Incorporating spruce-budworm impacts into the Acadian Variant of the Forest Vegetation Simulator

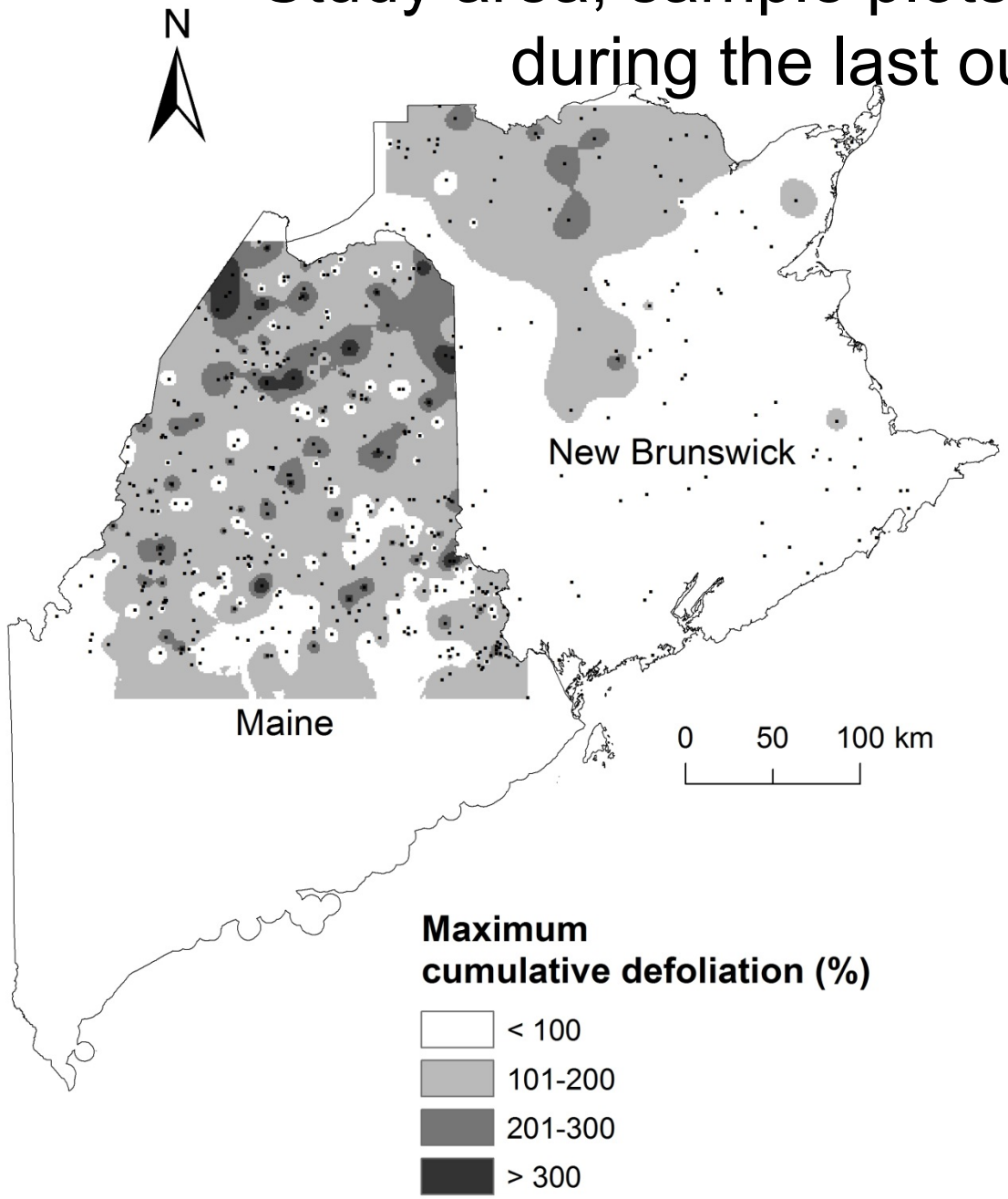
Principal Investigator: Mohammad Bataineh
Affiliation/Institution: School of Forestry & Natural Resources, University of Arkansas at Monticello
Email: Bataineh@uamont.edu
Mailing address: P.O. Box 3468, 110 University Ct, Monticello, AR 71655
Collaborators and Affiliations: Aaron Weiskittel, School of Forest Resources, University of Maine
Robert Seymour, School of Forest Resources, University of Maine
David MacLean, Faculty of Forestry and Environmental Management, University of New Brunswick
Brian Roth, Cooperative Forestry Research Unit, University of Maine
Laura Kenefic, Northern Research Station, U.S. Forest Service
Cen Chen, School of Forest Resources, University of Maine
Completion date: Nov. 2018

