ESTIMATION METHODOLOGY FOR FOREST BIOMASS IN MONGOLIA USING REMOTE SENSING

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ABSTRACT:

The forest biomass is one of the most important parameters for the global carbon stock. Information on the forest volume, coverage and biomass are important to develop the global perspective on the CO2 concentration changes. Objective of this research is to estimate forest biomass in the study area. The study area is Hangal sum, Bulgan province, Mongolia. Backscatter coefficients for vertical transmit and vertical receive (VV), for vertical transmit and horizontal receive (VH) from Sentinel data and Leaf Area Index (LAI) from Landsat data were used in the study area. We developed biomass estimation approach using ground truth data which is DBH, height and soil moisture. The coefficient α, β, δ, ɣ were found from the approach. The output map from the approach was compared with VV and VH, LAI data. The relationship between output map and VH data shows a positive result R^2=0.61. This study suggests that the biomass estimation using Remote sensing data can be applied in forest region in the North.

1. INTRODUCTION

Mongolia is a landlocked country and is situated in the central and semi-arid north-eastern part of Asia (Choimaa, et al. 2010). The forested area only amounts to 8 percent of the total territory of Mongolia (FCRD 2017). The northern part of Mongolia has taiga forest covers, which extend to Siberia in Russia in the North (Sata, Kimura and Kitoh 2007). The Mongolian forests are mainly coniferous, mixed with some broadleaf trees that grow on the mountain slopes between 800 - 2,500 m above the sea level (UN-REDD 2018). The Siberian larch (Larix sibirica Ledeb) is Mongolia's dominant tree species, which covers 80 % of the country's forested area (Jamsran 2004). The Mongolian forests have a low productivity and growth and are vulnerable to disturbance from drought, fire and plagues. Therefore, forests could easily lose their ecological balance such as the low natural regrowth rate, partly due to the boreal forests located in the northern hemisphere's harsh continental climate (which significantly limits the vegetative growth rate and soil moisture contents (UN-REDD 2018)). The soil moisture plays a considerably important role in ecology and the forest ecosystem (Wen, Lu and Li 2015). The investigation of the soil moisture in different contexts, such as in agriculture, hydrology, meteorology, forestry and natural disaster management is important (Hosseini and Saradjan 2011). The forest biomass is one of the most important parameters for the global carbon stock modeling, yet it can only be estimated with great uncertainty (Mette, et al. 2002).

The global forest inventory and an accurate forest (above-ground) biomass estimation still are the critical missing parts in the global climate change discussion (FAO 2001). The leaf area index (LAI), in turn, is defined as half the total intercepting leaf area per unit ground surface area (Lauri, et al. 2017). So far, no equations have been empirically established so as to estimate the tree biomass in the Mongolian forests (Purevragchaa, et al. 2013). However, the Institute of General and Experimental Biology (IGEB) of the Mongolian Academy of Sciences (MAS) has carried out a biomass field survey on the main tree species of Mongolia (Dorjsuren 2017, MET 2016). The allometric models were based on the relation between the above-ground biomass (AGB), diameter at breast height (DBH) and the total height of tree (H) measurements (UN-REDD 2018).

The forest biomass cannot be measured directly from space (yet) but the remotely sensed greenness can be applied to assess biomass on decadal and long-term scales in regions of a distinct seasonality, as in the north (Renchin, et al. 2002). However, there are many studies which utilized the remote sensing technique to estimate the forest biomass. Multi-regression and neural models based on the thematic mapper (TM) imagery and 232 plots of forest inventory in the southern side of Xiaoxing'an mountains have been established by Guo and Zhang (2003) to assess the forest biomass. The retrieval of the forest biomass using remote sensing data has received increasing attention for several reasons during the last decades.

