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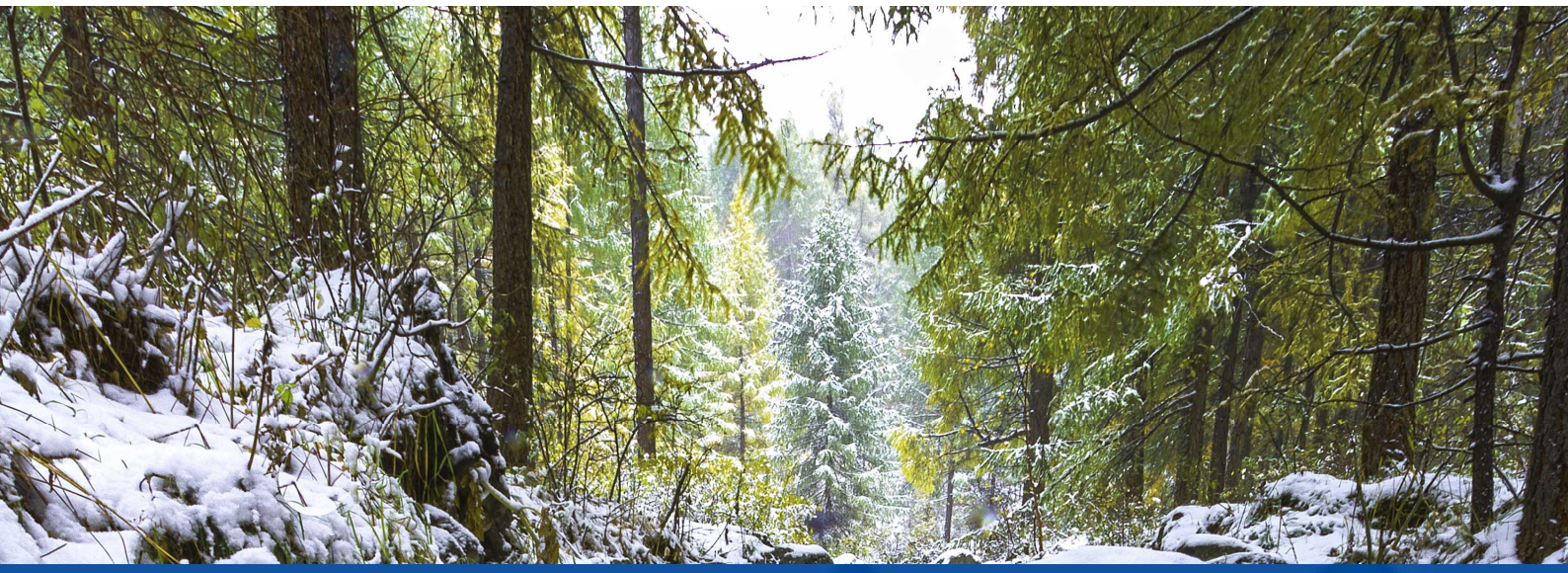

Estimating the Belowground Biomass and Root/Shoot Ratio of Larch forest in Northern Mongolia

Research Report of Young Forest Society NGO

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INTRODUCTION

Estimates of carbon (C) stocks and stock changes in tree biomass (above- and belowground) are required for reporting to the United Nations Framework Convention on Climate Change (UNFCCC) and will be required for Kyoto Protocol (KP) reporting. For countries which have certain amounts of afforestation, deforestation and reforestation, nationally specific information that can be used in the development of C stock and stock change estimates will greatly enhance the quality of greenhouse gas (GHG) reporting to the UNFCCC. Therefore, the Intergovernmental Panel for Climate Change (IPCC) highlights the importance of nationally specific information, regarding a country's forest resources, in order to increase the transparency and verifiability of national C inventories.

However, temperate and boreal forests act as major sinks for atmospheric CO_2 (Goodale et al., 2002), and have received increasing attention for the much greater climatic warming in mid- and high-latitudes compared with low-latitudes (IPCC, 2007). Understanding of forest biomass pattern is important for improving the estimation of carbon pools and predicting the carbon budgets in response to climate change (Brown, 2002; Houghton, 2005). The partitioning of above-and belowground biomass is a core parameter of carbon cycling in terrestrial biomes (Gilmanov et al., 1997; Hu and Jackson, 2005). Root: shoot ratio (R/S) is one of the most common descriptors of the relationship between root and shoot biomass, which has become a key method for estimating below-ground biomass (BGB) from above-ground biomass (AGB).

The biomass of root systems is difficult and expensive to measure accurately in forest trees. In addition, sampling protocols differ among studies, with the root excavation methods employed often dictated by site conditions, for example, the type of soil, the presence of hardpans, the rock content, and the type of equipment available (Beets et al., 2007). Root systems can extend both laterally and vertically to a considerable distance, and roots of different trees are usually interlaced. Comprehensive studies aim to extract the majority of the root system, which excludes the above-ground biomass in different regions (Watson and O'Loughlin, 1990; Mund et al., 2002). Root weight of individual trees can be estimated from stem diameter (Drexhage and Colin, 2001).

