Extending the Acadian Variant of the Forest Vegetation Simulator to Managed Stands

Principal Investigator:

Jeremy Wilson
Harris Center for Conservation Education
wilson@harriscenter.org
83 King's Highway, Hancock, NH 03449

Co-Principal Investigators:

Aaron R. Weiskittel, School of Forest Resources, UMaine, aaron.weiskittel@maine.edu
Chris Hennigar, Faculty of Forestry & Environmental Management, UNB, chris.hennigar@gnb.ca

Collaborators:

Christian Kuehne, School of Forest Resources, UMaine
Robert G. Wagner, Cooperative Forest Research Unit
Brian E. Roth, Cooperative Forest Research Unit

Developed commercial thinning response functions significantly improved prediction accuracy in stand- and individual-tree growth models and have been implemented in the Acadian Variant of the Forest Vegetation Simulator.

Funding support for this project was provided by the Northeastern States Research Cooperative (NSRC), a partnership of Northern Forest states (New Hampshire, Vermont, Maine, and New York), in coordination with the USDA Forest Service.
http://www.nsrcforest.org

Project Summary

Rationale

- Most forest growth & yield models such as the Acadian Variant of the Forest Vegetation Simulator do not adjust their predictions for certain management activities such as commercial thinning, which can lead to significant biases.

Project Objectives

Using a series of regional, comprehensive, multi-year, and replicated commercial thinning studies of the spruce-fir (*Picea-Abies*) forests of the Acadian Region:

- Develop annual thinning response modifiers for stand-level basal area growth, dominant height increment, and mortality
- Establish annual and species-specific thinning response modifiers for individual-tree diameter, height, and height to crown base increment as well as mortality
- Evaluate predictions of commercial thinning response across a range of treatments using both the stand- and individual tree-level modifiers

Approach

- Measurements from 16 study locations across northern Maine, which are part of the University of Maine’s Cooperative Forestry Research Unit's Commercial Thinning Research Network (CTRN) were used .
- Stand-level and individual tree response to various commercial thinning treatments were modeled as modifiers of growth and mortality baseline equations.

Project Summary

Major findings

- Stand-level thinning treatment response functions for spruce-fir stands were shown to significantly improve predictions of annual stand-level basal area growth and mortality.
- Additional improvement was demonstrated for species-specific, individual tree-level annual diameter increment, height to crown base increment, and mortality functions.
- When the developed thinning modifiers were included in stand- and individual-tree growth models, a significant improvement in prediction over baseline models was achieved, yet the individual-tree approach was superior for predicting long-term response to various thinning treatments.

Implications for the Northern Forest region

- Derived individual tree thinning response functions were implemented in the Acadian Variant of FSV and are ready-to-use.
- Additional testing of the developed growth modifiers also showed improved growth model prediction accuracy after pre-commercial thinning.

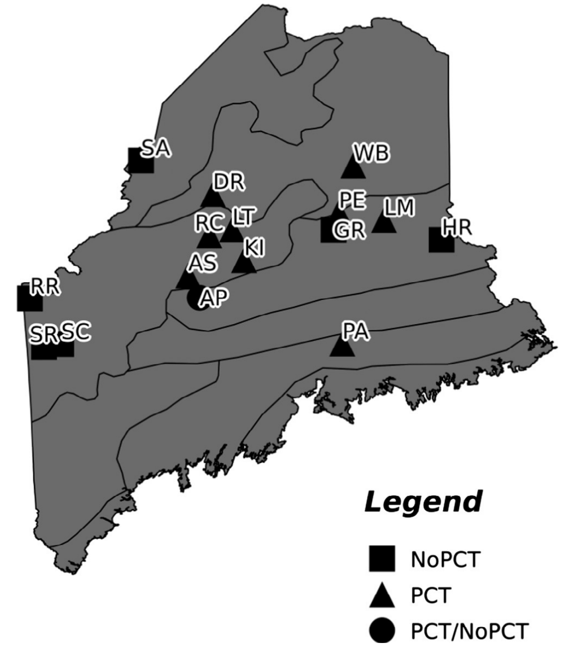
Background and Justification

- A forest growth and yield model called the Acadian variant of the Forest Vegetation Simulator (FVS-AD) was mostly developed using data from naturally-regenerated forest stands.
- Consequently, management activities like vegetation control, pre-commercial and commercial thinning, planting, and tree genetic improvement are not well represented in the model, which can lead to significant biases.
- Commercial thinning is a widely used silvicultural method in the spruce-fir (*Picea-Abies*) forests of the northeastern USA, but limited work has been done on predicting both short- and long-term individual tree- and stand-level responses to this treatment.
- In addition, stand response to partial harvest treatments such as commercial thinning were among the factors most influential with regard to the outcomes of the last wood supply assessment for Maine.

