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Northern Hardwoods Research Institute Inc.

Predicting stem volume for important hardwood species

2018

Technical Note

Resource Characterization

INTRODUCTION

Unlike softwood, hardwood stem is highly variable depending on crown form and branchiness (Baral 2016, Baral 2017, Castle et al 2017, McFarlane and Weiskittel 2016). Studies indicate that using precise characterization of crown form (crown morphology, presence and position le the largest branch) in volume prediction may help to reduce the associated uncertainty (Adu-Bredu et al 2008, Baral 2016, Baral 2017, Castle et al 2017, Girouard 2015, MacFarlane 2010, MacFarlane et Weiskittel 2016). Existing stem volume equations, i.e. Weiskittel and Li (2012) do not consider tree form (fork or branchiness) and are generally biased. This study aims to test and improve the existing equations using tree information to be able to predict stem profile more precisely for important hardwood species in New Brunswick.

HIGHLIGHTS

- **Inclusion of tree fork information of existing Kozak (2004) taper equation fitted by Weiskittel and Li (2002) improved the model by reducing MB, MAB and RMSE on diameter prediction for all species used in the study.**

METHODOLOGY

Data

Information on tree characteristics (Species, DBH, height, tree form class) and tree diameter measurements at different heights for four important hardwood species (sugar maple, yellow birch, red maple and white birch) in New Brunswick were obtained from different sources (the NHRI product recovery database, the NHRI field survey 2018, and Quebec ministry of natural resources data). The trees were sampled in nine different locations in central and northern New Brunswick and southeastern Quebec (Figure 1).

METHODOLOGY

Figure 1: Location of the sites where trees were samples for this study

The sample trees represent a large range of tree size gradient (DBH from 15 to 80 cm) with an average fo 25 to 30 cm (Table 1).

Table 1: Sample tree characteristics used in model development (training data) and model validation

	Training data (85%)			Validation data (15%)		
Species	n	Mean DBH (cm)	Mean height (m)	n	Mean DBH (cm)	Mean height (m)
SM	324	30.27	19.98	58	30.89	20.30
RM	215	26.71	18.17	40	25.56	17.97
YB	177	32.18	18.55	30	32.03	18.64
WB	97	26.89	15.92	25	27.75	17.03
Total	813			153		

Data analysis

A non-linear mixed effect modelling (nlme) was used to fit the Kozak taper equation (2004). The equation was modified by adding forking (a binary variable : Forked=1 and non-forked=0) as a variable on the exponent term of the model. Only the B2 parameter was used in random effect component. Usefulness of other parameters in random effect component could not be assessed due to model convergence problem. Autocorrelation within tree measurement was modeled using corAR1() function and the residuals were weighted to correct the heteroscedasticity problem using the varPower function available in the nlme package in R (Pinheiro et al. 2013). Observed and estimated volume inside bark (VIB) were calculated using Smalian's formula and the tree diameter and bark thickness relationship developed by Weiskittel and Li (2012). The model was validated with an independent data (Table 1: 153 trees) and model evaluation statistics (mean bias, mean absolute bias and root mean square error) were calculated for both diameter and volume prediction.

$$d = \alpha_0 D^{\alpha_1} H^{\alpha_2} X^{\left(\beta_1 Z^4 + (\beta_2 + b_i + b_{ij})\left(\frac{1}{e^{\left(\frac{D}{H}\right)}}\right) + (\beta_3 + \beta_7 Forked) X^{0.1} + \beta_4\left(\frac{1}{D}\right) + (\beta_5 + \beta_8 Forked) H^{Q} + \beta_6 X\right)} \quad \text{Eq. (1)}$$

where,

$X = \frac{1-(\frac{h}{H})^{1/3}}{1-P^{1/3}}$

$Q = 1 - Z^{1/3}$

$Z = h/H$

$p = 1.3/H$

h is the height of interest (m)

d is the outside diameter bark (cm) at height h,

H and D are total tree height (m) and diameter (ob) at breast height (cm)

Forked=binary variable (0=F1, F2, F6 and F8; and 1= F3, F4, F5 and F7)

α_0 - α_2 and β_1 - β_8 are the parameters to be estimated

b_i and b_{ij} are the site and trees nested within site level random effects.

RESULTS

Inclusion of tree fork information on the exponent of existing Kozak (2004) taper equation fitted by Weiskittel and Li (2012) improved the model by reducing MB, MAB and RMSE on diameter prediction for all species used in the study (Table 2).

Table 1: Bias (cm), absolute bias (cm) and root mean square error (cm) in predicting diameters along the bole for taper equations NHRI (2018) and Weiskittel and Li (2012) using validation data sets.

