Development of regional height to diameter allometric equations for naturally-regenerated, mixed species, and multi-cohort forests of the Acadian Region

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Eastern CANUSA
Edmundston, NB
October 14-16, 2010

Outline

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- Growth and yield models
- Acadian Forest

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- Summary statistics
- Model comparisons (Mean bias, RMSE,Residuals)

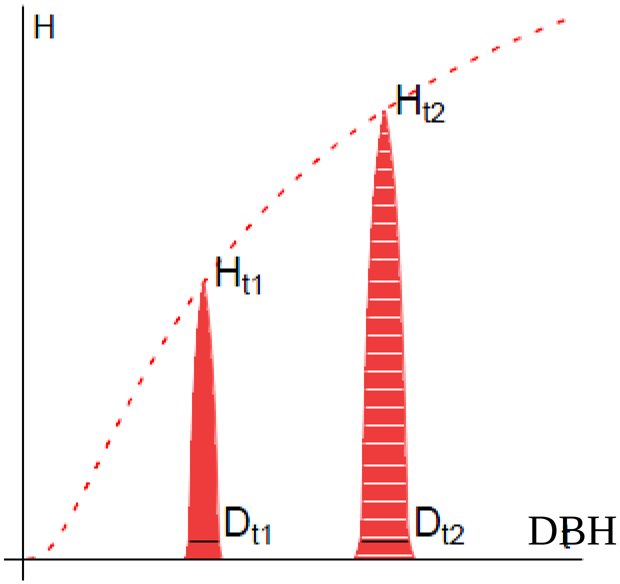
Conclusions

Introduction

Growth and Yield Models

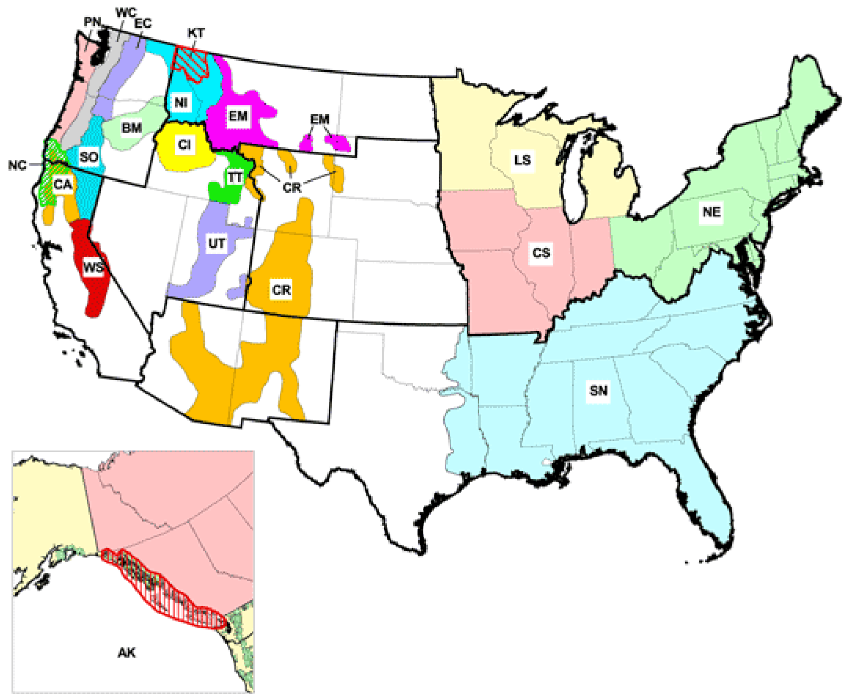
- Mathematical relations among the growth attributes (e.g. age, diameter, height, volume) use for predictions

- Allometric equations are a key component
  - Commonly use Diameter at Breast Height (DBH)

