Accuracy of Two Individual-Tree Growth Models for the Acadian Forest Region: FVS-ACD & OSM-ACD

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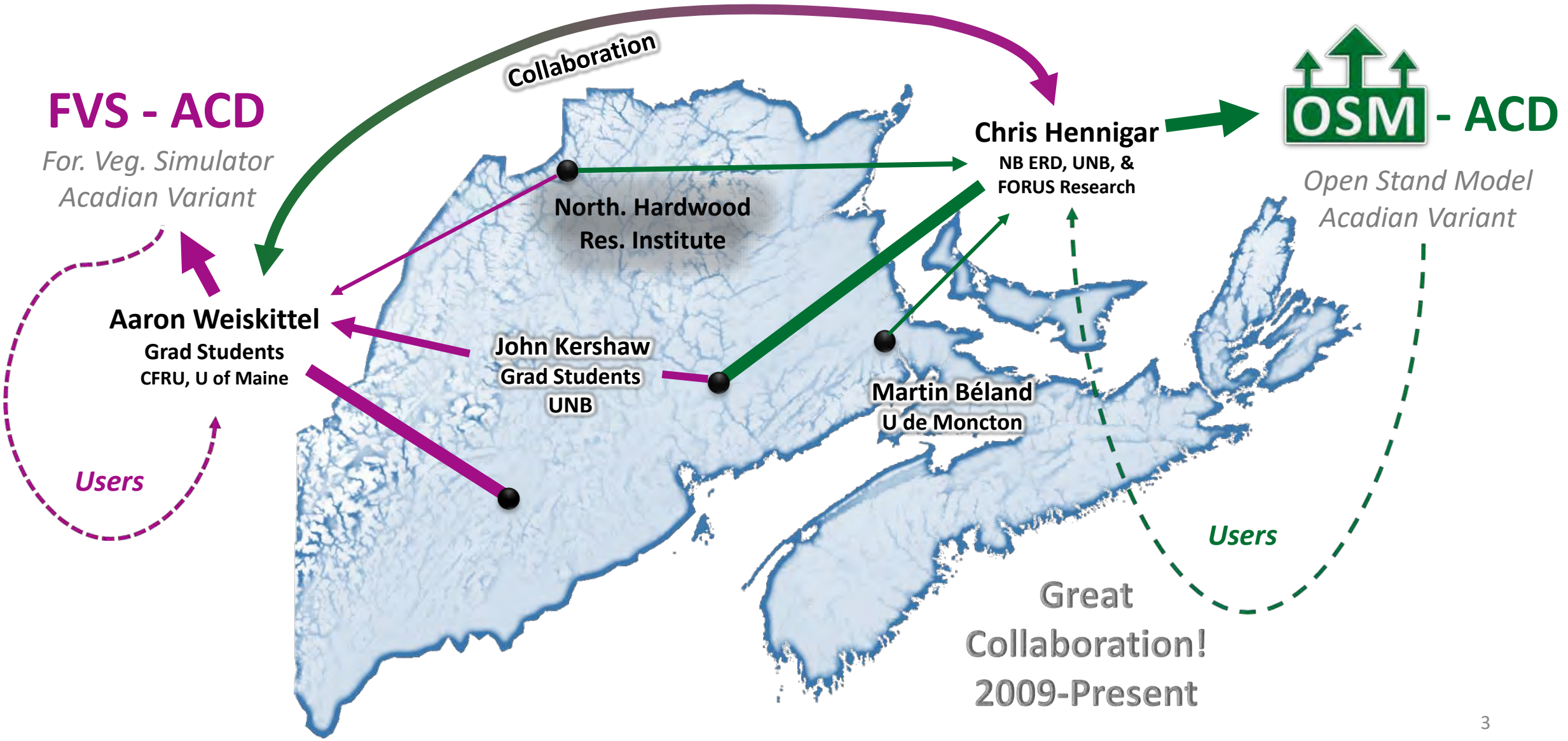
Empirical Individual-Tree & Stand Models Used for Acadian Forest Management Planning 1990s - Present

Recent Acadian-Forest Stand Modelling Work



User Experience

FVS-ACD (R version)

- **Coded in R** (statistical programming language)
  - Light weight and relatively easy to follow
  - Easy to share and transparent
  - Most equations published
  - **Procedural** (one big nested function)
- Modifiers for commercial thinning & spruce budworm defoliation
- **Annual** simulation time steps
- Equations have been ported to **FVS Online** and into a more simulation efficient DLL(s) by some users in Maine.