The use of regression equations based on stem diameter has been questioned, because shoot weight is known to vary with both stem diameter and height, whereas diameter-based estimates of root weight would be the same irrespective of tree height. However, the IPCC (2003) has proposed that root/shoot ratios are an acceptable method of estimating root biomass when reporting carbon stocks and changes in forest land and land converted to forest. Madgwick's analysis (Madgwick, 1991) showed that there was a rapid convergence of sample-

tree-based estimates towards the expected stand value as sample size increased above five trees, and that a sample of 12–17 trees yielded estimates within 5% of the stand biomass.

According to statistics Mongolia supports two major forest biomes, boreal forests in the north accounting for 14.2 million hectares (87%), dominated by larch and birch, and 2.0 million of sexual forests (13%) (FRDC, 2016), which typically grow on mountain slopes between 800-2500 m above sea level. In terms of growing stock, larch contributes around 80 percent, while all other trees are below 10 percent (UN-REDD, 2018).

The field biomass measurements, laboratory measurements of samples and data processing were conducted by the researchers:

Team leader: Dr. S.Gerelbaatar (National University of Mongolia)

Team member:

- Dr. P. Battulga (Institute of Geography and Geoecology, MAS)
- Dr. Z.Tsogt (Institute of General and Experimental Biology, MAS)
- Ms.S G.Batsaikhan (Institute of General and Experimental Biology, MAS)

A total of 4 students participated in the processes of field data collection, and laboratory measurements within the framework of this study.

The objective of our study were to:

1) Develop allometric equations to estimate the carbon in above-ground and below-ground biomass of larch stands
2) Estimate root/shoot ratio suitable for estimating root biomass in natural Larch forests in the northern Mongolia.

METHODS AND MATERIALS

Study area

The study was carried out on natural larch forests located in Batsumber soum of Tuv province which belongs to the West Khentii mountain range in Mongolia. The site is located within the south-eastern end of the continuous distribution of permafrost soils of Siberia. In this region, forests are generally dominated by *Larix sibirica* with occasional *Betula platyphylla* Sukaczev *Picea obovata* Ledeb. The climate is typically semi-humid harsh continental. Mean annual air temperature is 0.4 °C. Annual precipitation is 242 mm. Snowfalls generally begin in early October and continue until early May. Snow accumulation reaches a maximum of about 30 cm in March.

Destructive sampling

In summer 2018, a total of 40 *Larix sibirica* trees differing in stem diameter were harvested for biomass analyses. Fresh weights of three aboveground living components (stems, branches, and leaves) of these sample trees were measured separately. For the larger sample trees, fresh weights of branches and needles were estimated based on a subsample of branches taken randomly from different positions (top, middle and lower) in each crown (total fresh weight of branches with needles). Dry weights of aboveground parts were calculated based on the corresponding dry/fresh weight ratios obtained from oven-dried (105 °C) samples. Disk samples of stems were taken at different heights: at 0.5 m intervals for smaller trees and at 2 m intervals for larger trees. Stem volume with bark and tree height were calculated.

Root systems of all sample trees were investigated. All roots of each tree were excavated carefully by hand. Fresh weights of coarse (≥ 5 mm in diameter) and fine roots (<5 mm) were measured in the field, while fine roots were sorted into three diameter classes (≤ 0.5 cm; 0.5 – 2.0 cm; 2.0 – 5.0 см and ≥ 5.0 см), and their dry weights were determined based on the corresponding dry/fresh weight ratios obtained for subsamples. Root disks were collected at the locations where root diameter was measured. Relative horizontal and vertical positions of these roots also were mapped. Aboveground biomass was defined as the sum of dry weights of stems, branches, and needles of all larch trees in the permanent plot. Cones were excluded because few cones were present. Belowground biomass was estimated as the sum of dry weights of coarse roots and fine roots.

Statistical analyses

First, the stem volume in terms of plot measurements was calculated using equation (1):

$$V = ba1.3 \times h \times f1.3 \qquad (1)$$

where: V – stem volume (l), ba1.3 – basal area at DBH (m), h – height (m), f1.3– form factor.

Stem biomass from wood volume to wood biomass was estimated using the following equation: $W = V \times R$ (2)

where: W – weight (kg), V – stem volume (l), R – basic wood density (kg dry matter m^{-3} fresh volume).

Due to the lack of specific allometric equations for the selected tree species in Mongolia, we selected allometric equations from other countries that are more generic based on similarity to the species type. We collected number of allometric equations around Europe, America and Asia in terms of the geographical distribution of sampled trees, the range of dimensions (d, h) of sampled trees, accounted dimensions and applied definitions. We used following four allometric equations for estimating above- and belowground biomass developed by

Schumacher and Hall (1933) (involving nine tree species), Kira and Shidei (1967)(three conifers), Jenkins et al., (2003)(twenty two woody species) and Muukkonen (2007)(seven tree species) on the basis of biomass study in Europe, Asia and America. In the context of geographical distribution Mongolian larch forests belonged to northern boreal forests. These four allometric equations are considered as the most common models for estimating above- and belowground biomass especially in northern hemisphere.