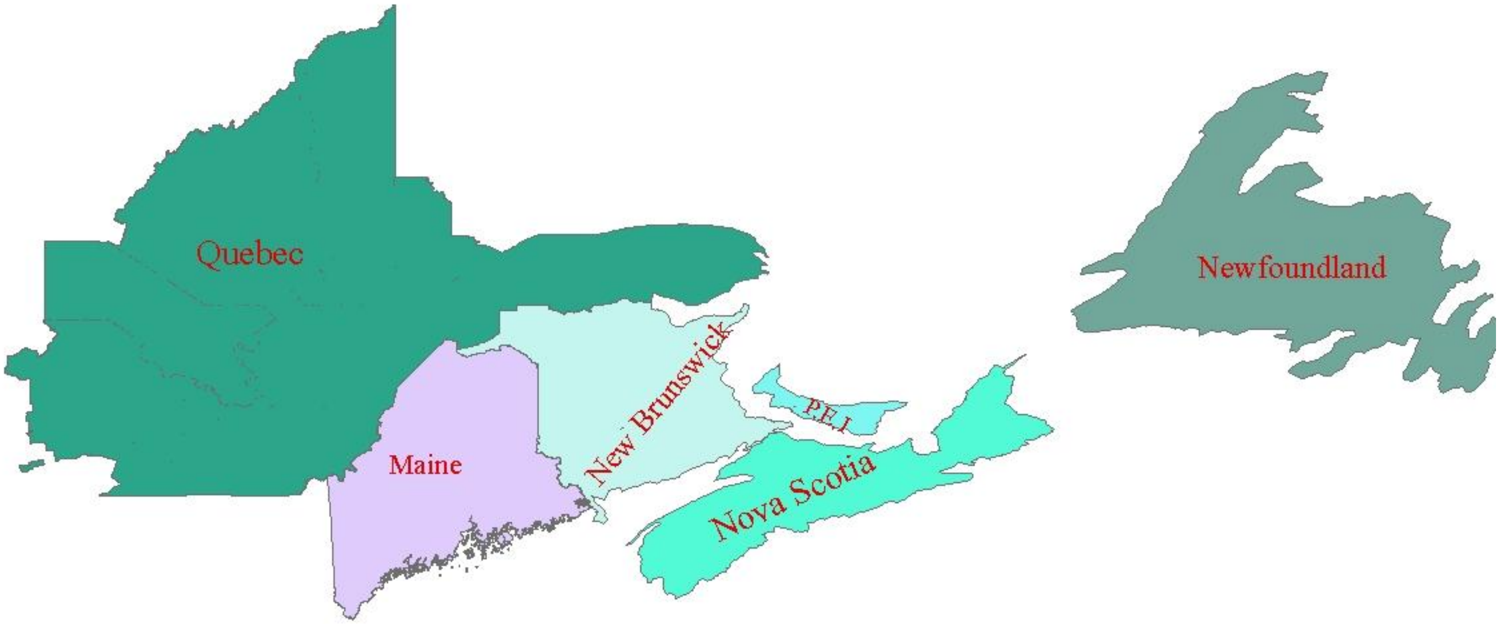


Growth and Yield Models

- More than 75 growth equations are well described (Kiviste 1988), for growth models
- Only a few are common in practice and there is not a universal function that would fit for all purposes,
- Forest Vegetation Simulator (FVS) is widely used forest growth model across US and many parts of Canada,
- FVS-NE variant is used in Acadian forest management



Acadian Forest



A transition zone between boreal conifer forest in north and hardwood of south,

Different forest types:

- Mixed conifer (e.g. Spruce-Fir),
- Mixed hardwoods (e.g. Aspen-Beech)
- Mixed Hardwood and Conifer (e.g. Oak-Pine)

Naturally regenerated,

All aged multiple species,

Long history of selection cutting

Forest Growth and Yield in Acadian Forest

- FVS is a model widely used in Northeast US
  - Wykoff and Curtis as well as Arney models to estimate missing tree heights,
  - Existing FVS model are giving bias in long-term predictions
- In addition, regional allometric equations specific to the Acadian Region are not available

Present study:

Diameter and Height Equations in Acadian Region

Objectives and Methods

Objective: restructure DBH-HT equation for better fits & predictive capacity of 15 commercially important tree species of Acadian Region,

Methods

– 30 different datasets of about 16,000 stands in the Acadian Region that includes data from Maine, New Brunswick, Nova Scotia, and Quebec

– Permanent research and inventory plots

Methods: Species

- 15 Species: Conifer (7) and Hardwood (8),
- Selected based on availability and abundance
- Sample covers 16,000 stands; 1.5 million individual tree

