Evaluating stem taper and bark thickness equations for the major conifer species in the Acadian Region of North America

ECANUSA
October 2010

Rongxia Li
Aaron Weiskittel
University of Maine

Introduction

- **Taper models can be used to predict merchantable and total individual tree volume**

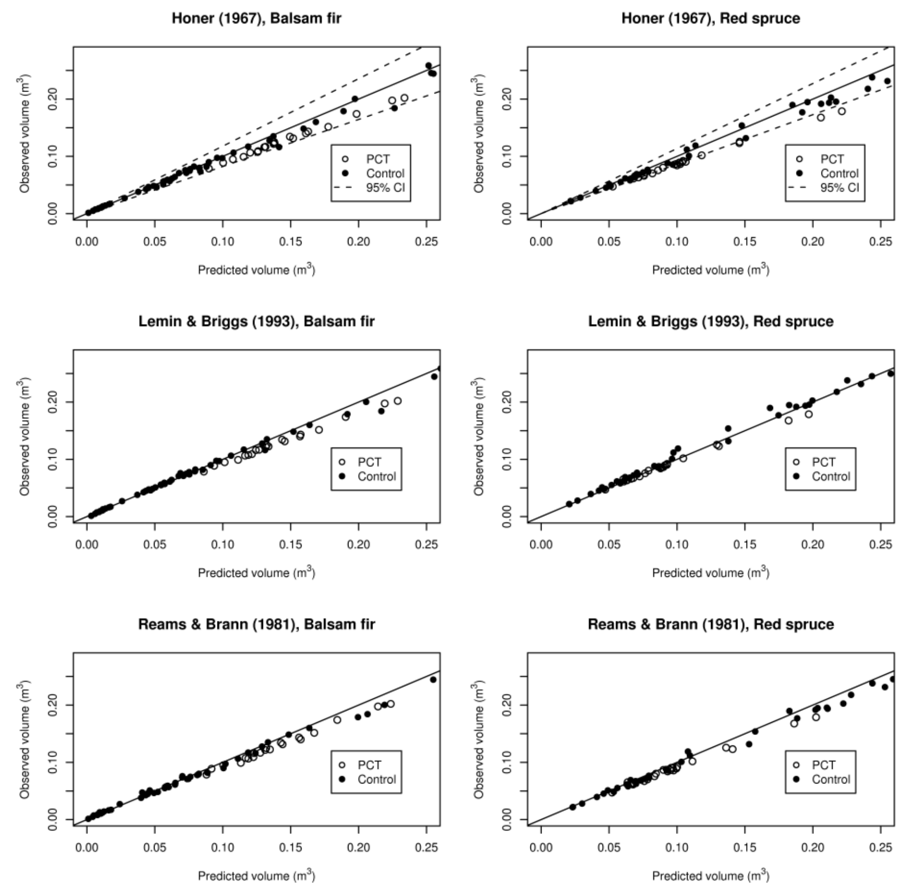
- **The amount of tree bark can range from 12 to 20% of the total wood volume (Heath et al. 2009) depending on species**

- **Diameter inside bark can be estimated through bark thickness equations given diameter outside bark**

Introduction

- A widely used taper equation does not exist for most species in the region

- Evidence that the widely used Honer (1963) volume equation may be biased



Objectives

- Evaluate ten widely used stem taper profile models for predicting both dib and total stem volume

- Assess the level of improvement across a range of species in dib and stem volume predictions with the incorporation of additional crown variables

