

EVALUATION OF ECOREGION-BASED VOLUME EQUATIONS FOR SCOTS PINE (*PINUS SYLVESTRIS*) IN THE EASTERN DAXING'AN MOUNTAINS, NORTHEAST CHINA

MBANGILWA, M. M.¹ – HE, P.¹ – JIANG, L. C.^{1*}

¹Key Laboratory of Sustainable Forest Ecosystem Management-Ministry of Education, School of Forestry, Northeast Forestry University, Harbin 150040, China

*Corresponding author
e-mail: jlichun@nefu.edu.cn

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Abstract. In this research total volume equations were developed for Scots pine (*Pinus sylvestris* var. *mongolica*) in Northeast China. Eighteen total volume equations were fitted to volumes from Forest Inventory Analysis data of the Eastern Daxing'an Mountains in Northeast China. Eight ecoregions including: Xinlin (XL), Tahe (TH), Huzhong (HZ), Shibazhan (SBZ), Hanjiayuan (HJY), Xilinji (XLJ), Tuqiang (TQ), Amuer (AME) belonging to two regions including: The northwest of the northern slope of Yilehuli Mountains (NWYLHLM) and The southeast of the northern slope of Yilehuli Mountains (SAYLHLM) were identified and the best volume equations were tested to determine if the differences between ecoregions were statistically significant. Results varied by ecoregion. Average bias prediction error ranged from -1.2% to 7.5% in XL, from -0.8% to 11.7% in TH, from -13.9% to 0.08% in HZ, from -3.5% to 10.3% in SBZ, from -8.9% to 0.9% in HJY, from -2.5% to 10.4% in XLJ, from -11.6% to 9.4% in TQ and from -11.7% to 1.5% in AME. However, the ecoregion-based volume equation developed in this study could provide more accurate information on tree growth and development of forest ecosystems to managers and planners.

Keywords: *conifer species, prediction error, ecoregion, total volume, forest management*

Introduction

Northeastern China is divided into four vegetation regions which include cold-temperate deciduous coniferous forest region, the temperate mixed evergreen coniferous-deciduous broad-leaved forest region, the warm temperate deciduous broad-leaved forest region, and the temperate steppe region (Qian, 2003). Temperate coniferous forests are geographically and taxonomically diverse, found on five continents (North America, Europe, Asia, South America and Africa) (Frelich, 2016). The latter constitute a type of terrestrial habitat defined by the World Wildlife Fund (WWF, 2012, 2019). Temperate coniferous forests are found predominantly in areas with warm summers and cool winters, and vary in their kinds of plant life. These forests are common in the coastal areas of regions that have mild winters and heavy rainfall, or inland in drier climates or mountainous areas. Many species of trees inhabit these forests including pine (Mongolian Scots pine), cedar, fir, and redwood (WWF, 2012, 2019) including the giant sequoia and the coastal sequoia (large known trees) in California and Fitzroya which live more than three thousand years in Chile (Frelich, 2016).

Mongolian Scots pine (*Pinus sylvestris* var. *mongolica*) is one of the major tree species in the network of Three-North Shelterbelt for windbreak and sand stabilisation in China (Wang et al., 2012). It is a geographic variety of Scots pine (*P. sylvestris*) and is widely distributed in northern China (Wang et al., 2017). It is considered as a crucial

ecological species in northern China, especially in sandy areas, due to its great adaptability to infertile soils and cold and arid habitats (Han et al., 1998; Wang et al., 2017). Its natural distribution is mainly located in the sandy soils of northeast China. Since it has high tolerance to cold, drought, soil infertility and grows naturally in the sandy land, this species had been introduced to the edge of sandy lands in northern China to protect nearby lands from moving sand dunes since the 1950s (Wang et al., 2012). Since its wind-sheltering functions are strongly correlated with the architecture and ecophysiological processes of each tree, the model-assisted analysis of the cover architecture and the functional dynamics of the Mongolian Scots pine would be useful to better understand its structure role and behavior in windbreak ecosystems of arid and semi-arid regions in China (Wang et al., 2012). For this investigation, we present a study of the model of Volume Equations based on Scots pine ecoregions in northeastern China.

Volume is referred to quantity and it is the common widely used measure of wood quantity in forest mensuration. Total stem volume equations are the commonly used tools in quantifying timber stocks (García-Espinoza et al., 2018). According to Li (2019), surveying is the determination of the diameters, heights or volumes of a standing tree or cut products such as sawn logs, as well as the determination or prediction of the growth rate. The volume equation is defined as various mathematical statements applied to the determination of quantities (Shuaibu, 2014). It is imperative to increase the supply of lumber, poles and picketing materials for socio-economic development through adequate forest stand measurements to determine and improve the quantity and quality of these stands. Adegoke et al. (2010) stated that the socio-economic development of any country depends largely on the efficient use of its natural resources. The importance of direct measurements of standing trees can not be overstated to obtain basic data on the relationship between different tree dimensions and volume used to estimate the volumes of other standing trees. Clutter et al. (1983) and Husch et al. (2003) explained that the stem volume of a tree is considered a function of the independent variables (diameter, height) and shape expressed as follows: $V = f(D, H, F)$ where V = volume, D = diameter in cm, H = total height, market value or height up to a specific limit and F = shape measurement such as Girard shape class or absolute shape quotient.

Diameter and height measurements are essential variables in determining volume. According to Shuaibu and Alao (2013), the diameter of a tree is a random variable that depends on age and height. Therefore, the size distribution of tree diameter in stands describes forest structure and can be used to estimate stand volume and biomass, forest biodiversity and density management. Although volume equations have been studied for many years, they continue to attract forest research. Indeed, there is no single theory of volume that can be used satisfactorily for all species; no single volume model is best for all purposes and volume equations must be more accurate, flexible, valid and normal in their predictions. Forestry measures also need to be improved as market requirements for timber, poles and firewood have become more specific in recent years and current stock volumes and future growth potential are important information for sustainable forest management (Shuaibu and Alao, 2016).

The objective of this study is to evaluate tree volume equations for Scots pine tree species (*Pinus sylvestris* var *mongolica*) in the boreal forests of northeastern China and set up a comparison of the inequalities between the volume-diameter relationships between the eight ecoregions; see if these volume equations are statistically justified to

verify ecoregion differences for selected Scots pine species and to assess the associated bias when a regional model is compared to individual ecoregion models.

