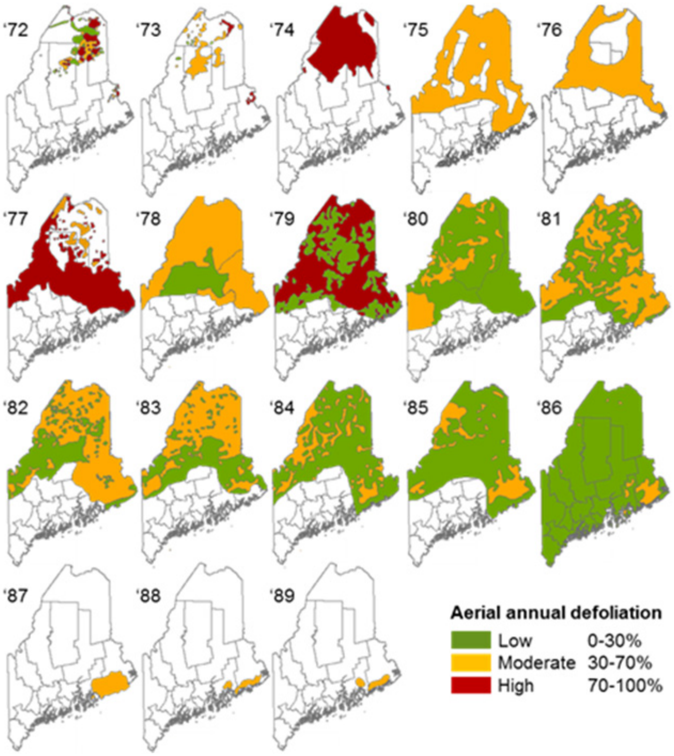

Figure 3-6. Aerial defoliation sketch maps of annual spruce budworm defoliation digitized from the Maine Forest Service for 1972-1989 (Maine Forest Service 1972-1989).

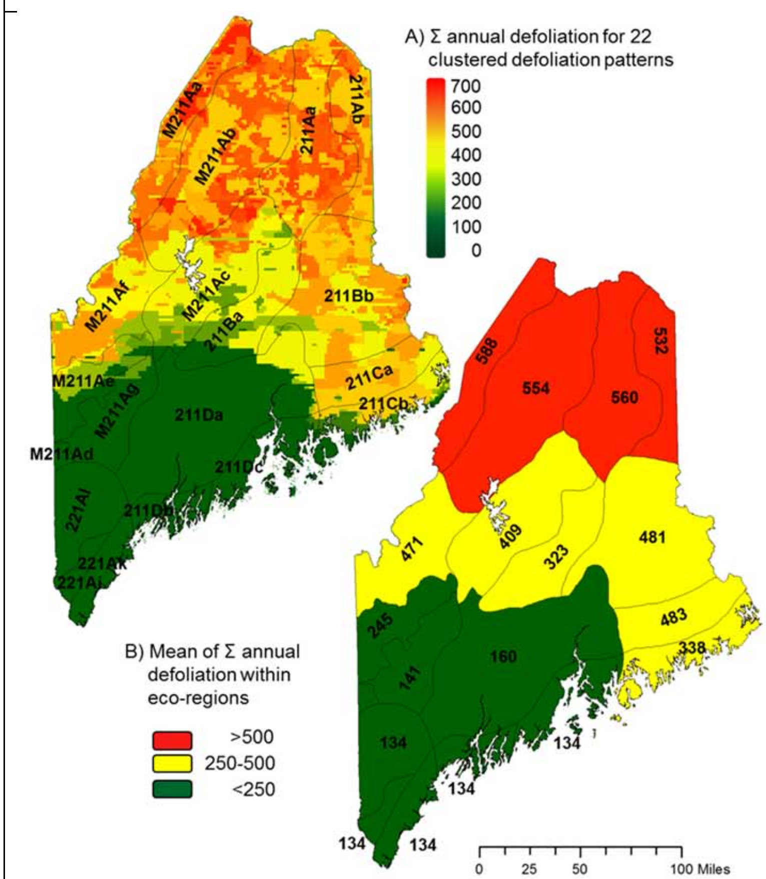

Figure 3-7. Summed annual defoliation for 22 clustered defoliation patterns for Maine (a) in 2 x 2 km grid cells and (b) averaged by eco-region with averaged values labeled in each eco-region. Eco-region alpha-codes used by the USDA Forest Inventory and Analysis branch are labeled in (a).

In comparison, Gray *et al.* (2000), using the same classification scheme, classed 35%, 24%, 16%, and 19% of forested area in Quebec respectively as negligible, low, moderate, and severe. Less percent area in the severe impact class in Maine compared to Quebec may have resulted from less balsam fir and white spruce relative abundance in Maine forests compared to Quebec, differences in aerial sketch mapping methods, differences in area protected, but perhaps mostly because prolonged moderate-severe defoliation in Maine was geographically limited to northern regions.

Despite extreme spatiotemporal defoliation variability in Maine, defoliation severity generally increased from southwest to northeast. Visually, breaks between severity levels corresponded roughly with some existing eco-region boundaries (figure 3-7). Summed annual defoliation percent, when averaged by eco-region, was >500% (equivalent to removal of five age-classes of foliage) in northern eco-regions, between 250-500% in central eco-regions, and <250% in southwestern eco-regions (figure 3-7b); these areas respectively comprised 30%, 37%, and 33% of the area in Maine. All southwestern eco-regions, which experienced <250% summed annual defoliation (figure 3-7b), also had <25% defoliation from 1972-1989, except for eco-region M211Ae (figure 3-7a), which had three years of defoliation between 30-37%. For the purposes of this analysis, these southern eco-regions were not considered at risk for a future SBW outbreak. For the remaining at risk area, defoliation patterns were averaged by eco-region (figure 3-8).

Defoliation patterns: confounding issues

Following from the defoliation summarization above, it was apparent that mapped defoliation patterns (figure 3-8) had levels simply too low to generate the observed levels of reported tree mortality during the last outbreak, and were at extreme odds with defoliation levels that would be expected based on the Maine egg-mass surveys. At no time did mean annual defoliation exceed 65% across eco-regions, or exceed 75% among clustered 2 x 2 km grid cell patterns. If these defoliation patterns were used in the SBWDSS, negligible tree mortality would be projected. Egg mass counts between 1974 and 1984 commonly exceeded 400 masses / 100 ft^2, which would be sufficient to cause 100% defoliation on balsam fir (Simmons 1974).[5]

While these patterns may indeed reflect mean regional defoliation observed, there are a number of confounding issues that precluded use of this information in constructing an 'unprotected' Maine outbreak pattern for use in the SBWDSS.

First, foliage protection treatments (table 3-4) undoubtedly reduced defoliation. Defoliation adjustments that accounted for protection (e.g., Porter *et al.* 2004; Gray and MacKinnon 2007), for even the most severe patterns, would still result in low levels of projected mortality.

Table 3-4. Hectares treated for foliage protection and hectares of medium- high defoliation reported from 1970 to 1981 (Maine Forest Service 1972-1989).

Year	Treated (ha)	Mod.-high defoliation (ha)
1970	82,677	unknown
1972	118,110	129,200
1973	177,165	110,400
1974	169,291	343,200
1975	922,441	648,000
1976	1,377,953	339,200
1977	361,811	430,400
1978	428,346	559,600
1979	1,087,008	499,200
1980	512,992	212,800
1981	461,417	485,200

Second, it is unclear exactly which host species the mapped defoliation pattern is reflective of, or whether the composition of non-host or less preferred host (red and black spruce) influenced the observed aerial defoliation estimates. Less defoliation occurs on red and black spruce relative to white spruce and balsam fir (Hennigar *et al.* 2008), and defoliation of balsam fir generally declines as stand hardwood content increases (Su et al. 1996). Therefore, within the broadly mapped defoliation polygons in figure 3-6, defoliation probably varied at least as much as stand composition.

Third, the degree of averaging in the observed records (low resolution defoliation classes and spatial delineation), and further simplification in our analysis (2 x 2 km grid cells, mean regional patterns), severely compromised our ability to

[5] In years or samples where counts of 2nd instar larva (L_2) were reported, these levels were converted to egg mass counts using defoliation class mid-points reported for both L_2 and egg mass levels in the annual Maine Forest Service reports.

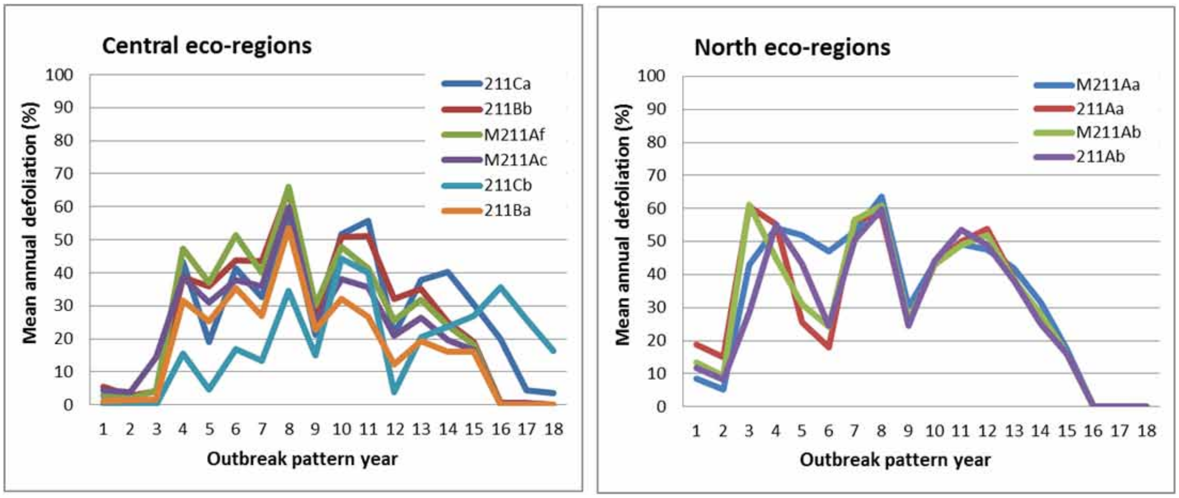

Figure 3-8. Mean annual defoliation (%) for outbreak patterns in central and northern eco-regions.

reproduce a representative distribution of defoliation patterns in terms of both severity and frequency. For example, maximum possible defoliation was 85% (mid-point of high severity class); yet it is probable that many balsam fir stands experienced 100% defoliation for multiple years. The difference between 85% and 100% cumulative defoliation on balsam fir would translate to a 40-80 percentage point difference in tree survival depending on age (Erdle and MacLean 1999). The non-linear nature of the defoliation: tree survival relationship necessitates use of an accurate distribution and frequency of stand-level defoliation patterns, rather than forest-level average patterns.

In light of these issues, defoliation patterns used in this analysis were derived instead from the egg mass survey data. Egg mass counts may be less influenced by foliage protection treatments than defoliation estimates, as a result of dispersal and immigration from non-protected areas. Also, the egg mass survey data is point based, meaning it provides stand-level population estimates rather than forest average defoliation estimates. Most importantly, however, the egg mass survey provides a more comprehensive measure of outbreak intensity than the defoliation survey. Four hundred egg masses per 100 ft^2 of foliage is enough to yield 100% balsam fir defoliation (Simmons 1974); however, the egg mass survey counts encompass a range from zero to 850+ egg masses per 100 ft^2 of foliage. Simmons (1974) reported observations in Maine of up to 5000 egg masses per 100 ft^2 of foliage. This additional severity resolution was very useful for making predictions regarding foliage protection efficacy, back-feeding, and defoliation on less-preferred hosts under exceptionally extreme population conditions, as described in the following section.

Maine Egg Mass Survey

In addition to the defoliation survey, an extensive egg-mass survey on balsam fir branches at approximately 1000 locations was conducted by the Maine Forest Service throughout the outbreak. As with the defoliation survey, the egg mass survey lacked standardization across years. For three years, egg mass survey points were presented as generalized polygon layers rather than a sample location point layer (figure 3-9).

The location and abundance of sample locations varied over time, and the sample design changed in the mid-1980s to switch to second instar larvae collections.[6] The egg mass count classification scheme changed during the outbreak as well. During the 1970s, extreme was considered to be 1000 egg-masses per 100 ft^2 of foliage. By 1982, the very heavy and extreme classes were grouped together, so extreme was considered to be greater than 400 egg-masses per 100 ft^2 of foliage. All Maine Forest Service egg-mass maps available (1973-1985) were scanned, geo-referenced, and digitized as point or polygon layers into a GIS (figure 3-9).