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

- Defoliation reduces the growth and survival of trees. Spruce budworm (SBW) is the primary defoliating insect in North America and has affected over 58 million ha of forests during its last major outbreak in 1970s and 1980s.
- Two large-scale sets of individual-tree level data collected at 1-3 years intervals from 560 permanent sample plots spanning the last SBW outbreak (1970s-1980s) in Maine, USA, and New Brunswick, Canada were available to support this study.
- Individual tree and stand growth responses to SBW defoliation, as well as variations and temporal dynamics of individual tree defoliation have been evaluated in this project.
- Based on these evaluations, annualized modifiers have been developed to be used in the Acadian Variant of the Forest Vegetation Simulator (FVS-ACD) to account for the impacts of SBW defoliation.
- When applied to both Maine and New Brunswick, this refined FVS-ACD consistently showed significantly lower biases and errors in predictions compared to a similar model used in Canada. It shows that the refined FVS-ACD is suitable to incorporate the impacts of SBW defoliation into predictions of stand dynamics to support management and protective activities against SBW defoliation in the Acadian Region.

Study area, sample plots, and defoliation during the last outbreak.



https://www.slu.se/globalassets/nyhet-kalend/2018/moth-outbreak-sbw.jpg

Forest Vegetation Simulator

- The Forest Vegetation Simulator (FVS) is a distance-independent, individual-tree forest growth model widely used in the United States and parts of Canada.
- FVS was developed to predict stand dynamics and development in response to various management alternatives and disturbance-causing agents.
- The Acadian Variant of FVS (FVS-ACD) is one of the latest developments among the geographically specific variants of FVS. It offers flexibility of accounting for effects of management activities and disturbance agents on individual trees at an annual resolution, and represents forests in the Acadian Region where SBW is endemic.
- The inputs required to run FVS-ACD include species, diameter at breast height (DBH), height, and crown ratio of each tree, the ID of the stand that a tree belongs to, an extension factor to estimate per unit area (e.g., hectare) values of individual tree attributes (e.g., basal area and volume), a threshold DBH of ingrowth, and climate site index of each stand.
- Projections of stand development by FVS-ACD are based on predictions of changes in the dimensions of each tree from each stand, as well as mortality, ingrowth, and their interactions.

Modifiers

$$[1]\ exp\left(b_{spp} \cdot CDEF\right)$$

$$[2]\ exp\left(b1_{spp} \cdot CDEF + b2_{spp} \cdot CR\right)$$

$$[3]\ b0 + b1 \cdot BAL_{mod} + b2 \cdot pBAL_{SW}{}^{0.5} + b3 \cdot CR + b4 \cdot log(CSI) + b5_{spp} \cdot CDEF$$

$$[4]\ b1 \cdot CDEF + b2$$

[1]: modifiers for DBH increment (cm yr^{-1}) and height increment (m yr^{-1}).
[2]: modifier for height to crown base (m).
[3]: modifier for mortality (probability in the form of a 0-1 ratio).
[4]: modifiers for ingrowth (trees ha^{-1}) and ingrowth proportion of each susceptible species (balsam fir, as well as red, black, and white spruce).