Background and Justification

- Given the wide use of, and importance placed on growth models such as FVS-ACD to evaluate the long-term financial return on alternative silvicultural treatments or the assessment of carbon storage the development of regional thinning modifiers is critical.
- This project's primary goal was to modify FVS-ACD to account for commercial thinning activities in the region.
- Project objectives:
  - develop annual thinning response modifiers for stand-level basal area growth, dominant height increment, and mortality
  - establish annual and species-specific thinning response modifiers for individual-tree diameter, height, and height to crown base increment as well as mortality
  - evaluate predictions of thinning response across a range of treatments using both the stand- and individual tree-level modifiers.

Methods



- Measurements from 16 study locations across northern Maine, which are part of the University of Maine's Cooperative Forestry Research Unit's Commercial Thinning Research Network (CTRN) were used
- Pre-commercial thinning (PCT) contrasted with non-PCT (NoPCT) was conducted in six and nine study locations respectively, during the mid- and late-1980s while one additional location comprised both PCT and NoPCT plots
- Stand and thinning treatment characteristics:

Characteristic	PCT	NoPCT
Number of locations	10	7
Number of annual post-treatment inventories	3-13	2-12
Breast height age (2000, years)	24 ± 8 (14-40)	46 ± 18 (18-68)
Site index (m)	21 ± 2 (18-24)	17 ± 4 (13-22)
Pre-treatment basal area (m^2 ha^{-1})	30 ± 5 (21-42)	44 ± 6 (32-56)
Pre-treatment spruce/fir proportion (%)[1]	90 ± 12 (29-100)	84 ± 14 (34-99)
Year of commercial thinning	2002/07/09/10/12/13	2000/01/02/14
Thinning method(s)	Crown	Crown, dominant, low
Basal area reduction (%)	49 ± 10 (32-74)	55 ± 13 (23-81)
Post-treatment spruce/fir proportion (%)[1]	93 ± 13 (29-100)	90 ± 15 (34-100)

Methods

- Response to commercial thinning ($\hat{y}$) was modeled as a treatment modifier equation (f_{thin}) multiplied upon separately developed untreated equations (f_{base}), i.e. a baseline models not including thinning treatment variables:
  $\hat{y} = f_{base} * f_{thin}$
- Stand-level f_{base} were developed for annual basal area growth of survivor trees (ΔBA), annual dominant height growth in balsam fir or red spruce (ΔHT_{DOM}), and annual mortality quantified as accumulated basal area of dead trees (BA_{MORT}).
- Individual tree f_{base} for the two most common conifer species of the CTRN data base, balsam fir and red spruce, were developed for annual diameter increment (ΔDBH), annual height increment (ΔHT), annual height-to-crown base increment (ΔHCB), and individual tree mortality (probability of a tree dying, P_{MORT}).
- Approximately 1,000 stand-level and 120,000 individual tree-level observations were available.

Methods

- Multiplicative modifiers (thinning treatment response functions, f_{thin}) were modeled using time since thinning (Y_t), percentage basal area removed (BA_t/BA_b), basal area before thinning (BA_b), and the ratio of quadratic mean diameter (QMD) before thinning and QMD after thinning (QMD_b/QMD_a) as predictor variables:

$$f_{thin} = 1 \pm \left(e^{\left(\gamma_0 + \frac{\gamma_1}{\left(\left(100 \cdot \frac{BA_t}{BA_b} + BA_b \right) \cdot \frac{QMD_b}{QMD_a} \right) + 0.01} \right)} \cdot {\gamma_2}^{Y_t} \cdot {Y_t}^{\gamma_3} \right)$$