OSM-ACD

- **.Net (Windows)** DLLs & EXE
  - Custom OSM command language
  - **Object-oriented** w application programing interface
  - Complete command & code documentation
- Flexible harvest and tree behavior modifier command language
- **5-year** (or annual) simulation time steps
- **Code optimized for speed and error handling**
- Can be executed from third-party Windows applications, including **R**

Modeling Platform Aside

- Keep in mind that the important difference between OSM-ACD and FVS-ACD presented here is the background calibration.
  - Microsoft Excel would do just as well with the same equations.

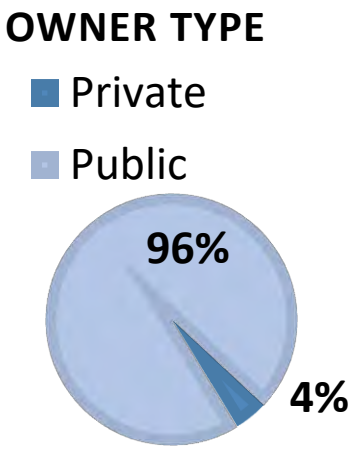
- OSM-ACD equations were fit between 2015-2018 and use an improved site productivity index and more managed stand data compared to FVS-ACD (fit 2010-2014), so we would expect higher accuracy in OSM-ACD.

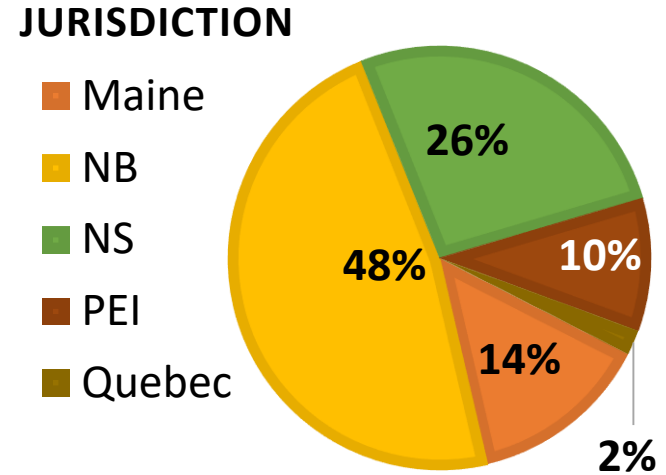
- What we are comparing here is a gradual improvement in calibration; not modeling platforms. Equations in OSM-ACD will undoubtedly be further tested and improved in FVS-ACD and/or OSM-ACD going forward.

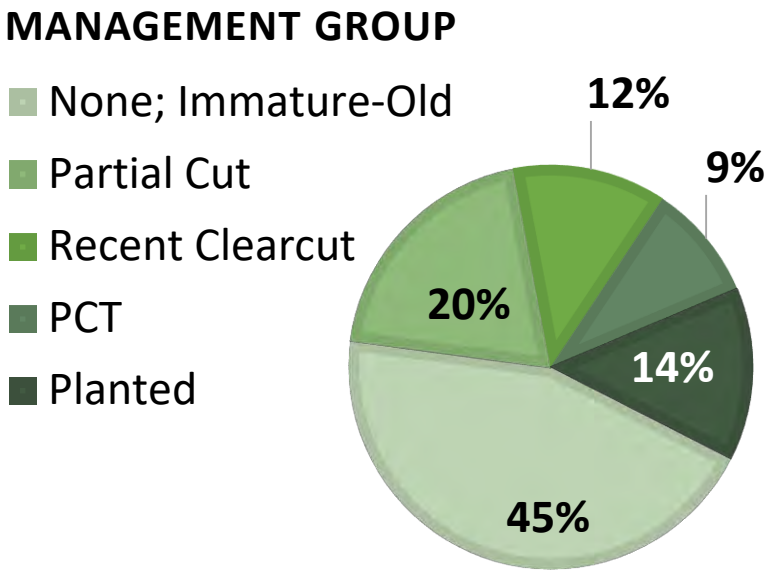
Total Data Compiled & Cleaned

- **Measurements for OSM-ACD calibration**
  - 19,500 plots with repeated measurements and spatial coordinates in ME, NS, NB, and PEI
    - 3.5 million tree growth/survival observations
  - Plus 37,000 stand timber cruises in NB
    - 2.5 million tree height measurements

