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Allometric equations for the estimation of above- and below-ground biomass for *Larix sibirica* Ledeb. in Northern Mongolia

Gerelbaatar Sukhbaatar[a,b], Dorjsuren Chimednyam[c], Baatarbileg Nachin[b], Batsaikhan Ganbaatar[d] and Alexander Gradel[e]

[a]Department of Environment and Forest Engineering, School of Engineering and Applied Sciences, National University of Mongolia, Ulaanbaatar, Mongolia; [b]Institute of Forest Science, National University of Mongolia, Ulaanbaatar, Mongolia; [c]Laboratory of Forest Phytocoenology, Botanic Garden and Research Institute, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia; [d]Devision of Forest Resources and Forest Protection, Institute of Geography and Geoecology, Mongolian Academy of Sciences, Ulaanbaatar, Mongolia; [e]Internationale Forstberatung Gradel, Goerlitz, Germany

ABSTRACT

The accurate estimation of tree above-ground (AGB) and below-ground (BGB) biomass components and their root/shoot ratio play key roles in stand and country-level forest biomass and carbon stock estimation. Nevertheless, site-specific and appropriate biomass equations and root/shoot ratio are hardly available for natural larch (*Larix sibirica* Ledeb.) forests in Mongolia. The present study aimed (1) to develop allometric equations to estimate the above- and below-ground biomass of *L. sibirica* trees, and (2) to estimate the root/shoot ratio applicable for estimating the root biomass based on above-ground biomass of natural larch forests in northern Mongolia. A total of 40 trees with DBH ranging from 6.8 to 40.8 cm were sampled for tree biomass analyses. For each biomass component, we calculated the proportion of biomass allocated to different components, and also tested four allometric equations based on diameter at breast height (DBH) and height (H) as independent variables. Our results, based on measurements of oven-dried biomass, revealed that stem biomass on average accounted for 44.5% and followed by branch (28.6%) and root (19.9%) biomass, respectively. Stem and branch biomass proportions were gradually increased with increasing DBH, while a contrary trend was observed for needles. The root/shoot ratio averaged 0.25. A comparison of the allocation of root biomass by diameter fractions showed an ever-growing trend of coarse roots with an increase in stem diameter, which often exceeded more than 50% of the total root biomass. However, biomass equations, which include both DBH and H were more precise than equations that are solely based only on DBH. Consequently, among the proposed allometric regression models for estimating the AGB and BGB, the equation $y = aD^bH^c$ was selected as the best-fitted equation for estimating each biomass component in Siberian larch forests. These allometric equations are available to be used for the estimation of natural larch forest biomass and carbon stocks in the Khentii Mountains of Mongolia, where extreme continental climate conditions dominate.

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Above- and below-ground biomass; root/shoot ratio; allometry; *Larix sibirica*; Northern Mongolia

1. Introduction

Tree biomass is an important predictor of the forest ecosystem, reflecting the accumulation of organic carbon and monitoring of ecosystem productivity (Madgwick 1991; Fang et al. 2014; He et al. 2018). The partitioning of above-ground (AGB) and below-ground biomass (BGB) is a core parameter of carbon cycling in terrestrial biomes (Gilmanov et al. 1997; Hui and Jackson 2006). The accurate estimates of carbon stocks depend on the availability and adequacy of the allometric equations used to estimate tree biomass (Jenkins et al. 2003; Fang et al. 2014). Species-specific allometric equations do exist for different forest regions (Muukkonen 2007; Hosoda and Iehara 2010; Battulga et al. 2013; Altanzagas et al. 2019), but they are not widely available for boreal trees. Especially, Litton and Kauffman (2008) emphasized that species-specific models remain more accurate than generalized models. In this regard, even where these models exist, they are often not transferable as the same species grow in a different environment (Usol'tsev 2017). In addition, the individual species allometry takes into account the differences in the relative distribution of each biomass component in total tree biomass (Hui and Jackson 2006; Wang et al. 2008). Several researches therefore noted that the most important variables for predicting AGB and BGB are the stem diameter, height, wood-specific density, and forest type

CONTACT Baatarbileg Nachin baatarbileg@num.edu.mn Institute of Forest Science, National University of Mongolia, Ulaanbaatar 14201, Mongolia

(Zianis et al. 2005; Ruiz-Peinado et al. 2012; Li and Zhao 2013).

Scientists use root/shoot ratio (R/S) as the most common approach for estimating BGB based on AGB (Marziliano et al. 2015; Kenzo et al. 2020). R/S ratios are considered as applied for estimating root biomass when reporting carbon stocks and changes in forest land (IPCC 2003). It is encouraged to use any other additional specific information on the development of C stock and stock change estimates (e.g. Mund et al. 2002; Goslee et al. 2016). This will greatly enhance the quality of greenhouse gas reporting to the UNFCC.