Materials and Methods

Study area and data

The study was conducted in the cold temperate forest regions of the Eastern Daxing'an Mountains who are the largest area of boreal forests in China (Hu et al., 2017) and is taking particularly the Northern slope of Yilehuli Mountains in Heilongjiang Province, northeast China (from 121° 12'E to 127° 00'E and from 50° 10'N to 53° 33'N) (Figure 1). The elevation of the area ranges from 300 to 1520 m above the sea level. The mean annual rainfall ranges from 500 to 750 mm and mean annual temperature is from -1 to -2.8°C (Enzinga and Jiang, 2019).

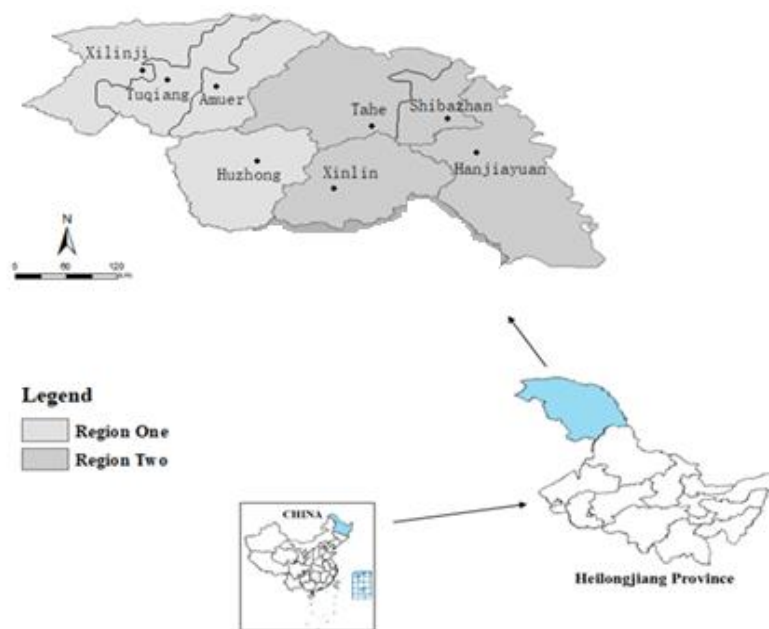


Figure 1. The geographical location of study area in the Northeast China

The two major regions (Zhang et al., 1992) employed are depicted in *Figure 1* and include:

- Region 1: The northwest of the northern slope of Yilehuli Mountains (NWYLHLM) which includes four subregions: Xilinji (XLJ), Tuqiang (TQ), Amuer (AME), Huzhong (HZ).
- Region 2: The southeast of the northern slope of Yilehuli Mountains (SAYLHLM) which includes four subregions: Xinlin (XL), Tahe (TH), Shibazhan (SBZ), Hanjiayuan (HJY).

A total of 1294 destructively sampled *Pinus sylvestris* var. *mongolica* trees species were used in this investigation. These trees were felled throughout the forest inventory areas of northeast China and all sampled trees were selected to ensure a representative distribution across a range of height and diameter classes within stands varying in

density, height, site condition, age and stand structure. Diameters at breast height (DBH, defined as 1.3 m above the ground) outside bark were measured for all sampled trees. Trees were felled to measure total height and their diameter outside bark near ground and at 2, 4, 6, 8, 10, 15, 20, 30, 40, 50, 60, 70, 80 and 90% of total height. Measurements for two perpendicular diameters (over bark) were taken in each part and arithmetically averaged. Smalian's formula (Eq.1) was used to calculate the log volumes in cubic meters. Total stem volume (over bark) above stump was computed by adding the logs volumes (over bark) and volume of the top section. Trees possessing broken tops, obvious cankers or crooked boles were excluded from the analysis. Summary statistics for tree diameter and total volume are provided for each subregion, the NWYLHLM, and SAYLHLM regions and all data combined (Overall) in Table 1.

Table 1. Summary statistics of tree diameter (DBH) at breast height, total height (H), total volume (V) for regional and ecoregional data sets for Scots pine

Ecoregion	DBH (cm)					H (m)				V (m ³)			
	N	Mean	STD	Min	Max	Mean	STD	Min	Max	Mean	STD	Min	Max
XL	65	35.79	9.70	8.60	64.00	18.52	2.35	10.80	23.30	0.94	0.55	0.03	3.78
TH	120	19.63	11.20	5.00	49.00	13.91	5.23	5.90	26.50	0.32	0.40	0.01	2.03
HZ	135	30.09	12.68	5.40	57.60	17.50	3.33	5.00	23.90	0.76	0.56	0.01	2.28
SBZ	68	19.90	10.69	5.40	41.30	14.31	4.05	7.10	24.20	0.31	0.35	0.01	1.66
HJY	335	25.05	10.86	5.20	54.00	18.41	4.46	6.10	25.60	0.56	0.48	0.01	2.61
XLJ	189	18.81	10.94	5.00	52.30	15.46	4.31	7.10	23.90	0.31	0.36	0.01	1.74
TQ	184	28.22	12.11	6.30	50.70	18.45	4.31	5.80	25.70	0.72	0.60	0.01	2.38
AME	198	36.16	11.88	5.30	55.90	19.68	3.77	7.04	25.40	1.09	0.63	0.01	2.55
NWYLHLM	706	28.29	13.49	5.00	57.60	17.81	4.29	5.00	25.70	0.72	0.62	0.01	2.55
SAYLHLM	588	24.53	11.72	5.00	64.00	17.03	4.85	5.90	26.50	0.52	0.49	0.01	3.78
Overall	1294	26.58	12.85	5.00	64.00	17.46	4.57	5.00	26.50	0.63	0.58	0.01	3.78

Note: N-sample size (number of trees), STD-standard deviation, Min.-minimum, Max.-maximum

Data and Methods

Smalian's Formula

$$V = \frac{S_1 + S_2}{2} \times l \quad (\text{Eq.1})$$

where:

V= is the Volume of logs in m³,

S₁= is the area at the small end of the log in m²,

S₂= is the area at the large end of the log in m²,

l= is the length of the log in m.