- **Compared to NB 2004 STAMAN Calibration**
  - In NB, 1,614 more plots, mostly in managed stands
  - In NB, 10 more years of plot measurements
  - Regionally, four times the number of measurements available for calibration







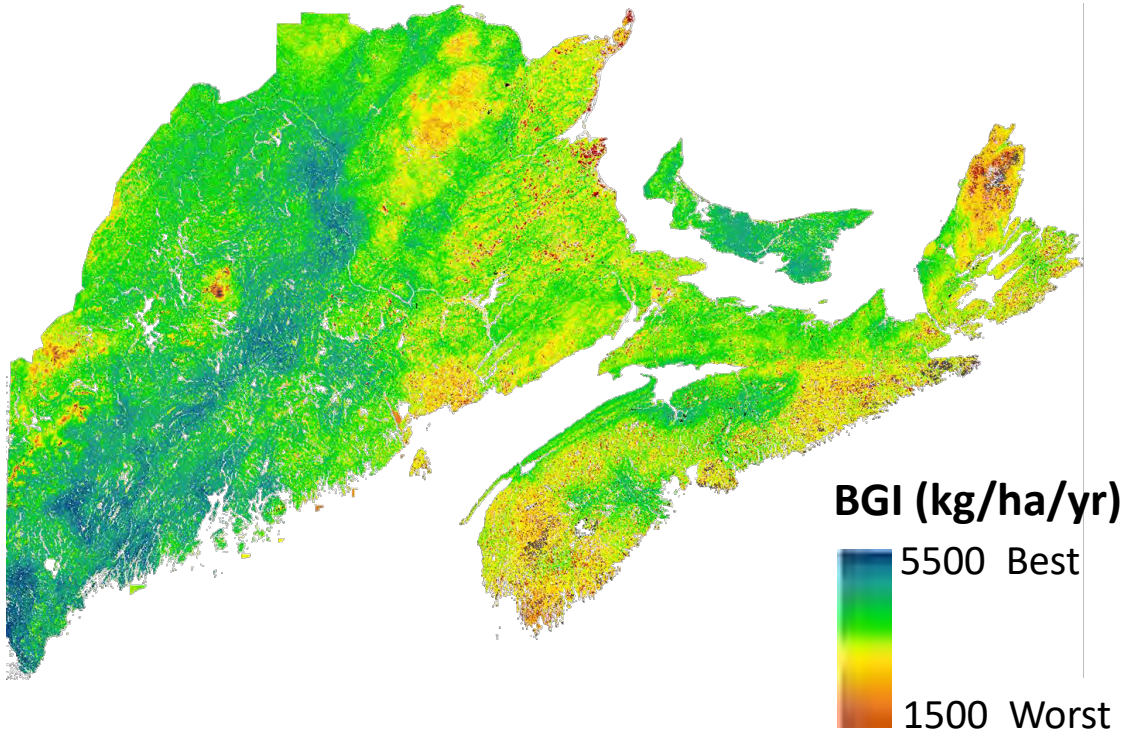
Calibration: Forest Productivity

FVS-ACD

- Climate Site Index (CSI)
  - *Weiskittel et al. 2010, CFRU 2010 Annual Report*

OSM-ACD

- Biomass Growth Index (BGI)
  - *Hennigar et al. 2016, Can. J. For. Res. 47*



Calibration: Key Tree-Model Differences

	FVS-ACD	OSM-ACD
Tree height	Fit with **CSI** (2012)	Fit with **Jurisdiction + BGI + Management** terms, more data, and different equations (2017)
Tree DBH growth	Fit with **CSI** (2012) ***Comm. thin modifier***	Fit with **Jurisdiction + BGI + Management** terms, more data, and different equations (2016)
Tree height growth	Fit with **CSI** (2014) ***Comm. thin modifier***	Deduced from DBH growth & height : DBH model predictions
Tree background mortality probability	Fit with **Jurisdiction** (2012) ***Comm. thin modifier***	Fit with **Management** term, more managed stand data, and different equations (2018)
Stand ingrowth probability, composition, and abundance	Fit with **CSI** (2011)	Same as FVS-ACD, but with modifiers for management and stand density.
Stand maximum stocking & self-thinning rules	Same as OSM-ACD with additional modifiers	Predicts and limits maximum stocking based on stand basal area weighted species specific-gravity. Fit with NB timber cruise data (2013)