$$W=aD^b \quad (1)$$

$$W=a(D^2H)^b \quad (2)$$

$$W=aD^bH^c \quad (3)$$

$$y = (D^2 H)/(a+bD) \quad (4)$$

The selection of allometric regression models for estimating the above-ground biomass y (in kg dry weight) of larch from DBH D (in cm) and tree height H (in m) followed Hosoda & Iehara (2010), who modeled the above-ground biomass in *Larix kaempferi* and two further species of coniferous trees. The parameters a, b and c in the models were calculated with SAS 9.13 software (SAS Institute Inc., Cary, North Carolina, U.S.A.). The parameters were determined through nonlinear regression following Payandeh (1981) and Zianis and Mencuccini (2003) assuming an additive error. Models were calculated separately for the stem, branch, needle and root biomass. The residuals were tested for homoscedasticity with the Breusch-Pagan test (with $p \leq 0.05$ indicating heteroscedasticity). The accuracy of the different biomass estimates from equations (1) to (4) was validated against the measured biomass data using four indices, viz. the root mean square error (RMSE; in kg or %), the mean bias (in kg), and the Fit index (FI):

$$RMSE(\%) = \sqrt{\sum_{i=1}^{n}((y_i - y'_i)/y_i)^2/n} \cdot 100 \quad (5)$$

$$RMSE(kg) = \sqrt{\sum_{i=1}^{n}(y_i - y'_i)^2/n} \quad (6)$$

$$Bias(kg) = \sum_{i=1}^{n}(y_i - y'_i)/n \quad (7)$$

$$FI = 1 - \frac{\sum_{i=1}^{n}(y_i - y'_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (8)$$

Where: y_i -real biomass,

$\bar{y}_i$ -estimated biomass using equation,

$\bar{y}$ -average of real biomass,

n-number of observations

The independent parameters used in equation (5) to (8) include the observed biomass (yi), the mean of the observed biomass (y), the biomass estimated using the Equations 1 to 4 (y'i), and the number of sample trees (n). The indices used are related parameters to test the deviation of the modeled biomass values from the ones estimated for the harvested trees. The validation procedure also follows closely Hosoda and Iehara (2010). The total biomass was calculated as the sum of the best models for stem, branch, needles and root biomass

$$y = y_{stem} + y_{branches} + y_{needles} + y_{root} \quad (9)$$

The biomass equations were then used to analyze the relationships of total biomass with stem diameter and tree height in a larger collective of trees from the studied stands.

RESULTS AND DISCUSSION

The results of fresh weight by biomass components were illustrated in Table 1. The above-ground biomass included the stems, branches and needles, and the below-ground biomass include the root biomass, respectively.

Table 1. Fresh weight of the above- and belowground biomass components of sampled trees

Sample	DBH (cm)	Height (m)	Above-ground biomass (kg)				Root biomass (kg)	Total biomass (kg)
			Stem	Branch	Needle	Above-ground biomass		
BM-1	10.2	8.3	30.20	5.09	4.71	40.00	14.50	54.50
BM-2	6.8	6	9.90	2.34	2.16	14.40	4.10	18.50
BM-3	4.4	3.3	3.50	1.35	1.15	6.00	1.56	7.56
BM-4	4.8	4.5	5.00	1.57	1.33	7.90	2.09	9.99
BM-5	7.3	7.6	15.80	2.77	2.43	21.00	9.62	30.62
BM-6	14.3	11.2	85.30	29.57	18.93	133.80	46.25	180.05
BM-7	20.5	13.3	102.60	33.23	69.37	205.20	114.54	319.74
BM-8	18.6	10.1	138.54	103.51	35.04	277.08	52.66	329.74
BM-9	25.5	16.4	348.40	259.12	89.28	696.80	166.52	863.32
BM-10	28.2	19.3	556.60	312.33	144.27	1113.20	327.76	1440.96
BM-11	30.0	20.06	578.90	432.29	123.71	1134.90	211.04	1345.94
BM-12	31.5	22.1	668.30	526.33	139.17	1333.80	257.63	1591.43
BM-13	35.5	22.22	762.20	605.57	156.63	1524.40	410.15	1934.55
BM-14	40.8	23.8	958.50	779.56	178.94	1917.00	547.21	2464.21
BM-15	22.7	15.93	256.10	173.01	83.09	512.20	133.91	646.11
BM-16	16.0	13.56	128.47	82.28	46.18	256.93	51.72	308.65
BM-17	11.7	9.95	46.79	26.74	20.05	93.58	25.64	119.22
BM-18	8.4	7.2	14.12	6.36	5.12	25.61	8.43	34.03
BM-19	9.6	7.9	25.58	9.67	7.24	42.49	12.22	54.71
BM-20	12.5	9.5	61.56	22.14	14.31	98.01	26.46	124.47
BM-21	13.2	10.2	72.00	26.27	16.47	114.74	30.97	145.71
BM-22	15.3	11.3	107.41	41.75	24.11	173.27	47.04	220.31
BM-23	16.1	12.1	120.58	48.04	27.07	195.69	53.23	248.92
BM-24	16.8	12.4	136.46	55.99	30.70	223.15	60.83	283.98
BM-25	17.4	12.8	148.96	62.51	33.62	245.08	66.88	311.96
BM-26	17.9	12.9	159.75	68.32	36.17	264.24	72.16	336.40
BM-27	19.7	13.9	201.50	92.28	46.33	340.11	92.94	433.05
BM-28	21.5	15.7	247.77	121.42	58.06	427.25	116.49	543.74
BM-29	23.2	16.4	295.60	154.17	70.68	520.44	141.29	661.73
BM-30	23.9	16.5	316.46	169.24	76.32	562.02	152.21	714.23
BM-31	24.4	16.7	331.78	180.60	80.51	592.89	160.28	753.17
BM-32	26.3	17.8	393.18	228.51	97.72	719.40	192.86	912.27
BM-33	27.1	18.2	420.53	251.04	105.58	777.15	207.51	984.66
BM-34	28.4	18.7	466.88	290.81	119.16	876.85	232.48	1109.32
BM-35	29.6	19.3	511.75	331.13	132.61	975.49	256.81	1232.30
BM-36	32.0	20	607.51	422.91	141.19	1171.61	309.17	1480.78
BM-37	33.2	20.8	658.39	474.70	154.76	1287.85	337.20	1625.05
BM-38	34.6	21.4	720.29	540.39	160.45	1421.14	371.46	1792.59
BM-39	37.4	22.2	852.27	689.86	172.63	1714.76	445.01	2159.77
BM-40	38.5	22.8	907.11	755.55	185.50	1848.16	475.74	2323.90