Code	Common name	Scienfic name
AB	American Beech	*Fagus grandifolia*
GB	Grey Birch	*Betula populifolia*
PB	Paper Birch	*Betula papyrifera*
QA	Quaking Aspen	*Populus tremuloides*
RM	Red Maple	*Acer rubrum*
RO	Northen Red Oak	*Quercus rubra*
SM	Sugar Maple	*Acer saccharum*
YB	Yellow Birch	*Betula alleghaniensis*
BF	Balsam Fir	*Abies balsamea*
BS	Black Spruce	*Picea mariana*
EH	Eastern Hemlock	*Tsuga canadensis*
RS	Red Spruce	*Picea rubens*
WC	White Cedar	*Thuja occidenstalis*
WP	White Pine	*Pinus strobus*
WS	White Spruce	*Picea glauca*

Methods: Model Form and Fitting

Base Model: Chapman-Richards

$$HT = 1.3 + a0 * (1 - e^{-b0*DBH})^{c0}$$

Where ,

- *HT* is Total height (m),
- *DBH* is Diameter at breast height (cm),
- *a0*, *b0* and *c0* are constants (model parameters),

added covariates:

stand level covariates to capture regional variation,

- Crown competition factor (CCF)
- Basal area larger than subject tree (BAL),

Methods: Model Form and Fitting

Mixed Effects Model with random effect in asymptote,

$$HT = 1.3 + (a0 + A0 + a1 * CCF + a2 * BAL) * (1 - e^{-b*DBH})^{c}$$

Where, *a0*, *b0* and *c0* are fixed parameters,
a1 and *a2* are fixed parameters associated with covariates CCF and BAL respectively,
A0 is random effect parameters set for asymptotic parameters

Design and Model Fitting

Three level hierarchical design: Source (dataset), Stand, and Year

General nonlinear least square (GNLS) with varying variance function,

Non-linear mixed effects (NLME)

Methods: Model Comparisons

Model comparison tools

Bias

Observed HT - Fitted HT

Model Fit

$$R^2 = 1 - \frac{SSE/df_{SSE}}{SST/df_{SST}}$$

Model Predictive capacity (Bootstrap)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{i=n}(H_i - \widehat{H_i})^2}{n}}$$

Summary Statistics of Diameter at Breast Height and Total Height

Species	No. of Source	No. of Stand	Total Obs.	DBH (cm)			
				Min	Mean	Max	SD
Hardwood							
AB	23	3388	25581	6.1	17.8	43.8	6.8
GB	18	1444	7774	2.9	14.4	38.2	6.4
PB	33	8808	82787	0.7	14.3	39.3	7.5
QA	19	2415	8625	0.5	17.6	44.2	7.9
RM	30	11760	144322	3.5	16.4	42.2	6.5
RO	13	1297	7501	9.2	18.6	46.5	7.1
SM	23	4439	62616	4.1	17.0	46.7	7.1
YB	30	6194	35961	3.4	17.7	47.8	7.7
Conifer							
BF	33	16078	497162	0.7	12.9	36.3	6.8
BS	26	3889	212852	0.7	10.8	32.3	6.3
EH	24	3074	19802	4.1	19.4	49.3	7.6
RS	26	9999	200143	3.3	16.7	41.3	6.7
WC	20	4176	33521	5.1	19.8	45.3	7.0
WP	24	3768	23502	4.2	19.3	55.9	8.8
WS	31	4683	69891	2.1	15.9	39.9	6.8

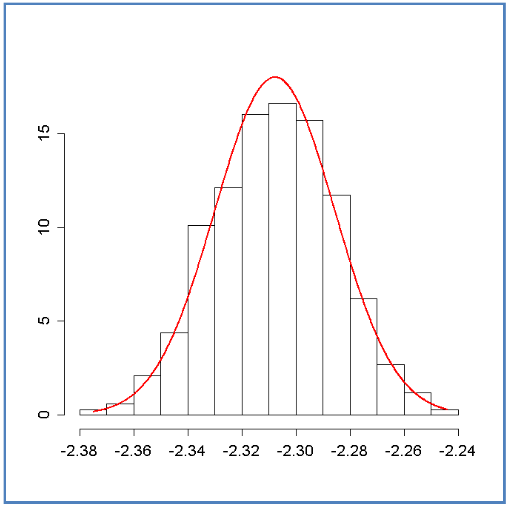
Results

Conifers

(*red are significant at 5%, CI in parenthesis*)