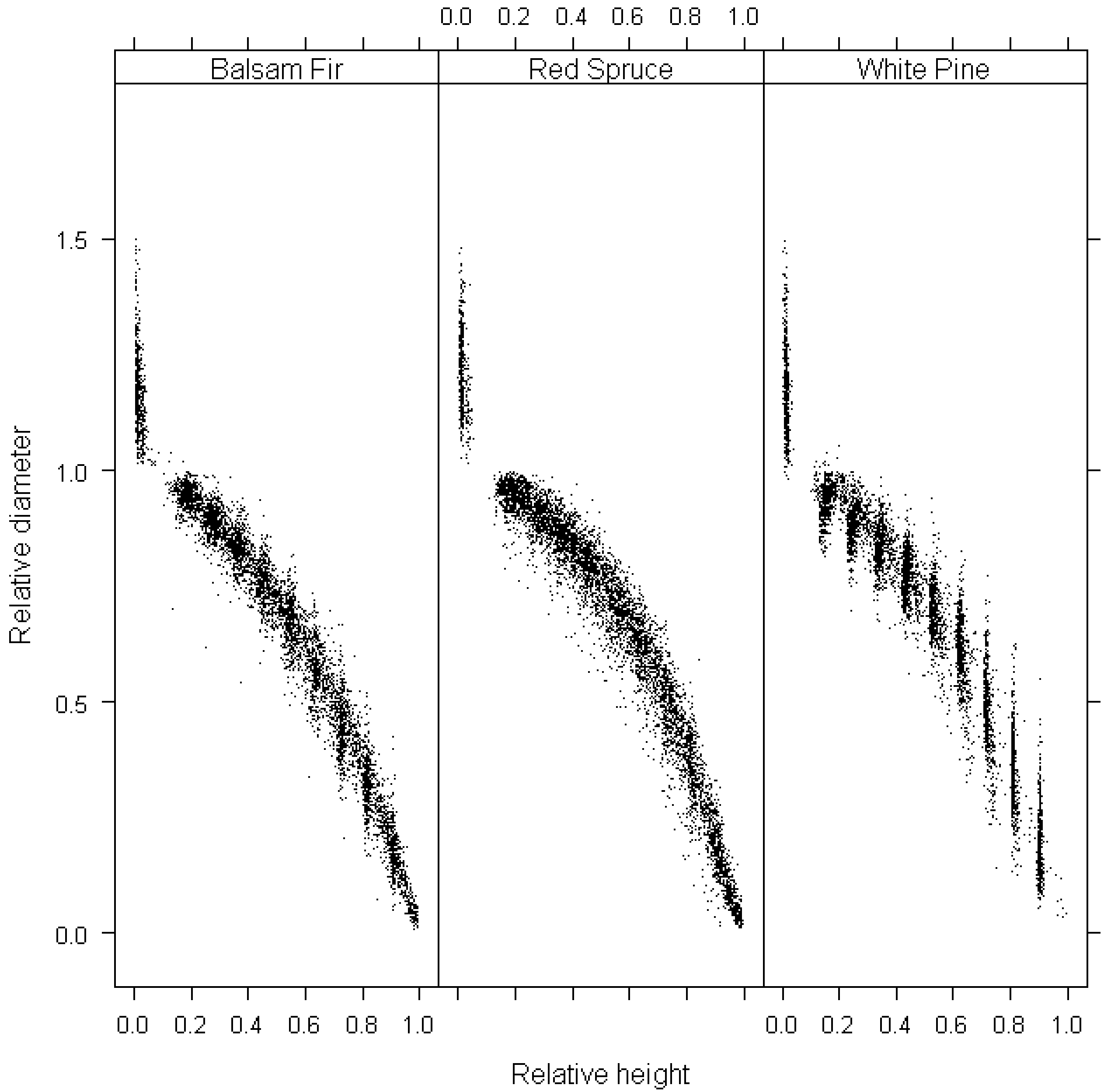
- Compare several commonly-used bark thickness equations for estimating dib given dob

- Investigate and identify prior measurements which can best predict dibs on a new dataset for each species