All models use combinations of stand-level (density, composition) & tree-level (species, competition) variables.
Jurisdiction: NB, NS, Maine, and sometimes PEI and Quebec. **Management:** Is Planted or PCT (yes/no)

Calibration: Species Tree-level Predictions

	FVS-ACD	OSM-ACD
Height	**Predictors:** DBH+BAL+CCF+CSI *Rijal et al. 2012b. Forestry 85*	**Predictors:** Zone+DBH+BA+QMD+BAL+BGI+Management *Hennigar 2017 (NB-ERD) – unpublished. Model equations and predictors vary by species depending on variable significance.* **Incl. routine to modify predictions w local observations**
DBH growth	Predictors: DBH+CR+BAL+pBAL.SW+BA+RD+CSI Weiskittel et al. 2012 – CFRU 2012 Annual Report	**Predictors:** Zone+DBH+BA+QMD+BAL+BGI+Management *Hennigar 2016 (NB-ERD) – unpublished. Model equations and predictors vary by species depending on variable significance.*
Height growth	**Predictors:** HT+CR+BAL.SW+BAL.HW+BA+CSI *Russell et al. 2014. Eur J. For. Res. 133*	Deduced from DBH growth and height predictions
Mortality Probability	**Stand Predictors:** Zone+BA+ΔBA+QMD+BA.BF+BA.IH **Tree Predictor:** DBH *Weiskittel et al. 2012 – CFRU 2012 Annual Report*	**Predictors:** Zone+DBH+BA+QMD+BAL+Management *Hennigar 2016 (NB-ERD) - unpublished. Model equations and predictors vary by species depending on variable significance.*

Zone: NB, NS, Maine, PEI; **BGI** - biomass growth index; **BA** – stand basal area ; **CCF -** crown competition factor **QMD** – stand quadratic mean diameter; **BAL** – basal area of larger trees; **Management:** is plantation or PCT stand? – yes/no; **CR –** crown ratio; **CSI –** climate site index; **pBAL.SW** - % BAL in softwoods; **RD** – stand relative density; **HT –** tree height; **BA.BF** - BA of balsam fir; **BA.IH** - BA of intolerant hardwoods

Calibration: Species Tree-level Predictions

	FVS-ACD	OSM-ACD
Crown width	**Predictors:** DBH *Russell and Weiskittel 2011. North J. Appl. For. 28*	Same as FVS-ACD
Height to Crown	**Predictors:** DBH+Height+DH+CCF+BAL *Rijal et al. 2012a. For. Chron. 88*	Same as FVS-ACD
Crown recession	**Predictors:** ShadeTolerance+Height+CR+HTI+CCF *Russell et al. 2014. Eur J. For. Res. 133*	Same as FVS-ACD
Taper, bark thickness, & volume	**Taper predictors:** DBH + Height **Bark predictors:** diameter **Volume**: Smalian's or numerical integration *Li & Weiskittel 2010a. For. Sci. 67* *Li & Weiskittel 2011. E. J. For. Res. 130* *Weiskittel & Li 2011. CFRU 2011 Annual Report* *Li et al. 2012. North J. App. For. 29*	**Predictors:** DBH + Height *Honer et al. 1983. Rep. M-X-140* NB users typically use *Li and Weiskittel taper & bark equations (shown left)* via the FORUS Slasher program, as was done here for these presentation results.

DH - DBH/height ratio; **CCF** – stand crown competition factor; **BAL** – basal area of larger trees; **CR** - crown ratio; **HTI** – height increment

Calibration: Snag Fall and Decay Predictions

	FVS-ACD	OSM-ACD
Snag fall & decay	Not coded into FVS-ACD at present *Russell and Weiskittel 2012. For. Ecol. Manage. 284*.	Snag fall probability model ported from STAMAN (NB-DNR 2004) by Hennigar - *unpublished*
Snag initialization	None developed	Stochastically imputed as a function of DBH, stand structure & management based on NB timber cruise snag abundance observations. *Hennigar et al. 2016 NB ERD – unpublished*

Calibration: Stand-level Predictions

	FVS-ACD	OSM-ACD
Ingrowth - Probability - Abundance - Composition	**Predictors:** BA.Species+HWBAR+TPH+QMD+CSI Li et al. 2011. CJFR 41.	Same as FVS-ACD, but with a number of unpublished adjustments by Hennigar in 2013 to improve behaviour in the context of harvest, current overstory species composition, and management type.
Self-Thinning Mortality	Same as OSM-ACD with additional modifiers	Predicts and limits maximum stocking **Predictors:** stand BA weighted species specific-gravity. *Hennigar 2013 (NB DNR - unpublished), following methods from Chris Woodall et al. 2005, For. Ecol. Manage. 216. Based on NB stand timber cruise surveys with > 3 plots / stand. Some manual stocking limit adjustments for red pine and poor productivity sites. Default A-line set to 85% of maximum relative density.*