[6] In years or samples where counts of 2nd instar larva (L_2) were reported, these levels were converted to egg mass counts using defoliation class mid-points reported for both L_2 and egg mass levels in the Maine Forest Service reports.

Because egg-mass sample design and locations changed throughout the outbreak, some assumptions were required to spatially correlate population levels over time and to estimate the area distribution of each resulting population pattern across the state.

First, we assumed that egg-mass counts at each sample point were representative of population levels in all surrounding forest conditions less than or equal to half the distance to any other sample point (i.e., Voronoi space). This allowed all egg-mass point layers to be translated into polygon layers. Polygon boundaries were dissolved where adjacent polygons contained the same egg-mass count, and then intersected along with the other polygon-based survey layers (1974, 1983, and 1985). The resulting multi-year layer was constrained spatially to the 1983 sample area, as this boundary generally reflected the maximum spatial extent of all survey years (figure 3-9).

Second, because reporting resolution for egg-mass classes above 400 was collapsed post 1981, we assumed that populations did not exceed 400 egg-masses per 100 ft^2 of foliage after 1981; perhaps justified given that only light to moderate defoliation was reported post 1981 (figure 3-7).

Temporal egg-mass patterns were then partitioned into equal-interval pattern severity classes based on cumulative egg mass counts averaged from 1973-1985 (figure 3-10). The spatial distribution of cumulative SBW population (figure 3-10) and cumulative defoliation (figure 3-7) levels over the outbreak were generally similar. However, when population patterns (figure 3-10a) were converted to balsam fir defoliation patterns (figure 3-10b; Simmons 1974, fir defoliation = 0.245 x egg-masses / 100 ft^2), forest-level mean fir defoliation was nearly double the levels measured from aerial sketch maps. As discussed in the previous section, foliage protection, species composition, and spatial and categorical averaging likely caused the much lower defoliation estimates derived from the aerial sketch maps.

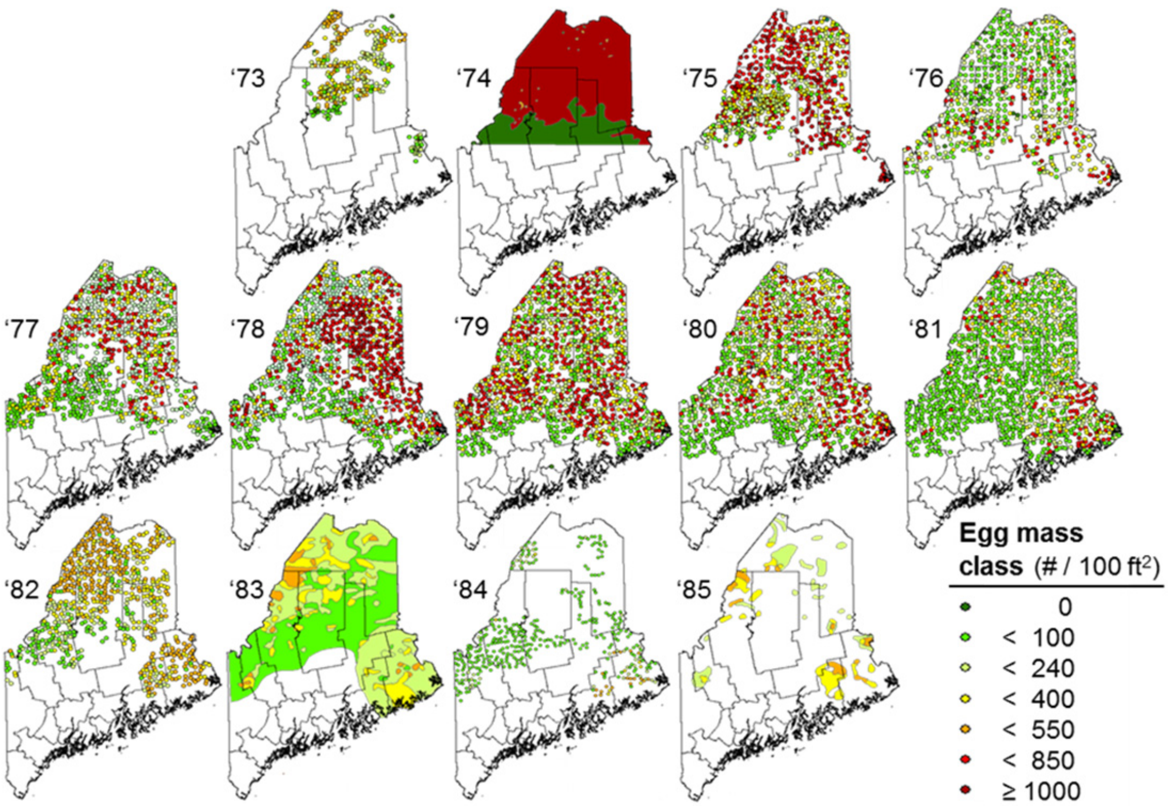

Figure 3-9. Egg-mass survey locations and count class measured in Maine from 1973 to 1985 (Maine Forest Service 1973-1985).

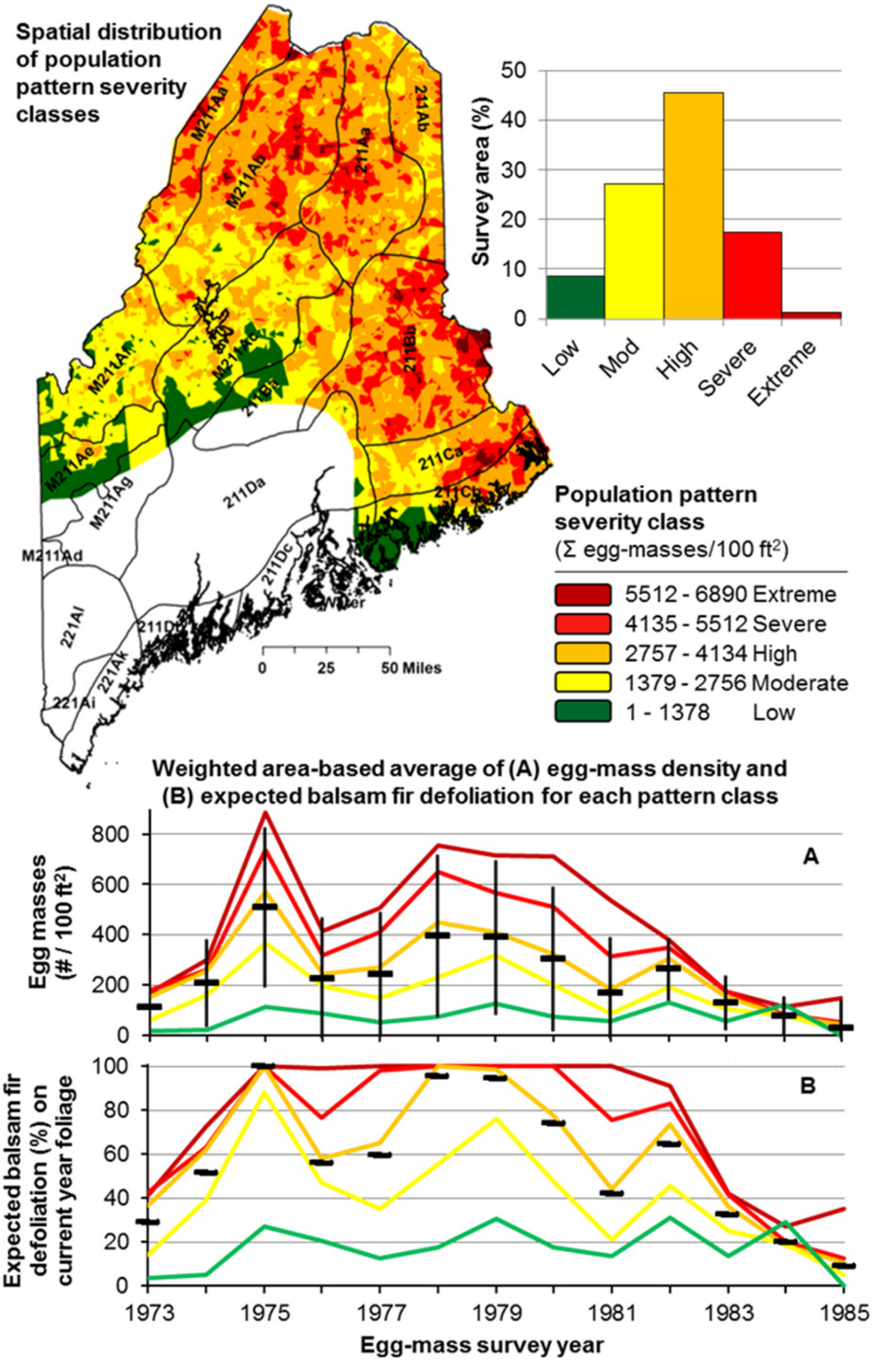

Figure 3-10. Maine spatiotemporal egg-mass distribution patterns for the 1970s-80s outbreak, estimated from egg-mass survey points measured from 1973-1985 (Maine Forest Service 1973-1985). The five aggregate patterns shown in each figure part represent mean trends for over 27,000 unique patterns partitioned into equal interval ranges (classes) based on cumulative egg mass counts over time (legend). Expected balsam fir defoliation (B) was calculated based on Simmons (1974; fir defoliation = 0.245 X egg-masses / 100 ft^2). Weighted mean (black dash; A, B) and standard deviation (black vertical lines; A) derived from individual patterns is also shown. Labels on map denote eco-region codes.

Spruce Budworm Scenarios

Outbreak Scenarios

We defined three plausible SBW outbreak patterns: one based on spatiotemporal variability of egg-mass densities recorded in Maine during the last outbreak (figure 3-10), and two generalized moderate (based on general NB outbreak in the 1970s-80s) and severe (equal to the moderate scenario but with two more years at the peak; generally similar to the Cape Breton, NS outbreak) defoliation patterns used in previous SBWDSS impact assessments (MacLean *et al.* 2001).

As the Maine SBW population scenario was not available at the time of the CFRU landowner inventory impact analysis (year one of this project), only impact projections for the moderate and severe outbreak scenarios were appended as columns within participating CFRU members' GIS layers. Despite this, the Maine average historical fir defoliation pattern (figure 3-10b) corresponded exceptionally well with the theoretically-based moderate fir defoliation pattern (figure 3-11). Therefore, volume impacts for the moderate outbreak scenario would be roughly the same as would be projected under the Maine average defoliation scenario (figure 3-11).

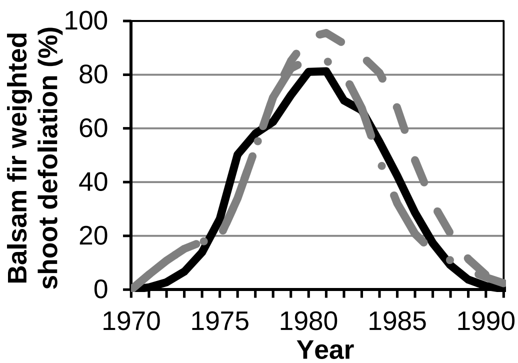

Figure 3-11. Balsam fir weighted shoot defoliation (solid black line) as a function of 1) mean SBW egg-mass density over time for susceptible area in Maine (figure 3-9b), 2) egg-mass to annual defoliation relationship (Simmons 1994), and 3) foliage age-class photosynthetic weights used in the SBW DSS (MacLean *et al.* 2001); compared to superimposed generalized moderate (dash-dotted gray line) and severe (dashed grey line) outbreak scenarios used in previous SBW DSS analyses (e.g., MacLean *et al.* 2001). Note that egg-mass density was extrapolated from 1973 levels to zero in 1970 for missing survey years.

For the state-wide timber supply analysis, the Maine historic SBW population-based defoliation scenario (figure 3-10) was used exclusively. Unlike all previous SBW DSS analyses, which have mostly simulated either a moderate or severe mean defoliation pattern (figure 3-11), here we retained spatiotemporal variability in population density patterns (figure 3-10). By doing so, we were able to utilize this variability within the timber-supply impact analysis by assigning susceptible area in the current inventory proportionally to area represented by the five temporal population patterns defined in figure 3-10a. Because host survival increasingly declines as defoliation increases, it is expected that this added outbreak resolution will result in greater mean volume impacts, compared to modeling a single mean outbreak pattern. As well, higher variation of modeled stand impacts ought to permit a higher effect of optimal scheduling of salvage or protection treatments.