Base volume model selection

A total of eighteen volume equations (Table 2) were selected from the literature (Alegria and Tome, 2011; Özçelik, 2019). In these studies, several models of volume equations are used in different forms to develop tree volume equations (Saraçoğlu, 1988; Bi and Hamilton, 1998; Bailey, 1994; Yavuz, 1999; Mısır and Mısır, 2004; Teshome, 2005; Akindele and LeMay, 2006; Perez, 2008; Alegria and Tome, 2011; Hjelm and Johansson, 2012; Stolarikova et al., 2014; Malata et al., 2017; Lee et al., 2017; Özçelik

and Çevlik, 2017; Kitikidou et al., 2017; Sakıcı et al., 2018). These equations were examined and evaluated to select the best model for further analysis.

Table 2. Volume functions selected for evaluation

Function form	References	Number
$V = a + (bD^2h)$	Borset (1954)	(1)
$V = aD^bH^c$	Bailey (1994)	(2)
$V = (a + bD)^2$	Perez and Kanninen (2003)	(3)
$V = aD^2H$	Spurr (1952)	(4)
$V = \frac{D^2}{a + b/H}$	Honer (1967)	(5)
$V = a + bD^2H + cH$	Rachid-Casnati et al. (2014)	(6)
$V = \frac{D^2H}{a + bD}$	Takata (1958)	(7)
$V = a + bD^cH^d$	Burkhart (1977)	(8)
$V = a + b(H/D)^c D^2H$	Teshome (2005)	(9)
$V = D^2(a + bH)$	Ogaya (1968)	(10)
$V = aD^2 + bD^2H - cD^2H^2 - dH + eDH^2$	Eriksson (1973)	(11)
$V = a + bD^2H + cD^3H + dD^2H^2 + eH$	Bi and Hamilton (1998)	(12)
$V = a(D^2H)^b$	Malata et al. (2017)	(13)
$V = a(D^2)^b H^c$	Malata et al. (2017)	(14)
$V = a + bD^2 + cD^2H^2$	Alegria and Tome (2011)	(15)
$V = a + bD + cD^2 + dD^2H^2$	Alegria and Tome (2011)	(16)
$V = a + bDH + cDH^2 + dD^2H^2$	Alegria and Tome (2011)	(17)
$V = a + bD + cDH^2 + dD^2H^2$	Alegria and Tome (2011)	(18)

Note: V = total Volume (m^3); D = diameter at breast height outside bark (cm); H = total height (m); a, b, c, d, e = parameters to be estimated

Through comparisons, the Schumacher and Hall (Bailey, 1994) function (model 2) was found to provide consistent and accurate results, and was therefore considered one of the best non-linear functions to describe the total volume of the Scots pine and selected as the base model:

$$V = aD^bH^c \quad (\text{Eq.2})$$

where V is volume in cubic meter (m^3), D is the tree diameter at breast height (DBH) (cm), H is the total height (m), (a, b, and c) are the parameters.

Equation 2 was fit to: (1) the overall data, (2) the NWYLHLM region data (region 1), (3) the SAYLHLM region data (region 2) and (4) each of the eight ecoregions separately. The PROC NLIN procedure in the Statistical Analysis System (SAS Institute, Inc. 2002) was utilized to estimate the model parameters and model statistics.

To assess whether the total volume equations are different among regions and ecoregions, the non-linear extra sum of squares method was used (Bates and Watts, 1988; Neter et al., 1996). This method demands the fitting of full and reduced models and has commonly been applied to evaluate if separate models are necessary for different species or different ecoregions and geographic regions (Huang et al., 2000; Peng et al., 2001; Zhang et al., 2002; Castedo-Dorado et al., 2005; Corral-Rivas et al.,

2007). The full model corresponds to different sets of parameters for each subregions and is gotten by enlarging each parameter by including an associated parameter and a dummy variable to distinguish among ecoregions. The reduced model corresponds to the same set of global parameters for all ecoregions. Using Indicator (dummy) variable approach for the *Equation 2*, the full model of the volume function can be written as:

$$V = \left(a + \sum_{i=1}^k a_i r_i \right) D^{(b + \sum_{i=1}^k b_i r_i)} H^{(c + \sum_{i=1}^k c_i r_i)} \quad (\text{Eq.3})$$

where:

V = volume parameter tested,

r_i = indicator variable for regions and ecoregions,

D = tree dbh (in cm),

a,b, c = parameters to be estimated from the data,

k = the number of indicator variables.

Evaluate the overall volume differences among ecoregions

This procedure involves the use of seven indicator variables (k=7) which are needed in *Equation 3* for eight ecoregions in the full model form in this case. They are defined as follows:

If subregion = XL, $z_1 = 1$, all other $z_i = 0$.

If subregion = TH, $z_2 = 1$, all other $z_i = 0$.

If subregion = HZ, $z_3 = 1$, all other $z_i = 0$.

If subregion = SBZ, $z_4 = 1$, all other $z_i = 0$.

If subregion = HJY, $z_5 = 1$, all other $z_i = 0$.

If subregion = XLJ, $z_6 = 1$, all other $z_i = 0$.

If subregion = TQ, $z_7 = 1$, all other $z_i = 0$.

If subregion = AME, all other $z_i = 0$.

While the reduced model form is represented by a three parameters model (*Equation 2*) representing the volume relationship across all ecoregions.

Evaluate the volume differences between the two regions

To test the difference between region NWYLHLM and SAYLHLM, one indicator variable (k=1) can be defined: if region = NWYLHLM, $z_1 = 1$; and if region = SAYLHLM, $z_1 = 0$. Similarly, the full model (*Equation 3*) has 6 estimable parameters.

Evaluate the volume differences between the eight ecoregions

A total of 28 ecoregion pairs can be formulated to test the pairwise differences between the eight ecoregions. The 28 testing pairs require 28 full models that take the form of *Equation 3*, and 28 reduced models that take the form of *Equation 2*. For example, to test the difference between ecoregion TH vs. HZ, one indicator variable (k=1) can be defined: if ecoregion = TH, $z_1 = 1$; and if ecoregion = HZ, $z_1 = 0$. Similarly, the full model (*Equation 3*) has 6 estimable parameters. All the reduced models for these tests take the form of *Equation 2* with 3 parameters.