Accurate assessment of biomass measurement is an expensive undertaking (Peri et al. 2006; Yuen et al. 2013) as root excavation methods are expensive, site-specific, and depend on soil type, presence of hardpans, rock content, available equipment (Beets et al. 2007) and other factors. Thus, the root biomass is often just estimated based on the stem diameter of individual trees (Drexhage and Colin 2001; Muukkonen 2007). Nevertheless, the use of regression equations based on stem diameter has been questioned. The main reason for this is that the shoot weights are known to depend on both stem diameter and height (UN-REDD Programme 2018) and the height potential and therefore overall productivity is known to be site-specific (Peng et al. 2018).

In Mongolia exist two major forest biomes: boreal forests in the north accounting for 14.2 million hectares (87% of national forest cover). These forests are especially dominated by larch and birch and other conifer tree species, and 2.0 million hectares of saxaul forests (13%) in the south (FRDC 2016). Saxaul forests grow in relatively dry regions of the country. According to statistics, larch contributes around 70% to the tree species composition of forests in Mongolia (Tsogtbaatar 2004), while each of the remaining tree species ranges below 10% (UN-REDD 2018). In assessing the contribution to global warming mitigation and determining organic carbon stocks in Mongolian forest ecosystems, it is essential to develop appropriate allometric equations to estimate total tree biomass for major tree species. But, the development of allometric equations for estimating tree biomass in Mongolia is limited only to the AGB of some forest-forming tree species (Battulga et al. 2013; Dulamsuren et al. 2016; Usol'tsev et al. 2019), and exist needs to conduct research related to total tree biomass and R/S ratio for main tree species in the country.

Thus, original studies related to the BGB and R/S ratio from Mongolia are lacking. Therefore, our study aimed at (1) the development of allometric equations for the estimation of AGB and BGB of *Larix sibirica* trees; (2) the estimation of the R/S ratio for the estimation of root biomass based on AGB in Mongolian larch forests.

2. Material and methods

2.1. Study area

Our study area is located in the Tuv province (48°26′–49°2′N; 106°46′–109°35′E), in an area in the western part of the Khentii Mountains (Figure 1). This area is part of the South Transbaikal forest region of Mongolia. The elevation ranges between 1300 and 1500 m above sea level. The natural forests of the study area are dominated by *L. sibirica*, with the occasional occurrence of *Betula platyphylla* Sukaczev and *Pinus sylvestris* L.

Forest distribution coincides with the geographical distribution of seasonal permafrost soil in the country, exhibiting an ultra-continental semihumid climate. According to information from meteorological stations, the annual rainfall is around 242 mm, and the mean annual air temperature is 0.4 °C. In northern Mongolia, most precipitation is falling during July and August. Black soils with relatively high clay content and organic matter dominate in our study region.

2.2. Sampling and data collection

All field data collection and sampling were conducted between June and August 2019. From each sample plot (4 plots), 10 sample trees of large, medium, and small representative trees were selected. Trees were cut as close as possible to the ground surface for the preparation of samples. Following felling, we determined the fresh weight for stems, branches, and leaves separately. The stem and branches were cut and weighed using a standard balance of 150 kg capacity with an accuracy of 1 g. We took disk samples of stems at different tree heights in 0.5 m intervals for smaller trees, and 2 m intervals for larger trees. We calculated stem volume with bark based on tree height and stem diameter at breast height. Whole root systems, including fine and coarse roots, were carefully excavated by hand. Live and dead roots were hand-sorted together from the material remaining in the sieve. We determined the weights of fresh coarse (≥5 mm in diameter) and fresh fine roots (<5 mm) in the field. All roots were sorted into the following diameter classes: ≤0.5 cm, 0.5–1.99 cm, 2.0–4.99 cm, and ≥5.0 cm, respectively. With regard to AGB, we collected all needles from sample trees by hand and recorded their fresh weight. Tree disks and samples of needles, branches, and roots were taken for further laboratory analysis. We oven-dried and weighed each fresh biomass sample at 75 °C (root and needle) and 105 °C (stem and branch), respectively. Overall we used a total of 40 *L. sibirica* trees for our biomass analyses.

2.3. Statistical analyses

Reviewing the literature we concluded that there are no sufficient specific allometric equations to determine the total biomass of *L. sibirica* in Mongolia. Therefore we selected and tested more generic allometric equations in terms of similarity to the species type and regions (Europe, America, Asia). We used the following allometric equations to estimate AGB and BGB (Table 1).