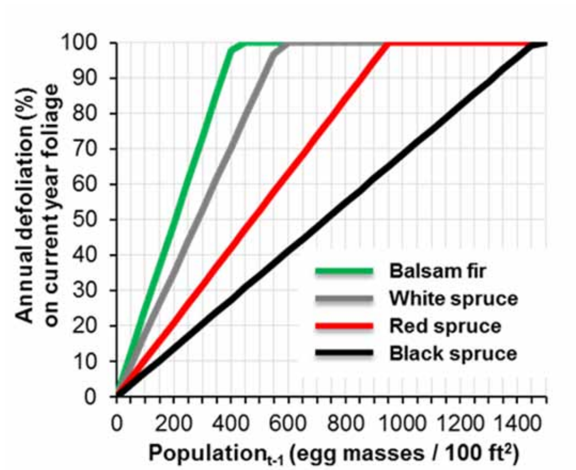

Figure 3-12. Relationship between SBW population density and percent defoliation of new foliage on each host species in the following year used for all outbreak scenarios explored here.

By relying on SBW population densities rather than percent defoliation as the primary input to the SBWDSS, a number of important modeling advantages became apparent. First, foliage protection treatment efficacy is generally a function of current population density (Régnière and Cooke 1998), not forecast percent defoliation. Therefore, one would expect improved prediction of efficacy using a population forecast. This is especially true for extremely high densities (e.g., > 400 egg masses

/ 100 ft^2; common in figure 3-10a), where typical levels of *Bacillus thuringiensis* (Bt) application may not be effective in reducing defoliation to target levels (Régnière and Cooke 1998). This may reduce the effectiveness of foliage protection on these extreme population levels in favor of salvage.

Second, as populations exceed densities that would cause 100% fir defoliation, it is probably not justified to estimate defoliation on other host species as a proportion of fir defoliation (e.g., Hennigar *et al.* 2008). This is because under extreme populations and limited supply of preferred host foliage, SBW has been observed to disperse and feed relatively more on lesser-preferred hosts (Greenbank 1963). Based on the linear relationship between fir defoliation and SBW population used in Maine (Simmons 1974), we assumed that host species defoliation ratios presented by Hennigar et al. (2008) could be applied to population levels. By doing so, we were able to generate defoliation to population relationships for all host species (figure 3-12). This host defoliation: population model provides a logical way to simulate gradual increases in spruce defoliation relative to fir as egg mass densities increase above what would cause 100% fir defoliation.

Foliage protection scenarios

In foliage protection scenarios, we assumed that *Bt* foliage protection would be applied (two treatments @ 30 BUI/ha) if annual defoliation was projected to exceed 40%. The Régnière and Cooke (1998) *Bt* efficacy model was used to predict defoliation reduction resulting from protection as a function of SBW density. Based on two treatments of *Bt* at 30 BUI/ha, defoliation was projected to be reduced by one-half by this model (interpreted from figure 5 in Régnière and Cooke 1998) for population densities less than would be needed to cause 100% fir defoliation. Because the Maine defoliation population relationship (Simmons 1974) was linear, we assumed this treatment would also reduce population levels by 50%. This allowed reduced treatment efficacy to be quantified for population densities above levels required to cause 100% defoliation on fir. This protection scenario was modeled in combination with the Maine historic outbreak patterns in the wood-supply impact model. As a result of these protection rules, areas assigned to extreme outbreak would receive more years of protection in the model, if protected, then less severe outbreak patterns (figure 3-10).

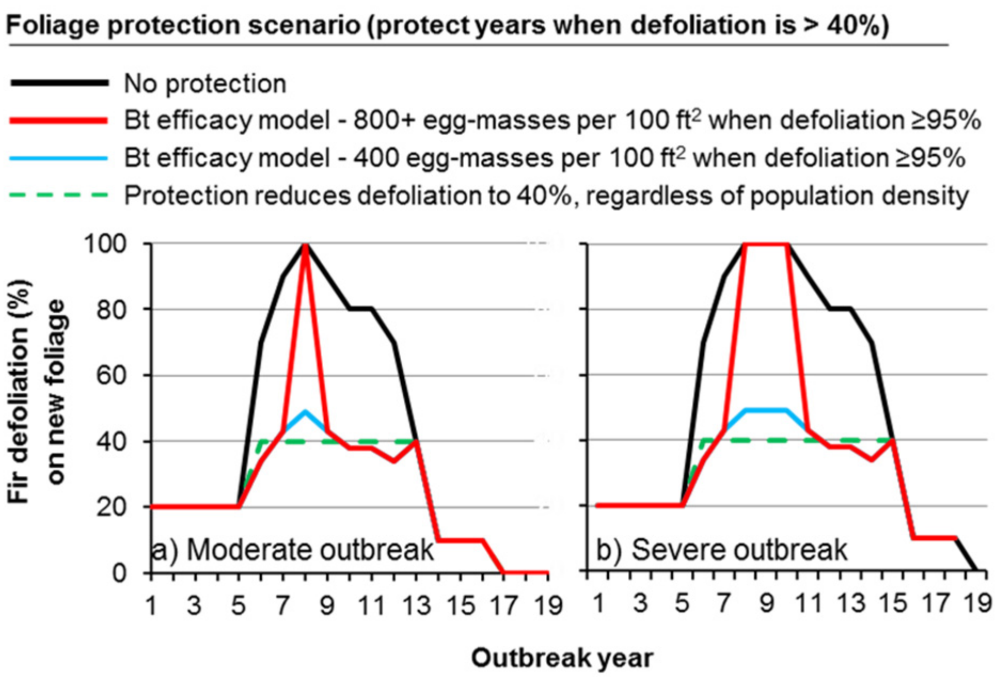

Figure 3-13. Spruce budworm outbreak and foliage protection scenarios included in the CFRU landowner impact analysis.

For the moderate and severe SBW DSS defoliation scenarios (used in the landowner impact analysis), SBW density was inferred from unprotected balsam fir defoliation levels using the Régnière and Cooke (1998) model. Because the SBWDSS defoliation scenarios lacked SBW density estimates, direct application of the *Bt* efficacy model is problematic for years when defoliation is severe (>95%), as density may vary greatly. To quantify foliage protection efficacy for a range of possible SBW density levels when annual defoliation is severe (≥95%), we included two alternate population scenarios:

1) Levels remain at the lower limit to cause 100% defoliation, and

2) Levels are extreme when fir defoliation is 100%, where no amount of foliage protection can avoid 100% defoliation (figure 3-13).

In addition to these two foliage protection scenarios, one more scenario was explored for the landowner inventory impact analysis, which assumed that defoliation would be reduced to exactly 40% when unprotected levels are >40% (figure 3-13). This latter scenario has been used in previous SBW DSS analyses (e.g., MacLean *et al.* 2001; Hennigar *et al.* 2012) and was included for comparison purposes.

Conclusions

These scenarios, while generalized, capture the range of potential SBW impacts that may occur in future SBW outbreaks. They have been modeled in the Maine wood-supply impact model and have provided insight into both SBW impacts and also mitigation benefits of alternative protection, salvage, silviculture options in Maine. A full report covering all deliverables, including final wood supply impacts and mitigation strategy analysis, is under review and expected to be released by no later than the Fall of 2013.

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REFINEMENT OF FOREST VEGETATION SIMULATOR INDIVIDUAL-TREE GROWTH & YIELD MODEL FOR THE ACADIAN REGION

Aaron Weiskittel, John Kershaw, and Chris Hennigar

Introduction

This CFRU project was initiated in October of 2008 and been a primary research focus since then. The project has basically involved compiling a database of permanent regional growth and yield plots and refitting the various component equations that currently comprise the Forest Vegetation Simulator (FVS) individual tree growth and yield model. Previous CFRU reports have presented the climate site index metric of site productivity, height to diameter, height to crown base, and diameter as well height increment equations. These equations continue to be evaluated and refined. Current model forms and parameter estimates are presented in this report. In addition, the current approach for predicting stand- and tree-level mortality is also presented. Finally, these equations are being incorporated into a software system that will be used to conduct model projections and summaries. This software system is presented and discussed.

Methods

The database, compiled and presented in Weiskittel *et al.* (2010), has been extensively cleaned and reformatted. Due to unresolved issues with some of the original data, certain datasets have currently been excluded. The current datasets being used for modeling are the permanent sampling plots from New Brunswick, Nova Scotia, and Quebec, the US Forest Service Forest Inventory and Analysis (FIA) plots, and long-term plots at the Penobscot Experimental Forest (PEF). This results in a database of 1,751,798 and 897,384 observations of individual-tree diameter at breast height (DBH) and height (HT).

Total Height

The total height equation of Rijal *et al.* (2012b) was generalized and extended to more species. The equation is:

$$[1] \qquad HT=1.37+\left(\left(b_0+d_{sp}\right)+CSI^{b_1}\right)*\left(1-\exp(-b_2*DBH)\right)^{\left(b_3+e_{sp}+b_4*\ln(CCF+1)+b_5*BAL\right)}$$

where HT is total tree height in m, CSI is climate site index (m), DBH is diameter at breast height in cm, CCF is crown competition factor of Krajicek et al. (1961) computed using the maximum crown width equations of Russell and Weiskittel (2011), BAL is tree basal area in larger trees (m^2 ha^{-1}), the b_i's are parameters estimated from the data, and d_{sp} and e_{sp} are species specific parameters also estimated from the data.

Height to Crown Base

Similar to the total height equation, the height to crown base equation of Rijal et al. (2012a) was generalized and extended to more species. The equation is:

$$[2] \qquad HCB=\frac{HT}{\left(1+\exp\left(\left(b_0+d_{sp}\right)+b_1*DBH+b_2*HT+b_3*\left(\frac{DBH}{HT}\right)+b_4*\ln(CCF+1)+b_5*BAL\right)\right)^{\left(\frac{1}{6}\right)}}$$

where HCB is height to crown base in m and all other variables have been defined above.

Diameter Increment

Individual tree diameter increment was modeled as basal area increment with the following equation:

$$[3] \qquad \Delta BA=\left(b_0+d_{sp}\right)*\left(BA^{\left(\left(b_1+e_{sp}\right)+b_2*CSI\right)}\right)*\exp\left(\left(\left(b_3+f_{sp}\right)+b_4*BAL_{SW}+b_5*BAL_{HW}\right)*BA\right)$$

where ΔBA is the basal area increment (m^2 yr^{-1}), BA is the tree initial basal area (m^2), BAL_{SW} is the basal area in larger softwood trees (m^2 ha^{-1}), BAL_{HW} is the basal area in larger hardwood trees (m^2 ha^{-1}), and f_{sp} is the species specific parameter.

Height Increment

Individual-tree height increment was modeled with the following equation:

$$[4] \qquad \Delta HT=\exp\left(\begin{array}{c}\left(b_0+d_{sp}\right)+\left(b_1+e_{sp}\right)*\ln(HT)+b_2*HT+b_3*BAL+b_4*\ln(CR)\\ +b_5*\ln(CSI)+b_6*\sqrt{BA}\end{array}\right)$$

where ΔHT is the annual height increment (m yr^{-1}), CR is crown ratio (0-1), and all other variables have been previous defined.

Mortality

For predicting mortality, a variety of approaches were initially evaluated and relatively poor performance was observed. Consequently, a three-stage approach was developed and used to predict the probability and amount of mortality at the stand-level, which is then allocated to individual trees. Each stage is described separately below.

Stage 1: Probability of Mortality

The probability that a plot experiences mortality was fitted using a general logistic equation form:

$$[5] \qquad Pr(Mortality)=\frac{e^{f(X)}}{1+e^{f(X)}}$$

where f(X) is a linear combination of independent variables. Boosted regression (REF) was used to identify potential independent variables and a number of equations fitted using backward and forward elimination/addition until all variables in the equation were significant and no additional variables further reduced the root mean square error (RMSE).

The final form of f(X) was:

$$[6]\ f(X)=b_0+b_{0,R}+b_1*BA_T+b_2*BA_T^2+b_3*\Delta BA_{30}+b_4*BA_{BF}+b_5*BA_{IH}$$

where BA_T is the total stand basal area (m^2 ha^{-1}), ΔBA_{30} is the annual basal area survivor growth of the largest trees within the stand that summed to a relative density of 0.30 (m^2 ha^{-1} yr^{-1}), QMD is the quadratic mean diameter (cm), BA_{BF} is the basal area of balsam fir (m^2 ha^{-1}), BA_{IH} is the basal area of intolerant hardwoods (m^2 ha^{-1}), and the $b_{j,R}$ were region-specific random effects (Maine, Nova Scotia, New Brunswick, Quebec). Equation 5 was the used to predict probability of mortality for each plot at each annualized measurement step.