(Laurin, et al. 2018) demonstrate the ability of remote sensing to spatially extrapolate the point field information on the forest parameters. Several researchers applied the synthetic aperture radar (SAR) images in order to estimate the forest biomass. A

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study by (Renchin, Tsolmon et al. 2002) focused on the use of the JERS-1 SAR data to measure various properties, such as the total tree biomass, age and height, by means of a least-square method. This technique included both the modeling approach and empirical estimations of the forest biomass (based on the ground data). In another research, one looked into the models based on a large set of different vegetation indices and the multivariable models. The spectral satellite data include the medium spatial-resolution ranges from 10 to 100 m. More recently, the high spatial resolution data (IKONOS, QuickBird, WordView 2) have shown a high increase in availability. The improved accuracy in biomass estimation is reached when compared with the former two spatial resolutions. The main disadvantage is derived from their spatial resolution, which makes the data processing more time- consuming and thus better suited for local or regional scales (Lu 2006). The biomass estimation equations, also known as the allometric equations or regression models, are used to estimate the biomass or volume of the aboveground tree components based on a diameter at breast height (DBH) and the height data (Kebede et Soromessa 2018). The generality of the allometric equations can be evaluated either by comparing species within a region (or a broad vegetation type) or by comparing the same species appearing on various sites (Keith, Barrett et Keenan 2000). Most of the allometric models were based on the relation between the aboveground biomass (AGB) and diameter at breast height (DBH) and the total height of the tree (H) measurements. The species' specific constant coefficients have also been employed. The biomass is found allometrically, generally on a species level, using the DBH alone or where available and generally more accurately, the DBH and height (Goetz et Dubayah 2011). The satellite radar is often proposed as the best tool so as to overcome the substantial spatial frequency and cost limitations of the allometric-based field surveys (Woodhouse, et al. 2012).

In this study, we have selected the boreal forested area which is located in the northern part of Mongolia. The vegetation index is enhanced by the strong reflectance of the near infrared (NIR) leaf internal scattering and the high chlorophyll absorption by the red wavelength region. The LAI can be utilized for the biomass estimation. Nevertheless, we used the LAI and backscatter coefficients for vertical transmit and vertical receive (VV), for vertical transmit and horizontal receive (VH) of the SAR images for the validation of the forest biomass in this research.

The objectives of the study are: Firstly, to estimate the forest biomass which is modified from the general equation using ground truth measurements in which the species' specific coefficients of various trees (DBH, Height and soil moisture) can be found. Secondly, a need exists to correlate between the forest biomass and the VV, VH backscattering respectively. And thirdly, we aim to assess the relations between the forest biomass and leaf area index (LAI) derived from the Landsat 8 satellite data operational land imager (OLI). The innovative part of this research aims to consider the soil moisture measurements with the DBH and tree height and correlates with the LAI. The soil moisture measurements have been applied for this methodology, which have not been considered yet in previous studies.

2. STUDY AREA

The study area is located in the southern area of Khangal soum, a Bulgan province in the northern part of Mongolia (Figure 1). Bulgan is one of the northern provinces of Mongolia, located between the latitude 47° 14' - 50° 23' N and longitude 101°37' - 104° 45' E, in the territory of the Khangai mountain forest steppe zone. The north part (of this province) is characterized by alpine forests, gradually blending in the arid steppe plains of the central Mongolian highlands. Temperatures fluctuate between +38 ℃ in summer and -49 ℃ during winter. The average annual temperature amounts to -2.4 ℃, and the average precipitation ranges from 200 to 350 mm with a discontinuous permafrost. The soil type is sandy with semi desert features in the southern part, while fertile land mainly appears in the north for crop cultivation. The northern part of the province is characterized by alpine forests, gradually blending into the arid steppe plains of the central Mongolian highlands. According to the Holdridge life zones' system of bioclimatic classification, Bulgan is situated in the boreal dry scrub biome (larch, birch and shrub), where larch measures 86,12 % and birch 13,88 % (FRDC 2016). The Ministry of Environment and Tourism (MET) forest report records 5 species of trees and bushes in the Bulgan province forests and 3 main forest types: Larch (*Larix sibirica*), Pine (*Pinus silvestris*), Cedar (*Pinus cembra*), Birch (*Betula*) and Poplar (*Populus diversifolia*).