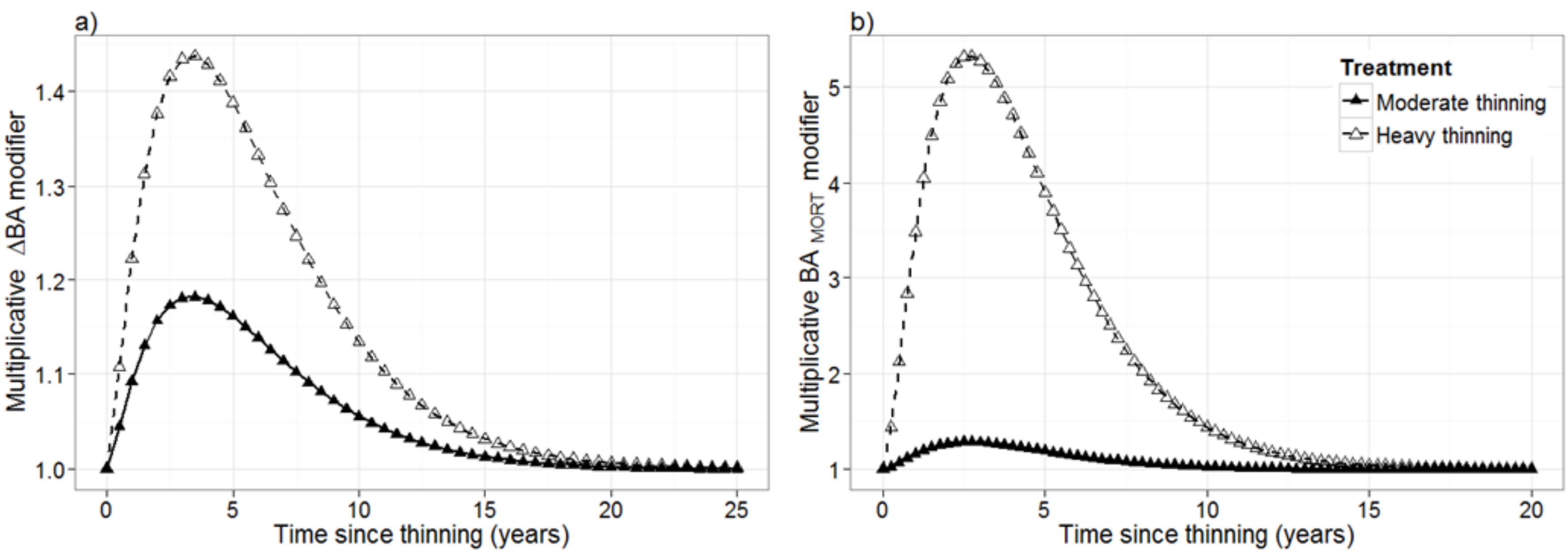
- Performance of stand- and tree-level equations with and without the developed modifiers were compared and evaluated using AIC, mean bias (MB; observed - predicted), mean absolute bias (MAB), root mean squared error (RMSE), and area under the curve (AUC).
- To further evaluate the predictive ability of the thinning-response functions short- and long-term predictions of stand-level basal area increment from the first to last post-treatment measurement were derived using tree- and stand-level equations with and without the developed modifiers.

Results

- Developed thinning modifiers were shown to significantly improve predictions of
  - Annual stand-level basal area growth and mortality as well as
  - Species-specific, individual tree-level annual diameter increment, height to crown base increment, and mortality.
- For these response variables, duration and magnitude of the response functions were significantly influenced by thinning intensity and to a lesser extent by thinning method.
- Based on the derived modifiers commercial thinning increased stand- and tree-level growth as well as mortality and slowed individual tree crown recession.
- In contrast, modifiers for stand-level dominant height increment as well as tree-level height increment did not show significant improvement when compared to the baseline model.