Stage 2: Basal Area Mortality Prediction

Using only those plots in which mortality was observed, a nonlinear mixed effects model was fitted to predict basal area mortality (BA_{MORT}, m^2 ha^{-1} yr^{-1}), again using region was a random effect. Boosted regression was initially used to identify variables that potentially influenced BA_{MORT}, then these variables were tested in a number of equation forms typically found in the literature for predicting mortality. The final equation form selected was:

[7]

$$BA_{MORT} = \left(b_0 + b_{0,R} + b_1 * (BA_{BF}/BA_T) + b_2 * (BA_{IH}/BA_T)\right) (BA_T)^{\left(b_3 + b_{3,R} + b_4 \Delta BA_{30}\right)} + \left(b_5 + b_{5,R}\right) * BA_{BF}^{\left(b_6 + b_{6,R} + b_7 (QMD_{BF}/QMD)\right)}$$

where QMD_{BF} is the quadratic mean diameter of balsam fir and all of the variables have been previously defined above.

<u>Stage 3: Individual Tree Mortality Prediction</u>

To allocate the predicted BA_{MORT} to individual trees, a logistic regression equation linked with a right censored three parameter Weibull was used. The equation is:

$$[8] \quad Pr(Survival) = \frac{e^{\left(b_0 + d_{sp} + (b_1 + e_{sp}) * DBH + b_2 * DBH^2 + b_3 * BAL + b_4 * \left(\frac{DBH}{QMD}\right) + b_5 * \Delta BA_{30} + b_6 * BA_T\right)}}{1 + e^{\left(b_0 + d_{sp} + (b_1 + e_{sp}) * DBH + b_2 * DBH^2 + b_3 * BAL + b_4 * \left(\frac{DBH}{QMD}\right) + b_5 * \Delta BA_{30} + b_6 * BA_T\right)}} * K$$

where Pr(Survival) is the probability of tree survival and K is defined as:

$$[9] \quad K = \begin{Bmatrix} 1 \text{ if } DBH < 40 \\ e^{-\left(\frac{DBH-40}{b}\right)^c} \text{ if } DBH \geq 40 \end{Bmatrix}$$

where b and c are the scale and shape parameters of the Weibull distribution, respectively.

Total height

A total of 365,380 observations of total height were available for analysis. Equation 1 explained 72.6% of the original variation in total height and the inclusion of the species-specific parameters increased this to 77.8%. All parameters were statistically significant and had a biologically logical sign (table 3-5). For a given set of covariates, quaking aspen was the tallest species, while eastern hemlock was the shortest (figure 3-14).

Height to Crown Base

A total of 269,255 observations of height to crown base were available for analysis. Equation 2 explained 65.0% of the original variation in height to crown base and the inclusion of the species-specific parameters increased this to 67.0%. All parameters were statistically significant and had a biologically logical sign. For a given set of covariates, yellow birch and black spruce had the highest height to crown base, while eastern hemlock had the lowest (figure 3-14)

Diameter and Height Increment

A total of 504,689 and 88,956 observations of diameter and height increment were available for analysis, respectively. Equation 3 explained 45.0% of the original variation in diameter increment and the inclusion of the species-specific parameters increased this to 47.2%. Equation 4 explained 25.2% of the original variation in height increment and inclusion of the species-specific parameters increased this to 26.1%. All parameters were statistically significant and had a biologically logical sign. For given a level of tree and stand variables, white pine and black spruce showed the highest and lowest diameter increment, respectively, while species differences in height increment were not great (figure 3-15).

Table 3-5. Generalized parameter estimates and standard errors (SE) for the total height (Eqn. 1), height to crown base (Eqn. 2), diameter increment (Eqn. 3), and height increment (Eqn. 4) equations.

Parameter	Total Height		Height to Crown Base		Diameter Increment		Height Increment	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
b_0	12.44847305	0.389041	0.29070	0.17514067	0.0195744	0.00441	0.6644887	0.45666
b_1	0.801705832	0.001222	0.00636	0.001816315	0.6890597	0.029771	-1.715156	0.27303
b_2	0.043617034	0.000225	-0.02288	0.002556165	-0.000013	0.000008	0.1139081	0.02068
b_3	1.048674338	0.039192	0.08232	0.02387724	-2.099691	0.006219	-0.013541	0.00132
b_4	0.011483716	0.000324	-0.03086	0.004257092	-0.202029	0.000403	-0.626488	0.03081
b_5	-0.00755099	4.26E-05	-0.01701	0.000384455	-0.141399	0.000563	0.1381055	0.01574
b_6	-	-	-	-	-	-	0.0058419	0.00001

Table 3-6. Species specific parameter estimates for the total height (Eqn. 1), height to crown base equations (Eqn. 2), diameter increment (Eqn. 3), and height increment (Eqn. 4).

Species	Total Height		Height to Crown Base	Diameter Increment			Height Increment	
	d_{sp}	e_{sp}	d_{sp}	d_{sp}	e_{sp}	f_{sp}	d_{sp}	e_{sp}
American beech	-0.60586	-0.08105	-0.61448	-0.03216	-0.07583	-2.505	-0.0533	0.0206
Balsam fir	0.874025	0.161628	0.17913	-0.02386	0.059918	-1.96717	0.1237	-0.1102
Black spruce	1.81723	0.176327	-0.67838	-0.03763	-0.13488	3.176286	0.1472	-0.1116
Eastern hemlock	-0.24547	0.225872	1.04882	-0.02129	0.086307	-0.67182	-0.2719	0.1645
Jack pine	6.322689	0.504639	-0.86368	-0.00963	0.315134	-10.0582	0.3575	-0.1707
Paper birch	1.437664	-0.05351	-0.52524	-0.03576	-0.08039	-1.66648	-0.1104	0.0355
Quaking aspen	2.635654	-0.02573	0.24077	-0.03114	-0.09987	1.417473	-0.4196	0.2995
Red maple	0.538154	-0.12317	-0.55332	-0.0312	0.007209	0.101817	0.3750	-0.2335
Red spruce	1.668609	0.201859	-0.40110	-0.03012	0.01523	0.389315	-0.1465	0.0949
Sugar maple	0.903342	-0.15214	-0.46608	-0.02674	0.072611	-0.60242	0.4608	-0.2566
White pine	0.910013	0.213712	-0.45910	-0.01588	0.107642	0.049527	0.0521	0.0393
White spruce	1.419979	0.290358	0.17039	-0.02269	0.072533	-2.89254	0.2094	-0.1757
Yellow birch	-0.69698	-0.18123	-0.04040	-0.03242	-0.08005	-0.78848	0.5100	-0.2797

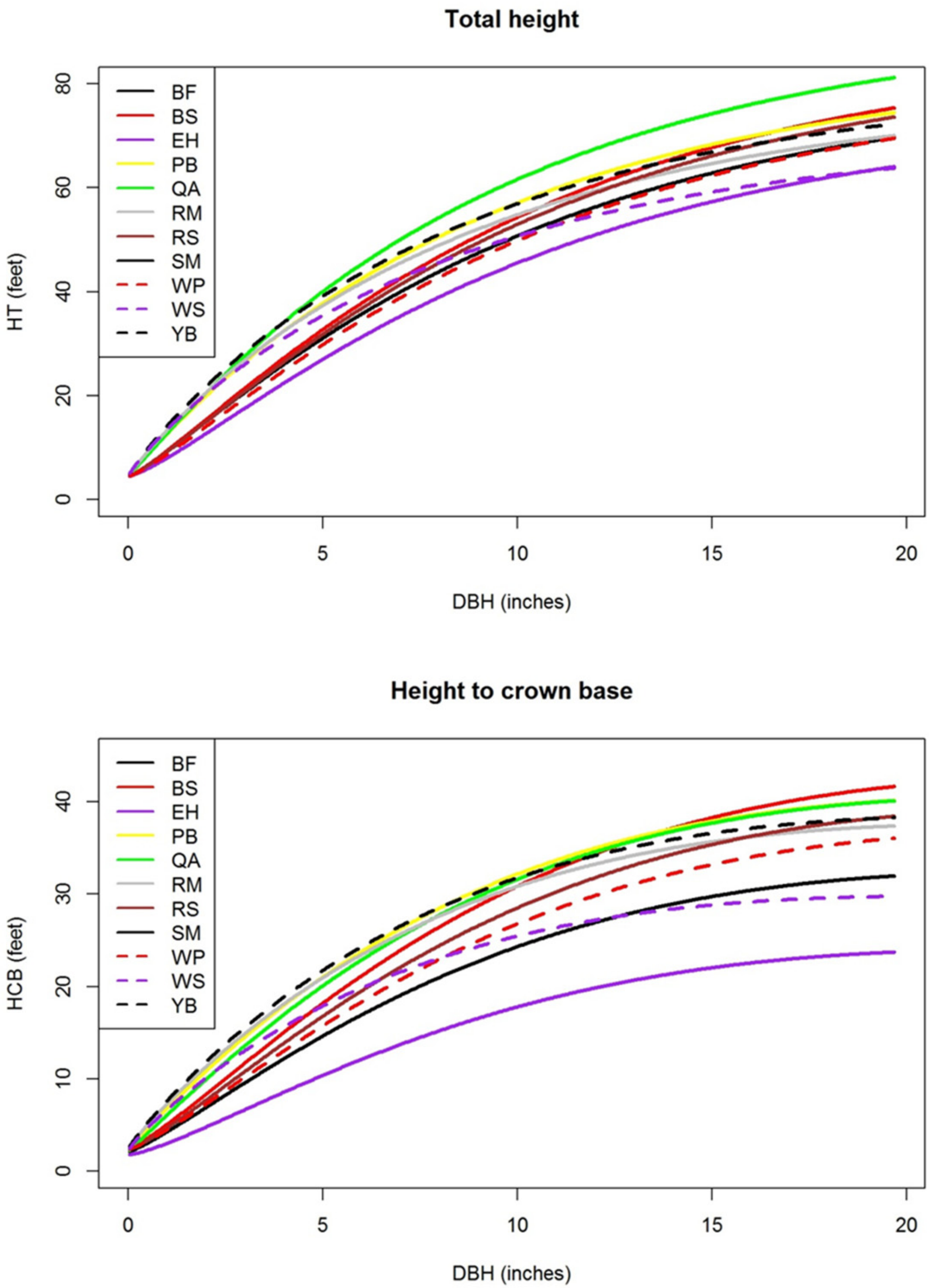

Figure 3-14. Predicted total height (top) and height to crown base (bottom) over diameter at breast height using Equations 1 and 2, respectively, for an open-grown tree.