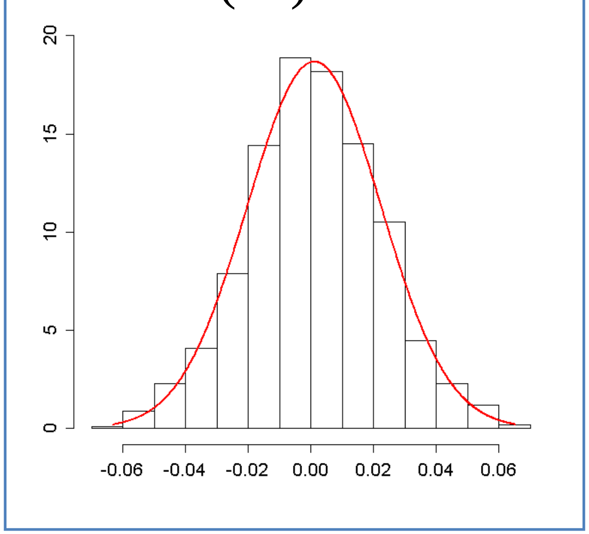
Species	FVS	FVS-Refitted	Chapman-Richards
BF	-1.394 (-1.4--1.39)	0.0605 (0.05-0.07)	0.0001 (0.00-0.01)
BS	-1.376 (-1.38--1.37)	0.0871 (0.08-0.09)	0.001 (-0.04-0.04)
EH	-2.308 (-2.35--2.26)	0.0096 (-0.3-0.06)	0.0011 (-0.04-0.04)
RS	-1.582 (-1.59--1.57)	0.018 (0.01-0.03)	0.0001 (-0.01-0.01)
WC	-2.982 (-3.01--2.98)	0.003 (-0.03-0.03)	0.0001 (-0.03-0.03)
WP	-2.883 (-2.92--2.84)	0.0187 (-0.02-0.06)	-0.001 (-0.04-0.04)
WS	-1.959 (-1.98--1.94)	0.0228 (0.01-0.04)	0.001 (-0.02-0.02)

FVS Bias (m.) – Eastern Hemlock



Significant negative bias

CR Bias (m.) – Eastern Hemlock



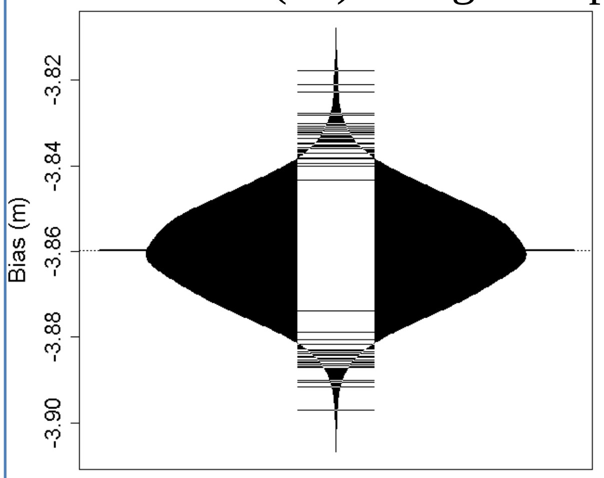
Improvement in bias

Hardwoods

(*red are significant at 5%, CI in parenthesis*)

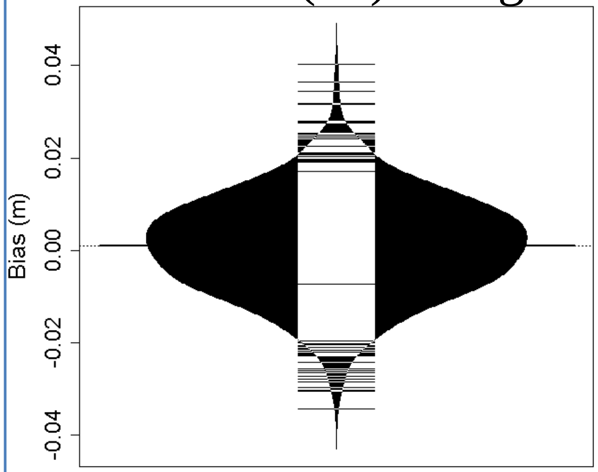
Species	FVS	FVS-Refitted	Chapman-Richards
AB	-2.976 (-3.01--2.94)	0.0036 (-0.03-0.04)	0.0018 (-0.03-0.04)
GB	-0.986 (-1.06--0.99)	0.0359 (-0.03-0.1)	0 (0.06--0.06)
PB	-3.124 (-3.14-3.11)	0.0818 (0.06-0.10)	0.0041 (-0.01-0.02)
QA	-2.756 (-2.83--2.69)	0.0655 (0.01-0.13)	-2.00E-04 (-0.06-0.06)
RM	-2.959 (-2.98--2.94)	0.0219 (0.01-0.04)	0.0024 (-0.01-0.01)
RO	-3.946 (-4.01--3.78)	-0.0016 (-0.07-0.07)	-3.00E-04 (-0.02-0.02)
SM	-3.860 (-3.88--3.86)	0.0173 (-0.01-0.04)	0.001 (-0.02-0.02)
YB	-4.017 (-4.05--3.99)	0.0273 (-0.00-0.06)	0.001 (-0.03-0.03)