All sampled trees were relatively equally distributed by diameter classes (from 4 cm to 40 cm) (smallest DBH was 4.4 cm; largest 40.8). The total fresh biomass of largest tree (BM-14) reached 2.464.21 kg, and of which 77 percent belonged to above-ground biomass. Our results showed that the total water content occurs 47.35 ± 2.27 percent of the total fresh biomass of the larch tree. Remaining percent (52.64 ± 2.3) belongs to dry biomass.

Table 2. Dry weight of the above- and belowground biomass components of sampled trees

Sample	Height (m)	Above-ground biomass (kg)				Belowground biomass (kg)	Total biomass (kg)
		Stem	Branch	Needle	Total		
BM-1	8.3	17.46	2.58	1.50	21.53	6.98	28.51
BM-2	6	5.89	1.28	0.75	7.92	1.58	9.50
BM-3	3.3	2.07	0.54	0.32	2.93	0.93	3.86
BM-4	4.5	2.65	0.64	0.36	3.65	1.11	4.76
BM-5	7.6	8.99	1.14	0.63	10.76	4.62	15.38
BM-6	11.2	47.71	16.43	6.79	70.94	23.37	94.30
BM-7	13.3	61.90	22.78	26.26	110.93	62.47	173.40
BM-8	10.1	70.80	55.92	12.32	139.04	25.33	164.37
BM-9	16.4	214.50	141.13	32.02	387.65	77.26	464.91
BM-10	19.3	339.95	166.64	57.51	564.11	154.14	718.25
BM-11	20.06	346.03	233.42	50.67	630.12	108.84	738.96
BM-12	22.1	412.84	315.20	61.16	789.19	134.71	923.90
BM-13	22.22	409.83	279.04	54.27	743.15	193.61	936.76
BM-14	23.8	483.55	419.32	69.53	972.41	268.91	1241.31
BM-15	15.93	123.98	93.15	33.32	250.45	72.43	322.88
BM-16	13.56	72.27	45.35	16.92	134.54	27.89	162.42
BM-17	9.95	28.31	14.17	7.09	49.57	12.87	62.44
BM-18	7.2	8.91	3.49	2.14	14.53	4.96	19.49
BM-19	7.9	15.56	5.16	2.75	23.47	7.04	30.51
BM-20	9.5	36.14	12.19	5.35	53.68	14.13	67.81
BM-21	10.2	44.14	14.08	7.00	65.22	16.97	82.19
BM-22	11.3	60.69	22.60	9.53	92.82	24.04	116.86
BM-23	12.1	64.15	24.97	9.71	98.83	28.34	127.17
BM-24	12.4	78.60	32.22	12.38	123.20	34.71	157.91
BM-25	12.8	83.27	32.98	14.43	130.68	35.31	165.98

Sample	Height (m)	Above-ground biomass (kg)				Belowground biomass (kg)	Total biomass (kg)
		Stem	Branch	Needle	Total		
BM-26	12.9	93.30	37.87	13.89	145.06	39.79	184.84
BM-27	13.9	106.19	52.36	16.20	174.76	47.43	222.19
BM-28	15.7	134.29	66.01	23.04	223.33	55.52	278.85
BM-29	16.4	177.95	83.06	26.46	287.47	71.67	359.14
BM-30	16.5	178.17	92.77	31.33	302.27	69.49	371.76
BM-31	16.7	178.50	94.89	31.11	304.50	82.45	386.95
BM-32	17.8	226.86	130.91	41.70	399.47	89.35	488.83
BM-33	18.2	248.53	136.53	39.21	424.27	103.92	528.19
BM-34	18.7	286.66	153.76	40.93	481.35	113.12	594.48
BM-35	19.3	284.02	178.52	41.94	504.48	131.33	635.81
BM-36	20	369.97	218.79	53.87	642.64	161.73	804.36
BM-37	20.8	361.46	252.69	64.72	678.87	160.30	839.17
BM-38	21.4	362.31	313.68	54.33	730.31	198.43	928.74
BM-39	22.2	456.82	361.70	64.62	883.14	234.43	1117.57
BM-40	22.8	523.40	389.21	60.51	973.12	242.06	1215.18

In terms of overall biomass structure, dry biomass percentage was varied among tree biomass components. The structural analyses revealed that most of dry biomass went to stem (47.77 ± 5.75%), followed branch (23.4 ±7.16%) and root system (21.07 ± 3.82%). The remaining percent (less than 8 percent) of dry biomass belongs to the needles which play important role in carbon dioxide absorption (Table 1, 2).