	NHRI (2018)			Weiskittel and Li (2012)		
Species	MB (cm)	MAB (cm)	RMSE (cm)	MB (cm)	MAB (cm)	RMSE (cm)
SM	-0.6411	0.9580	1.8235	0.5381	1.7823	2.6636
YB	-0.5117	2.1505	3.4058	0.9214	2.3185	3.8043
RM	-0.2734	1.3482	1.9636	0.8552	1.6921	2.4482
WB	0.2398	1.5569	2.2779	1.3435	1.7827	2.8675

The fixed effect parameter estimates for the improved equation (Eq. 1) is provided in Table 3.

Table 3: Species specific parameter estimates for equation (1)

Fixed effect parameters	Species			
	SM	RM	WB	YB
α_0	0.9402	0.9099	1.2879	1.0552
α_1	0.9420	0.9544	0.9686	0.8958
α_2	0.0890	0.0828	-0.0512	0.1047
β_1	1.0949	1.1439	0.7928	0.9654
β_2	0.7691	1.2127	-0.0389	0.6299
β_3	0.6406	0.5210	0.8071	0.5869
β_4	-8.1032	-11.2292	-5.0570	-7.2095
β_5	0.0108	-0.0234	0.0669	0.0251
β_6	-0.1685	0.1746	-0.5130	-0.1068
β_7	0.2688	0.0615	0.1512	0.2881
β_8	-0.0213	-0.0007	-0.0346	-0.0268

The improved model validated well with the independent data for predicting both (i) outside bark diameter

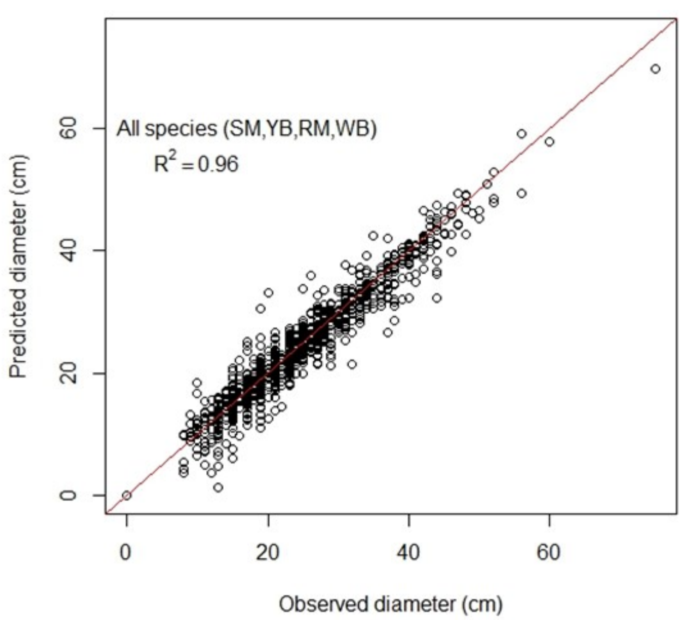

Figure 2: The relationship between observed and predicted diameter (validation data).

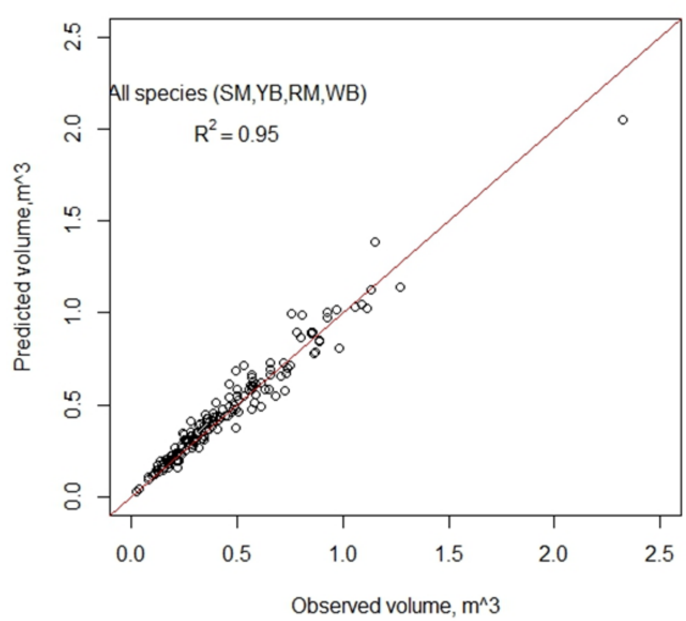

Figure 3: The relationship between observed and predicted merchantable volume up to the observed height of measurement for validation data.

The model (Eq. 1) gave logical stem taper profile for different size trees of different stem forms. Figure 4 is one of the examples of the stem taper profile that shows how stem taper varies due to the presence of fork within the first five meter for a tree of given height, DBH and species.