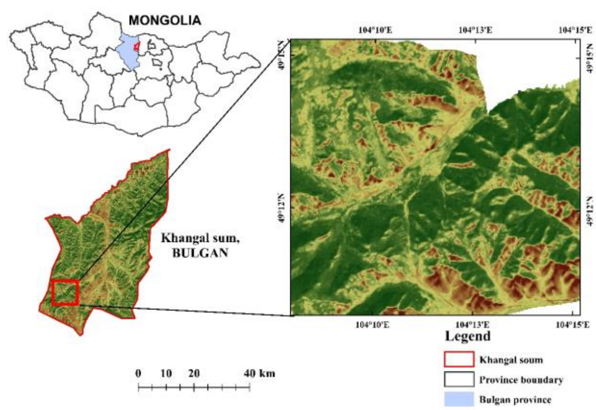

Figure 1. Study area of the southern side of Khangal sum (49° 11′ to 49°15′ N and 104° 8′ to 104° 15′ E)

3. DATASETS

3.1 Ground truth data

The ground truth data have been collected in the Bulgan province. We took 150 samples, which are the soil moisture data, diameter at breast (DBH) and height of the Larch and Birch in July and August, 2018. For the wood sampling, we collected the leaf presence and type of field plots (size, shape and number) and measured the DBH and height from the Larch and Birch. The forest biomass growth is high in July. We have gathered the soil moisture data during the ground truth in the Bulgan province. We used the soil moisture data in this study and measured the soil samples from all the corresponding different types of larch and birch wood loam soil. The water held tightly on the surface of the soil colloidal particles, is known as the soil moisture. It is essentially non-liquid and moves primarily in the vapour form, it cannot be separated from the soil (unless it is heated).

3.2 Synthetic Aperture Radar (SAR) images

Sentinel-1B is an imaging radar mission providing all-weather, day-and-night imagery at a C-band continuously. The Sentinel-1B SAR C-band data interferometric wide swath mode was used, with a 250-km swath width at a 5×20 m spatial resolution, an incidence angle between the 29.1 degree and 46.0 degree and the VH and VV dual polarizations. The scenes were multi looked (one look in range and four azimuth), geocoded based on the Shuttle Radar Topography Mission (SRTM) data and were radiometrically calibrated with a final pixel spacing of 10×10 m (Tsyganskaya, et al. 2018).

3.3 Landsat 8 satellite data

The Landsat 8 satellite payload consists of 2 scientific instruments-the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI and TIRS designs incorporate technical advancements that improve the performance in the previous Landsat sensors (Irons, Dwyer et Barsi 2012). Landsat 8 data are nominally processed into 185 km × 180 km Level 1 terrain-corrected (L1T) products that have a typical 950 MB compressed GeoTiff file size, more than twice those of the former Landsat sensor L1T products. All the OLI and TIRS spectral bands are stored as geolocated 16-bit digital numbers in the same L1T file. The 100 m TIRS bands are resampled by a cubic convolution to 30 m and co-registered with the 30 m OLI spectral bands. An associated metadata file stores the spectral band gain and offset numbers that can be used to convert the digital numbers into the at-sensor radiance (W m− 2 sr− 1 μm− 1) linearly (and to transform the OLI digital numbers into the at-sensor reflectance (unitless)) (Roy, et al. 2010).

4. METHODOLOGY

Biomass can be estimated using allometric equations. Generally, tree trunk is cylindrical for the volume calculation given as in the equation (1) does not hold for the majority of the trees. We selected equation 1 in order to assess the tree trunk biomass in this study area. Where the V, R and H represent the trunk volume (m^3), radius (m) and height (m). We modified the general equation (1), using the assumption that the tree trunk is cylindrical.

$$V = \pi R^2 H \tag{1}$$

We assume that tree volume can be in the equation (2). Where α, β, ɣ and δ illustrate the coefficients for the parameters regarding the general type of the tree trunk volume. R shows the radius of breast, H the height of trees, M the soil moisture, α varies across the forest types. By solving this system, we will find the final solution α, β, ɣ, δ coefficients. In the equation (2) V, R and H demonstrate the trunk volume, dbh (in m) and height (in m). This equation is useful for various tree types.
The least-square method was applied in this study. The resultant tree coefficients can be utilized in the estimation of the total tree biomass. In this study, we assume that a regression model for the tree trunk biomass is as follows:

$$V = \alpha R^{\beta} H^{\gamma} M^{\delta} \tag{2}$$

In order to find the coefficients, we used a logarithm function and least square method in order to find the coefficients α, β, ɣ, δ that we need to solve the following unconstrained minimization problem equation (3). The least square method was applied in this problem concerning formula.