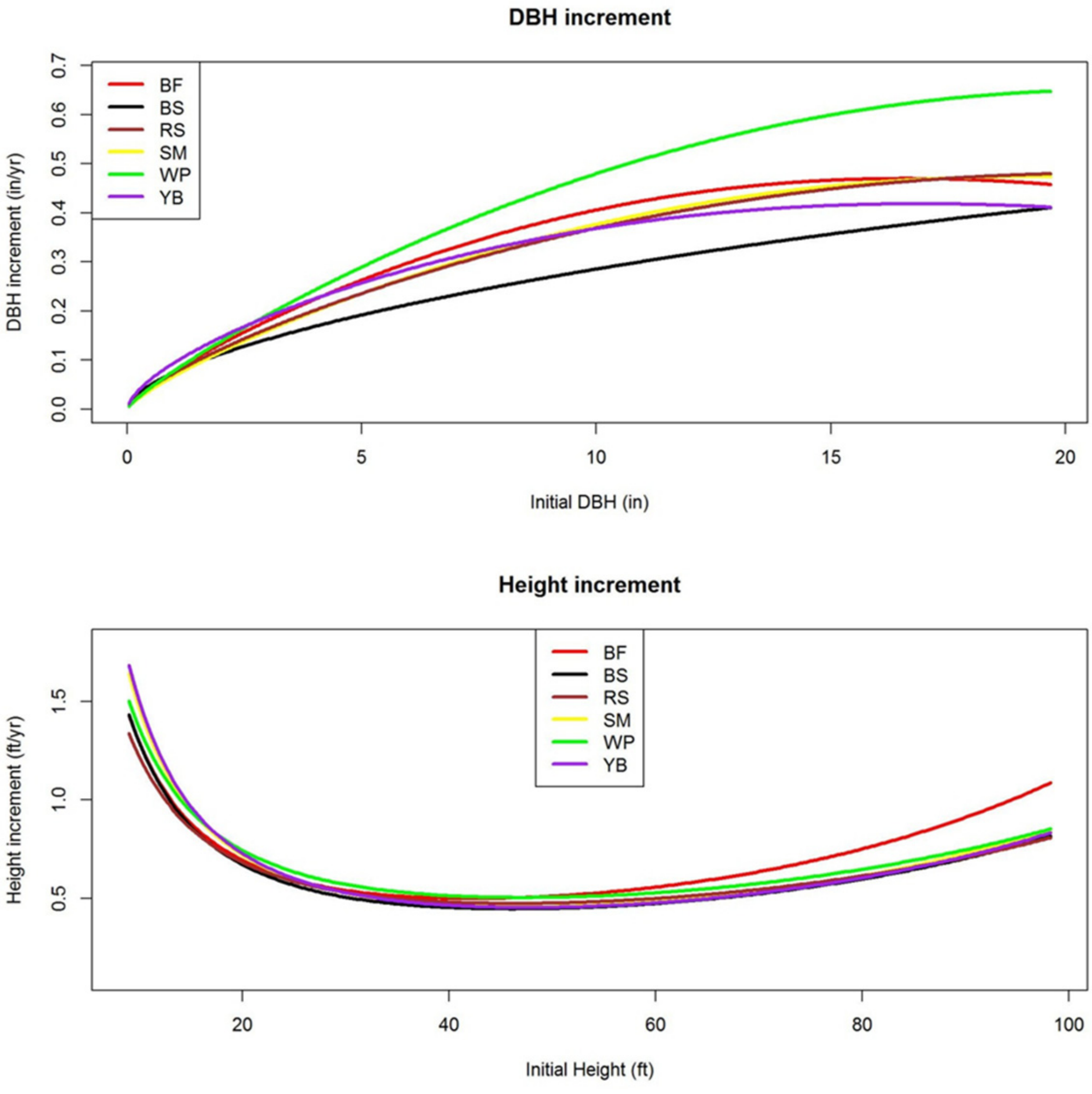

Figure 3-15. Predictions of diameter (top) and height increment for different species for an open-grown tree.

Mortality

The final dataset had 1,171,515 tree- and 150,763 plot-level observations. Overall, individual tree mortality was relatively rare as less than 10% of the trees were classified as dead and only 33% of the plot re-measurement periods had a mortality event. Across the entire dataset, BA_{MORT} averaged 0.35 m^2 ha^{-1} yr^{-1}, while it was closer to 0.45 m^2 ha^{-1} yr^{-1} when only plots experiencing mortality were evaluated. Despite the noisiness of the underlying data, Equations 6 through 8 fit the data well with all parameters being statistically significant and with a biologically logical sign.

For the stand-level probability of mortality model, the RMSE was 0.37 and had a R^2 of 16.1%. There were significant regional differences in stand-level probability of mortality trends (figure 3-16). Overall, the most influential variable was ΔBA_{30} followed by BA_T. All of the influential factors had a positive relationship with stand-level probability of mortality.

The stand-level basal area mortality model had a R^2 of 23% and again highlights significant regional differences. Overall, mortality rates for a given stand structure and composition were highest in New Brunswick followed by Maine, Nova Scotia, and Quebec (figure 3-17). Like the stand-level probability of mortality model, the most influential variable was ΔBA_{30} followed by BA_T. Basal area mortality increased with both greater percent balsam fir basal area and with a higher ratio of balsam fir QMD to overall stand QMD; though the effect of increasing percent balsam fir had a greater effect.

The tree-level mortality model had a R^2 of 9.2% and residual standard error of 0.29. All parameters were statistically significant and had a biological logical sign. There were significant differences between the species (table 3-8). For given tree and stand conditions, white pine showed a higher probability of annual mortality, while black spruce showed the lowest (figure 3-18).

Discussion

With the finalization of these equations, all of the necessary component equations have been fit and are currently being inserted into the Open Stand Model (OSM) being developed by Dr. Chris Hennigar (figure 3-19). The OSM is a highly flexible software framework that will allow rapid incorporation of future alterations of the model, the ability to link to other existing software, and capability to process stands rapidly with high degree of user control. A more complete description of OSM was provided to the CFRU at the October 2012 Advisory Committee meeting by Dr. Hennigar. Consequently, this discussion will focus solely on the performance of the equations.

The generalization of the total height and height to crown base equations extended them to other minor species in the region and provide a more robust prediction for the more common species. Local calibration of these equations will be possible when measurements are available and is highly recommended. The diameter increment equation is currently being refitted as Russell *et al.* (2011) found that long-term predictions using basal area increment rather than diameter increment can increase model bias. The diameter increment will likely be similar in form to the current height increment equation. Despite showing a reasonable fit to the data, the height increment equation is not showing very distinct species differences in predictions. Further evaluation will be necessary to ensure it is behaving correction across the range of the available data.

Mortality will be the most difficult model component to improve. The three-stage approach outlined here is fairly robust and has drastically improved predictions. However, the overall performance for a given stand will like be poor due to the complex array of factors that influence mortality with many of them being highly stochastic. The analysis also highlighted significant differences in mortality patterns between the different regions evaluated. Maine often had a mortality behavior in between the other Canadian provinces, which is likely due to differences in past management and disturbance histories. The stand-level mortality models clearly show the sensitivity of mortality to stand density. In addition, the models are also dependent on stand growth, which should help the model to be capable of representing stand dynamics during stagnation. At the tree-level, species differences in mortality patterns were evident. White pine was predicted to be the most likely to die for a given set of covariates, but the probability was only slightly higher than other species. Continued evaluation of the equation and the overall model predictions will be necessary to ensure proper behavior.

Future efforts will work on evaluating system behavior as the equations have generally been fit independently and between equations interactions can cause strange behavior. The release of the beta version of OSM will allow users to test run and provide feedback on the model behavior. Continued efforts to improve equation fits, increase representation of different site factors like soil drainage and aspect, and extend the model to managed stand conditions.

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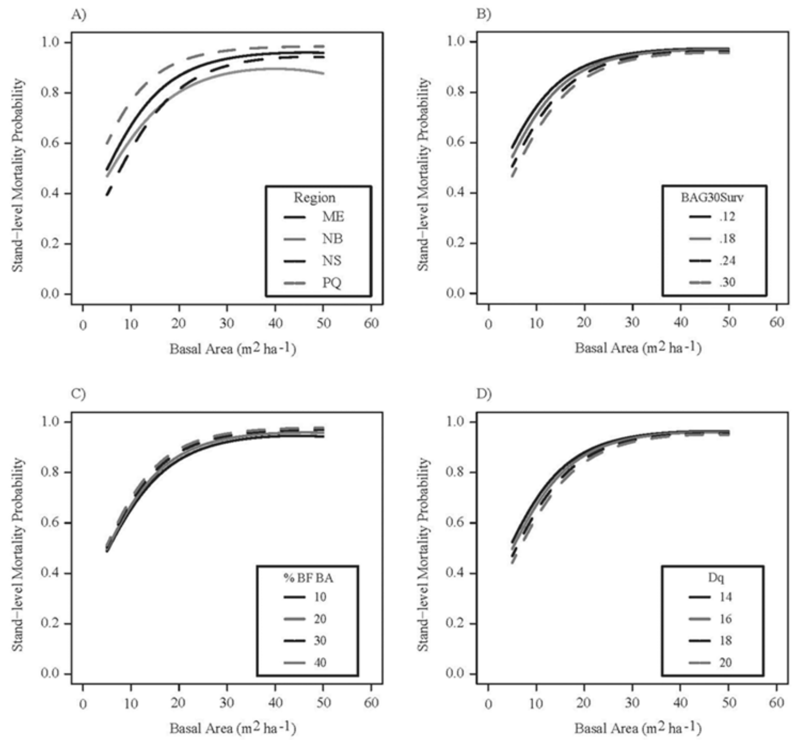

Figure 3-16. Predictions of stand-level basal area mortality given its occurrence using Eqn. 7 for the different regions (A), survivor basal area growth rate (B), percent balsam fir basal area (C), and quadratic mean diameter (D) over stand basal area (m^2 ha^{-1}).

Table 3-7. Generalized parameter estimates and standard errors (SE) for the probability of stand mortality (Eqn. 6), basal area mortality amount (Eqn. 7), and individual tree mortality probability (Eqn. 8) prediction equations.

Parameter	Probably of stand mortality (Eqn. 5)		Basal area mortality amount (Eqn. 6)		Individual tree mortality probability (Eqn. 7)	
	Estimate	***SE***	***Estimate***	***SE***	***Estimate***	***SE***
b_0	-0.6959509	0.3462012	0.2554043	0.10023921	2.224763	0.14843420
b_1	0.0703694	0.0024818	0.2315199	0.00481723	0.076734	0.00933890
b_2	-0.0009841	0.0000441	0.0202025	0.00249382	-0.000907	0.00002928
b_3	0.7818633	0.0164109	0.5067010	0.09433632	-0.024431	0.00057838
b_4	0.0486126	0.0022536	-2.0370423	0.02150724	-0.311719	0.01054643
b_5	0.0325371	0.0018925	0.0781800	0.02414730	3.402583	0.02181862
b_6	-	-	0.3453608	0.05176340	0.014305	0.00049544
b_7	-	-	0.0995085	0.01632631	-	-
$b_{0,Maine}$	-0.7768921	-	-0.069619	-	-	-
$b_{0, New Brunswick}$	-0.3874579	-	0.3433697	-	-	-
$b_{0, Nova Scotia}$	0.0985491	-	-0.1251712	-	-	-
$b_{0, Quebec}$	1.0658010	-	-0.1485785	-	-	-
$b_{3,Maine}$	-	-	0.06072934	-	-	-
$b_{3, New Brunswick}$	-	-	-0.3178151	-	-	-
$b_{3, Nova Scotia}$	-	-	0.08274501	-	-	-
$b_{3, Quebec}$	-	-	0.17434071	-	-	-
$b_{5,Maine}$	-	-	-0.0100276	-	-	-
$b_{5, New Brunswick}$	-	-	0.0678903	-	-	-
$b_{5, Nova Scotia}$	-	-	0.00860064	-	-	-
$b_{5, Quebec}$	-	-	-0.0664633	-	-	-
$b_{6,Maine}$	-	-	-0.010830	-	-	-
$b_{6, New Brunswick}$	-	-	-0.016878	-	-	-
$b_{6, Nova Scotia}$	-	-	-0.1210011	-	-	-
$b_{6, Quebec}$	-	-	0.14871012	-	-	-

Table 3-8. Species specific parameter estimates for the individual tree mortality equation (Eqn. 8).