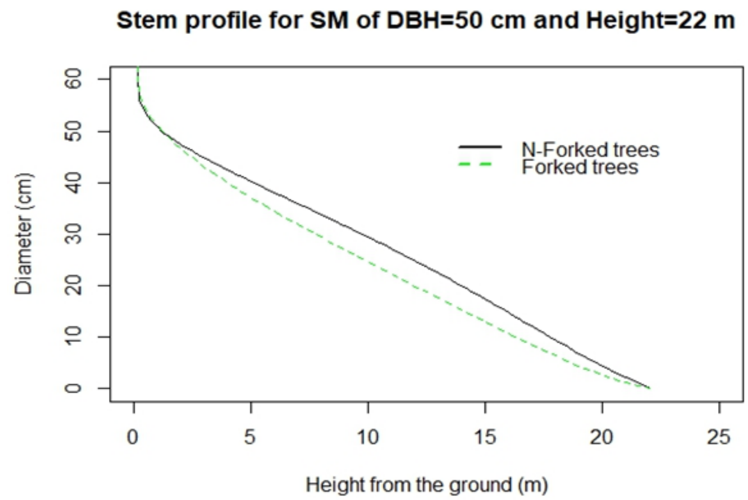

Figure 4: Predicted stem profile for a forked and a non-forked sugar maple tree of 50 cm DBH amd 22 m height.

The NHRI (2018) performed better when accuracy (%) on predicted merchantable volumes for different species were compared against Weiskittel and Li (2012) and Honer t al. (1983) except for RM (Table 4).

Table 4: Accuracy (%) on predicting merchantable volume. The lowest values are in bold.

	NHRI (2018)	Weiskittel and Li (2012)	Honer et al. (1983) *
SM	**9.59**	16.04	10.59
RM	14.21	17.33	**10.84**
YB	**13.80**	18.23	17.85
WB	**14.30**	23.84	19.57

* Calculation of merchantable volume using Honer et al. (1983): Total volume was calculated using species, DBH and total height information (Honer et al. 1983, Table 3). The total volume was then converted to merchantable volume up to the desired bole height using height ratio method (Honer et al. 1983, Table 4).

The similar trend was observed when MB, MAB and RMSE were assessed (Table 5). However the difference in MAB and RMSE for RM between NHRI (2018) and Honer et al. (1982) is not very large.

Table 5: Bias (m3), absolute bias (m3) and root mean square error (m3) in predicting merchantable bole volume for taper equations NHRI (2018), Weiskittel and Li (2012) and Honer et al. (1983) using validation data sets.

	NHRI (2018)			Weiskittel and Li (2012)			Honer et al. (1983)*		
Species	MB (m^3)	MAB (m^3)	RMSE (m^3)	MB (m^3)	MAB (m^3)	RMSE (m^3)	MB (m^3)	MAB (m^3)	RMSE (m^3)
SM	**0.0173**	**0.0505**	**0.0696**	0.0701	0.0781	0.1146	0.0187	0.0531	0.1041
YB	**0.0062**	**0.0595**	**0.0792**	0.0546	0.0776	0.111	0.0554	0.0826	0.1243
RM	0.0057	0.0381	0.0490	0.0328	0.0419	0.0528	**-0.0004**	**0.0328**	**0.0436**
WB	**0.0440**	**0.0525**	**0.0696**	0.0826	0.0834	0.1146	0.0678	0.0699	0.1041

* Calculation of merchantable volume using Honer et al. (1983): Total volume was calculated using species, DBH and total height information (Honer et al. 1983, Table 3). The total volume was then converted to merchantable volume up to the desired bole height using height ratio method (Honer et al. 1983, Table 4).

CONCLUSION

The inclusion of tree fork as an explanatory variable in the existing stem taper model has improved the model performance significantly. The model provides relatively less biased estimates for trees between 20 and 50 cm dbh as most of the sample trees were limited to this diameter range. The diameter of forked trees tapers off rapidly after about 2 m height as all the forks below first 5m were grouped together. If we measure the exact fork height (or height of the biggest branch in the canopy), it will allow to build a model that provides deviation of stem profile just above the fork height which is biologically more realistic. This may further improve the model performance. Although the Honer et al. (1983) equation performed better for red maple than NHRI (2018), the taper equation will be more useful to obtain stem volume up to different user specified top height, top end diameter and stump height. This study evaluated merchantable volume only up to the certain height of the trees which is considered as merchantable during current commercial timer harvesting practices. Therefore, it is recommended to evaluate this model against the standard stem analysis data. Since this study is limited to the data collected in northern New Brunswick and some methodological inconsistencies among the datasets, it is recommended to validate this model before using it outside of the observed geographical range.

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