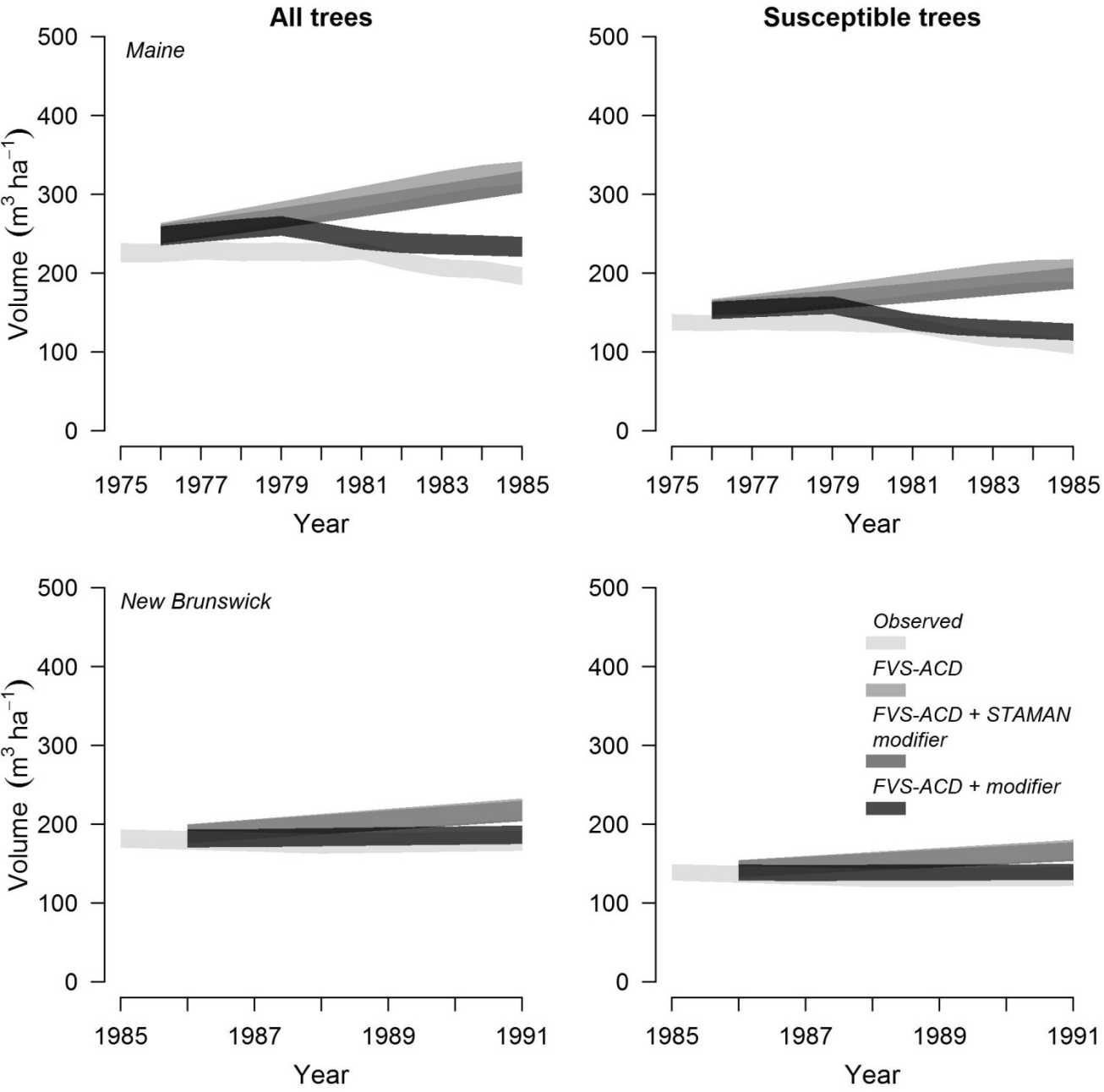
where BAL_{mod} is a modified metric of basal area of trees larger than the subject tree in DBH (*BAL*; $m^2\ ha^{-1}$) computed as $(BAL \cdot topht)/(100 \cdot BA \cdot tph^{-0.5})$, in which *topht* is top height (m), *tph* is trees ha^{-1}; and *BA* is basal area ($m^2\ ha^{-1}$); $pBAL_{SW}$ is the proportion of *BAL* of softwood; *CR* is crown ratio; *CSI* is climate site index; *CDEF* is cumulative defoliation (%); and *b* as well as *b1-b5* are parameters.