To develop allometric regression models to estimate the AGB, y (in kg dry weight) of larch from DBH (cm) and tree H (m), we applied the approach of Hosoda and Iehara (2010), who modeled AGB in *Larix kaempferi* Lamb. Model parameters were determined using nonlinear regression (Payandeh 1981). We calculated separate models for the biomass of needles, branches, stems, and roots, respectively. We tested residuals for homoscedasticity using the Breusch–Pagan test ($p \leq 0.05$ indicates heteroscedasticity). Finally, we checked the accuracy of various biomass estimates from the equations in Table 1 against measured biomass data using four indices.

$$\mathrm{RMSE}(\%) = \sqrt{\sum_{i=1}^{n}\left(\frac{\left(y_i - y_i^{'}\right)^2/y_i}{n}\right)} \times 100 \quad (1)$$

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - y_i^{'}\right)^2}{n}} \quad (2)$$

$$\mathrm{Bias\ (kg)} = \sum_{i=1}^{n}(y_i - y_i^{'})/n \quad (3)$$

$$R^2 = \mathrm{FI} = 1 - \frac{\sum_{i=1}^{n}\left(y_i - y_i^{'}\right)^2}{\sum_{i=1}^{n}\left(y_i - \square\right)^2} \quad (4)$$

Where

- y_i = real biomass,
- $y_i^{'}$ = estimated biomass using equations of Table 1,
- $\square$ = average of real biomass,
- n = number of observations,
- FI = fit index,
- RMSE (in kg or %) = root mean square error,
- Bias (kg) = mean bias in kg.

Independent parameters used in Equations (1–4) include:

- Observed biomass (y_i).
- Mean observed biomass (y).
- Biomass estimated using equations of Table 1 ($y_i^{'}$)
- Number of tree samples (n)

These indices are linked to the respective parameter to test for deviations of the simulated biomass values from actual harvested trees. A respective validation procedure was applied (Hosoda and Iehara 2010). We used weighted least squares regression to accent the heterogeneity. The model parameter in our models was calculated with SAS 9.13 software (SAS Institute Inc., Cary, NC, USA).

Table 1. Allometric equations used to estimate above- and below-ground biomass for *L. sibirica* L.

Source	Allometric equation forms	Note
Schumacher and Hall (1933)	$y = aD^b$	1
Kira and Shidei (1967),	$y = a(D^2H)^b$	2
Jenkins et al. (2003)	$y = aD^bH^c$	3
Muukkonen (2007)	$y = D^2H)/(a + bD)$	4

3. Results

3.1. Relative distribution of biomass by tree biomass components

An overview of the descriptive statistics of the measured variables is presented in Table 2. Regarding differences in tree sizes for selected sample trees, we found a high variation not only among tree morphological parameters ($p < 0.001$), but also in biomass variables ($p < 0.001$). In our study, the mean height, DBH, and volume for selected trees were 14.6 ± 5.5 m, 21.4 ± 10.0 cm, and 0.4 ± 0.3 m^3, respectively (Table 2).

The volume of the largest diameter was 1.23 m^3 (Table 2). Regarding tree biomass structure, we found that the predominant part of the total biomass (TB) belonged to the biomass of stem (SB) (44.5%), followed by biomass of branches (BB) (28.6%) and roots (BGB) (19.9%) (Figure 2). Contrarily, the biomass of needles (NB) was less than 7.0% in the TB. Based on the estimation of AGB and BGB, we estimated that the R/S ratio in the study region averaged 0.25, varying from 0.32 for the smallest and 0.28 for the largest diameter class. The comparison of the allocation of root biomass by diameter fractions showed a growing trend of the relative increase of coarse roots (≥5 cm) often exceeding more than 50% of total root biomass. Moreover, the appearance of fine roots tended to decrease relatively with increasing DBH, and the smallest root diameter fraction at the largest DBH class finally accounted for only less than 5% of the overall BGB (Figure 3).

Table 2. Statistical characteristics of tree biomass components.

Variables	n	Max.	Min.	Mean	SE	SD	Skewness	Kurtosis
Tree parameters								
Height, m	40	23.8	3.3	14.6	0.9	5.5	−0.170	−0.90
DBH, cm	40	40.8	4.4	21.4	1.6	9.9	0.103	−0.918
Volume, m^3	40	1.2	0.004	0.4	0.1	0.3	0.807	−0.409
Tree biomass, kg/tree								
Stem biomass (SB)	40	532.4	2.1	175.7	24.9	157.4	0.691	−0.831
Branch biomass (BB)	40	419.3	0.5	113.0	19.3	121.9	1.108	0.144
Needle biomass (NB)	40	69.5	0.3	27.5	3.5	22.3	0.410	−1.200
Above-ground biomass (AGB)	40	973.1	2.9	316.2	47.3	299.4	0.821	−0.556
Below-ground biomass (BGB)	40	268.9	0.9	78.6	11.8	74.3	1.020	0.145
Total biomass (TB)	40	1241.3	3.9	394.7	58.9	372.3	0.849	−0.448
Root/shoot ratio	40	0.28	0.22	0.25	0.01	0.08	2.301	8.808