FVS Bias (m.) – Sugar Maple



Significant negative bias

CR Bias (m.) – Sugar Maple



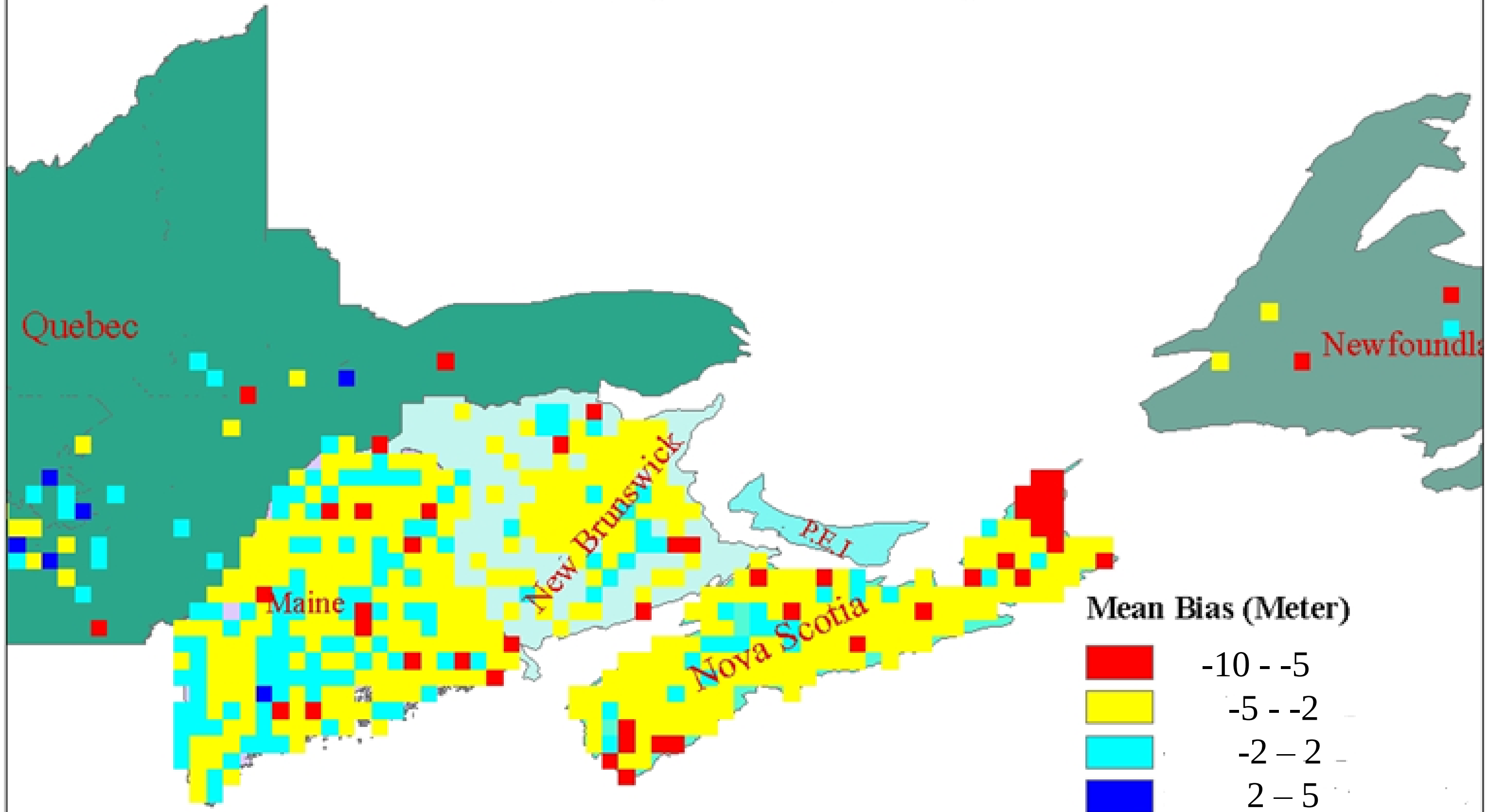
Improvement in bias

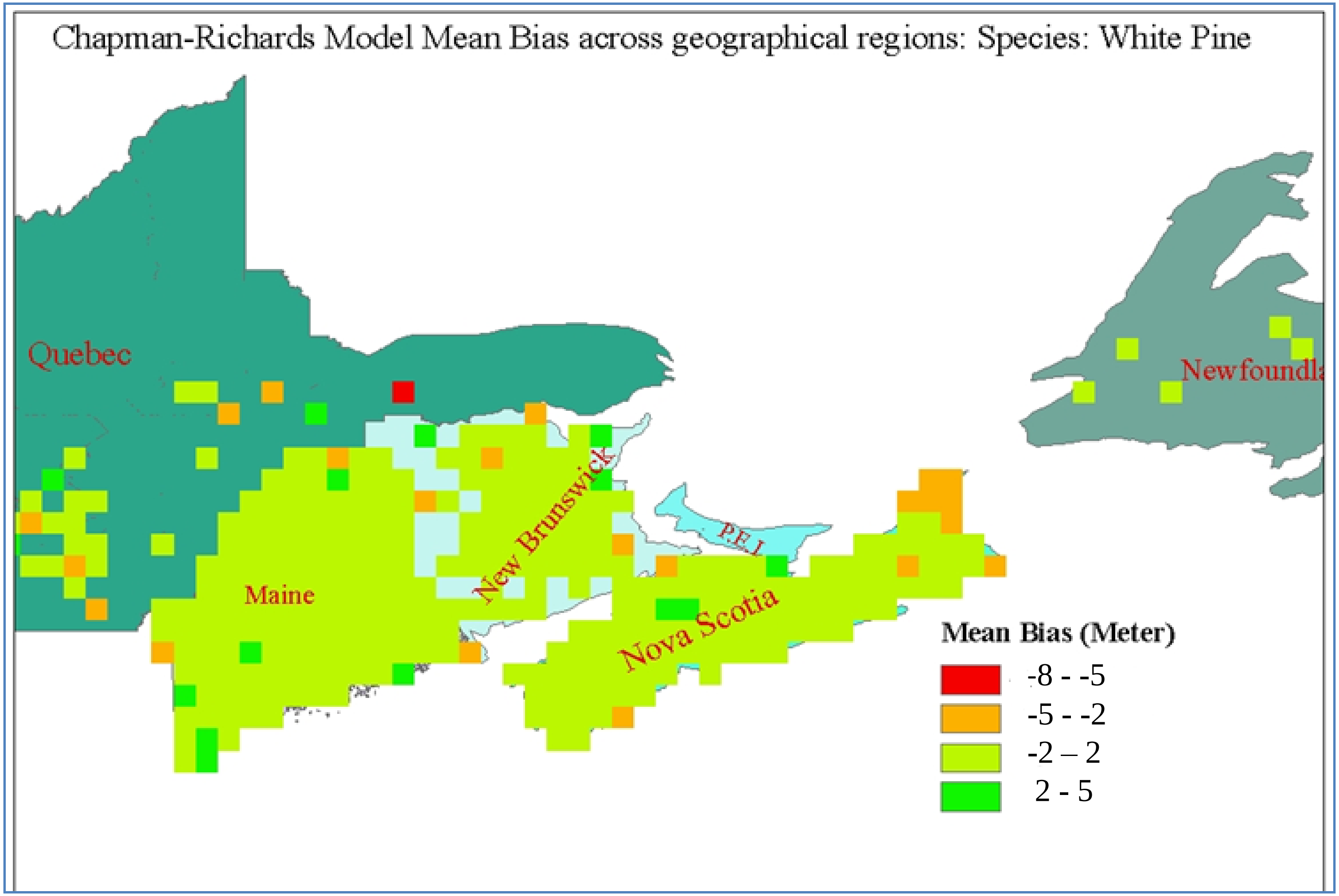
Results

R square produced by two competing models

Species	FVS-Refitted	Chapman-Richards
AB	0.343	0.356
GB	0.388	0.445
PB	0.633	0.672
QA	0.589	0.603
RM	0.39	0.452
RO	0.404	0.449
SM	0.42	0.467
YB	0.449	0.485
BF	0.743	0.771
BS	0.824	0.853
EH	0.404	0.433
RS	0.555	0.597
WC	0.3	0.34
WP	0.526	0.55
WS	0.634	0.679