Species	d_{sp}	e_{sp}
American beech	0.938413880	-4.0560e-02
Balsam fir	1.032042586	-8.5124e-02
Black spruce	1.562311307	-5.9391e-02
Eastern hemlock	1.468455064	-1.6517e-03
Jack pine	-0.113945145	3.7824e-02
Paper birch	0.783286007	-2.8016e-02
Quaking aspen	-0.756473287	1.9419e-02
Red maple	0.789828397	1.1527e-02
Red spruce	0.901504617	-2.1202e-02
Sugar maple	0.840389245	3.0382e-02
White pine	0.210710332	2.2268e-02
White spruce	0.772213691	-3.2541e-02
Yellow birch	0.962532973	-1.6120e-03

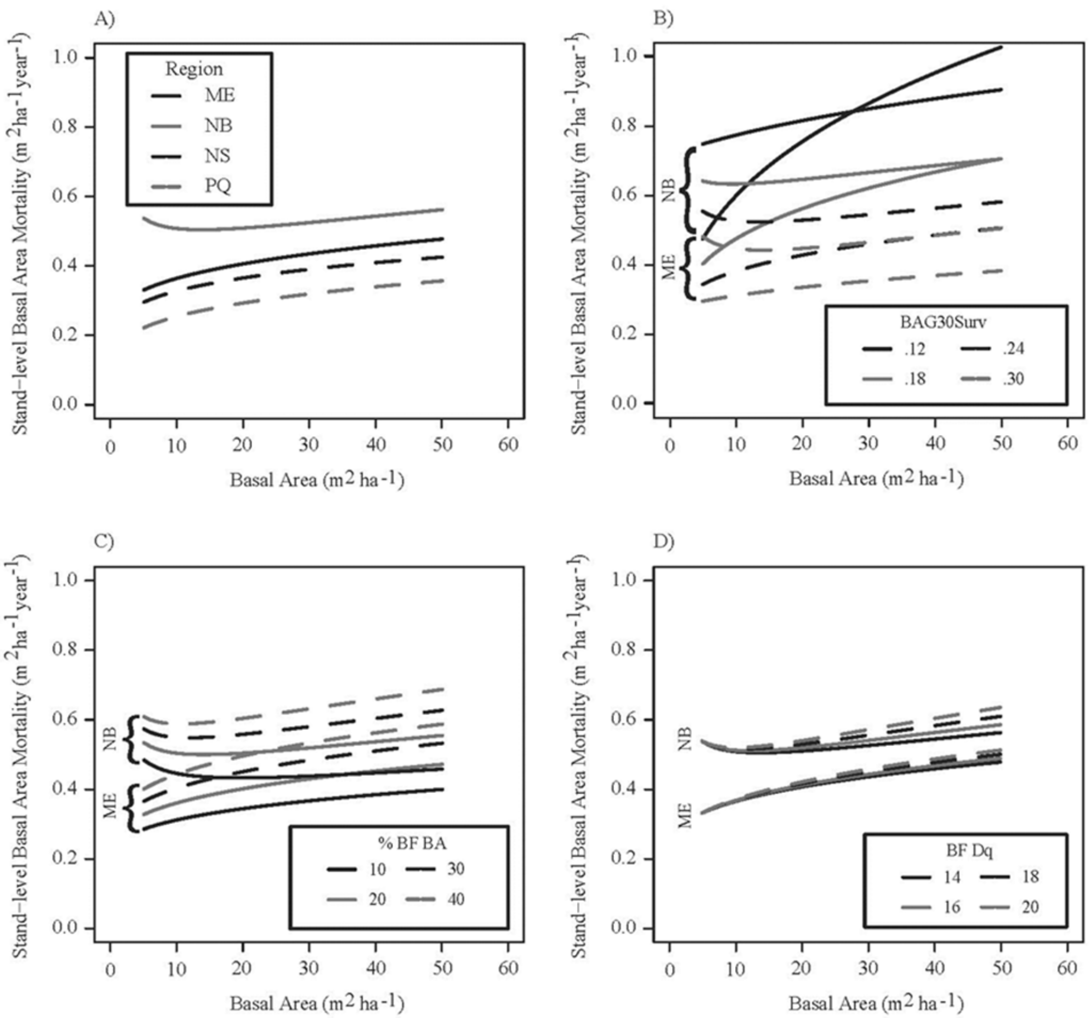

Figure 3-17. Predictions of stand-level basal area mortality given its occurrence using Eqn. 8 for the different regions (A), survivor basal area growth rate (B), percent balsam fir basal area (C), and balsam fir quadratic mean diameter (D) over stand basal area (m^2 ha^{-1}).

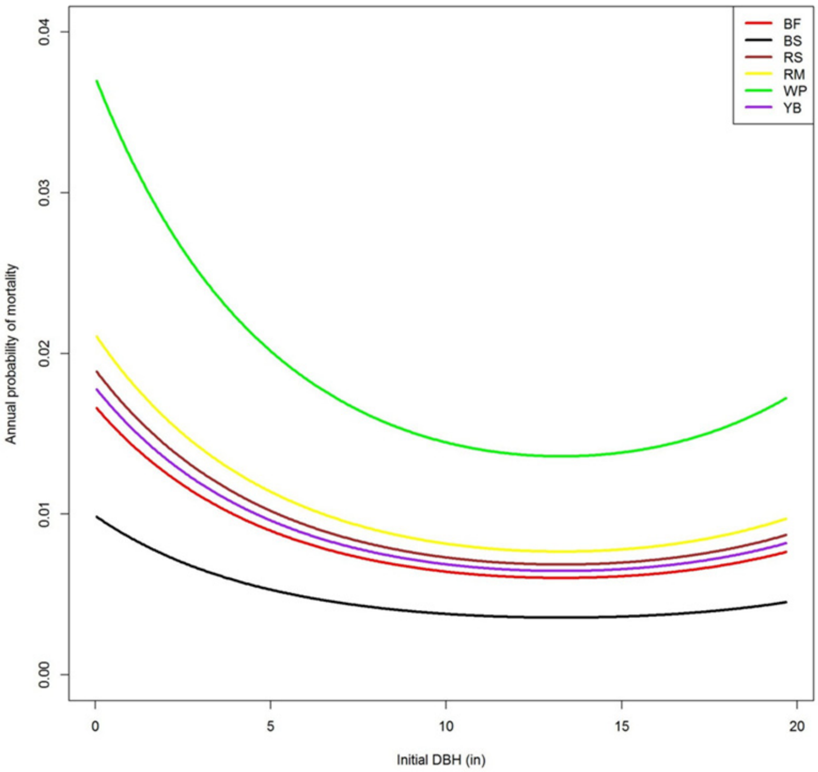

Figure 3-18. Annual probability of tree mortality over tree diameter at breast height (inches) using Eqn. 8 for selected species.

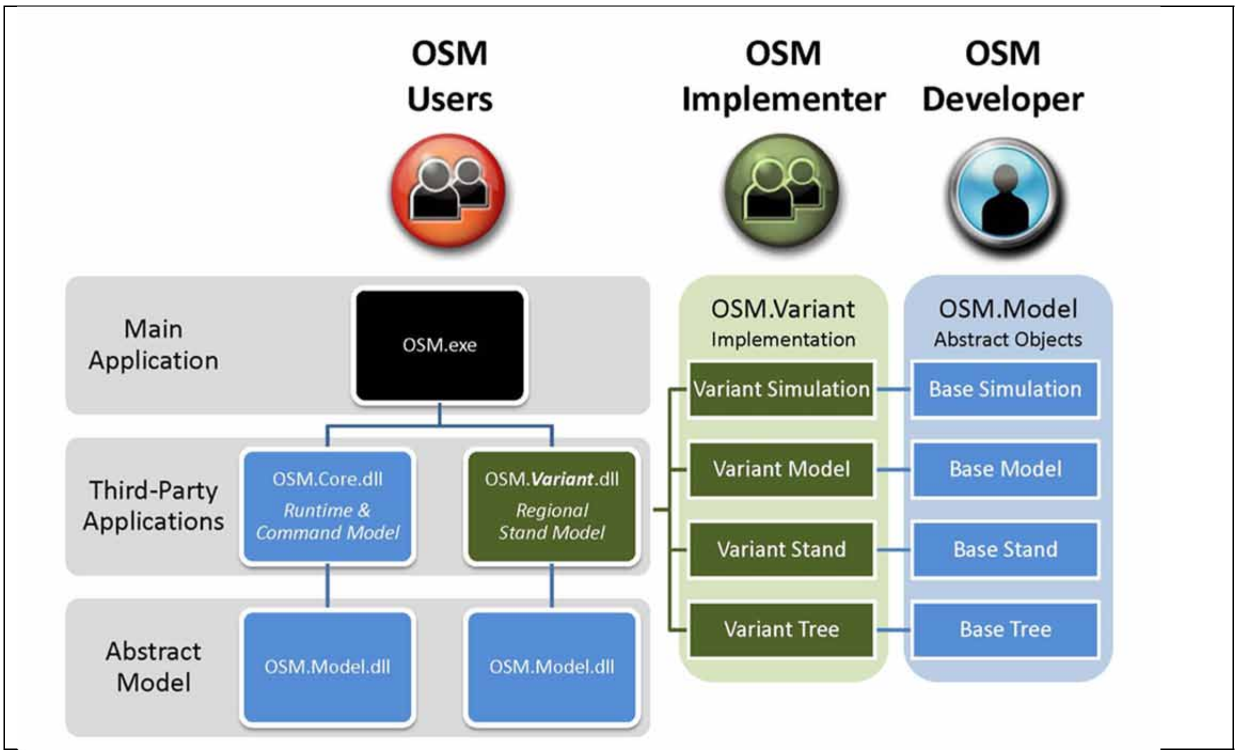

Figure 3-19. Structure and architecture of the Open Stand Model (OSM) currently being developed by Dr. Chris Hennigar.

Wildlife

Snowshoe Hare and Canada Lynx

Spruce Grouse

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

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

Background and Project Overview

Throughout their range in northern forests of North America, snowshoe hares (*Lepus americanus*) are a crucial component of prey base supporting a diverse array of mammalian and avian carnivores. In the Acadian forests of Maine, where much of the critical habitat for the U.S. federally threatened Canada lynx (*Lynx canadensis*) occurs, hares are expected to dominate lynx diets, especially during winter.

Hare populations are temporally dynamic and exhibit classic 10-12 year cycles in boreal forests. Correspondingly, northern population of lynx studied in the Northwest Territories, Yukon, and Alaska respond to lower snowshoe hare densities by increasing their home ranges and decreasing reproductive output. Snowshoe hares occur in higher densities where dense vegetative structure provides thermal cover and predator refugia, and commercial forest management practices affect vegetative species composition and structure important for high quality hare habitat (HQHH).

Thus, assessing the effects of commercial forestry practices on snowshoe hare habitat, snowshoe hare densities, hare responses to changing structural conditions in managed forests, and responses of lynx to changing snowshoe hare densities have been the primary focus of an ongoing collaborative project (since 1999) by The University of Maine, the Maine Department of Inland Fisheries and Wildlife, the CFRU, and the U.S. Fish and Wildlife Service.

Summary of 2012 Activities

Monitoring of Snowshoe Hare Densities

Snowshoe hare densities are monitored by counting, then clearing fecal pellets, a surrogate for snowshoe hare densities, from 28 subsampled plots in each of 30 established stands that represent four harvest and silvicultural treatments. In collaboration with the spruce grouse investigation (see Spruce Grouse Update in this report), we established three additional regenerating clear-cut conifer and two mature conifer stand types in 2011. We monitored these five stands beginning in 2012.

As of 2012, treatments include the following stand types:

1) 18 regenerating conifer-dominated 24 to 39 year old stands that were herbicide (Glyphosate) treated 3 to 5 years post clear-cut;

2) 7 selection harvest stands;

3) 5 mature stands at least >50 years since last cut; and

4) a partial harvest group including ten overstory removal and shelterwood retention stands.

However, these stands have been successively removed from the study as they have been commercially thinned or overstories removed and only two remained when pellets were surveyed and cleared in May 2011. Those two stands from the shelterwood group were subsequently harvested during July 2011 and March 2012; therefore, we did not monitor this stand type in 2012. We began monitoring mature stand types in 2008, and combined results from mature softwood and mature mixed wood stands for this report.

We conducted snowshoe hare fecal pellet counts for May - early June to determine leaf-off (overwinter) densities and during late September – early October to assess leaf-on (summer) densities of hares. Our laboratory has previously published a paper demonstrating that counts of snowshoe hare fecal pellets can be used to accurately estimate actual snowshoe hare densities over a range of 0.5 to 2.4 hares per hectare (Homyack *et al.* 2006).

Since 2007, inter-annual winter hare densities exhibited a decline in two stand types, regenerating conifer-dominated and selection-harvest stands, whereas mature stand types showed no trend over time (figure 4-1). Summer hare densities exhibited similar trends until 2012, when fecal pellet densities increased from the previous year in all stand types (figure 4-2). Given that winter densities of hares lag the previous summer reproductive season, we predict that winter densities of hares may exhibit increases based on surveys that will be conducted in spring 2013.

Regenerating conifer stands that exhibited inter-annual declines in hare densities began to show hare density increases in summer 2012. To determine the relative roles of successional changes and/or seasonal differences among stand types on hare densities, we re-measured vegetation attributes across our all of our stands during summer 2011 and winter 2012.