Note. n: total number sample trees; Max.: maximum value; Min.: minimum value; SE: standard error; SD: standard deviation

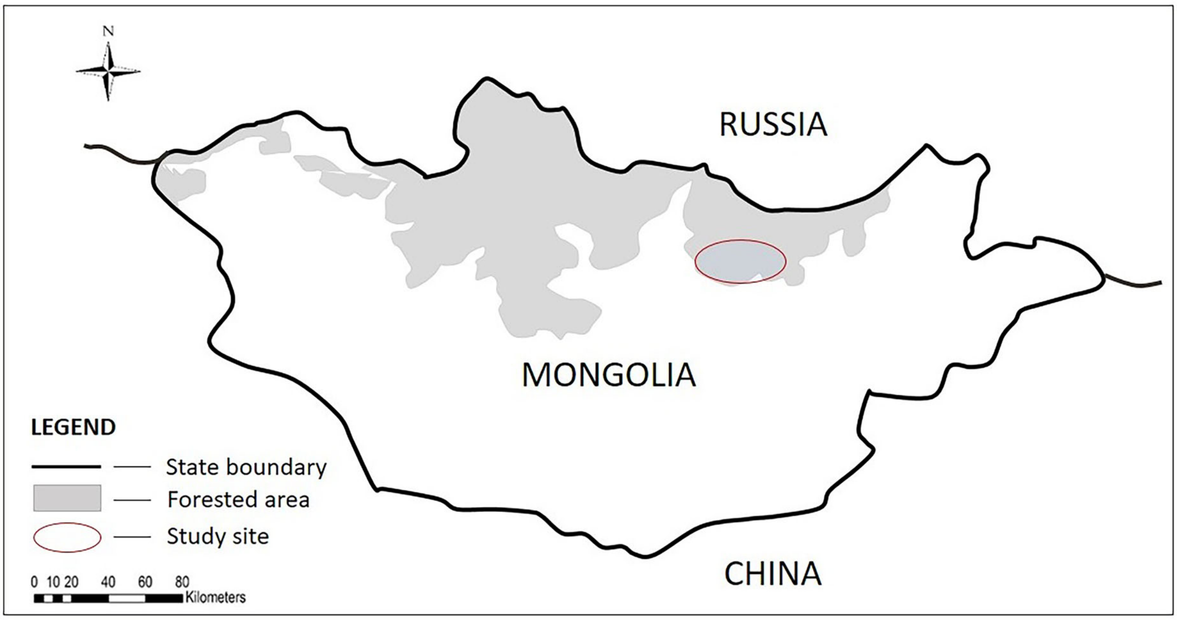

Figure 1. Location of the study area.

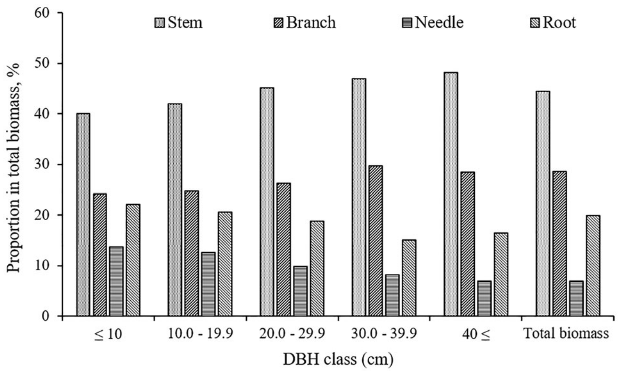

Figure 2. Proportion of each biomass component in total tree biomass.

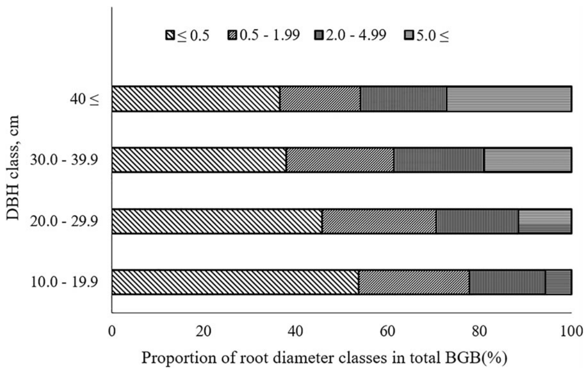

Figure 3. Relative distribution of root diameter fractions in total root biomass depending on DBH classes.