BA.Species – stand basal area by species; **HWBAR** – stand hardwood basal area ratio; **TPH** – stand trees/ha;

QMD – quadratic mean diameter; **CSI** – Climate Site Index

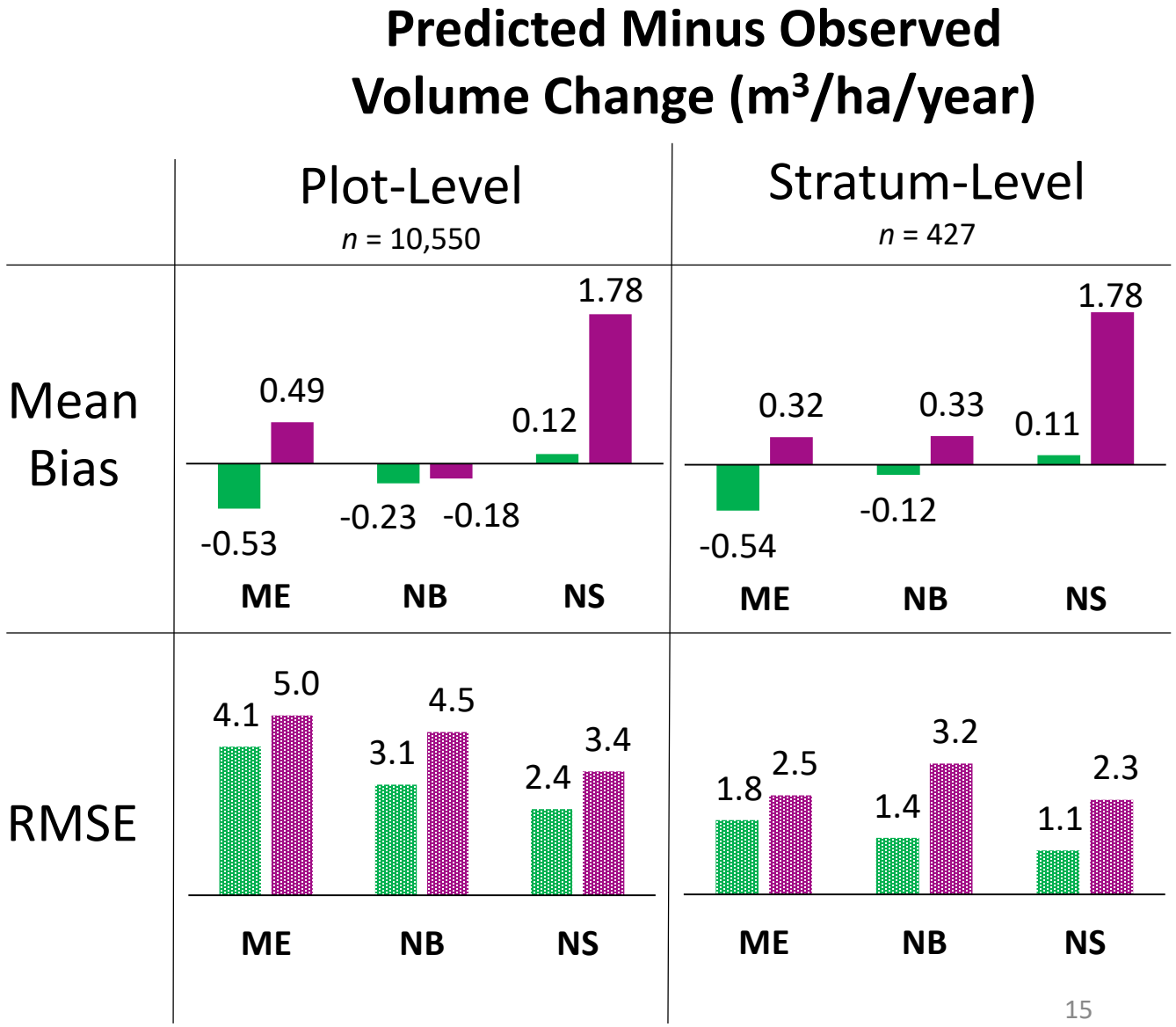
Accuracy Test

- Mean Bias & RMSE of predicted minus observed average merchantable volume change (m^3/ha/year) from plot establishment to last measurement
  - If a plot was treated, then growth before and after treatment was evaluated separately.
  - Removed plots with >10% of trees having obvious & uncorrectable errors