Observed vs. predicted volumes

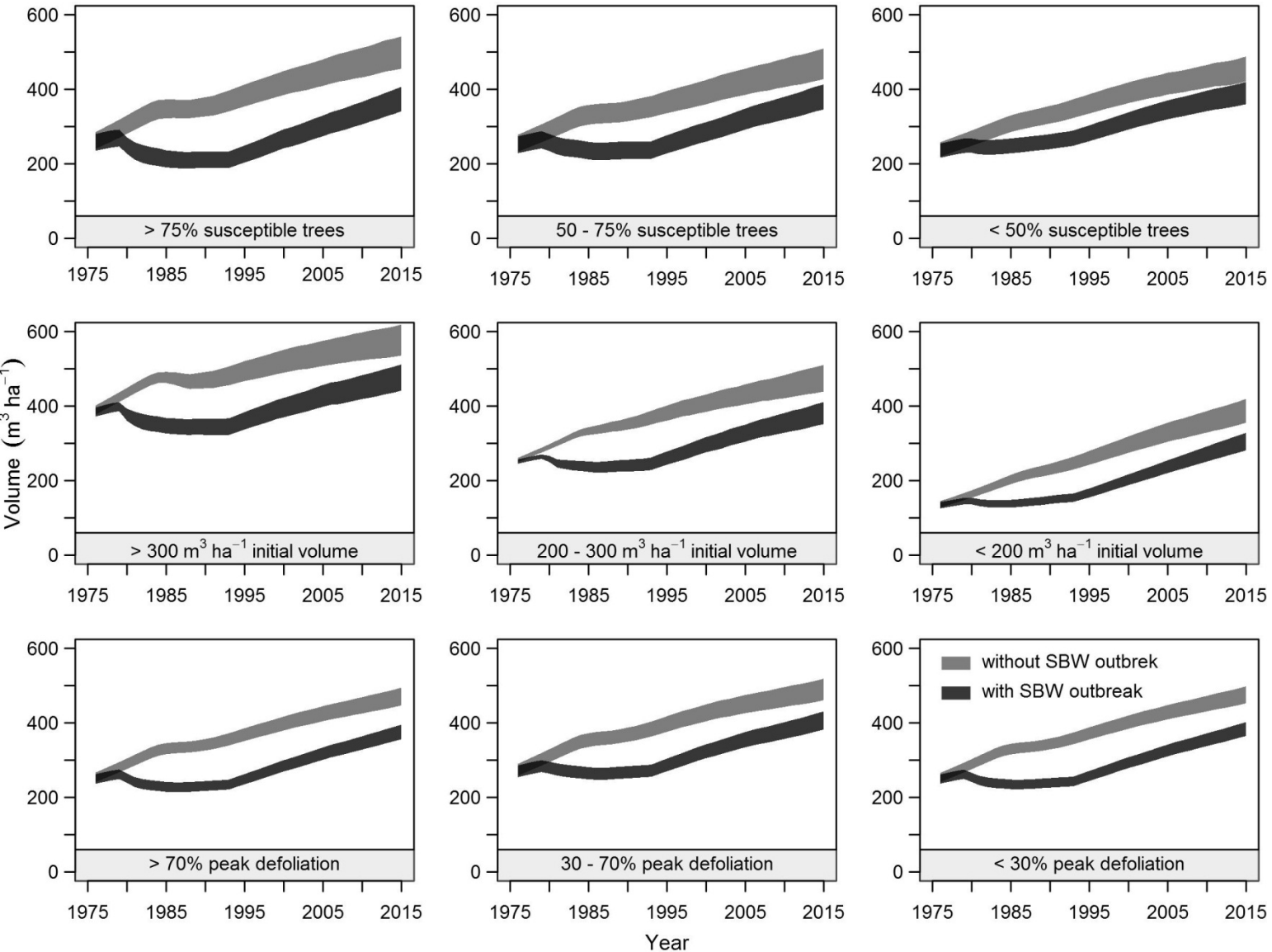
where STAMAN, a stand growth model used in the Spruce Budworm Decision Support System from Canada