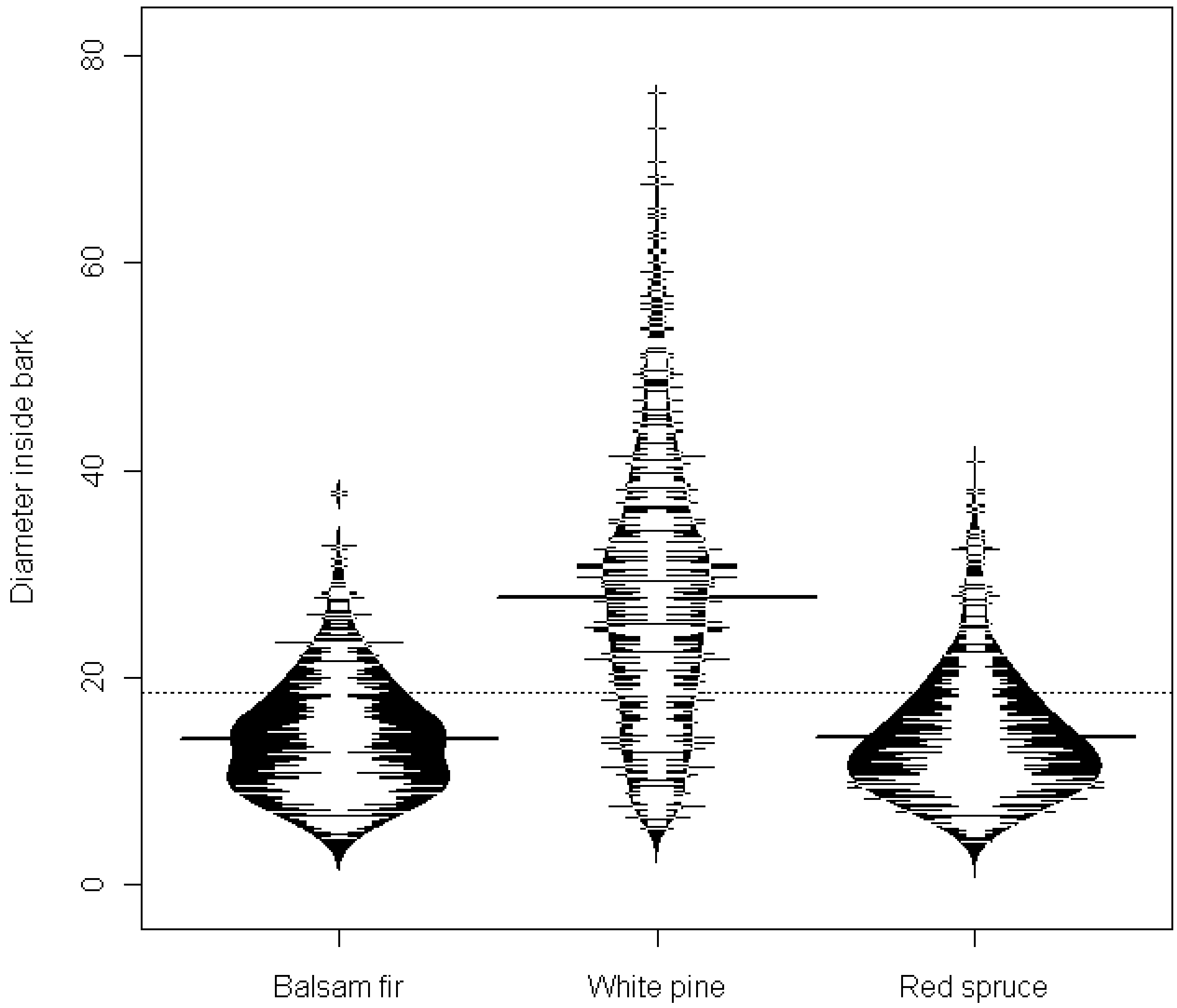
Data

- Three species: balsam fir, red spruce, and white pine
- Came from a variety of sources in the Acadian region, primarily from Honer (1963) study gathered from New Brunswick and Ontario
- 990 balsam fir trees
- 1086 red spruce trees
- 949 white pine trees

Part I: Taper Models



Part I: Taper Models



Taper Equations

- Segmented polynomial Max & Burkhart (1967)
- Variable exponent Kozak (2004) Model 01
- Variable exponent Kozak (2004) Model 02
- Variable form Bi (2000)
- Variable form Zakrzewski (1999)
- Variable form Valentine & Gregoire (2001)
- Variable exponent Sharma & Zhang (2004)
- Variable exponent Sharma & Parton (2009)
- Segmented Clark et al. (1991)
- Segmented Fang & Bailey (2000)

Honer Equation (1963)

- Volume predictions compared to the regional standard

$$V = \frac{D^2}{\alpha + \beta / H}$$

$\alpha = 2.139$ $\beta = 301.634$ for balsam fir.

$\alpha = 1.226$ $\beta = 315.832$ for red spruce.

$\alpha = 2.139$ $\beta = 301.634$ for white pine.

Model fitting process

- Nonlinear mixed effects model with random effects for each tree
- Included a variance power function and a continuous first-order autoregressive error structure
- All models were fitted using R nlme library