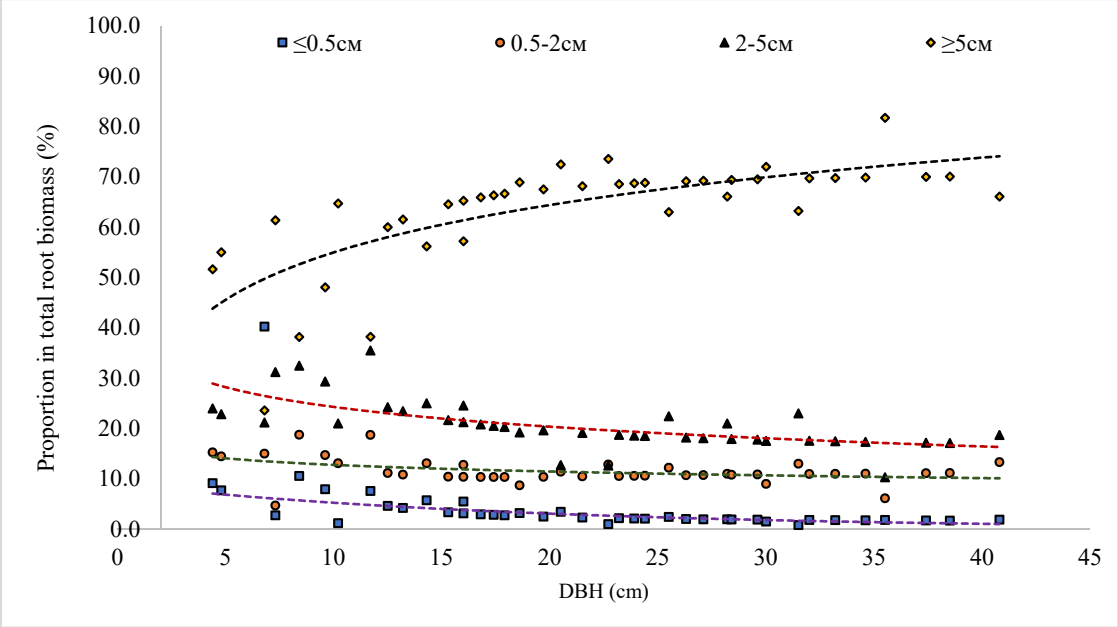

Figure 2. Relationships between stem diameter and the relative distribution of root diameter classes in total root biomass. Dashed lines indicate a trend of change with increasing stem diameter.

A comparative picture of the distribution of root diameter classes showed the ever-growing trend of course roots with an increase in diameter, which often exceeded more than 50 percent of the total biomass. In contrary, occurrence of fine roots tended to reduce with an increase in diameter and it amounts for only less than 5 percent in total root biomass. The gradual reduction also observed in both diameter classes 0.5 – 2.0 cm and 2.0-5.0 cm. However, we found a greater proportion of fine roots recorded in younger larch trees. For instance, for sample tree with DBH-6.8 cm (BM-2) had greatest proportion (40.8 %) of fine roots (Fig. 2). In general, at the early stage of individual tree growth, small roots occupied a relatively higher proportion than older trees in the total root biomass. The overall picture showed that fine roots with a diameter of less than 2.0 cm amounted for 15.8 % of the total root biomass, and remaining 84.2 % belonged to the course roots, respectively.

Table 3. Mean dry weight, root/shoot ratio of Siberian larch forests

Sample	Root biomass	Total tree biomass	Root/shoot ratio	Sample	Root biomass	Total biomass	Root/shoot ratio
BM-1	6.98	28.51	0.24	BM-21	16.97	82.19	0.21
BM-2	1.58	9.50	0.17	BM-22	24.04	116.86	0.21
BM-3	0.93	3.86	0.24	BM-23	28.34	127.17	0.22
BM-4	1.11	4.76	0.23	BM-24	34.71	157.91	0.22
BM-5	4.62	15.38	0.30	BM-25	35.31	165.98	0.21
BM-6	23.37	94.30	0.25	BM-26	39.79	184.84	0.22
BM-7	62.47	173.40	0.36	BM-27	47.43	222.19	0.21
BM-8	25.33	164.37	0.15	BM-28	55.52	278.85	0.20
BM-9	77.26	464.91	0.17	BM-29	71.67	359.14	0.20
BM-10	154.14	718.25	0.21	BM-30	69.49	371.76	0.19
BM-11	108.84	738.96	0.15	BM-31	82.45	386.95	0.21
BM-12	134.71	923.90	0.15	BM-32	89.35	488.83	0.18
BM-13	193.61	936.76	0.21	BM-33	103.92	528.19	0.20
BM-14	268.91	1241.31	0.22	BM-34	113.12	594.48	0.19
BM-15	72.43	322.88	0.22	BM-35	131.33	635.81	0.21
BM-16	27.89	162.42	0.17	BM-36	161.73	804.36	0.20
BM-17	12.87	62.44	0.21	BM-37	160.30	839.17	0.19
BM-18	4.96	19.49	0.25	BM-38	198.43	928.74	0.21
BM-19	7.04	30.51	0.23	BM-39	234.43	1117.57	0.21
BM-20	14.13	67.81	0.21	BM-40	242.06	1215.18	0.20
Average ± standard error							**0.21 ± 0.006**