			Mean (m^3 ha^{-1})		Mean bias (m^3 ha^{-1})			Root mean squared error (m^3 ha^{-1})		
			1976	*1985*	*Overall*	*1976*	*1985*	*Overall*	*1976*	*1985*
Maine	Observed	*all trees*	225	196	--	--	--	--	--	--
		susceptible trees	136	106	--	--	--	--	--	--
	Our modifiers	*all trees*	247	233	+21	+11	+35	70	30	98
		susceptible trees	153	125	+9	+6	+13	58	21	76
	STAMAN modifiers	*all trees*	249	316	+57	+13	+117	94	31	155
		susceptible trees	154	194	+41	+8	+86	75	22	124
	FVS-ACD	*all trees*	251	327	+67	+15	+129	103	32	164
		susceptible trees	156	204	+50	+9	+96	84	23	131
			*1986**	*1991*	*Overall*	*1986**	*1991*	*Overall*	*1986**	*1991*
New Brunswick	Observed	*all trees*	182	179	--	--	--	--	--	--
		susceptible trees	139	134	--	--	--	--	--	--
	Our modifiers	*all trees*	182	187	+5	0	+8	26	2	36
		susceptible trees	139	139	+4	0	+6	24	2	34
	STAMAN modifiers	*all trees*	185	212	+19	+3	+33	33	8	47
		susceptible trees	140	161	+15	+2	+27	29	7	41
	FVS-ACD	*all trees*	188	219	+24	+6	+41	37	7	53
		susceptible trees	144	168	+20	+5	+34	33	5	47