In here we $lnV = \widetilde{V}$, $ln\alpha = \tilde{\alpha}$, $lnR = \widetilde{R}$, $lnH = \widetilde{H}$, $lnM = \widetilde{M}$ to indicate the function. Where $V_i = lnV_i$; $\alpha_i = ln\alpha$; $\widetilde{R}_i = lnR_i$; $\widetilde{H}_i = lnH_i$ is a convex function reaching its minimum point.

$$F(\tilde{\alpha}, \beta, \gamma, \delta) = \sum_{i=1}^{n} \left[\tilde{\alpha} + \beta \widetilde{R}_i + \gamma \widetilde{H}_i + \delta \widetilde{M}_i - \widetilde{V}_i\right]^2 \rightarrow min \tag{3}$$

Equation (4) is obtained by taking the partial derivatives from where the error function (3).

$$\begin{aligned}
\frac{dF}{d\tilde{\alpha}} &= 2\sum_{i=1}^{n} [\tilde{\alpha} + \beta \widetilde{R}_i + \gamma \widetilde{H}_i + \delta \widetilde{M}_i - \widetilde{V}_i] = 0 \\
\frac{dF}{d\beta} &= 2\sum_{i=1}^{n} \widetilde{R}_i [\tilde{\alpha} + \beta \widetilde{R}_i + \gamma \widetilde{H}_i + \delta \widetilde{M}_i - \widetilde{V}_i] = 0 \\
\frac{dF}{d\gamma} &= 2\sum_{i=1}^{n} \widetilde{H}_i [\tilde{\alpha} + \beta \widetilde{R}_i + \gamma \widetilde{H}_i + \delta \widetilde{M}_i - \widetilde{V}_i] = 0 \\
\frac{dF}{d\delta} &= 2\sum_{i=1}^{n} \widetilde{M}_i [\tilde{\alpha} + \beta \widetilde{R}_i + \gamma \widetilde{H}_i + \delta \widetilde{M}_i - \widetilde{V}_i] = 0
\end{aligned} \tag{4}$$

If we simplify (4), we noticed the system of (5). Then our model will be as follows in equation 5:

$$\begin{aligned}
& n * \tilde{\alpha} + \beta \sum_{i=1}^{n} \widetilde{R} + \gamma \sum_{i=1}^{n} \widetilde{H}_i + \delta \sum_{i=1}^{n} \widetilde{M}_i = \sum_{i=1}^{n} \widetilde{V}_i \\
& \tilde{\alpha} \sum_{i=1}^{n} \widetilde{R}_i + \beta \sum_{i=1}^{n} \widetilde{R}_i^2 + \gamma \sum_{i=1}^{n} \widetilde{R}_i \widetilde{H}_i + \delta \sum_{i=1}^{n} \widetilde{R}_i \widetilde{M}_i = \sum_{i=1}^{n} \widetilde{R}_i \widetilde{V}_i \\
& \tilde{\alpha} \sum_{i=1}^{n} \widetilde{H}_i + \beta \sum_{i=1}^{n} \widetilde{H}_i \widetilde{R}_i + \gamma \sum_{i=1}^{n} \widetilde{H}_i^2 + \delta \sum_{i=1}^{n} \widetilde{H}_i \widetilde{M}_i = \sum_{i=1}^{n} \widetilde{H}_i \widetilde{V}_i \\
& \tilde{\alpha} \sum_{i=1}^{n} \widetilde{M}_i + \beta \sum_{i=1}^{n} \widetilde{M}_i \widetilde{R}_i + \gamma \sum_{i=1}^{n} \widetilde{M}_i \widetilde{H}_i + \delta \sum_{i=1}^{n} \widetilde{M}_i^2 = \sum_{i=1}^{n} \widetilde{M}_i \widetilde{V}_i
\end{aligned} \tag{5}$$

Applying the ground truth data to (5), the respective coefficients and equation are dealt with as shown in table 1. Total biomass for the forest types, namely larch, birch, were estimated using the equation mentioned above. In order to consider the environmental factors like the moisture contents of various trees, the equation (2) can be modified using the above methodology. By modifying the equation (1), the forest biomass contents of various trees could be found.