Evaluate statistic

The significance of the full and reduced model comparisons were based on an F-test of the form:

$$F = \frac{\frac{SSE_R - SSE_F}{df_R - df_F}}{\frac{SSE_F}{df_F}} \quad (\text{Eq.4})$$

where SSE_R is the error sum of squares of a reduced model with the degrees of freedom df_R , and SSE_F is the error sum of squares of a full model with the degrees of freedom df_F . This test statistic is F-distributed for a non-linear model if the data used represent a large sample generally; the F-test is significant if the P-value for the test is less than 0.05.

In order to understand the consequences of inappropriate application of a volume model in different ecoregions, each of the eleven models (global model, regional model 1 (NWYLHLM 1), regional model 2 (SAYLHLM 2), and 8 ecoregional models was used to predict total volume of trees for each ecoregion.

To quantify the magnitude of the prediction error when a specific region model is used, the average volume prediction error ($\bar{\epsilon}$), the standard error of the prediction error (S_ϵ), and the prediction bias as a percentage of average "real" volume (% bias) were calculated and defined as:

$$\bar{\epsilon} = \frac{\sum_{i=1}^m (\hat{V}_i - V_i)}{m} \quad (\text{Eq.5})$$

$$S_\epsilon = \sqrt{\frac{\sum_{i=1}^m (\epsilon - \bar{\epsilon})^2}{m-1}} \quad (\text{Eq.6})$$

$$\text{Bias}(\%) = \frac{\bar{\epsilon}}{\bar{V}} \times 100 \quad (\text{Eq.7})$$

where:

m= Number of trees,

V_i = Data reported volume for tree i,

\hat{V}_i = Predicted volume for tree i,

\bar{V} = Mean data reported volume.

Results and Discussion

Model fitting to regional and ecoregional data

Based on the different data sets, *Equation 2* was separately fitted using non-linear least squares. Parameter estimates and MSE for each ecoregion and region are displayed in *Table 3*. In all situations, parameter estimates and model forms were statistically significant ($P < 0.01$). Among the eight ecoregional models, the lowest MSE value was found in the TH ecoregion, and the highest MSE value was found in the AME ecoregion. The parameter estimates varied among the eight ecoregions, indicating that each ecoregion may have a different volume with DBH and H relationship from others. The three regional models also have different parameter estimates.

Table 3. Parameter estimates and MSE of volume function for the regional and ecoregional models

Ecoregions	N	a	b	c	MSE
XL	65	0.000020	2.0737	1.0984	0.0121
TH	120	0.000029	1.8453	1.2382	0.00078
HZ	135	0.000200	1.9262	0.5259	0.00522
SBZ	68	0.000015	1.8184	1.5004	0.00233
HJY	335	0.000081	2.1093	0.6063	0.00657
XLJ	189	0.000132	1.8660	0.7028	0.0012
TQ	184	0.000044	1.5513	1.4665	0.0146
AME	198	0.000117	1.9022	0.7312	0.0159
NWYLHLM	706	0.000111	1.9041	0.7453	0.0109
SAYLHLM	588	0.000034	2.0686	0.9313	0.0063
Overall	1294	0.000075	1.9719	0.7906	0.00915

Note: N-sample size (number of tree), a, b, c-three parameters of volume model, MSE-model mean squared error

Comparison of the total volume equations between regions and ecoregions

Table 4 shows the testing results for the differences of the overall volume models for the eight ecoregions. The F-test indicates that there are differences among the total volume models from eight ecoregions ($P < 0.0001$). This implies that the overall model is not sufficient to describe the volume with DBH and H relationships for the eight ecoregions selected. The difference between the different regions (NWYLHLM-SAYLHLM) was also tested and the P-values were less than 0.0001 for the two regional paired comparisons. This means that the difference in volume between the two geographic regions is also statistically significant. The same approach was used to test for differences among the eight ecoregions (Table 4). Among the 28 pairs of ecoregion comparisons, only three ecoregion pairs (e.g., XL versus SBZ, HZ versus AME, and SBZ versus TQ) showed the non-significant difference ($P > 0.05$).

Prediction errors of applying overall and regional volume equations to each ecoregion

According to the tests above, there were significant differences for many paired comparisons of the volume model among the eight ecoregions and between regions. Inappropriately applying a total volume model in these ecoregions may result in prediction biases. To understand the consequences, all eleven models (overall model, NWYLHLM model, SAYLHLM model and eight sub-regional models) were used to predict total tree volume for each ecoregion individually.

If the overall model was used to predict the volume of trees in each ecoregion, excessive or underestimated predictions were made for different ecoregions. On average, the overall model under-estimated (i.e., positive Bias %) tree volume from 0.1% to 3.2% for ecoregions AME, HJY, TQ, and HZ, and over-estimated (i.e., negative Bias %) tree volume about -2.1% to -8.1% in ecoregions XL, XLJ, SBZ and TH (Table 5).

Applying the NWYLHLM regional model to each ecoregion would result in similar patterns and magnitudes of the prediction errors as the overall model. This model under-estimated tree volumes in the HZ (1.9%), AME (0.07%), and over-estimated tree volumes in the XL (-3.01%), TH (-11.1%), SBZ (-9.8%), HJY (-1.4%), XLJ (-9.3%) and TQ (-0.0735%) (Table 6).