- Stand Types Evaluated (454)
  - **Jurisdictions:** Maine (ME); Nova Scotia (NS); New Brunswick (NB)
  - **Species Composition Class** (40) + '**Poor Site**' designation (e.g., very poor drainage, high elevation, barren)
  - **Management type:** none (no recent harvest); partial-cut; clearcut; PCT; planted; and commercial thinned
  - **Plot initial volume class:** <50, 50-99, 100-149, 150-300, and >300 m^3/ha

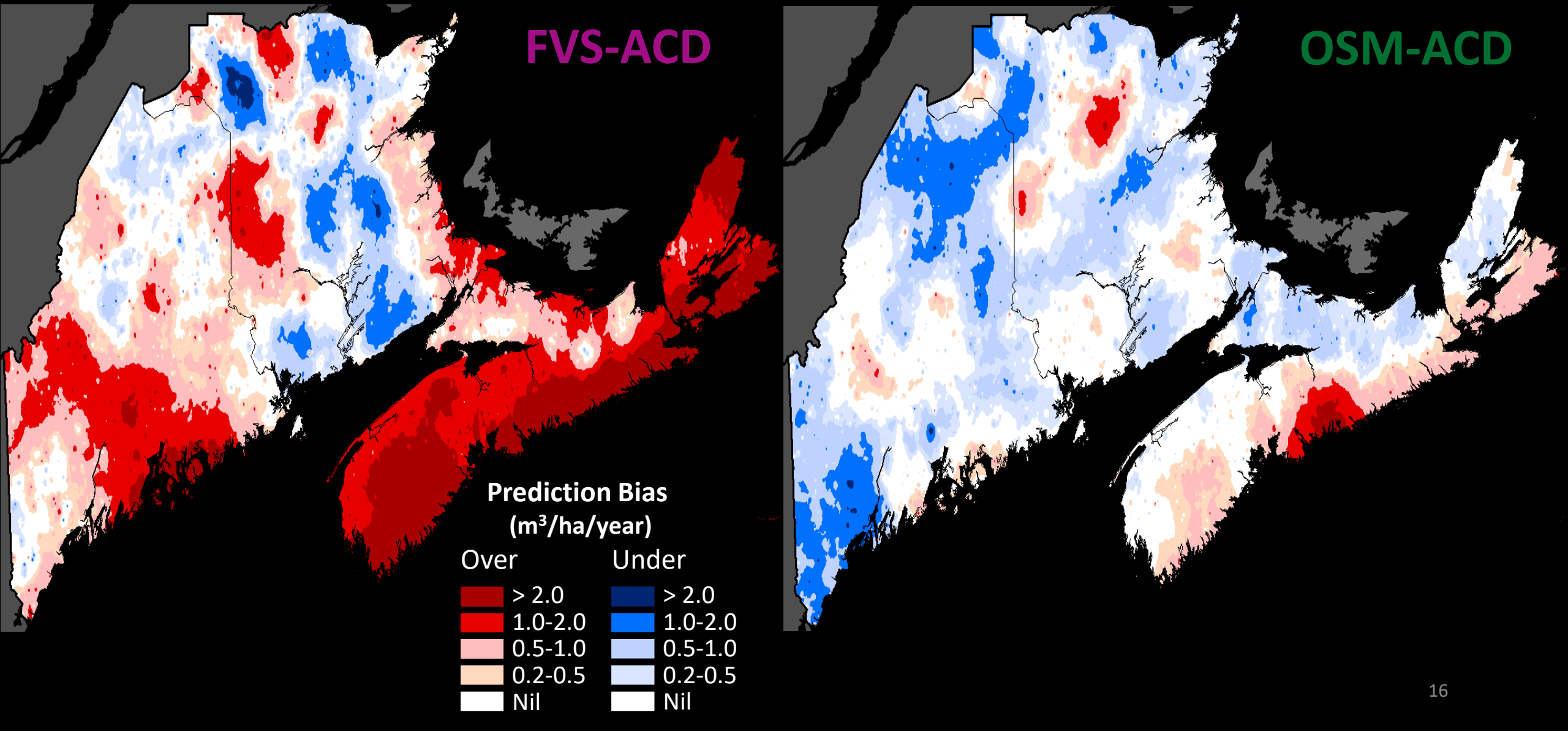
Regional Accuracy

- FVS-ACD generally under predicted both mortality and ingrowth, with low mortality leading to higher than observed volume increment in NS.
- OSM-ACD under predicted volume accrual in Maine, but was relatively unbiased in NB and NS overall.
- OSM-ACD RMSE was 20-60% lower than FVS-ACD across jurisdictions.