Comparisons between observed and predicted volumes

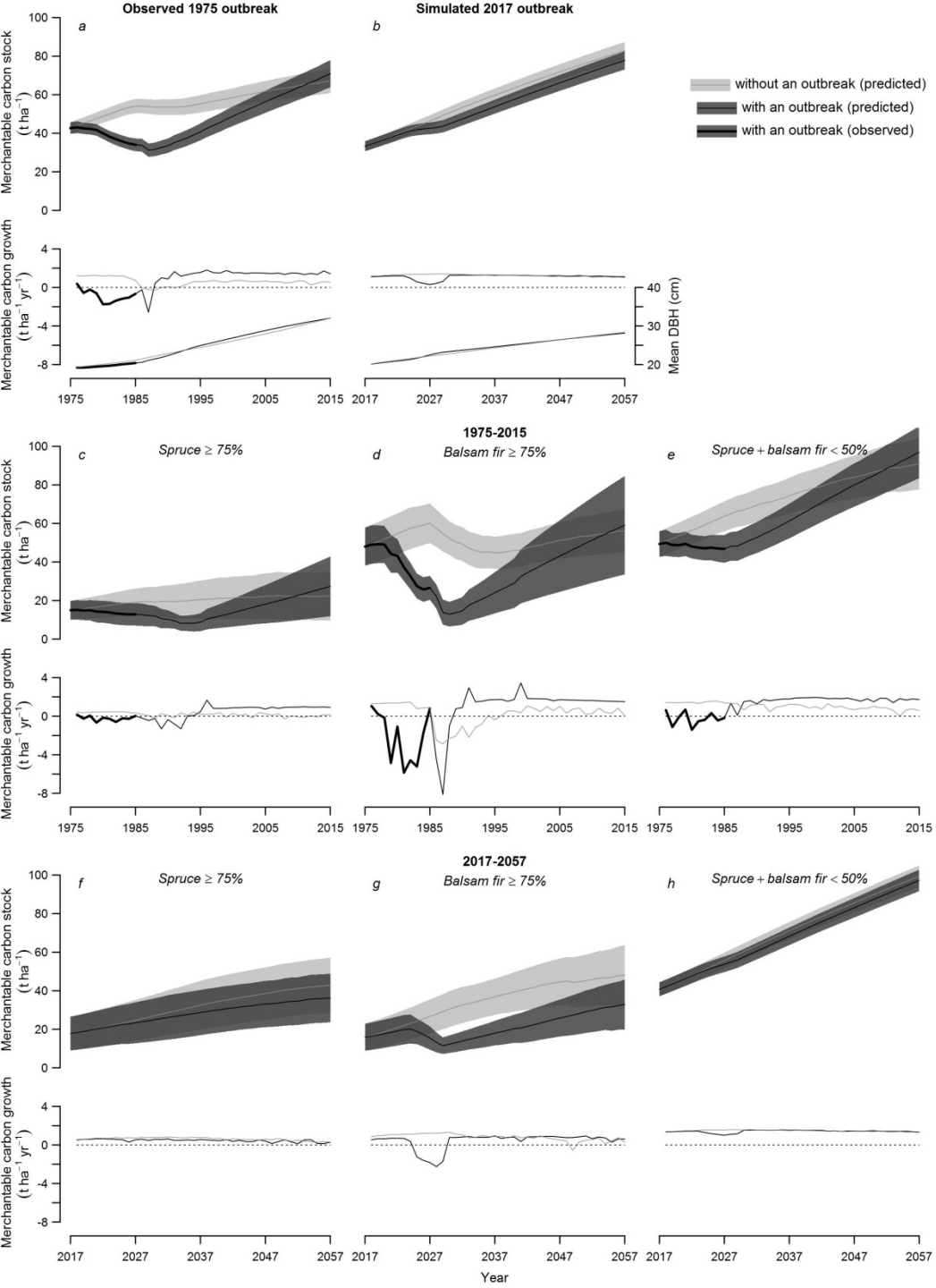


Forty-year projections of volume of various types of stands with and without the influence of SBW defoliation using FVS-ACD refined by our modifiers



Implications and applications in the Northern Forest region

- FVS-ACD refined by modifiers developed in this study is suitable to predict forest stand dynamics and support management as well as protection activities against SBW defoliation in the Acadian Region.
- The refined FVS-ACD showed significant improvement compared to previous works like STAMAN modifiers. This improvement includes more accurate predictions of volume, species composition, and diameter distribution, as well as a much closer resemblance of the patterns in volume changes.
- Economic impact of SBW outbreaks and viability of insecticide spraying may need to be further examined based on this study.
- The modifier framework should be extendable to other regions and other forms of defoliation.



Future directions

Influences of SBW defoliation on above-ground carbon stock in merchantable trees

- Due to significant increases of hardwood species, this carbon stock of spruce-fir forests was not reduced and not significantly different than what it would be without an outbreak at the end of either cycle of outbreaks.
- There were temporary decreases in carbon growth immediately following these outbreaks. These decreases were at smaller scales in the 40-year cycle starting 2017 where significant increases of hardwood species along with decreases of SBW's primary host species were observed.
- As this trend of changing species composition continues in this region, a future SBW outbreak would cause less reduction in carbon growth and less likely to result in a decrease of carbon stock in spruce-fir forests.

Future directions

Simulated spatial and temporal dynamics of an SBW outbreak under various scenarios

List of products

- Chen, C., Rahimzadeh-Bajgiran, P., and Weiskittel, A. In review. Modeling spatial and temporal dynamics of a spruce budworm outbreak across the complex forested landscape of Maine, USA. Submitted to Ecological Modelling.
- Chen, C. 2019. Spruce budworm defoliation dynamics and its influence on the Acadian forest. PhD dissertation. University of Maine, Orono, ME.
- Chen, C., Wei, X., Weiskittel, A., and Hayes, D.J. 2019. Above-ground carbon stock in merchantable trees not reduced between cycles of spruce budworm outbreaks due to changing species composition in spruce-fir forests of Maine, USA. Forest Ecology and Management 453: 117590.
- Chen, C., Weiskittel, A., Bataineh, M., and MacLean, D.A. 2018. Modelling variation and temporal dynamics of individual tree defoliation caused by spruce budworm in Maine, US and New Brunswick, Canada. Forestry 92: 133-145.
- Chen, C., Weiskittel, A., Bataineh, M., and MacLean, D.A. 2018. Refining the Forest Vegetation Simulator for projecting the effects of spruce budworm defoliation in the Acadian Region of North America. Forestry Chronicle 94: 240-253.
- Chen, C., Weiskittel, A., Bataineh, M., and MacLean, D.A. 2017. Evaluating the influence of varying levels of spruce budworm defoliation on annualized individual tree growth and mortality in Maine, USA and New Brunswick, Canada. Forest Ecology and Management 396: 184-194.
- Chen, C., Weiskittel, A., Bataineh, M., and MacLean, D.A. 2017. Even low levels of spruce budworm defoliation affect mortality and ingrowth but net growth is more driven by competition. Canadian Journal of Forest Research 47: 1546-1556.