Table 4. F-test for testing the difference between regions and among eight ecoregions

Subregions	n	Full Model			Reduced Model			Extra sum of squares		
		SSE _F	PF	df _F	SSE _R	PR	df _R	df _R – df _F	F-value	P-value
Overall	1294	9.8339	30	1267	11.8065	3	1291	24	10.5898	0.0000
NWYLHLM-SAYLHLM	1294	11.3292	6	1288	11.8065	33	1291	3	18.0893	0.0000
XL - TH	185	0.8429	6	179	0.9774	3	182	3	9.5188	0.0000
XL - HZ	200	1.4410	6	194	1.7510	3	197	3	13.9109	0.0000
XL - SBZ	133	0.9032	6	127	0.9322	3	130	3	1.3577	0.2587
XL - HJY	400	2.9341	6	394	3.1322	3	397	3	8.8686	0.0000
XL - XLJ	254	0.9753	6	248	1.2592	3	251	3	24.0628	0.0000
XL - TQ	249	3.4031	6	243	3.9713	3	246	3	13.5243	0.0000
XL - AME	263	3.8440	6	257	4.0791	3	260	3	5.2411	0.0015
TH - HZ	255	0.7807	6	249	1.2053	3	252	3	45.1421	0.0000
TH - SBZ	188	0.2428	6	182	0.2786	3	185	3	8.9416	0.0000
TH - HJY	455	2.2737	6	449	2.6379	3	452	3	23.9775	0.0000
TH - XLJ	309	0.3150	6	303	0.3822	3	306	3	21.5336	0.0000
TH - TQ	304	2.7428	6	298	2.8935	3	301	3	5.4611	0.0011
TH - AME	318	3.1836	6	312	3.4648	3	315	3	9.1839	0.0000
HZ - SBZ	203	0.8409	6	197	1.1099	3	200	3	21.0047	0.0000
HZ - HJY	470	2.8718	6	464	3.0242	3	467	3	8.2085	0.0000
HZ - XLJ	324	0.9131	6	318	1.1756	3	321	3	30.4673	0.0000
HZ - TQ	319	3.3409	6	313	3.8997	3	316	3	17.4522	0.0000
HZ - AME	333	3.7817	6	327	3.8206	3	330	3	1.1204	0.3408
SBZ - HJY	403	2.3340	6	397	2.5168	3	400	3	10.3639	0.0000
SBZ - XLJ	257	0.3753	6	251	0.4846	3	254	3	24.3789	0.0000
SBZ - TQ	252	2.8030	6	246	2.8453	3	249	3	1.2369	0.2968
SBZ - AME	266	3.2439	6	260	3.4207	3	263	3	4.7232	0.0031
HJY - XLJ	524	2.4062	6	518	2.8629	3	521	3	32.7782	0.0000
HJY - TQ	519	4.8339	6	513	5.6557	3	516	3	29.0706	0.0000
HJY - AME	533	5.2748	6	527	5.5064	3	530	3	7.7127	0.0000
XLJ - TQ	373	2.8752	6	367	3.2028	3	370	3	13.9407	0.0000
XLJ - AME	387	3.3161	6	381	3.6265	3	384	3	11.8870	0.0000
TQ - AME	382	5.7438	6	376	6.1290	3	379	3	8.4049	0.0000

Note: N – sample size, SSE_F – error sum of squares of the full model, df_F – degrees of freedom of SSE_F, SSE_R – error sum of squares of reduced model, df_R – degrees of freedom of SSE_R, P is the number of parameters

Table 5. Prediction error of applying the overall model for each ecoregion

Subregions	N	\bar{V} (m)	\hat{V} (m)	$\bar{\epsilon}$	S _e	t	Bias (%)
XL	65	0.9352	0.9547	-0.0195	0.1183	-1.3284	-2.0835
TH	120	0.3198	0.3456	-0.0258	0.0479	-5.9040	-8.0736
HZ	135	0.7603	0.7360	0.0243	0.0768	3.6748	3.1946
SBZ	68	0.3136	0.3329	-0.0194	0.0629	-2.5392	-6.1728
HJY	335	0.5550	0.5516	0.0034	0.0852	0.7356	0.6167
XLJ	189	0.3128	0.3319	-0.0191	0.0507	-5.1842	-6.1184
TQ	184	0.7181	0.7117	0.0064	0.1329	0.6504	0.8876
AME	198	1.0919	1.0904	0.0015	0.1269	0.1655	0.1367

Note: N – sample size, \bar{V} – average of observed tree volume, \hat{V} – average of predicted tree volume from the model, S_e – standard deviation of prediction error

Table 6. Prediction errors of applying regional models to each ecoregion

Reg-Eco	N	\bar{V} (m)	\hat{V} (m)	$\bar{\epsilon}$	S_e	t	Bias (%)
NWYLHLM - XL	65	0.9352	0.9633	-0.0281	0.1255	-1.8056	-3.0053
NWYLHLM - TH	120	0.3198	0.3554	-0.0356	0.0502	-7.7685	-11.1237
NWYLHLM - HZ	135	0.7603	0.7455	0.0148	0.0756	2.2782	1.9507
NWYLHLM - SBZ	68	0.3136	0.3443	-0.0307	0.0659	-3.8394	-9.7935
NWYLHLM - HJY	335	0.5550	0.5626	-0.0076	0.0879	-1.5896	-1.3757
NWYLHLM - XLJ	189	0.3128	0.3419	-0.0291	0.0493	-8.1208	-9.3051
NWYLHLM - TQ	184	0.7181	0.7186	-0.0005	0.1312	-0.0546	-0.0735
NWYLHLM - AME	198	1.0919	1.0911	0.0008	0.1253	0.0886	0.0722
SAYLHLM - XL	65	0.9352	0.9362	-0.0009	0.1099	-0.0702	-0.1024
SAYLHLM - TH	120	0.3198	0.3301	-0.0103	0.0448	-2.5288	-3.2368
SAYLHLM - HZ	135	0.7603	0.7177	0.0426	0.0837	5.9206	5.6079
SAYLHLM - SBZ	68	0.3136	0.3139	-0.0003	0.0566	-0.0498	-0.1091
SAYLHLM - HJY	335	0.5550	0.5359	0.0190	0.0837	4.1592	3.4277
SAYLHLM - XLJ	189	0.3128	0.3168	-0.0040	0.0548	-1.0091	-1.2857
SAYLHLM - TQ	184	0.7181	0.7037	0.0144	0.1389	1.4091	2.009
SAYLHLM - AME	198	1.0919	1.0908	0.0011	0.1367	0.1135	0.1009

Note: N – sample size, \bar{V} – average of observed tree volume, \hat{V} – average of predicted tree volume from the model, S_e – standard deviation of prediction error

The same approach was used for SAYLHLM regional model to each ecoregion (Table 6). SAYLHLM regional model under-estimated tree volumes in the HZ (5.6%), HJY (3.4%), TQ (2.01%), AME (0.1%) and over-estimated tree volumes in the XL (-0.1%), TH (-3.2%), SBZ (-0.1%) and XLJ (-1.3%).