Spatially Interpolated Plot Volume Increment Bias

Inverse distance weighted with a minimum 100 plot inclusion threshold (total plots = 10,500)



FVS - Worst Cases

- Severely under-predicted young (5 to 15 year old) planted and PCT softwood in NB

Stand (Plot) Type					Mean Bias (m^3/ha/yr)	
Zone	Recent Treatment	Species Composition	Initial m^3/ha	Plots	OSM	FVS
Most severely UNDER predicted stand-types by FVS-ACD						
ME	PCT	BFIR	100-150	29	-4.5	-6.8
NB	Plant	JPSW	<50	97	-1.4	-5.0
NB	Plant	BFIR	<50	39	-1.5	-4.8
NB	PCT	BFIR	<50	110	-0.6	-4.2
NB	PCT	SPBF	<50	27	0.1	-4.1
NB	Plant	BSPR	<50	174	-0.4	-4.1
NB	PCT	BSPR	<50	28	1.0	-3.0

Ranking limited to stand types with > 25 plots

FVS - Worst Cases

- Severely under-predicted young (5 to 15 year old) planted and PCT softwood in NB
- Severely over-predicted mature-old softwood; especially mature-old spruce-fir stands
- OSM-ACD bias was relatively minor compared to FVS-ACD in most of these cases

Stand (Plot) Type					Mean Bias (m^3/ha/yr)	
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NB	Plant	BSPR	<50	174	-0.4	-4.1
NB	PCT	BSPR	<50	28	1.0	-3.0
Most severely OVER predicted stand-types by FVS-ACD						
ME	-	Tolerant SWD	>300	42	-3.5	7.1
NB	-	Fir	151-300	70	2.4	7.0
ME	-	Red Spruce	151-300	57	1.7	6.6
NS	-	Spruce-Fir	100-150	30	0.9	4.9
ME	-	Red Sp. MWD	151-300	26	0.8	4.3
NB	-	Red Spruce	151-300	47	0.8	4.3
ME	-	White Pine	>300	35	-4.9	4.3
ME	-	Spruce-Fir	151-300	33	-0.4	4.0

Ranking limited to stand types with > 25 plots

OSM - Worst Cases

- Severe under-prediction in some clearcut and softwood conditions, but stand type trend not clear
- Moderate over-prediction in mature-old spruce-fir in NB and Maine; and in young-immature spruce in NS
- FVS-ACD absolute bias was higher for most of the worst OSM-ACD cases.

Stand (Plot) Type					Mean Bias (m^3/ha/yr)	
Zone	Recent Treatment	Species Composition	Initial m^3/ha	Plots	OSM	FVS
Most severely UNDER predicted stand-types by OSM-ACD						
ME	-	White Pine	>300	35	-4.9	4.3
ME	PCT	Fir	100-150	29	-4.5	-6.8
ME	-	Tolerant SWD	>300	42	-3.5	7.1
NB	Clearcut	Fir	<50	49	-2.5	-2.9
ME	-	Spruce-Fir	<50	32	-2.1	-1.3
ME	-	Spruce-Fir HWD	<50	52	-2.1	-1.8
NB	Clearcut	Poplar	<50	29	-2.1	0.4
Most severely OVER predicted stand-types by OSM-ACD						
NB	-	Fir	151-300	70	2.4	7.0
NB	-	Black Spruce	151-300	31	2.1	2.9
ME	-	Red Spruce	151-300	57	1.7	6.6
NS	-	Red Spruce	<50	32	1.6	3.1
NS	-	Red Spruce	50-100	28	1.5	3.8
NS	-	Spruce	<50	63	1.4	2.9
ME	-	Intolerant HWD	100-150	42	1.3	2.5
NB	-	Fir-Spruce	151-300	27	1.1	3.8