3.2. Biomass model fitting

Table 3 shows the necessary coefficients of proposed equations that are available for estimating the biomass of each of the tree biomass components. The parameters obtained from this study showed a relatively high correlation with real biomass data, which often exceeded $R^2 = 0.9$ (Table 3).

Our results, therefore, showed different means of fitting the index among purposed equations. The tree biomass estimated using Jenkins' equation (Table 3; Jenkins et al. 2003) was closest to actual tree biomass, indicated by the applied statistical parameters. In addition, for whole tree biomass components involving both AGB and BGB parts, Jenkins' equation with parameter estimates from weighted regression was selected as the best fitting among suggested equations, which had the lowest values of bias, percentage RMSE, absolute RMSE, and highest FI (Table 3). We conclude that the equation form $y = aD^bH^c$ (Jenkins et al. 2003) was the most convenient for estimating both AGB and BGB of *L. sibirica* trees in Mongolia, which takes into account tree height and DBH values for the estimation.

4. Discussion

4.1. Biomass allocation and root/shoot ratio

Estimation of AGB and BGB plays an important role in evaluating the organic carbon stocks and their dynamics (Goodale et al. 2002; Liski et al. 2003; Houghton 2005; Yuen et al. 2013). The ratio of tree BGB to AGB is referred to as the R/S ratio (IPCC 2006), which can be used to estimate BGB from a relatively easily measured AGB for carbon estimation and modeling (Jiang and Wang 2017). In some regions of France (Drexhage and Colin 2001), the USA (Jenkins et al. 2003), Argentina (Peri et al. 2006), and New Zealand (Beets et al. 2007) have estimated R/S ratios for their main forest-forming tree species that used to organic carbon stocks and contribution to climate change mitigation. However, the references emphasize that there can be quite large intraspecific differences in terms of biomass distribution (Forrester et al. 2017; Kenzo et al. 2020). Therefore, we consider the results of our study on *L. sibirica* as being particularly

Table 3. Comparison of statistical characteristics of regression models used to estimate the AGB and BGB biomass estimation for *L. sibirica*.

Model		Parameters	SE	RMSE, kg	RMSE, %	Bias, kg	R^2	p-Value
Stem								
$y = aD^b$	*a*	0.023	0.009	30.5	26.3	−4.1	0.91	0.239
	b	2.665	0.107					
$y = a(D^2H)^b$	*a*	0.145	0.047	26.5	21.4	−2.8	0.93	0.242
	b	0.78	0.032					
$y = aD^bH^c$	*a*	0.057	0.022	22.5	17.9	−1.7	0.95	0.315
	b	0.321	0.324					
	c	2.514	0.453					
$y = (D^2H)/(a + bD)$	*a*	21.87	5.003	24.6	18.8	−2.6	0.94	0.259
	b	1.229	0.156					
Branches								
$y = aD^b$	*a*	0.023	0.009	21.0	25.1	−3.8	0.93	0.270
	b	2.665	0.107					
$y = a(D^2H)^b$	*a*	0.008	0.003	18.1	19.2	−1.0	0.95	0.311
	b	1.033	0.038					
$y = aD^bH^c$	*a*	0.002	0.001	16.2	16.1	2.6	0.98	0.469
	b	0.777	0.34					
	c	2.936	0.501					
$y = (D^2H)/(a + bD)$	*a*	93.271	10.513	18.2	20.6	−2.2	0.94	0.221
	b	−0.113	0.301					
Needles								
$y = aD^b$	*a*	0.127	0.04	5.5	16.7	−1.2	0.86	0.213
	b	1.729	0.093					
$y = a(D^2H)^b$	*a*	0.076	0.027	5.0	14.3	−0.6	0.87	0.210
	b	0.653	0.036					
$y = aD^bH^c$	*a*	0.032	0.014	4.5	13.4	−0.5	0.9	0.252
	b	0.0001	0.414					
	c	2.444	0.567					
$y = (D^2H)/(a + bD)$	*a*	29.442	32.581	4.8	13.7	−0.5	0.9	0.278
	b	11.926	1.094					
Above-ground total								
$y = aD^b$	*a*	0.211	0.067	48.7	30.6	−6.9	0.93	0.224
	b	2.305	0.091					
$y = a(D^2H)^b$	*a*	0.1275	0.037	40.6	24.1	−4.6	0.95	0.230
	b	0.854	0.028					
$y = aD^bH^c$	*a*	0.048	0.016	32.9	18.9	−4.7	0.97	0.333
	b	0.506	0.26					
	c	2.564	0.369					
$y = (D^2H)/(a + bD)$	*a*	18.453	2.539	37.7	17.5	−4.7	0.95	0.220
	b	0.462	0.077					
Below-ground total								
$y = aD^b$	*a*	0.035	0.009	9.4	9.9	−0.2	0.97	0.427
	b	2.424	0.073					
$y = a(D^2H)^b$	*a*	0.022	0.006	9.9	9.4	0.1	0.98	0.495
	b	0.893	0.029					
$y = aD^bH^c$	*a*	0.034	0.012	9.4	9.8	−0.1	0.98	0.430
	b	2.388	0.303					
	c	0.051	0.415					
$y = (D^2H)/(a+bD)$	*a*	95.514	11.961	10.1	9.5	0.4	0.99	0.392
	b	1.223	0.355					