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5. ANALYSIS

Given the extreme continental climate of the region, the forests have a low growth rate and productivity, making them vulnerable to various disturbances (UN-REDD 2018). Most of the allometric models are based at breast height and the total height of the tree measurements. These approach used species' specific coefficients found by the multi-purpose national forest inventory report (MET 2016). Our analysis relies upon a compilation to differ from the tree. We developed algorithms so as to estimate the total stand biomass and the shapes of the considered tree trunks. A least-square method was applied in order to establish the tree trunk shape coefficients, which were then used to assess the total stand biomass by means of ground data. Additionally, the soil moisture is enhanced by supplementary factors. We used the Sentinel-1B satellite data. The Sentinel-1B has been utilized in order to assess the forest biomass. A backscatter coefficient from the VV, VH polarizations was estimated for the larch and birch biomass. Leaf area index (LAI) were derived from the Landsat 8 satellite data operational land imager (OLI) afterwards. The innovative part of this research includes the consideration of the soil moisture measurement for the equation (2).

6. RESULTS AND DISCUSSION

All four types coefficients yielded estimates which approximate the measured dry weights of the stem and branch biomass. Most models had to be forced by the weighted regression (Choimaa, et al. 2010). A satellite radar is often proposed as the best tool so as to overcome the substantial, spatial frequency and cost limitations of the allometric-based field surveys. Our study area's predominant forests are the Siberian larch (*Larix sibirica*) and Birch (*Betula platyphylla*). We selected 30 samples on larch and 18 samples on birch wood from the ground truth data. This study focused on the total tree biomass, radius, height and soil moisture contents using a least-square method. This approach included both a modeling approach and the empirical estimations of the forest biomass based on the ground data. The allometric equation performed in this study was used to calculate the biomass. It might also be applied to investigate the manner in which the trunk biomass is related to other soil moisture contents in stands. The tree shape coefficients α, β, δ and ɣ appear to be useful (tools) to estimate the stand biomass and will allow a refinement of the simple methods from former studies. We developed the allometric equations. Most of the dependence DBH (D in equations), woods radius (R), height (H) and variables are obtained through calculations and measurements. The soil moisture measurements were applied for this methodology (which have not yet been considered in previous studies). These regression equations are related to AGB with the DBH, height (H) and wood density (R) individually (and in combination). In order to minimize the problems concerning the equality and inequality constraints, necessary conditions for the allometric equation extremum are being presented. These conditions apply when the constraints do not satisfy the traditional regularity assumptions.

Forest type	α	β	ɣ	δ	Equations
Larch	1.5	1.98	1.03	0.43	$V=1.5R^{1.98}H^{1.03}M^{0.43}$
Birch	2.9	2.07	0.85	0.23	$V=2.9R^{2.07}H^{0.85}M^{0.23}$

Table 1. Coefficients and volume equations for the forests in the study area

The Sentinel-1B SAR data are very useful for the forest biomass study. The backscatter is determined by a variety of vegetation structural properties that may or may not, correlate with the AGB (in addition to the possible perturbations of the signal from the soil moisture, slope and surface roughness characteristics). The biomass scatter plot from the model and backscattering coefficient VV from the Sentinel-1B satellite is shown in Figure 2 with (R^2=0.55). Figure 2 and 3 describe the relation between the VH and VV backscatter larch biomass.
Therefore, the VH backscatter coefficient for larch biomass is higher than the VH backscatter coefficient for the birch biomass. From the analysis, we can conclude that there is a high biomass for the samples where the heights measure 20 m or more concerning the larch forest. This method is suitable to evaluate the forest biomass in the region.

Overall, the Sentinel-1B SAR imagery relationship showed reasonable results, while the model provides good outcomes for the biomass.