FVS Mean Bias across geographical regions: Species White Pine



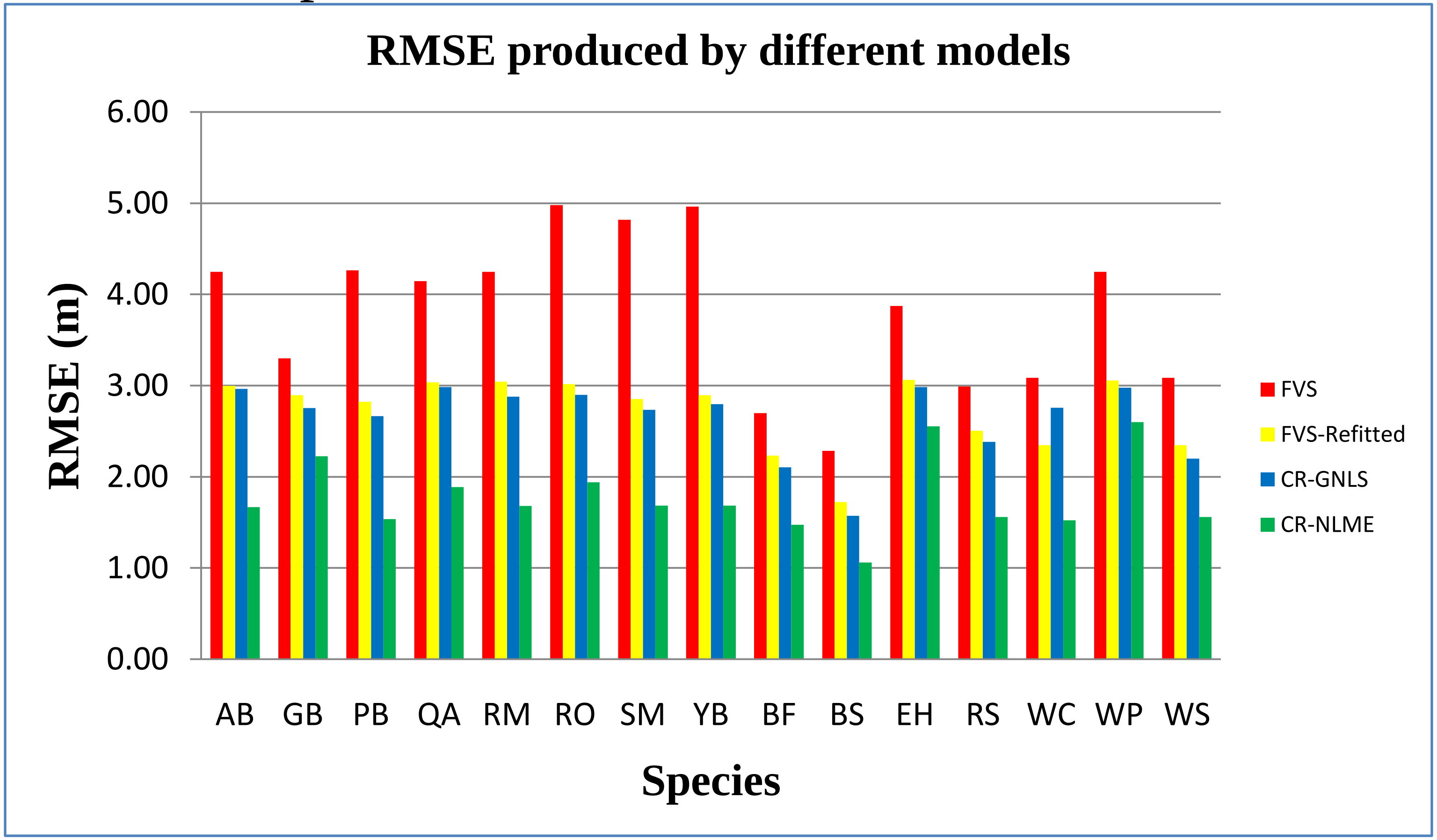


Mean FVS : -2.883m. (significant at 5% credible interval)