Note. D: diameter; H: height; RMSE: root mean square error; SE: standard error of parameter estimates *a*, *b*, *c*; R^2: coefficient of determination; p-values are results of Breusch–Pagan test for homoscedasticity (data are heteroscedastic at $p \leq 0.05$).

representative of the specific conditions of the Mongolian Khentii mountain range. Since there are no similar intensive studies from other regions of the country, we consider our results to be the most suitable for application in Mongolia. Our study revealed that the mean R/S ratio in the study region amounted to 0.25. This mean is consistent with Cairns et al. (1997) (USA) and Wang et al. (2008) (China), who confirmed that the R/S ratio in primary conifers ranges between 0.23 and 0.25 (in larch forests 0.25, in spruce 0.24 and in pine 0.23). In comparison, the mean R/S ratio in our study area was comparable to those in northeastern China and Russian Siberia. It is also in the general range of conifer trees mentioned in other studies (Lee et al. 2018). There is a strong indication that poor water and nutrient availability can lead to relatively higher root biomass in conifer trees (Gower et al. 1992, Buras et al. 2020). This has been specifically also noted for larch species in Siberia by Kajimoto et al. (1999; 2006), who concluded that the relatively large root mass observed on their study sites was primarily a result of investment of annual carbon gains in roots growing in the nutrient-poor, permafrost soils. The slightly higher R/S ratio in BGB for the younger trees may be due to the increased need of sufficient water and nutrients. For other species, even under different conditions, this relationship between tree size and R/S ratio is similar as shown by Marziliano et al. (2015) in the example of the rather short Mediterranean tree species *Phillyrea latifolia*. In this study, the R/S also decreased with increasing tree size. However, the ratio was with values of up to 0.8, generally at a higher level compared to our findings for larch. The R/S ratio for large teak trees in Thailand