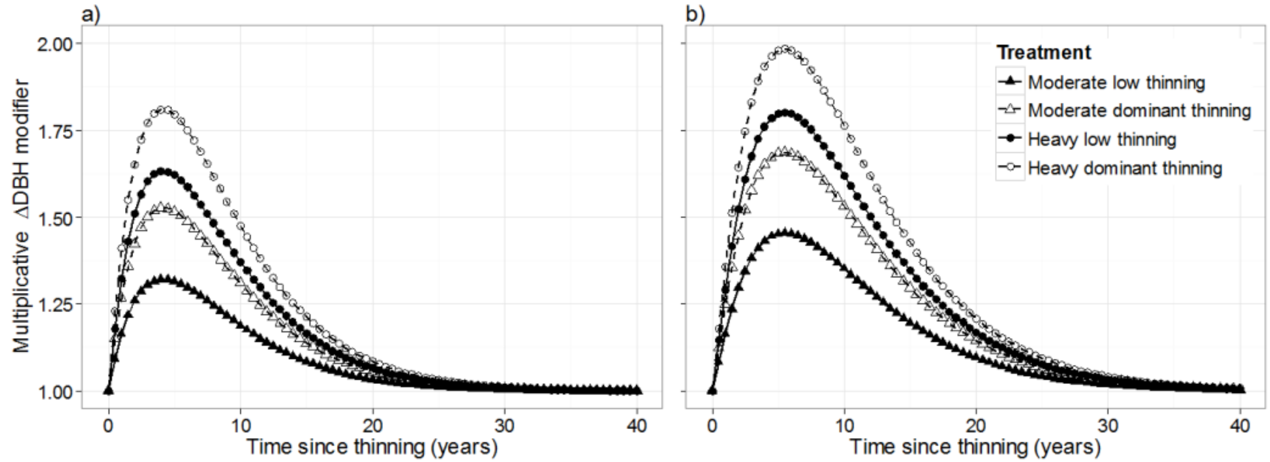
Results

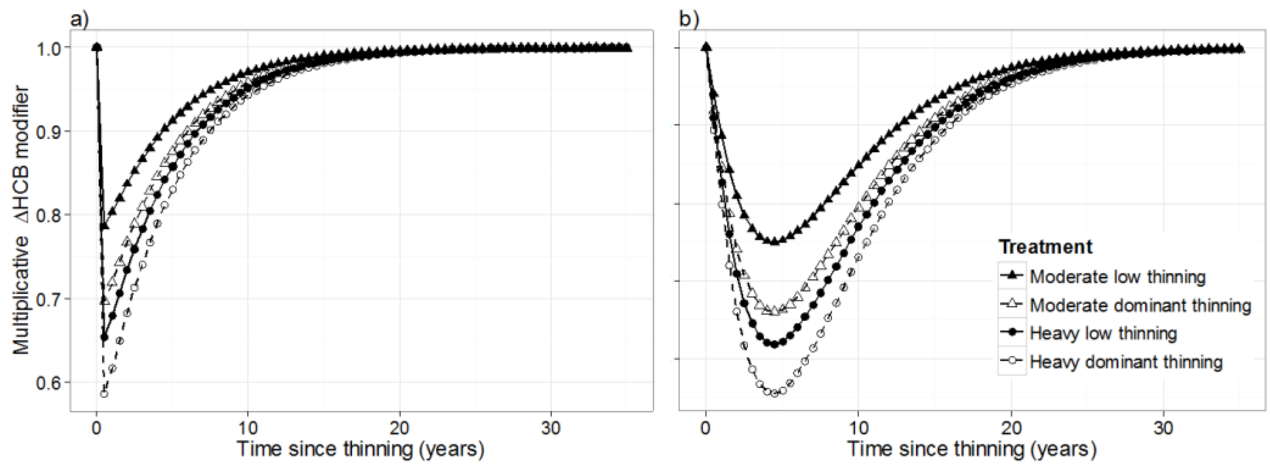
Stand-level thinning-response functions for exemplary moderate and heavy commercial thinnings (25% or 50% basal area removal, respectively) for a) annual basal area increment of survivor trees (ΔBA) and b) annual stand mortality (BA_{MORT}) of Acadian spruce-fir forests.