Mean CR Bias: 0.001 (not significant at 5% Credible interval)

Result

Model Comparison: RMSE

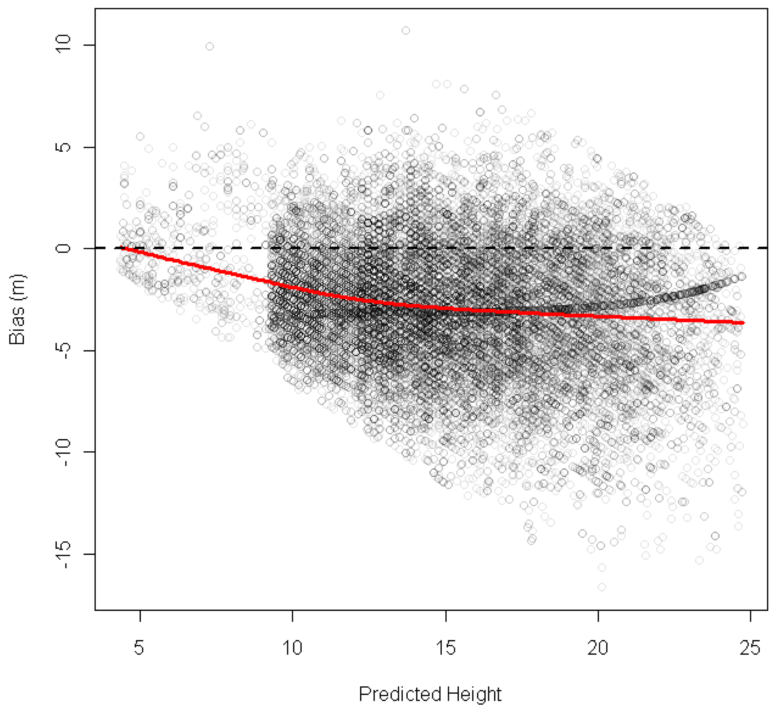


RMSE improved by GNLS- 16%- 43%, and NLME 33%-67%

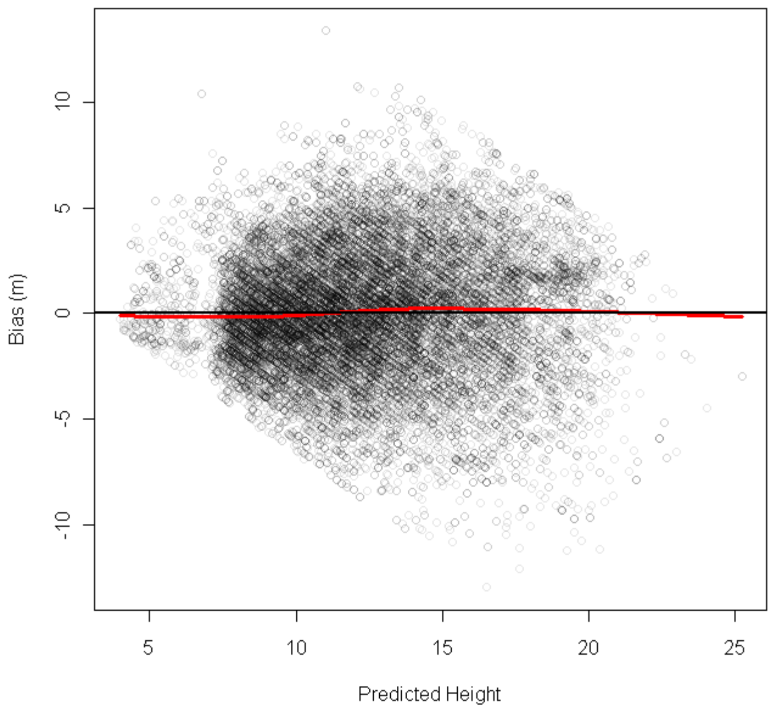
Result

Model Comparison: Residuals

FVS Model - White pine



CR Model- White pine



As predicted height increases, bias increases

Conclusions

- FVS models were significantly biased in the Acadian Region.
- Chapman-Richards model form was superior
  - Non significant (improved in) bias across the predicted height, and geographic region,
  - Covariates useful for localizing predictions
  - Mixed effects improved predictions, even when fixed effect parameter estimates were used
- Future work will focus on the applicability of these equations to thinned stands and the development of regional height to crown base equations

Thank You