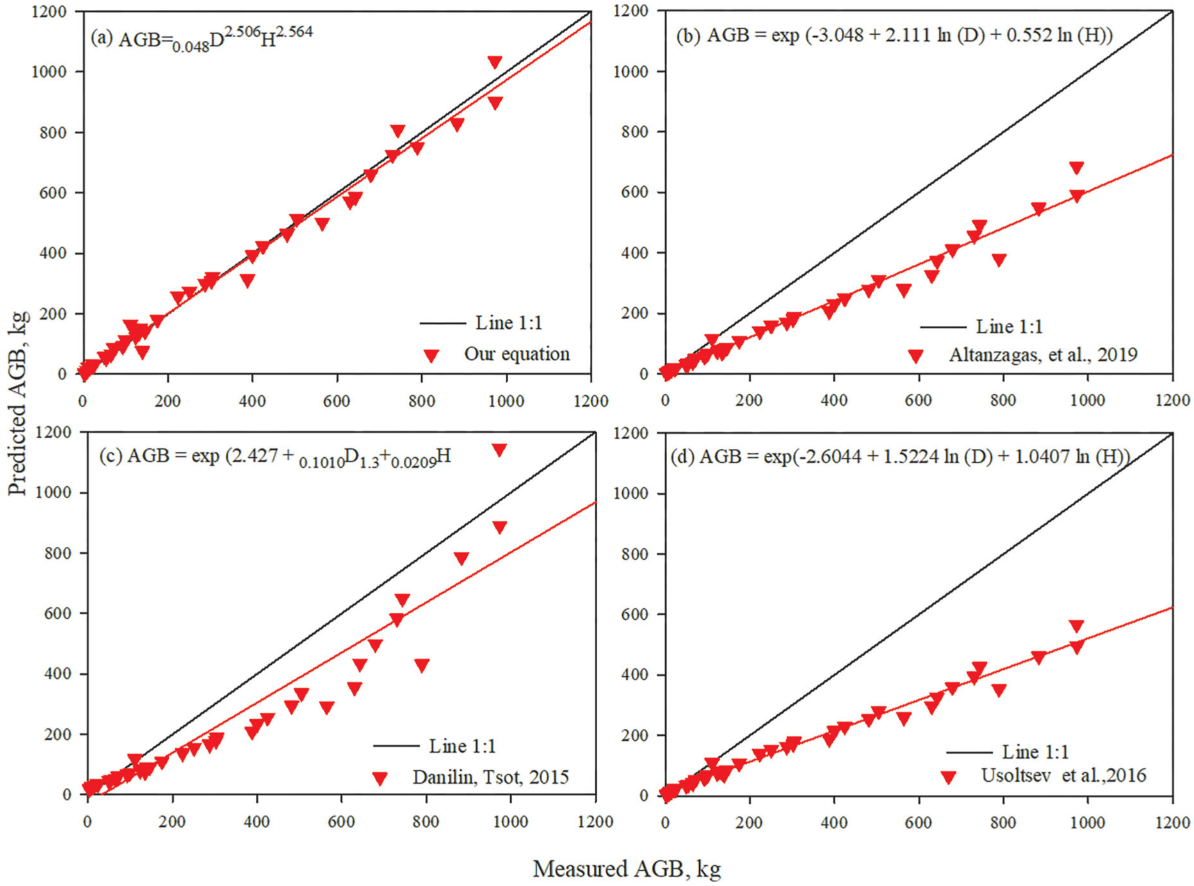

Figure 4. Total ABG predicted with our selected and alternative equations. Measured total AGB is represented with 1:1 line. Inverted triangles represent the predicted AGB biomass of Siberian larch sample trees. (a) Predicted AGB biomass with our best equation AGB $= 0.048 \times (D^{2.506}) \times (H^{2.564})$; (b) predicted AGB with equation from Altanzagas et al. (2019); AGB $= \exp(-3.048 + 2.111 \times \ln(D) + 0.552 \times \ln(H))$; (c) predicted AGB with equation from Danilin and Tsogt (2015) AGB $= \exp(2.427 + 0.1010 \times D_{1.3} + 0.0209 \times H)$; (d) predicted AGB with equation from Usol'tsev et al. (2016) AGB $= \exp(-2.6044 + 1.5224 \times \ln(D) + 1.0407 \times \ln(H))$.

ranged from 0.17 to 0.33 with an average of 0.23 (Kenzo et al. 2020). These values are also very similar to ours, and these values were obtained from a tropical deciduous tree species. This estimate is close to the R/S ratio we found for Siberian larch in our study.

4.2. Selected biomass prediction model

A number of researchers have noted that the developed biomass equations based on DBH and H are more accurate than equations based solely on DBH (Payandeh 1981; Zianis and Mecuccini 2002; Muukkonen 2007; Battulga et al. 2013) and are of great importance for estimation of organic carbon dynamics and forest ecosystem functioning (Brown 2002; Goodale et al. 2002; Bjarnadottir et al. 2007). Our findings have led to the estimation of AGB and BGB for *L. sibirica*, one of the most common tree species in Mongolian forest ecosystems. Here, the statistical values for all the equations developed in our assessment were consistently significant and showed strong adaptability to the values.

Consequently, among the proposed allometric regression models for estimating AGB and BGB, the equation $y = aD^bH^c$ (Jenkins et al. 2003) was selected as the most fitting equation for estimating the biomass of Siberian larch trees. Furthermore, we performed comparative analyses with estimated AGB and BGB values using models developed by Usol'tsev et al. (2016) for Eurasia, Altanzagas et al. (2019) for Central Khangai, Danilin and Tsogt (2015) for northeastern Khangai in Mongolia (Figures 4 and 5). Simultaneously, the line built in accordance with our estimated values was closest to line (1:1) for both AGB and BGB. Based on comparative graphs, we can see that all these equations underestimate both AGB and BGB.

Here we presented a comparison of our best-fitting biomass model for the estimation of AGB and BGB with alternative equations that were developed for larch forests in different regions of Eurasia using 1:1 line. In comparison, all these selected biomass models showed underestimated values compared to our values ranging from 75 to 150 kg (Figures 4 and 5). The 1:1 line presented in Figures 4 and 5 indicated that our developed biomass models are well-fitted only for the Khentii mountains, Mongolia. For BGB estimation, the biomass model developed model by Usol'tsev et al. (2016) underestimated 25 to 28 kg (Figure 4).