Based on tree biomass measurements, we estimated the root/shoot ratio by dividing below-ground biomass by total tree biomass, and the results are illustrated in Table 3. Our findings indicated that in the study region root/shoot ratio for Siberian larch forests is 0.21± 0.006 and this ratio can be used for further estimation of carbon pools, for predicting carbon budget in response to climatic change, land use and forest management. Root/shoot ratio in coniferous forests of northeast China showed relatively higher mean than in Mongolian larch forests. Wang et al. (2008) reported that root/shoot ratio in primary conifers were between 0.23 and 0.25 (in larch forests - 0.25, in spruce 0.24 and in pine 0.23, respectively). Therefore, we found very poor development and less biomass of fine roots in larch stand compared to other studies conducted in different countries. Root biomass is reported to change significantly with abiotic factors in some local scale (Carnus et al., 1997) and it remains unclear whether root biomass is affected by climate at the large scale. Wang et al. (2008) also highlighted that R/S ratio was negatively related to water availability, shoot biomass, stand age, height and volume, suggesting significant effects of climate and ontogeny on biomass allocation.

Most regression models calculated with the equations (1) to (4) revealed heteroscedasticity in the Breusch-Pagan test (Table 4). Exceptions included the models for branch and needle biomass with equation (3), which were thus selected for examining the goodness of the fit. In all other cases, weighted least square regression was applied to enforce homoscedasticity, which was successful except for the branch biomass in the models with equations (2) and (4). In all cases, except the two models where the original data were homoscedasdic, weighted regression reduced the standard error of the parameter estimates. Therefore, the parameters from the weighted regressions were selected for further quality check in these cases.

Table 4. Regression equations for modeling stem, branch, needle and root (in kg dry weight) of Siberian larch with diameter (D) at breast height and height (H) data

No	Model	Parameters		SE	R^2	P
Stem:						
1	$y=aD^b$	a	0.02272	0.008597	0.91	0.239
		b	2.66549	0.107036		
2	$y=a(D^2 H)^b$	a	0.144475	0.0467932	0.93	0.242
		b	0.780139	0.0324114		
3	$y=aD^b H^c$	a	0.05711	0.022235	0.95	0.315
		b	0.32079	0.323816		
		c	2.51441	0.453354		
4	$y=(D^2 H)/(a+bD)$	a	21.8722	5.00271	0.94	0.259
		b	1.2291	0.15634		
Branches:						
1	$y=aD^b$	a	0.02272	0.008597	0.93	0.270
		b	2.66549	0.107036		
2	$y=a(D^2 H)^b$	a	0.00803	0.0031449	0.95	0.311
		b	1.03284	0.0387010		
3	$y=aD^b H^c$	a	0.00225	0.001135	0.98	0.469
		b	0.77724	0.340760		
		c	2.93612	0.500753		

No	Model		Parameters	SE	R^2	P
4	$y=(D^2 H)/(a+bD)$	a	93.2704	10.5134	0.94	0.221
		b	-0.1129	0.3013		
Needles:						
1	$y=aD^b$	a	0.12664	0.0405357	0.86	0.213
		b	1.72881	0.0926565		
2	$y=a(D^2 H)^b$	a	0.076103	0.0273173	0.87	0.210
		b	0.653363	0.0362413		
3	$y=aD^b H^c$	a	0.03202	0.014286	0.90	0.252
		b	0.00010	0.413604		
		c	2.44418	0.567362		
4	$y=(D^2 H)/(a+bD)$	a	29.4428	32.5809	0.90	0.278
		b	11.9260	1.0941		
Above-ground total:						
1	$y=aD^b$	a	0.21039	0.0670494	0.93	0.224
		b	2.30498	0.0910512		
2	$y=a(D^2 H)^b$	a	0.127212	0.0365673	0.95	0.230
		b	0.854308	0.0286426		
3	$y=aD^b H^c$	a	0.04770	0.015857	0.97	0.333
		b	0.50556	0.260136		
		c	2.56399	0.369014		
4	$y=(D^2 H)/(a+bD)$	a	18.4533	2.53940	0.95	0.220
		b	0.4621	0.07689		
Roots						
1	$y=aD^b$	a	0.03451	0.0088394	0.97	0.427
		b	2.42437	0.0729967		
2	$y=a(D^2 H)^b$	a	0.021555	0.0063139	0.98	0.495
		b	0.892470	0.0291287		

No	Model	Parameters	SE	R^2	P
3	$y=aD^b H^c$	a 0.03358	0.011687	0.98	0.430
		b 2.38765	0.302658		
		c 0.05142	0.414938		
4	$y=(D^2 H)/(a+bD)$	a 95.5137	11.9612	0.99	0.392
		b 1.2233	0.3550		

SE- Standard error of parameter estimates a, b, c; R^2- Coefficient of determination; P- P value; Results (p value) of Breusch-Pagan test for homoscedasticity (data are heteroscedastic at $p \leq 0.05$);

We used mean absolute error (MAE), percentage MAE, Bias and fit index FI to test the conformity between real and estimated data using (1), (2), (3) and (4) equations (Table 5).