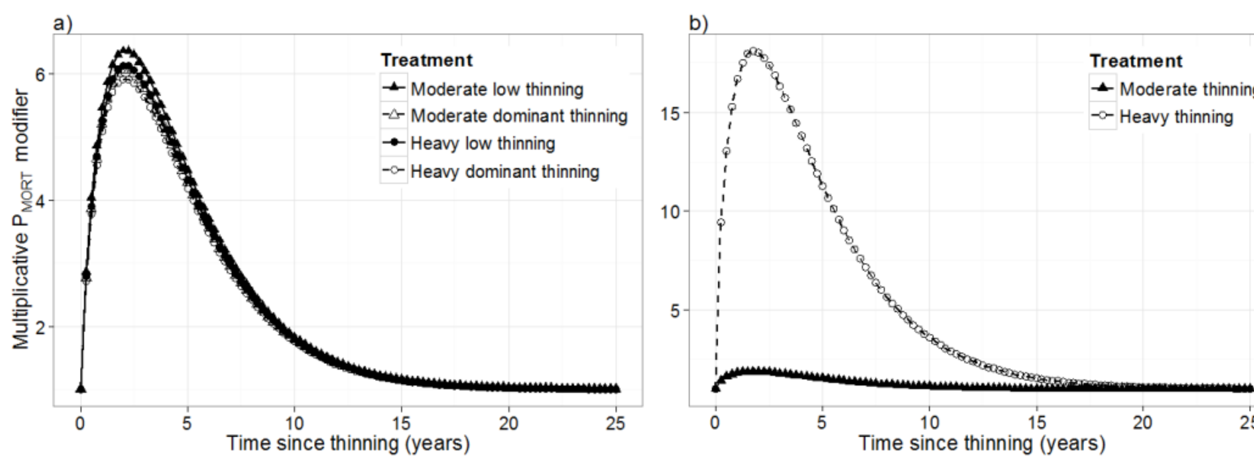


Results

Individual tree-level annual DBH increment (ΔDBH), annual height to crown base increment (ΔHCB), and annual tree mortality (P_{MORT}) thinning-response functions for exemplary moderate and heavy (25% or 50% basal area removal, respectively) low or dominant thinnings (QMD ratio = 0.7 or 1.1, respectively) for a) balsam fir and b) red spruce.







Results

- Regardless of approach, the accuracy of post-treatment predictions for stand-level basal area increment were mostly greater for $f$thin model outcomes when compared to $f$base results (Table 8).
- Tree-level based predictions outperformed predictions derived in the stand-level approach, which was especially evident for NoPCT plots.

Results

Annual stand-level basal area increment ($m^2\ ha^{-1}\ yr^{-1}$) predictions using observed data from commercially thinned spruce fir stands of the Acadian forest that were (PCT) and were not pre-commercially thinned (NoPCT), baseline models ($f$base), and baseline models multiplied by stand- (ΔBA, BA_{MORT}) or tree-level (ΔDBH, P_{MORT}) thinning-response functions ($f$base & $f$thin).

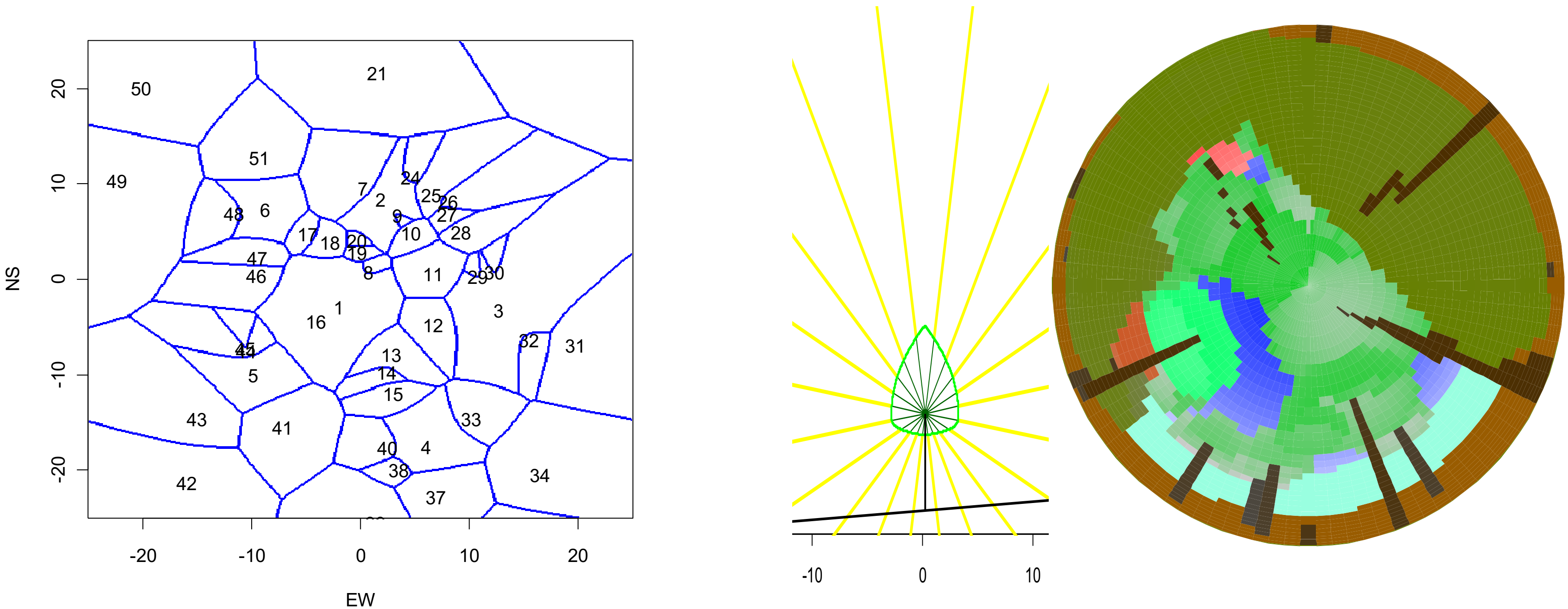
	N	Observed (Mean ± SD)	Approach	Model	Predicted (Mean ± SD)	MB	MAB	RMSE
PCT	43	0.70 ± 0.67	Stand-level	f_{base}	1.09 ± 0.35	-0.3937	0.5790	0.7621
				f_{base} & f_{thin}	1.20 ± 0.35	-0.5005	0.5897	0.7736
			Tree-level	f_{base}	0.80 ± 0.22	-0.1013	0.4701	0.6159
				f_{base} & f_{thin}	0.65 ± 0.35	0.0451	0.4635	0.6009
NoPCT	35	0.01 ± 0.66	Stand-level	f_{base}	-0.64 ± 1.31	0.6527	1.2177	1.6024
				f_{base} & f_{thin}	0.81 ± 0.28	-0.7955	0.8297	0.9854
			Tree-level	f_{base}	0.50 ± 0.19	-0.4857	0.5676	0.7331
				f_{base} & f_{thin}	0.38 ± 0.38	-0.3707	0.5177	0.6616