Prediction errors of applying ecoregional equation to each ecoregion

When the eight ecoregional models were applied to each ecoregion, they generally performed well in the ecoregions in which the models were developed. Otherwise, the models produced the prediction errors. The prediction biases ranged from -1.2% to 7.5% in XL, from -0.8% to 11.7% in TH, from -13.9% to 0.08% in HZ, from -3.5% to 10.3% in SBZ, from -8.9% to 0.9% in HJY, from -2.5% to 10.4% in XLJ, from -11.6% to 9.4% in TQ and from -11.7% to 1.5% in AME (Table 7). Figure 2 shows the mean prediction errors across 5-cm diameter classes when ecoregional models are applied to predict tree volume in each of the eight ecoregions separately. This further confirmed that ecoregional model developed in that ecoregion performed well for most diameter classes.

The expected results show that the different ecoregions have large differences in climatic, soil and ecological conditions. Corral-Rivas et al. (2007) and Brooks and Wiant (2008) reported in their study of the use of stump diameter to estimate DBH and tree volumes (V) at El Salto, Durango, Mexico and Ecoregion-based local volume equations for Appalachian hardwoods, USA. Part of the differences between the dbh and volume models between tree species may be caused by differences in genetics, growing conditions, and site quality. Previous studies of different species have also revealed differences between ecoregion-based height-diameter models (Huang, 1999; Huang et al., 1999; Zhang et al., 2002; Peng et al., 2004; Brooks and Wiant, 2005; Özçelik et al., 2014, 2016; Chourou, 2014; Enzinga and Jiang, 2019). In our case, the updated ecoregion classification in the cold temperate coniferous forest regions of Eastern Daxing'an Mountains (Figure 1) provides comprehensive information on changes in the relationships between ecoregions and tree species of *Pinus sylvestris* along ecological and macroclimatic gradients from different regions. These ecoregions are characterized by large climatic regimes that include temperature and precipitation, soil moisture and nutrient regimes, and succession and vegetation types (Hills, 1959, 1960; CEC, 1997; ELC Working Group, 2000).

Table 7. Prediction errors of applying a specific ecoregion model to each ecoregion

Subregions	N	$\bar{V}(m)$	$\hat{V}(m)$	$\bar{\varepsilon}$	S_{ε}	t	Bias (%)
XL model							
XL - XL	65	0.9352	0.9193	0.0159	0.1079	1.1904	1.7047
XL - TH	120	0.3198	0.3235	-0.0037	0.0435	-0.9268	-1.1510
XL - HZ	135	0.7603	0.7036	0.0567	0.0908	7.2498	7.4529
XL - SBZ	68	0.3136	0.3044	0.0092	0.0518	1.4662	2.9399
XL - HJY	335	0.5550	0.5326	0.0224	0.0865	4.7333	4.0319
XL - XLJ	189	0.3128	0.3114	0.0014	0.0568	0.3298	0.4359
XL - TQ	184	0.7181	0.7038	0.0142	0.1429	1.3528	1.9851
XL - AME	198	1.0919	1.0904	0.0015	0.1454	0.1451	0.1373
TH model							
TH - XL	65	0.9352	0.8686	0.0666	0.1334	4.0237	7.1185
TH - TH	120	0.3198	0.3224	-0.0026	0.0288	-0.9789	-0.8052
TH - HZ	135	0.7603	0.6713	0.0889	0.1109	9.3206	11.7032
TH - SBZ	68	0.3136	0.3044	0.0092	0.0510	1.4795	2.9203
TH - HJY	335	0.5550	0.5331	0.0219	0.1026	3.9010	3.9401
TH - XLJ	189	0.3128	0.3149	-0.0021	0.0432	-0.6728	-0.6765
TH - TQ	184	0.7181	0.6861	0.0319	0.1248	3.4741	4.4509
TH - AME	198	1.0919	1.0322	0.0597	0.1345	6.2439	5.4667
HZ model							
HZ - XL	65	0.9352	0.9858	-0.0506	0.1323	-3.0819	-5.4076
HZ - TH	120	0.3198	0.3641	-0.0443	0.0619	-7.8473	-13.8603
HZ - HZ	135	0.7603	0.7635	-0.0032	0.0716	-0.5242	-0.4252
HZ - SBZ	68	0.3136	0.3564	-0.0428	0.0754	-4.6792	-13.6435
HZ - HJY	335	0.5550	0.5639	-0.0089	0.0878	-1.8544	-1.6029
HZ - XLJ	189	0.3128	0.3472	-0.0345	0.0486	-9.7367	-11.0184
HZ - TQ	184	0.7181	0.7175	0.0005	0.1366	0.0545	0.0765
HZ - AME	198	1.0918	1.0928	-0.0009	0.1273	-0.1049	-0.0869
SBZ model							
SBZ - XL	65	0.9352	0.8832	0.05199	0.1277	3.2817	5.5595
SBZ - TH	120	0.3198	0.3296	-0.0098	0.0459	-2.3302	-3.0569
SBZ - HZ	135	0.7603	0.6820	0.0783	0.1181	7.6986	10.2934
SBZ - SBZ	68	0.3136	0.3064	0.0071	0.0471	1.2503	2.2755
SBZ - HJY	335	0.5550	0.5563	-0.0013	0.1063	-0.2239	-0.2343
SBZ - XLJ	189	0.3128	0.3236	-0.0108	0.0566	-2.6365	-3.4702
SBZ - TQ	184	0.7181	0.7194	-0.0013	0.1355	-0.1343	-0.1868
SBZ - AME	198	1.0919	1.0770	0.0148	0.1489	1.4032	1.3601
HJY model							
HJY - XL	65	0.9352	0.9928	-0.0576	0.1201	-3.8677	-6.1634
HJY - TH	120	0.3198	0.3484	-0.0286	0.0627	-5.0008	-8.9488
HJY - HZ	135	0.7603	0.7617	-0.0014	0.0833	-0.1998	-0.1886
HJY - SBZ	68	0.3136	0.3368	-0.0232	0.0711	-2.6901	-7.3933
HJY - HJY	335	0.5550	0.5499	0.0051	0.0807	1.1471	0.9116
HJY - XLJ	189	0.3128	0.3307	-0.0179	0.0609	-4.0378	-5.7259
HJY - TQ	184	0.7181	0.7179	0.0002	0.1433	0.0218	0.0321
HJY - AME	198	1.0919	1.1206	-0.0287	0.1360	-2.9686	-2.6277
XLJ model							
XLJ - XL	65	0.9352	0.8785	0.0567	0.1523	2.9991	6.0591
XLJ - TH	120	0.3198	0.3278	-0.0081	0.0514	-1.7201	-2.5235
XLJ - HZ	135	0.7603	0.6815	0.0788	0.1006	9.0999	10.3661
XLJ - SBZ	68	0.3136	0.3189	-0.0053	0.0689	-0.6373	-1.6998
XLJ - HJY	335	0.5550	0.5157	0.0393	0.1088	6.6097	7.0821
XLJ - XLJ	189	0.3128	0.3155	-0.0027	0.0344	-1.1024	-0.8816
XLJ - TQ	184	0.7181	0.6546	0.0635	0.1431	6.0196	8.8414
XLJ - AME	198	1.0919	0.9887	0.1032	0.1432	10.1385	9.4492
TQ model							
TQ - XL	65	0.9352	0.8789	0.0563	0.1721	2.6386	6.0235
TQ - TH	120	0.3198	0.3498	-0.0300	0.0449	-7.3275	-9.3986
TQ - HZ	135	0.7603	0.6890	0.0713	0.1423	5.8229	9.3779
TQ - SBZ	68	0.3136	0.3308	-0.0172	0.0529	-2.6879	-5.4961
TQ - HJY	335	0.5550	0.5847	-0.0297	0.1261	-4.3129	-5.3526
TQ - XLJ	189	0.3128	0.3491	-0.0363	0.0542	-9.2083	-11.6156
TQ - TQ	184	0.7181	0.7269	-0.0088	0.1204	-0.9941	-1.2288
TQ - AME	198	1.0919	1.0513	0.0405	0.1503	3.7956	3.7123