Table 5. Evaluation index according to biomass components and regression model

Equation	MAE (kg)	MAE (%)	Bias (kg)	FI
Stem:				
1	30.477	26.3	-4.147	0.962
2	26.536	21.4	-2.823	0.971
3	22.537	17.9	-1.652	0.979
4	24.615	18.8	-2.561	0.975
Branch:				
1	21.011	25.1	-3.800	0.970
2	18.071	19.2	-0.980	0.977
3	16.215	16.1	2.591	0.982
4	18.202	20.6	-2.248	0.977
Needle:				
1	5.503	16.7	-1.150	0.938
2	5.025	14.3	-0.632	0.948
3	4.473	13.4	-0.451	0.959
4	4.770	13.7	-0.458	0.953
Roots:				
1	9.370	9.9	-0.157	0.984
2	9.918	9.4	0.059	0.982
3	9.370	9.8	-0.069	0.984
4	10.122	9.5	0.439	0.981

For stem biomass equation (3) with parameter estimates from weighted regression was selected, which had the lowest values for bias, percentage MAE, absolute MAE and highest FI. Therefore, for branch biomass, equation (3) was selected, which had the lowest percentage MAE, absolute MAE, the lowest bias and the highest FI. For needle biomass, equation (3) with the parameters estimated with ordinary least square regression yielded the best fit, as indicated by the lowest values for MAE (percentage and absolute) and bias as well as the highest FI for this equation. Since equation (3) with the parameters calculated the lowest values for absolute

ME and highest values for FI, and the second highest values for bias, we selected this equation for estimating root biomass (Table 4).

Consequently, among the suggested allometric regression models for estimating the above- and below-ground biomass, the equation $W=aD^bH^c$ was the most fitted equation to estimate biomass by each biomass component in Siberian larch forests. Biomass functions which include both stem diameter and tree height as in our models for stem and needle biomass have repeatedly been found to be more precise than equations that are solely based on stem diameter.

Table 5. Carbon stocks accumulating in live tree biomass for sampled larch trees

Sample	Total biomass (kg)	Carbon fraction	Carbon stock	Sample	Total biomass (kg)	Carbon fraction	Carbon stock
BM-1	28.51	0.51	14.54	BM-21	82.19	0.51	41.92
BM-2	9.5	0.51	4.85	BM-22	116.86	0.51	59.60
BM-3	3.86	0.51	1.97	BM-23	127.17	0.51	64.86
BM-4	4.76	0.51	2.43	BM-24	157.91	0.51	80.53
BM-5	15.38	0.51	7.84	BM-25	165.98	0.51	84.65
BM-6	94.3	0.51	48.09	BM-26	184.84	0.51	94.27
BM-7	173.4	0.51	88.43	BM-27	222.19	0.51	113.32
BM-8	164.37	0.51	83.83	BM-28	278.85	0.51	142.21
BM-9	464.91	0.51	237.10	BM-29	359.14	0.51	183.16
BM-10	718.25	0.51	366.31	BM-30	371.76	0.51	189.60
BM-11	738.96	0.51	376.87	BM-31	386.95	0.51	197.34
BM-12	923.9	0.51	471.19	BM-32	488.83	0.51	249.30
BM-13	936.76	0.51	477.75	BM-33	528.19	0.51	269.38
BM-14	1241.31	0.51	633.07	BM-34	594.48	0.51	303.18
BM-15	322.88	0.51	164.67	BM-35	635.81	0.51	324.26
BM-16	162.42	0.51	82.83	BM-36	804.36	0.51	410.22
BM-17	62.44	0.51	31.84	BM-37	839.17	0.51	427.98
BM-18	19.49	0.51	9.94	BM-38	928.74	0.51	473.66
BM-19	30.51	0.51	15.56	BM-39	1117.57	0.51	569.96
BM-20	67.81	0.51	34.58	BM-40	1215.18	0.51	619.74

In addition, for further calculations require the use of the IPCC default to convert estimated tree live biomass into carbon stocks (IPCC, 2006).

$$Cp = DM * CF$$

Where:

Cp - carbon stock in plot (t C ha^{-1})

DM - dry biomass in plot (t dry matter ha^{-1})

CF - carbon fraction (t C t^{-1} dry matter).

For tree vegetation, use the Carbon Fraction 0.51 t C t^{-1} dry matter or species-specific values from the literature (per IPCC 2006 GL, V4, Ch4, Table 4.38).

CONCLUSION

Based on the research results obtained from biomass estimates, we made the following conclusions:

1) Among the suggested allometric regression models for estimating the above- and below-ground biomass, the equation $W=aD^bH^c$ was the most fitted equation to estimate each biomass component in Mongolian larch forests.
2) The root/shoot ratio in *Larix sibirica* forests was 0.21 ± 0.006 and is applicable for further biomass estimation.
3) The critical low proportion of fine root biomass, and ever-increasing trend of course root biomass with increasing diameter were found in overall biomass structure.