Accurate estimation of tree biomass and organic carbon stocks accumulated in the forest ecosystems plays an important role in assessing each country's contribution to mitigating global warming. With this regard, the Paris Agreement stated that "parties shall account for their Nationally Determined Contributions (NDC)," including agriculture, forestry, and other land

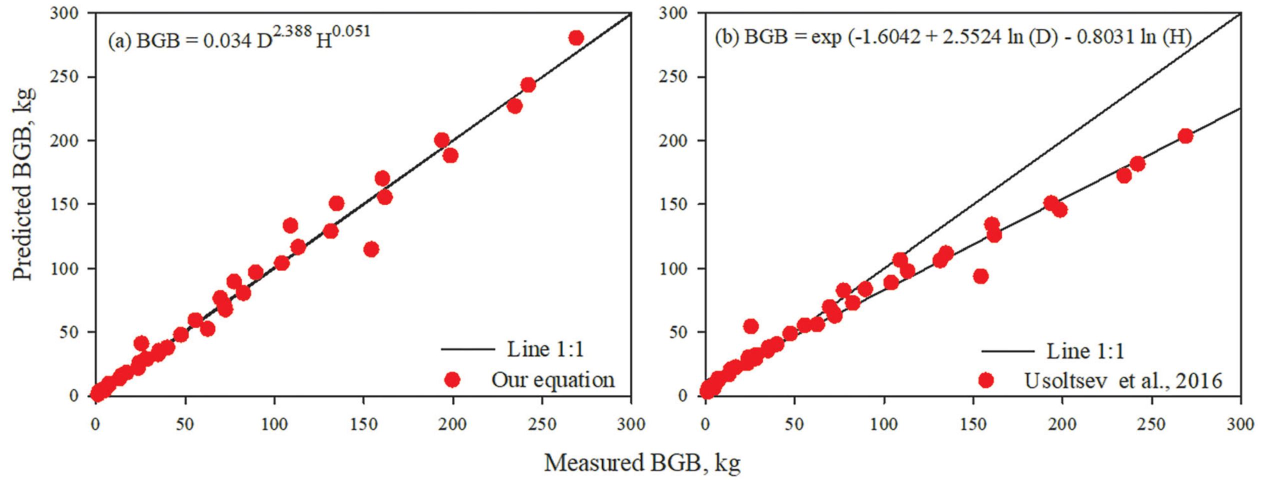

Figure 5. Below-ground biomass predicted with our selected equation and an alternative equation that was developed for larch forests in Eurasia. Measured BGB is represented with 1:1 line. Circles represent the predicted BGB of Siberian larch sample trees. (a) Predicted BGB with our selected equation $BGB = 0.034 \times (D^{2.388}) \times (H^{0.051})$. (b) Predicted below-ground biomass with equation from Usol'tsev et al. (2016); $BGB = \exp(-1.6042 + 2.5524 \times \ln(D) - 0.8031 \times \ln(H)$.

use sectors (UNFCCC 2015). In addition, several studies (Mokany et al. 2006; Lee et al. 2018) and reports (UN-REDD Programme 2018; MET decree A/533 2019) therefore highlighted the need for robust R/S ratio to improve the accuracy of root biomass estimates, including requirements for assessing the impact of land management and land-use change in national GHG reporting. The developed biomass models and R/S ratio for *L. sibirica* good fitted with real biomass measurements (Figures 4 and 5). Here, the difference between the predicted and measured biomass means for AGB was only 12.5 kg (7.9%). Hence, we conclude that our developed allometric equations and estimated R/S ratio are reliable for further estimation of tree biomass in natural larch forests in the Khentii mountains in northern Mongolia.

5. Conclusion

The development of allometric models for predicting tree biomass applicable to a specific forested region is critical not only for accurate accounting of carbon stock for REDD + but also for silvicultural purposes. Our findings, including allometric equations and R/S ratio, are particularly applicable to the boreal larch forests in Mongolia and will play an important role in estimating the organic carbon stocks of trees. Our results revealed that stem biomass averaged 44.5%, followed by branches (28.6%) and roots (19.9%) biomass, and the root/shoot ratio averaged 0.25. A comparison of the allocation of root biomass by diameter fractions showed an ever-growing trend of coarse roots with increasing stem diameter, often exceeding more than 50% of the total root biomass. However, biomass equations, which include both DBH and H were more precise than equations that are solely based only on DBH. Consequently, among the proposed allometric regression models for estimating the AGB and BGB, the equations $y = {}_{0.048}D^{0.506}H^{2.564}$ and $y = {}_{0.034}D^{2.388}H^{0.051}$ were selected as the best-fitted equations for Siberian larch forests. These allometric equations can be used to estimate the biomass of natural larch forests and carbon stocks in the Khentii Mountains of Mongolia.

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ORCID

Gerelbaatar Sukhbaatar http://orcid.org/0000-0002-9561-5256
Dorjsuren Chimednyam http://orcid.org/0000-0002-7104-3353
Baatarbileg Nachin http://orcid.org/0000-0002-3489-1257
Batsaikhan Ganbaatar http://orcid.org/0000-0001-7752-2286
Alexander Gradel http://orcid.org/0000-0002-6298-4151

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