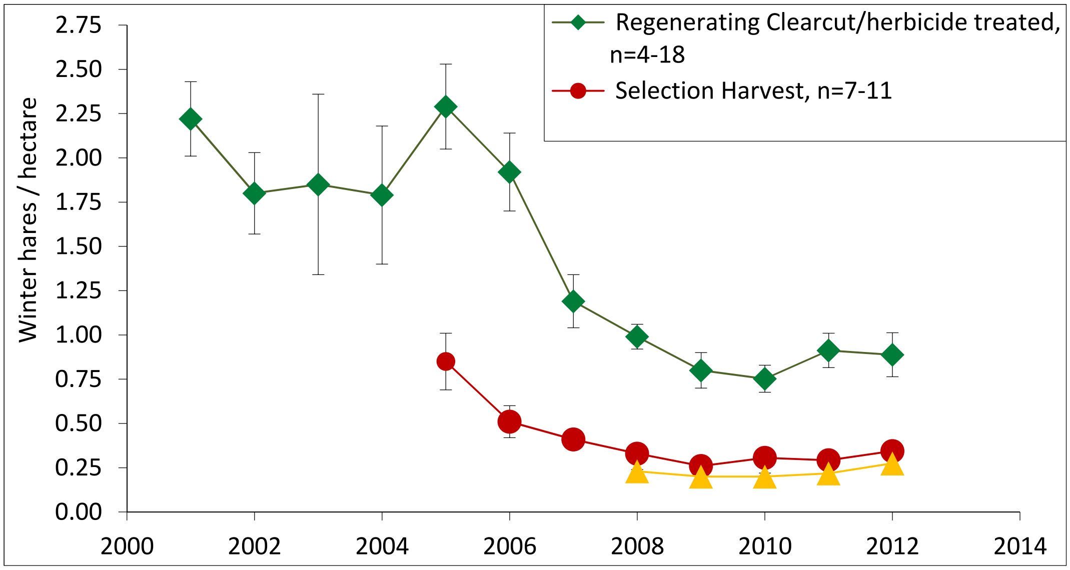

Figure 4-1. Preliminary (do not cite) snowshoe hare densities during winter in three forest stand types: regenerating conifer dominated stands 24 -39 years post-clearcutting; selection harvests; and mature conifer and mixed conifer-deciduous stands (pooled). Whiskers span the mean ± one standard error.

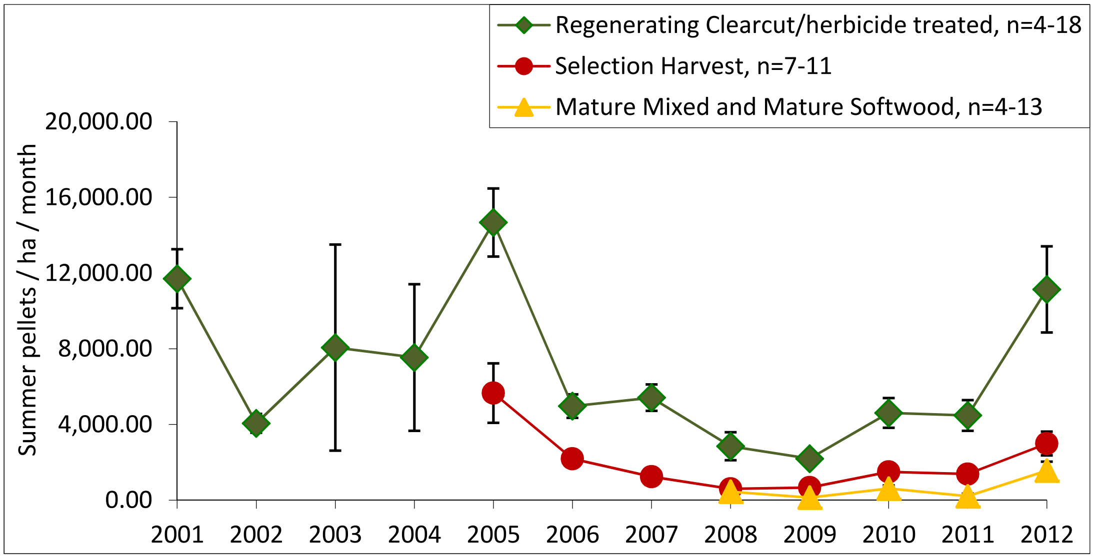

Figure 4-2. Preliminary (do not cite) snowshoe hare fecal pellet densities during summer in three forest stand types: regenerating conifer dominated stands 24 -39 years post-clearcutting, selection harvests, and mature conifer and mixed conifer-deciduous stands (pooled). Whiskers span the mean ± one standard error.

Hare Habitat Assessment

The goal of this portion of the hare study is to determine whether snowshoe hares use different forest stand types differentially by season in response to changing food and cover resources. Sheryn Olson completed the field habitat vegetation measurements summer 2012 for her Master's thesis project. She collected seven habitat variables to examine understory cover and species composition in 20 plots surveyed within 29 stands during summer 2011 and from three stands (additional mature conifer stands) surveyed in summer 2012.

From January through March 2012, Sheryn and crews collected three winter habitat variables from 10 plots in 28 stands during a rigorous winter field season conducted across > 2000 km^2 of northern Maine. Sheryn is currently analyzing these data and plans to complete her MS thesis in 2013. Primary objectives of that aspect of the study are to determine:

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

2) Which seasonal changes in structural and food-related attributes of those stands are most strongly associated with seasonal shifts in hare use.

Preliminary results indicated that hare do not shift activities as much seasonally in mature stands, where they maintain low densities throughout the year, as compared to selection harvested and regenerating conifer stands, which support intermediate and high hare densities, respectively.

Succession on Hare Densities

From 2001 to 2012 winter hare densities in northern Maine exhibited declines of approximately 50% in conifer-dominated stands (figure 4-1). Are hare densities declining because of forest management, succession, and habitat transition to more mature landscapes, or alternatively, because of broader-scale natural processes (e.g., cycles)?

The goal of this portion of our work is to assess the suitability of habitat for snowshoe hares using a forestry management tool, the Density Management Diagram (DMD). The DMD for spruce-fir stands in Maine was developed by Wilson *et al.* 1999, and is a familiar tool that foresters use to make decisions about the optimal time to harvest a forest stand based on tree densities and tree diameters. We can integrate the DMD with hare density data to predict the relative densities when habitat for snowshoe hares becomes suboptimal, and those inferences will inform decisions about when stand succession will drive future declines in stand-scale densities of hares.

In 2005, 2008, and 2009 our laboratory re-measured tree densities and basal area in 15 regenerating conifer stands. Our results indicated that succession played no significant role in declining hare densities from 2005 to 2009 (Scott 2009). However, in 2012, some stands in our regenerating conifer stand cohort may have matured to the pole stage and self-thinned, which would cause them to transition from optimal to sub-optimal hare habitat. Those results are currently being analyzed and a report will be completed in 2013 that will describe effects of succession on hare densities for application in predictive models of hare and lynx habitat.

This tool will allow managers to predict future habitat conditions for hares and lynx based on the DMD's developed for regenerating stands surveyed three times during the interval of 16-40 years after clearcut, in conjunction with a paper that will be published in 2013 on approaches for using habitat attributes to model lynx occurrences (Simons *et al.*, *in press*).

Seasonal Food Habits of Lynx

Canada lynx (figure 4-3) are considered specialist predators of snowshoe hares, and can depend on snowshoe hares for up to 97% of their diet (Apps 1999), but are capable of using other prey and may exhibit shifts in diet both seasonally and when hares are at low density. Seasonal prey switching has been documented to occur during summer when a greater diversity of potential prey species are available. In Nova Scotia, 93% of winter lynx scats contained snowshoe hare, while only 70% of summer scats contained snowshoe hare (Parker *et al.* 1983). Near Maine, on the Gaspé peninsula, Québec, hares were 58% of lynx summer diet, but increased to 85% during winter (Fortin and Huot 1995). Forest stands that support various prey species may provide superior foraging habitats.

Alternatively, if lynx are extreme hare specialists in the Acadian forests of Maine, then regenerating conifer habitats may have disproportionate importance for lynx.

Figure 4-3. Canada lynx in the snow. Photo by David Mallet.

To evaluate the range in dietary diversity that lynx may exhibit in Maine, we collected scats in winter during a period of high relative hare abundance and, conversely, in summer during a period of lower hare abundance. We contracted with the University of Washington's Center for Conservation Biology (CCB) Canine Detection Unit to collect summer lynx scats, which would be difficult to find without trained scat detection dogs. Though we collected 265 scats, some were in multiple species latrines, and some were suspected fisher or coyote, so we had all scats analyzed at CCB's genetics laboratory to definitively identify those deposited by lynx and to determine the gender of the lynx. Resulting from limited funding, scats were analyzed as 3 separate groups and the final group is currently being genetically analyzed to determine the gender of lynx. We have 175 summer lynx scats confirmed to be produced by lynx, and 62 winter scats verified as deposited by lynx from tracks on snow. Analyses to determine diet composition in scats is scheduled for spring 2013, and a report summarizing seasonal diets of lynx in is anticipated by September 2013.

Analysis of 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 via a separate agreement with MDIFW. David's M.S. project 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.

Efforts in 2012 were directed towards testing the hypotheses that:

1) Home-range scale habitat use by lynx would reflect a positional shift of home ranges towards landscapes that are more dominated by high quality hare habitat during a period of lower hare densities; and

2) Lynx would exhibit increased selection of high quality hare habitats during a period of hare decline.

To address these hypotheses, the percent high quality hare habitat in home ranges of male and female lynx were compared among 66 resident adult (> 1 year) lynx monitored during a period of high (2001-2006) hare densities and for 45 lynx monitored during a period of lower (2007-2010) hare densities.

Preliminary results indicate that lynx maintained home ranges with approximately half of the area comprised of high quality hare habitat (HQHH) during both periods, and those percentages of HQHH did not change appreciably with changes in relative hare density (table 4-1). Additionally, the selection intensity of lynx {defined as ln (% radio locations of a lynx observed in HQHH / % HQHH in a lynx's home range)} for HQHH was compared between the high (23 lynx) and low (17 lynx) hare density periods to evaluate our second hypothesis. Our preliminary results indicate that lynx exhibited positive selection for HQHH during both the high and low periods of hare density, but that the intensity of selection for HQHH lessened when hares became relatively scarce (table 4-2).

This suggests that lynx may respond in other ways (e.g., decreasing effort invested in reproduction, or increasing dietary breadth) to compensate for declining hare densities. We will evaluate those possibilities in analyses planned for 2013, and a final report of the lynx telemetry portion of the project will be completed by the Fall of 2013.

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Table 4-1. Percent of the home range comprised of high-quality hare habitat (HQHH) for male and female lynx during periods of relative high (2001-2006) and lower (2007-2010) hare density in northern Maine, USA (preliminary data, do not cite).

Sex (Period)	**N**	**Mean ± SE**	**Range**
M (HIGH)	35	56.1 ± 2.1	19.7 – 74.7
M (LOW)	31	46.8 ± 2.6	19.6 – 72.6
F (HIGH)	31	53.9 ± 1.8	38.2 – 72.4
F (LOW)	14	51 ± 3.4	23.9 – 66.5
M & F pooled (HIGH)	66	55.1 ± 1.4	19.7 – 74.7
M & F pooled (LOW)	45	48.1 ± 2.1	19.6 – 72.6

Table 4-2. Habitat selection [ln(use/availability)] of high-quality hare habitat (HQHH) for male (M) and female (F) lynx during periods of relative high (2001-2006) and lower (2007-2010) hare density in northern Maine, USA. Selection indices above zero indicate positive selection, whereas negative selection indices indicate avoidance (preliminary data, do not cite).

Sex (Period)	**N**	**Mean ± SE**	**Range**
M (HIGH)	12	0.23 ± 0.05	-0.05 – 0.65
M (LOW)	10	0.08 ± 0.08	-0.4 – 0.49
F (HIGH)	11	0.23 ± 0.03	0.05 – 0.37
F (LOW)	7	0.03 ± 0.04	-0.14 – 0.21
M & F pooled (HIGH)	23	0.23 ± 0.03	-0.05 – 0.65
M & F pooled (LOW)	17	0.06 ± 0.05	-0.4 – 0.49

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

Stephen Dunham and Daniel Harrison

Background and Project Overview

Spruce grouse (*Falcipennis canadensis*) (figure 4-4) 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 extends only marginally into the northernmost of the contiguous United States. Coincidentally, a recent assessment by the International Association of Fish and Wildlife Agencies concluded that populations in the southeastern portion of the species' range including those in New England and New York are rare or declining (Williamson *et al.* 2008).

Figure 4-4. Spruce Grouse in mid-successional stand in northern Maine. Photo by Steve Dunham.

The southeastern extent of the geographic range of spruce grouse coincides with southeastern distribution of red and black spruce within the Acadian forests of Maine, northern New Hampshire, northernmost Vermont, the Adirondacks region of New York State, as well as the eastern maritime provinces of Canada. Within this region, spruce grouse are listed as endangered in Vermont and New York, and are a species of conservation concern in New Hampshire.