Subregions	N	\bar{V} (m)	\hat{V} (m)	$\bar{\epsilon}$	S_e	t	Bias (%)
AME model							
AME - XL	65	0.9352	0.9672	-0.0320	0.1258	-2.0523	-3.4251
AME - TH	120	0.3198	0.3571	-0.0373	0.0513	-7.9756	-11.6782
AME - HZ	135	0.7603	0.7487	0.0116	0.0750	1.8000	1.5289
AME - SBZ	68	0.3136	0.3463	-0.0327	0.0668	-4.0393	-10.4336
AME - HJY	335	0.5550	0.5646	-0.0096	0.0877	-1.9954	-1.7236
AME - XLJ	189	0.3128	0.3434	-0.0307	0.0498	-8.4672	-9.8101
AME - TQ	184	0.7181	0.7206	-0.0025	0.1314	-0.2590	-0.3494
AME - AME	198	1.0919	1.0938	-0.0019	0.1253	-0.2191	-0.1787

Note: N – sample size, \bar{V} – average of observed tree volume, \hat{V} – average of predicted tree volume from the model, S_e – standard deviation of prediction error

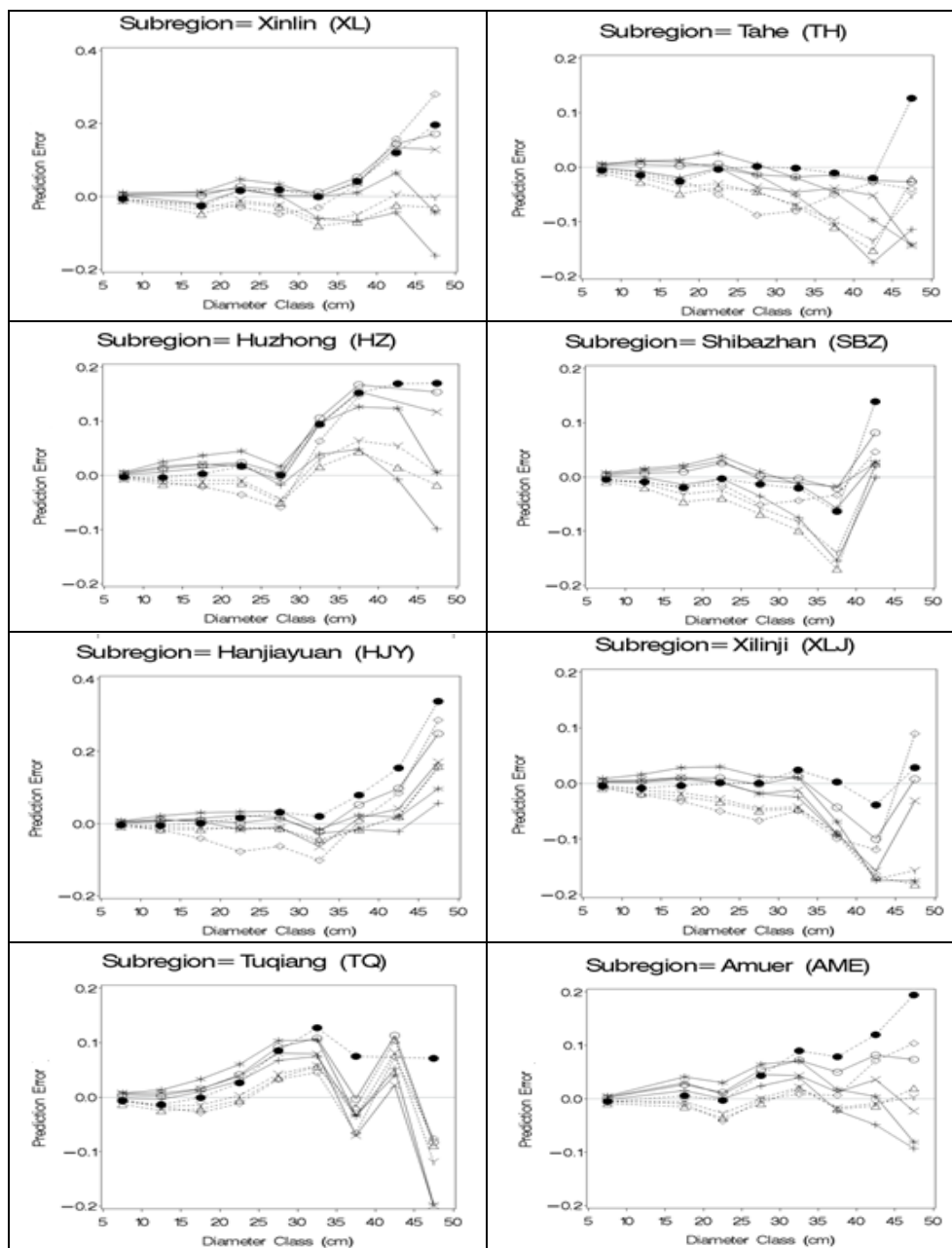


Figure 2. Average prediction errors (m) across 5-cm diameter classes when each ecoregional model is applied to predict total volume in each of the eight ecoregions with symbols: XL (star), TH (circle), HZ (triangle), SBZ (X), HJY (plus), XLJ (dot), TQ (diamond) and AME (Y)

Enzinga and Jiang (2019) provide comprehensive analysis of the climatic characteristics of the eastern Daxing'an Mountains which include the two regions (NWYLHLM and SAYLHLM) selected for the study. In addition, local ecological conditions such as vegetation types also affect growth and productivity as well as species dominance in these ecoregions. For example, in the 8 subregions selected for the study, it was demonstrated that the Scots pine (*Pinus Sylvestrix* var. *mongolica*) population was not present in the NDXAM region containing the subregions: Songling (SL), Jiagedaqi (JGDQ) within which the Scots pine stand was not observed by observing the previous 10 subregions of the Daxing'an mountains. Therefore, the combination of all climatic, environmental and vegetation factors plays an important role in determining the different volume relationships among the 8 ecoregions linked to our study.

These results are consistent with the last and recent results reported by Brooks and Wiant (2008), Li and Zeng (2016), and Liu and Jiang (2016). Based on six ecoregions from Central Appalachian, United States, Brooks and Wiant (2008) evaluated the ecoregion-based volume equations for six hardwood species and found that the average bias between a regional model with a single species and specific forms of ecoregion ranged from -9.1 to 8.5% for the gross volume of board feet, from -3.5 to 9.2% for the gross volume of marketable cubic feet, and -9.5 to 16.7% for the weight of the marketable dry bole. Li and Zeng (2016) used the datasets of *Larix* spp. from four regions (northeastern, northern, northwestern, and southwestern) of China and same total volume equation used in our study to test the difference among regions. Their results indicated that the difference of volume estimates was noticed between northeastern and northern regions, northern and northwestern regions. Based on the classification in eastern Daxing'an Mountains, Northeast China by Zhang et al. (1992), three regions were identified. Liu and Jiang (2016) evaluated the regional difference of volume estimates using dahurian larch (*larix gmelinii*) datasets from eastern Daxing'an Mountains. Results indicated that volume models were significant difference among different regions, therefore, region-based volume equation is required to avoid increasing prediction error. Enzinga and Jiang (2019) evaluated the region and subregion-based height-diameter models for dahurian larch (*larix gmelinii*) in Eastern Daxing'an Mountains which led to conclusions demonstrating that there were distinct variations in height-diameter relationships for Dahurian larch between the different subregions in three forest regions and that usually, height-diameter models based on ecoregions report forecasts more reliably on a regional basis and avoid likely errors that may arise when applying the models in other areas. The same is true in the case of our study on ecoregional assessments based on volume equation models in Northeast China.