Evaluation Criteria

- Mean absolute bias

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

- Root mean square error

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n}}$$

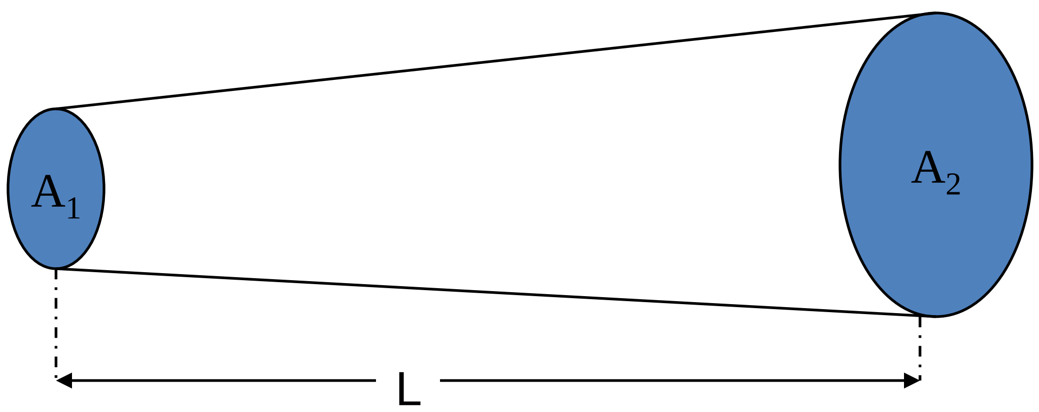
- Bias Percentage

$$PB = 100\frac{\sum_{i=1}^{n}\left|Y_i - \hat{Y}_i\right|}{\sum_{i=1}^{n} Y_i}$$

Volume estimation

- Smalian's

$$V = \frac{A_1 + A_2}{L}$$



Diameter bias summary

Model	Balsam fir			Red spruce			White pine		
	AMB (cm)	RMSE	% bias	AMB (cm)	RMSE	% bias	AMB (cm)	RMSE	% bias
Max & Burkhart (1976)	0.532	0.801	5.189	0.592	0.929	5.551	1.365	1.922	6.742
Kozak_01 (2004)	0.688	0.960	6.714	0.870	1.205	8.160	1.679	2.226	8.296
Kozak_02 (2004)	0.504	0.762	4.918	0.538	0.818	5.039	1.156	1.655	5.713
Bi (2000)	0.495	0.759	4.832	0.538	0.825	5.047	1.194	1.721	5.897
Zakrzewski (1999)	0.510	0.771	4.979	0.622	0.936	5.831	1.297	1.917	6.410
Valentine & Gregoire (2001)	0.480	0.744	4.683	0.572	0.858	5.367	1.280	1.811	6.323
Sharma & Zhang (2004)	0.540	0.812	5.270	0.629	0.965	5.898	1.320	1.829	6.519
Sharma & Parton (2009)	0.544	0.850	5.304	0.624	1.012	5.854	1.334	1.886	6.591
Clark et al. (1991) I	0.523	0.751	5.100	0.581	0.852	5.445	1.420	2.043	7.018
Clark et al. (1991) II	0.642	0.873	6.260	0.722	0.993	6.765	1.617	2.211	7.991
Fang & Bailey (2000)	0.552	0.813	5.385	0.618	0.928	5.791	1.345	1.862	6.647
geometric mean	0.474	0.720	4.626	0.527	0.807	4.939	1.147	1.631	5.666

Volume bias summary

Model	Balsam fir			Red spruce			White pine		
	AMB (cm)	RMSE	% bias	AMB (cm)	RMSE	% bias	AMB (cm)	RMSE	% bias
Max & Burkhart (1976)	0.011	0.024	8.157	0.012	0.027	7.940	0.095	0.209	10.902
Kozak_01 (2004)	0.010	0.019	7.384	0.010	0.018	6.752	0.062	0.104	7.154
Kozak_02 (2004)	0.009	0.017	6.673	0.009	0.016	5.955	0.057	0.100	6.580
Bi (2000)	0.009	0.017	6.643	0.009	0.017	6.312	0.056	0.100	6.386
Zakrzewski (1999)	0.009	0.017	6.733	0.010	0.018	6.888	0.056	0.100	6.384
Valentine & Gregoire (2001)	0.009	0.016	6.306	0.009	0.018	6.312	0.065	0.125	7.440
Sharma & Zhang (2004)	0.010	0.020	7.670	0.011	0.023	7.507	0.072	0.146	8.287
Sharma & Parton (2009)	0.011	0.024	7.990	0.012	0.028	8.142	0.087	0.190	10.028
Clark et al. (1991) I	0.008	0.015	6.060	0.007	0.013	4.789	0.054	0.102	6.186
Clark et al. (1991) II	0.011	0.020	7.771	0.011	0.022	7.550	0.075	0.152	8.572
Fang & Bailey (2000)	0.009	0.017	6.767	0.009	0.016	6.029	0.058	0.096	6.616
Honer equation (1967)	0.010	0.018	7.337	0.011	0.023	7.590	0.085	0.167	9.800
geometric mean	0.007	0.014	5.101	0.008	0.016	5.417	0.050	0.085	5.697