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

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

The extent that some management approaches in conifer stands may maintain or increase habitat quality for spruce grouse is unknown. Spruce grouse have been documented to occur in plantations and PCT stands (Boag and Schroeder 1992, Homyack 2003), and Rattie *et al.* (1984) reported that over half of sites occupied by grouse had lowest live limb heights between 1.5

and 4.5 meters. Although those conditions may be common in mature, uncut, lowland conifer stands, we hypothesize that favorable conditions for spruce grouse may also be created in some plantations and precommercially thinned (PCT) fir-spruce stands within the Acadian Forest.

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

Progress in 2012

During 2012 the bulk of the research activity was divided between three components of the study:

1) Occupancy surveys in 19 reference stands (table 4-3, figure 4-5);

2) Home range analysis of spruce grouse broods using radio telemetry, and

3) Monitoring of survival and brood rearing success of adult female spruce grouse across a range of stand conditions.

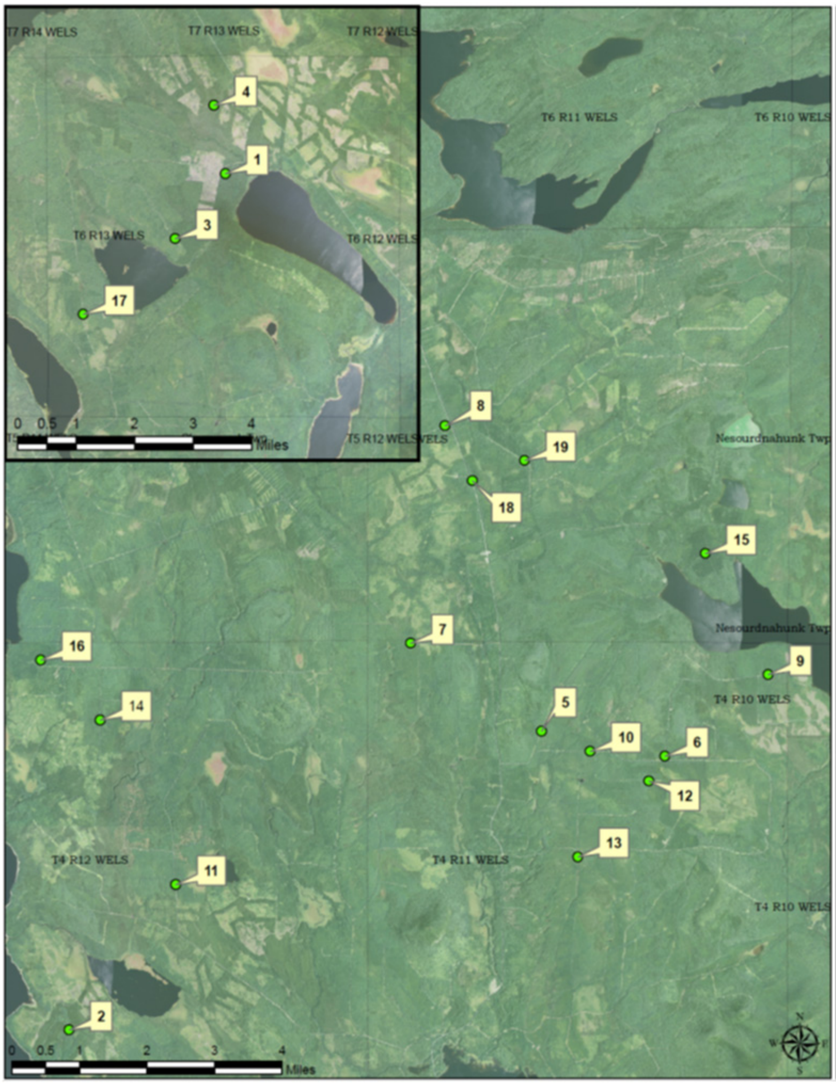

Figure 1. Locations of 19 stands (referenced by numbers in Table 1) studied during May-September 2012 within 4 townships (T4R11, T4R12, T5R11, and T6R13), Piscataquis County, Maine.

Table 4-3. Location, stand treatment, history, occupancy by male spruce grouse detected during cantus call surveys, and number of females equipped with VHF transmitters within 19 conifer-dominated stands studied in northern Maine during May-October 2013. Locations of stands (by stand number) are depicted in figure 4-5.

Stand	Northing	Easting	Stand Treatment	Treatment History	Occupied by Responding Males	Number of Marked Males	Number of Radioed Females
1	5114593	0468528	Mature softwood	Not cut since at least 1970	Yes	1	0
2	5088849	0476112	Mature Softwood	Not cut since at least 1970	No	0	0
3	5112809	0467144	Mature Softwood	Not cut since at least 1970	No	0	0
4	5116481	0468210	Mature Softwood	Not cut since at least 1970	Yes	0	2
5	5096050	0487450	Advanced Regen	Cut:78 Herb:88	Yes	4	3
6	5095454	0490399	Advanced Regen	Cut:78 Herb:83	No	0	
7	5098147	0484328	Advanced Regen	Cut:81 Herb:84	Yes	0	2
8	5103344	0485151	Advanced Regen	Cut:83 Herb:88	Yes	1	0
9	5097403	0492861	Advanced Regen	Cut:75 Herb:85	No	0	0
10	5095457	0488242	10y post PCT	Cut:82 Herb:88	Yes	3	1
11	5092585	0478833	10y post PCT	Cut:80 Herb:83	Yes	1	1*
12	5094656	0490237	10y post PCT	Cut:77 Herb:83	Yes	0	0
13	5092928	0488228	10y post PCT	Cut:82 Herb:88	Yes	1	1
14	5096155	0476768	10y post PCT	Cut:76 Herb:83	Yes	1	1
15	5100288	0491362	15y post PCT	PCT in 95	No	0	0
16	5097643	0475526	15y post PCT	PCT in 95	Yes	1	0
17	5110730	0464625	15y post PCT	PCT in 94	Yes	3	1
18	5102028	0485802	15y post PCT	PCT in 94	Yes	1	3
19	5102769	0487173	15y post PCT	PCT in 94	No	0	0

*Female dropped collar after 10 locations

Occupancy Surveys

During the month of May we performed three cantus call surveys within 19 conifer stands representing uncut mature (n = 4), regenerating clearcuts (cut 29-37 years previously and subsequently treated with herbicide to control deciduous competition; n = 5), stands approximately 10 years after PCT (n = 5), and stands approximately 15 years after PCT (n = 5). Of these 19 stands, 13 were occupied by spruce grouse. We had > 30 responses (flutter flights) from males and were successful in capturing 17 males, which were fitted with a numbered aluminum leg band and one to three colored plastic leg bands (figure 4-6). No females responded during surveys using cantus calls, although a few were observed near the end of the survey period. We hypothesized that with advanced spring phenology in 2012, females were nesting during the dates that cantus call surveys were conducted (7 May to 28 May).

Figure 4-6. Captured Spruce Grouse. Photo by Steve Dunham.

Radio-Telemetry

During June and early July we conducted chick distress call surveys to elicit the response of brood rearing females. We completed at least two surveys of all stands known to contain spruce grouse (i.e., grouse heard and/or captured during cantus call surveys). We captured 14 females during those surveys and fitted them with bands, as well as with necklace mounted VHF radio transmitters. Additionally, three spruce grouse nests were located during those surveys. Surveys were discontinued after 9 July because responses to the distress calls were diminishing and temperatures were becoming stressful to captured birds.

During the period from 8 June to 30 September we located all VHF-equipped females using radio telemetry. One of the 14 original females shed her radio after only 10 locations were collected and another female was opportunistically captured and fitted with that transmitter. The resulting 14 females were located 29 times each.

Survival Monitoring

Of the 15 spruce grouse that were equipped with radio transmitters, 14 were verified to have survived until 30 September; fate of the remaining spruce grouse who shed her radio was unknown.. Of the 14 broods tracked until the beginning of brood break-up (30 September), 13 had at least one surviving chick (figure 4-7).

Figure 4-7. Spruce Grouse chick. Photo by Steve Dunham.

Future Plans

Occupancy surveys will be conducted again during 2013, but will occur earlier in an attempt to detect and capture females before they initiate nesting. Unmarked females that respond to call will be captured using noose poles and fitted with radio transmitters to locate nests and to document spatial position and size of their home ranges. If we cannot successfully deploy all 15 radios prior to nesting, chick distress surveys will be used during late June to capture additional females with broods. Occupancy surveys and leg banding of male grouse will also be conducted again in 2014, but we do not plan to deploy transmitters during those surveys. All responses from previously marked birds will be recorded during both years to analyze male survival and/or movement patterns among stands.

Vegetation measurements will be conducted during the summer of 2013. All survey stands will be measured using protocols previously established during companion snowshoe hare studies. Measurements will include basal area, stem density, tree height, crown ratio, species composition, understory height and composition, ground cover composition, and lateral cover. Additionally, the height to the lowest dead branch will be measured, as it may provide roosting opportunities for grouse. We are also developing protocols to measure a comparable suite of vegetation variables at individual telemetry locations. The project is scheduled to for completion by December 2014.

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Appendix

Outreach

OUTREACH

Journal Publications

Li, R., Weiskittel, A.R., Dick, A.R., Kershaw, J.A., and R.S. Seymour. 2012. Regional Stem Taper Equations for Eleven Conifer Species in the Acadian Region of North America: Development and Assessment. Northern Journal of Applied Forestry. 29(1):5-14.

Li, R., Weiskittel, A.R., Dick, A.R., and J.A. Kershaw. 2011 Modeling annualized occurrence, frequency, and composition of ingrowth using mixed-effects zeroinflated models and permanent plots in the Acadian Forest Region of North America. Canadian Journal of Forest Research. 41: 2077–2089.

Nelson, A.S., Saunders, M.R., Wagner, R.G., and A.R. Weiskittel. 2012. Early stand production of hybrid poplar and white spruce in mixed and monospecific plantations in eastern Maine. New Forests 43: 519-534.

Olson, M.G., Wagner, R.G., and J.C. Brissette. 2012. Forty years of spruce–fir stand development following herbicide application and precommercial thinning in central Maine, USA. Canadian Journal of Forest Research. 42: 1–11.

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Russell, M.B., Weiskittel, A.R., and J.A. Kershaw. 2011. Assessing model performance in forecasting longterm individual tree diameter versus basal area increment for the primary Acadian tree species. Canadian Journal of Forest Research. 41: 2267–2275.

Nelson, A.S. and R.G. Wagner. 2011. Improving the composition of beech-dominated Northern hardwood understories in northern Maine. Northern Journal of Applied Forestry. 28(4):186-193.

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Meyer, S.R. (Ed.) 2012. Center for Research on Sustainable Forests Annual Report – 2011. University of Maine. Orono, Maine. 107 p.

Olson, M.G., S.R. Meyer, R.G. Wagner, and R.S. Seymour. 2012. Response of tree regeneration to commercial thinning in spruce-fir forests of the Northeast. Progress report to U.S. Forest Service, Northeastern States Research Cooperative. 5 p.

Roth, B.E. (Ed.). 2012. Cooperative Forestry Research Unit Annual Report - 2011. The University of Maine, Orono, ME. 111 p.

Theses

Pekol, J.R. 2011. The influence of commercial thinning on stand- and tree-level mortality patterns of balsam fir (*abies balsamea*) and red spruce (*picea rubens*) forests in Maine that have or have not received precommercial thinning. M.S. thesis, University of Maine, Orono. 103 p.

Russell, M.B. 2012. Modeling individual tree dynamics in the mixed species Acadian Forest. Ph.D. dissertation, University of Maine, Orono. 215 p.

Presentations

Bataineh, M.M., R.G. Wagner, and A.R. Weiskittel. 2012. Capturing value through thinning - Forty-year results from the Austin Pond study. Cooperative Forestry Research Unit Forester's Workshop, May 16, 2012, Orono, ME.

Benjamin, J.G., Meacham, E., Seymour, R.S., and J. Wilson. 2012. Early Commercial Thinning (ECT) project update. Presented at the CFRU Winter Advisory Committee meeting, January 25th. Orono, ME.

Benjamin, J.G., Meacham, E., Seymour, R.S., and J. Wilson. 2012. Early commercial

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Pekol, J. Weiskittel, A.R., Seymour, R.S., and R.G. Wagner. 2012. Influence of commercial thinning on stand- and tree-level mortality patterns of balsam fir and red spruce forests in Maine with & without precommercial thinning. Presented at the CFRU Winter Advisory Committee meeting, January 25th. Orono, ME.

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