Conclusion

In the study, the total tree volume equations were developed for *Pinus sylvestris* var. *mongolica* in northeastern China. Using dummy variables and the non-linear extra sum of squares procedure, the volume with diameter and total height relationship was not the same for all ecoregions when tested by regions and ecoregions of Scots pine. For comparisons by ecoregion, statistical differences in total volume were found in many ecoregions, which can be explained in part by the longitudinal, latitudinal and elevation properties that exist in the soil, the length of the season, growth rates and annual precipitation rates in these regions. This brings us to prove the importance of the

relationship between the volume, the diameter and the total height of the trees of the *Pinus sylvestris* var mongolica species studied.

Differences in height and diameter reported for the same northeast China ecoregions are probably the main factor behind the different volume models. The average bias varies at different percentage levels for the market value of wood in the two regions, the equations for total volume of trees specific to Scots pine and ecoregions are presented and can be easily used in situations of wood intrusion into the eight ecoregions, although there are significant volume relationships between the *Pinus sylvestris* species in the two regions studied for this case. The inappropriate application of overall or regional volume models to these different ecoregions for Scots pine in Eastern Daxing'an Mountains can in this case lead to significant errors in the estimation of total volumes.

Apart from all these investigations we recommend the following:

- Develop different models for different ecoregions wherever the data are favorable;
- Furthermore, the difference in the growth of *Pinus sylvestris* between the two regions as well as the eight ecoregions being explained in a summary manner, climatic research must be done in order to determine the factors responsible of the difference in tree growth between the two regions and the eight ecoregions on the one hand and on the other, to better understand the variations in the volume-diameter and height relationship on large scales;
- In the light of the results obtained during this study, the predicted volumes of *Pinus sylvestris* Var Mongolica trees, obtained through the development of models of volume equations in the two regions, can be used as explanatory variables for the calculation of the allowable cut by forestry managers. However, it is preferable to use the volume that has been predicted from ecoregional models since it enjoys, to our knowledge, unprecedented precision.
- Regarding the GIS aspect, the main objective of this article being to reflect the differences between regions and ecological regions from total volume models, in the future, we will recommend cartographic studies related to remote sensing at the level of different regions and ecoregions using GIS-based methods and finally to develop a quantitative and multivariate regionalization model capable of delineating ecoregions on several levels from remote sensed information and other spatial data on environmental and natural resources so have a general vision of the evolution of the forest cover and the landscape for each defined region and ecoregions. The development of the model will thus provide a new useful approach to the mapping of ecoregions for resource managers and researchers.

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