Dib bias with crown variables

Model	Balsam fir			Red spruce			White pine		
	AMB (cm)	RMSE	% bias	AMB (cm)	RMSE	% bias	AMB (cm)	RMSE	% bias
Kozak_02 (2004) without Crown	0.504	0.762	4.918	0.538	0.818	5.039	1.156	1.655	5.713
Kozak_02 (2004) with CR	0.493	0.740	4.812	0.524	0.796	4.914	1.155	1.651	5.705
Kozak_02 (2004) with CL	0.498	0.748	4.859	0.527	0.799	4.939	1.157	1.653	5.716
Kozak_02 (2004) with HCB	0.497	0.746	4.844	0.532	0.807	4.984	1.154	1.653	5.699
Clark et al. (1991) I without Crown	0.523	0.751	5.100	0.581	0.852	5.445	1.420	2.043	7.018
Clark et al. (1991) I with CR	0.500	0.721	4.881	0.568	0.811	5.321	1.402	2.022	6.928
Clark et al. (1991) I with CL	0.504	0.725	4.918	0.568	0.813	5.323	1.459	2.095	7.206
Clark et al. (1991) I with HCB	0.518	0.743	5.051	0.595	0.845	5.580	1.534	2.178	7.580
Clark et al. (1991) II without crown	0.642	0.873	6.260	0.722	0.993	6.765	1.617	2.211	7.991
Clark et al. (1991) II with CR	0.629	0.860	6.136	0.706	0.968	6.619	1.620	2.215	8.005
Clark et al. (1991) II with CL	0.634	0.863	6.180	0.711	0.971	6.661	1.654	2.275	8.171
Clark et al. (1991) II with HCB	0.646	0.879	6.300	0.741	1.007	6.946	1.701	2.348	8.402
Fang et al. (2000) without crown	0.552	0.813	5.385	0.618	0.928	5.791	1.345	1.862	6.647
Fang et al. (2000) with CR	0.758	1.008	7.392	0.689	1.004	6.458	1.374	1.904	6.787
Fang et al. (2000) with CL	0.643	0.925	6.273	0.658	0.983	6.171	1.378	1.908	6.809
Fang et al. (2000) with HCB	0.992	1.284	9.681	0.780	1.093	7.313	1.325	1.835	6.544

Volume bias with crown variables

Model	Balsam fir			Red spruce			White pine		
	AMB (m^3)	RMSE	% bias	AMB (m^3)	RMSE	% bias	AMB (m^3)	RMSE	% bias
Kozak_02 (2004) without crown	0.0090	0.0171	6.6734	0.0087	0.0159	5.9555	0.0574	0.0996	6.5803
Kozak_02 (2004) with CR	0.0085	0.0156	6.2899	0.0086	0.0161	5.8985	0.0587	0.1014	6.7258
Kozak_02 (2004) with CL	0.0085	0.0156	6.3153	0.0086	0.0161	5.9332	0.0582	0.1008	6.6668
Kozak_02 (2004) with HCB	0.0087	0.0165	6.4656	0.0086	0.0163	5.9139	0.0583	0.1014	6.6838
Clark et al. (1991) I without Crown	0.0082	0.0147	6.0595	0.0070	0.0128	4.7888	0.0540	0.1025	6.1865
Clark et al. (1991) I with CR	0.0070	0.0131	5.1463	0.0065	0.0109	4.4702	0.0469	0.0924	5.3738
Clark et al. (1991) I with CL	0.0070	0.0129	5.1798	0.0068	0.0115	4.6791	0.0541	0.1015	6.2023
Clark et al. (1991) I with HCB	0.0078	0.0143	5.7969	0.0079	0.0130	5.4126	0.0641	0.1125	7.3535
Clark et al. (1991) II without crown	0.0105	0.0200	7.7710	0.0110	0.0220	7.5495	0.0748	0.1516	8.5723
Clark et al. (1991) II with CR	0.0098	0.0188	7.2301	0.0108	0.0198	7.4272	0.0731	0.1477	8.3773
Clark et al. (1991) II with CL	0.0098	0.0187	7.2870	0.0109	0.0195	7.4755	0.0781	0.1576	8.9493
Clark et al. (1991) II with HCB	0.0106	0.0201	7.8187	0.0119	0.0215	8.2216	0.0856	0.1696	9.8180
Fang et al. (2000) without crown	0.0091	0.0169	6.7673	0.0088	0.0158	6.0287	0.0577	0.0964	6.6159
Fang et al. (2000) with CR	0.0086	0.0153	6.3329	0.0086	0.0154	5.8940	0.0576	0.0963	6.6065
Fang et al. (2000) with CL	0.0084	0.0151	6.1996	0.0085	0.0154	5.8388	0.0577	0.0963	6.6145
Fang et al. (2000) with HCB	0.0086	0.0153	6.3526	0.0086	0.0155	5.9427	0.0576	0.0963	6.6057