RECOMMENDATIONS

The present research was the first study to estimate below-ground biomass and root / shoot ratio estimation of natural larch forests, conducted in the western Khentii Mountains. To ensure a qualitative and accurate improvement of carbon stocks and biomass estimates, it is necessary to develop country- and species specific regression model equations for main tree species as *Larix sibirica* Ldb., *Pinus Sylvestris* L., *Pinus sibirica* Du Tour., *Picea obovata* Ldb., *Betula platyphylla* Sukach., *Populus suaveolens* Rehd., *Populus tremula* L. and *Abies sibirica* based on the diameter at the breast height (D1.3) and height (H). However, we would suggest conducting these studies with the involvement of different forest vegetation zones of the Mongolian forest distribution. The facing forest degradation and deforestation caused by global warming and over-exploitation become one of the pressing issues of Mongolian forestry sector.

Consequently, for complete estimation of carbon stocks accumulated in Mongolian forest ecosystems, biomass estimates should not be limited only to healthy, productive forests, but also need to extend research covering degraded forests in the future.

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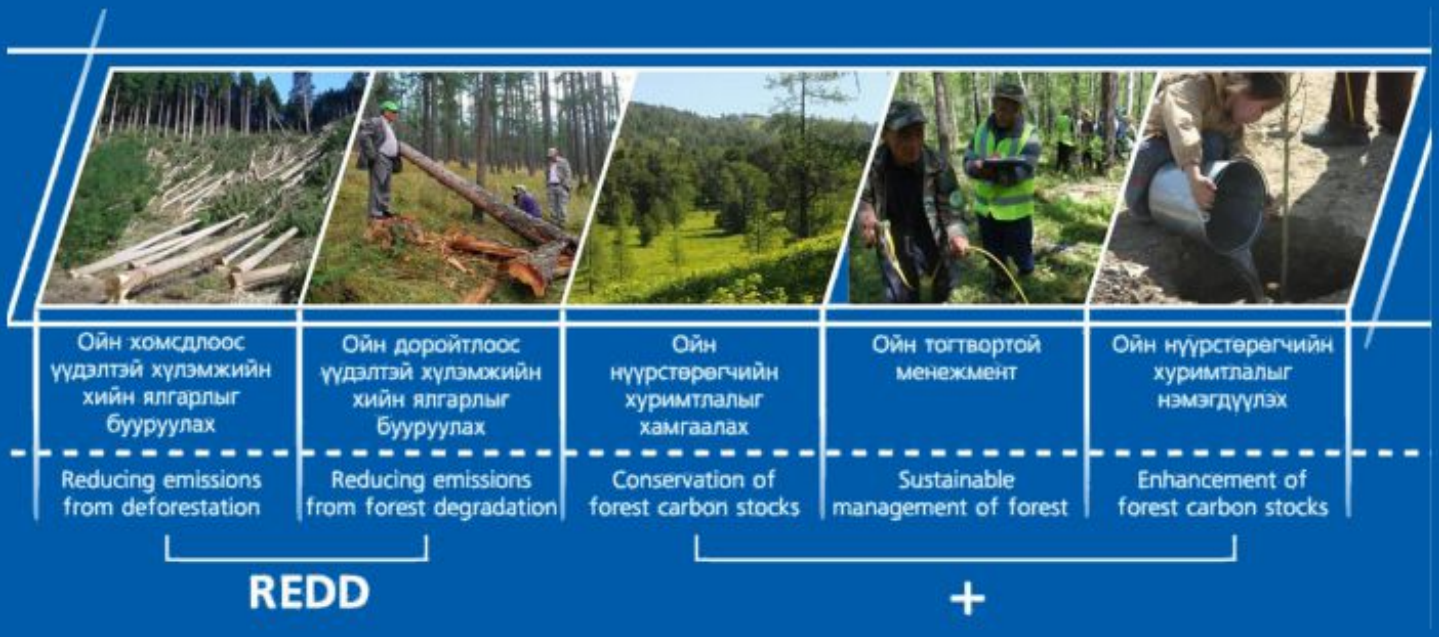
Figure 3. Location of sampling sites in Batsumber soum, Tuv province

Table 6. Geographical coordinates of sampling sites

Site	Latitude	Longtitude
1	48°14'53.18"N	106°49'4.37"E
2	48°13'0.37"N	106°49'48.41"E
3	48°11'46.49"N	106°52'14.07"E
4	48°20'43.56"N	106°25'12.72"E
5	48°22'28.04"N	106°55'5.40"E
6	48°12'56.10"N	106°59'56.13"E
7	48°22'1.51"N	106°37'22.97"E
8	48°25'19.73"N	106°51'13.36"E
9	48°21'53.39"N	107° 4'24.88"E
10	48°18'13.71"N	106°49'37.74"E
11	48°15'3.35"N	106°34'23.97"E
12	48°30'18.84"N	106°31'55.94"E
13	48°18'29.02"N	106°33'22.73"E
14	48°17'46.51"N	106°58'44.67"E
15	48°26'46.58"N	106°38'51.97"E
16	48°17'53.10"N	106°19'47.21"E
17	48°27'39.39"N	106°44'42.65"E
18	48°30'57.69"N	107° 0'22.42"E
19	48°14'16.21"N	106°30'38.63"E
20	48°21'6.55"N	107°10'49.46"E
21	48°17'10.68"N	107°15'54.16"E



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