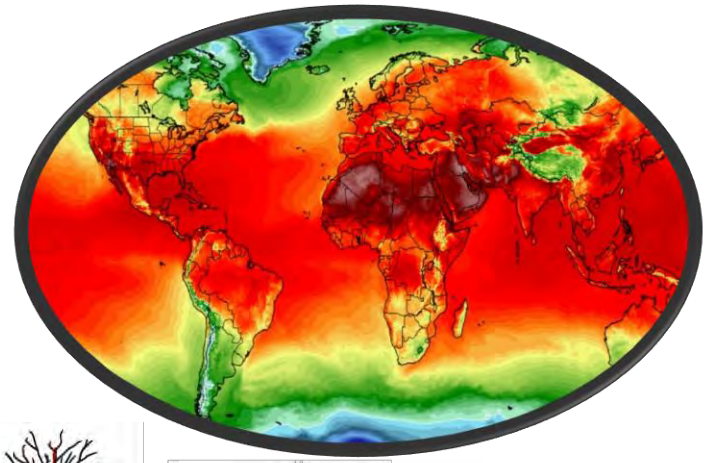
Ranking limited to stand types with > 25 plots

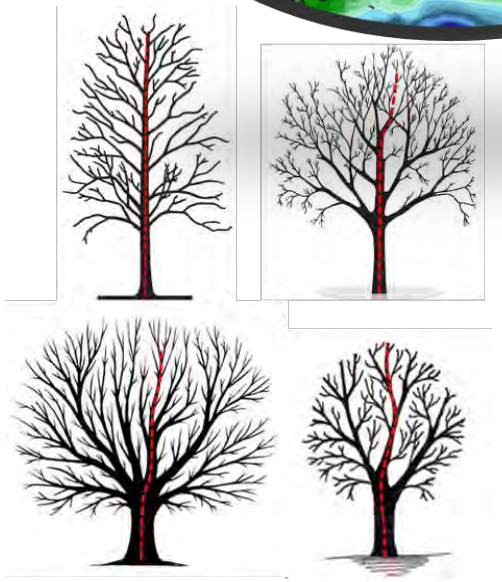
Priority TO-DOs

- Adjustment of FVS-ACD equations is underway
  - Integrating explicit modifiers for management type and leveraging more managed data will be key.
  - Mortality of large trees was under-estimated, but there may be simple solutions for this.
  - Ingrowth occurs too infrequently, but again, there are quick fixes for this.
  - Replacing CSI with BGI would help, but we probably need to look beyond BGI.
- For both models, volume increment was too high in areas that have growth and stocking limitations; e.g., Atlantic coastal, high elevation, poorly drained sites
  - Advancement in site productivity mapping is still needed (improved soil mapping; LiDAR topography).
  - Probably wise to consider stand-alone calibrations for extreme eco-regions and eco-sites in future work.
  - In OSM-ACD, there is a 'Poor-Site' modifier that reduces growth and stocking, but this is a hack. Explicit stratification of extremely poor or distinct sites before model calibration would be a better approach.

Current Research

- Developing time-dependent climate-change modifiers for growth, survival, and regeneration
  - Can. For. Service (CFS); UNB; NB-ERD collaborators
- Collecting hardwood tree data to improve taper and volume models for complex crowns
  - NB-ERD; North. Hardwood Res. Institute; CFS; U of Maine
- Exploring use of Sentinel satellite imagery to enhance Biomass Growth Index (BGI)
  - Cooperative Forest Research Unit; U of Maine; FORUS Research





Thanks

- **OSM-ACD** (Version 1.18.5.1)
  - http://www.forusresearch.com/downloads/osm/index.html
  - Username: **OSM** Password: **GetIt!**
- **FVS-ACD** (Version 10.6)
  - FVS-Online: https://forest.moscowfsl.wsu.edu/FVSOnline/
  - Email Aaron.Weiskittel@maine.edu for most recent R version
- **Collaborators, Funding, Data Providers, Users**
  - John Kershaw, UNB
  - Sean Lamb, FORUS Research
  - Coop. Forest Res. Unit, U of Maine
  - NB, PEI, and NS Forestry Departments
  - National Science Foundation, Center for Advanced Forestry Systems
  - Northern Hardwood Research Institute
  - Northeastern States Res. Cooperative
  - Forest Watershed Res. Center, UNB
  - US Forest Service, Agenda 2020
  - US Forest Service, FIA
  - Natural Resources Canada
  - JD Irving, Acadian Timber, Penobscot Research Forest, Bowater
  - **Many Grad Students!**
  - **Many Users!**

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