Part II Bark thickness equations

Data

- 708 black spruce, 235 red spruce, 438 white spruce, 736 jack pine, 732 red pine, 983 white pine, and 429 balsam fir
- Sample plots covered various sites throughout central and eastern Canada as well as eastern, northern, and western Maine
- Sampled trees were all felled with dib and dob measurements recorded at stump height, breast height and successive 1 or 2 m intervals to the tip of the tree

Bark thickness equations

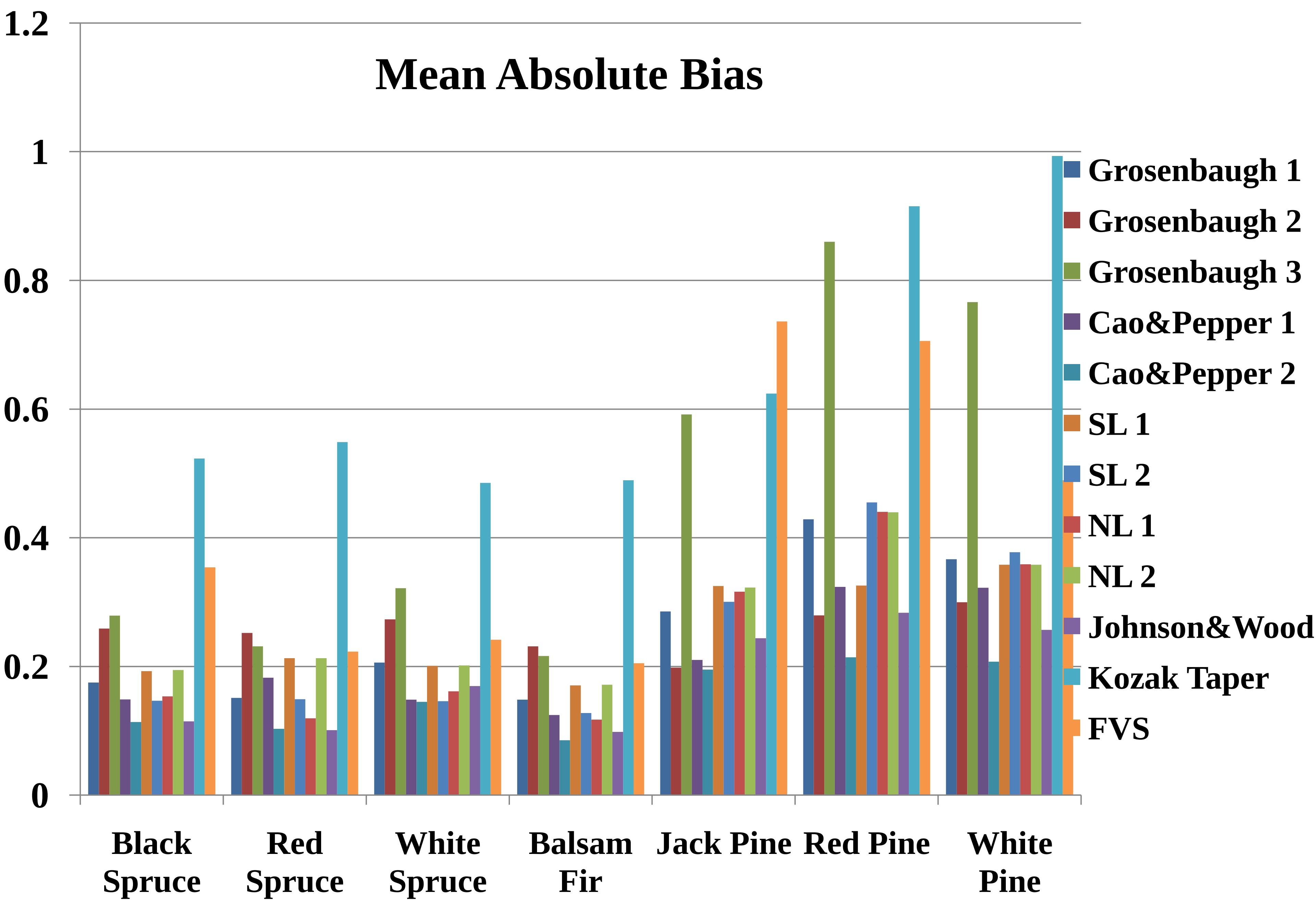
- Grosenbaugh's 3 STX ratio equations
- Cao and Pepper (1986)

$$dib = dob * \left(\beta_1 + \beta_2 * \frac{h}{H} + \beta_3 * \left(\frac{h}{H}\right)^2 + \beta_4 * H\right)$$

$$dib = dob * \left(\beta_1 + \beta_2 * \frac{h}{H} + \beta_3 * \left(\frac{h}{H}\right)^2 + \beta_4 * H + DBHIB/DBHOB\right)$$