Implications and applications in the Northern Forest region

- Derived individual tree thinning response functions were implemented in the Acadian Variant of FSV and are ready-to-use.
- Due to the varying characteristics of the studied stands and the broad range of thinning treatments examined, the derived modifiers are assumed to be suitable for growth response predictions over a wide range of contemporary partial harvest practices.
- Additional testing of the developed growth modifiers also showed improved growth model prediction accuracy after pre-commercial thinning.

Future directions

- Development of thinning response functions for common hardwood species such as yellow birch, red and sugar maple, and red oak.
- Better quantification of individual-tree responses using distance-dependent competition indices such as area potentially available (APA) or point of view index (POV) that can effectively capture the spatial variability created by thinning.



Schematic illustrations of summarizing the competitive status of trees using area potentially available (quantification of available growing space, left) and point of view index (quantification of tree crown surface area facing sky, right).

Modified from Waskiewicz J. and Weiskittel A.R. 2011.
An R package of spatially-explicit competition and structural indices.
Presentation at NorthEastern Mensurationists Organization (NEMO) Annual Meeting in State College, PA.

List of products

Peer-reviewed publication

- Kuehne C., Weiskittel A.R., Wagner R.G., and B.E. Roth. 2016. Development and evaluation of individual tree- and stand-level approaches for predicting spruce-fir response to commercial thinning in Maine, USA. Forest Ecology and Mangement 376: 84-95.

Other publications

- Kuehne C., Weiskittel A., Wagner R., and B. Roth. 2016. Development and evaluation of stand and individual tree-level growth and mortality modifiers for thinned spruce-fir (Picea-Abies) forests of the Acadian Region. In: Roth B.E. (Ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME. p. 21-23.
- Weiskittel A., Hennigar C., and J. Kershaw. 2015. Extending the Acadian variant of FVS to managed stands. In: Wagner, R.G. (Ed.) Cooperative Forestry Research Unit: 2014 Annual Report. University of Maine. Orono, ME. 94 p.

Presentations

- Kuehne C., Weiskittel A., and R. Wagner. 2015. Growth and mortality modifiers for thinned spruce-fir stands of the Acadian Forest. 2015 Northeastern Mensurationists Organization (NEMO) Annual Meeting. Stowe VT, USA
- Hennigar, C. 2014. Open Stand Model: Hardwood partial harvest simulation advancement. Northern Hardwoods Research Institute. Université de Moncton. Edmundston, New Brunswick.