- $dib = \beta_1 + \beta_2$*dob
- $dib = \beta_1$*dob
- $dib = \beta_1 * dob^{\beta_2}$
- $dib^2 = \beta * dob^2$
- $RBT = \beta_1 + \beta_2 * RD^{\beta_3}$
- Kozak Taper
- FVS

Part II: Bark thickness

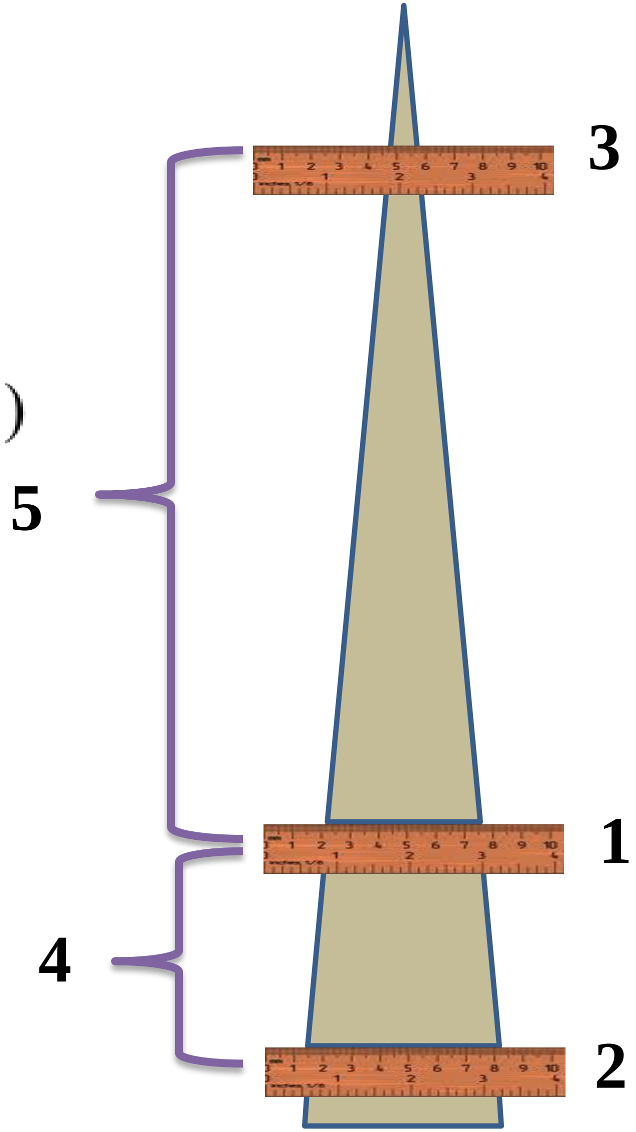


Leave-one-out cross validation and EBLUP

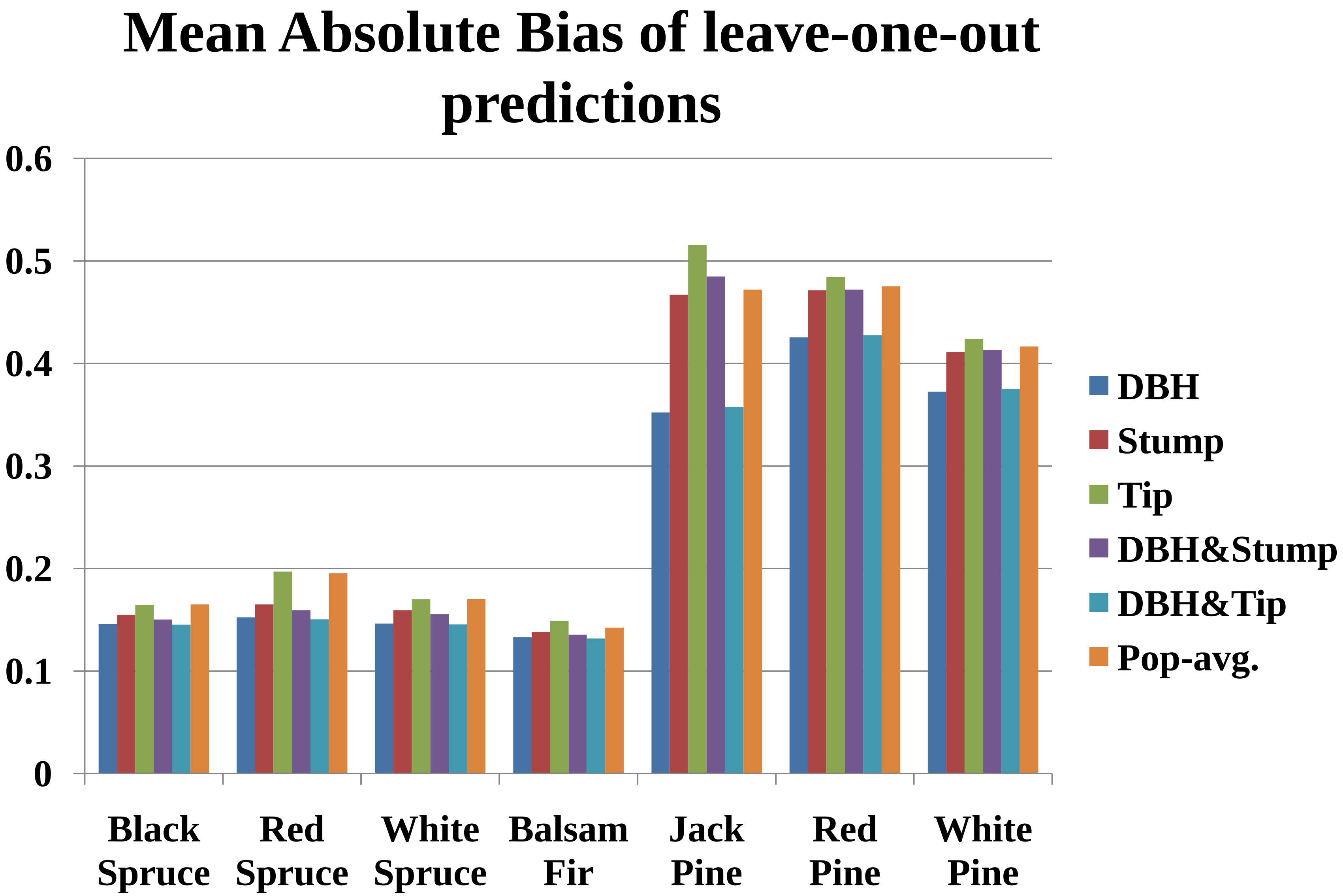
- Leave-one-out vs. splitting data
- EBLUP

$$b_i = \widehat{\emptyset}\, \mathrm{Z_i}\, \widehat{\mathrm{V_i}^{-1}} (y_i - f(Xi, \hat{\beta}, 0))$$

- Five scenarios
  1. DBH
  2. Stump
  3. Tip
  4. DBH&Stump
  5. DBH&Tip



Part II: Bark thickness



Conclusions

- The segmented taper model of Clark et al. (1991) was the best at predicting stem volume across the species when upper stem diameter measurements are available
- The Kozak (2004) Model 02 equation was the most accurate equation of predicting red spruce and white pine stem form
- The inclusion of additional crown variables generally had a minimal or modest impact on improving predictions of either stem form or volume
- The bark thickness equation published by Cao and Pepper (1986) with the ratio of DBHIB to DBHOB as an additional covariate besides dob and tree height was found to be superior to other equations for most of our species
- EBLUP should be used in mixed model validation or prediction. For back thickness models, subject-specific predictions were slightly improved compared with population average predictions

Further reading

- **Li, R. and A. Weiskittel, 2010. Development and evaluation of regional taper and volume equations for the primary conifer species in the Acadian Region. *Annals of Forest Science*.**

- **Li, R. and A. Weiskittel, 2010. Estimating and predicting bark thickness for seven conifer species in the Acadian Region of North America using a mixed-effects modeling approach: Comparison of model forms and subsampling strategies. *European Journal of Forest Research.***

Acknowledgments

- University of Maine, Forest Bioproducts Research Initiative for funding the project
- Ontario Ministry of Natural Resources for maintaining and providing access to the Honer data
- University of Maine, Cooperative Forestry Research Unit for providing access to the Lemin data
- Bob Seymour, Laura Kenefic, Leah Phillips, Dan Gilmore, and Doug Maguire also provided data