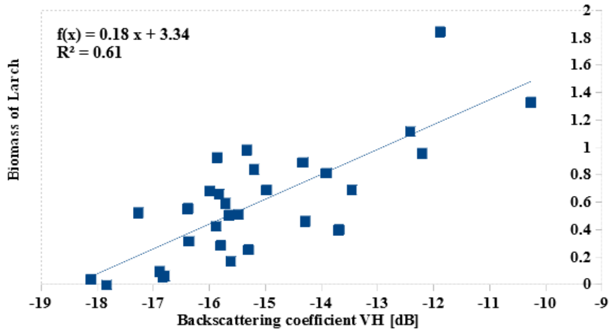

Figure 2. The relationship between the Larch biomass and the backscattering coefficient VH

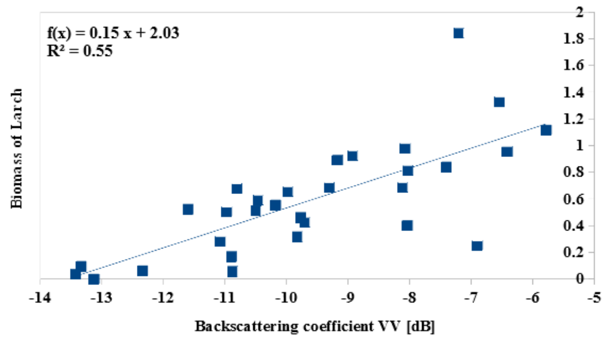

Figure 3. The relationship between the Larch biomass and the backscattering coefficient VV

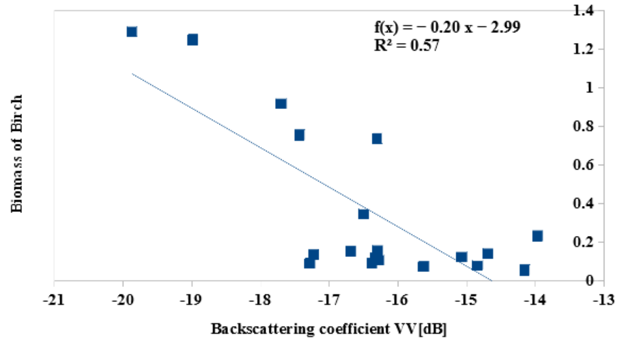

Figure 4. The relationship between the Birch biomass and the backscattering coefficient VV

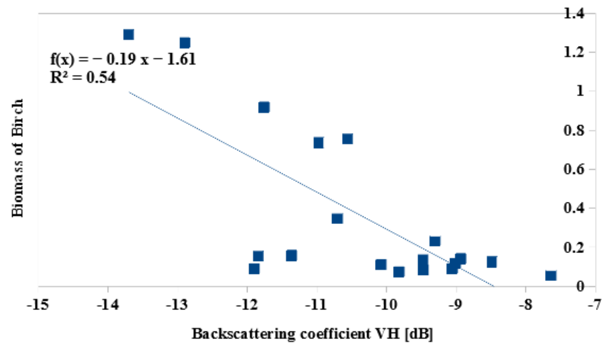

Figure 5. The relationship between the Birch biomass and the backscattering coefficient VH.

In order to validate the model result (table 1), we measured the LAI from Landsat 8. The biomass from the model was compared with the LAI from the satellite data (R^2=0.55) for larch wood (R^2=0.56) for birch wood respectively (Figure 6 and 7). The leaf area index (LAI) is commonly used to characterize the structure and function of the forest ecosystems. The forest estimation results using recently launched Sentinel 1 data are handled in this research. The forest biomass approach was developed and its relation with the Sentenil-1B SAR data has been established

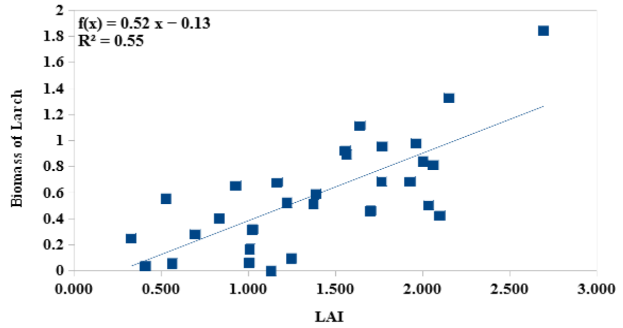

Figure 6. Relationship between the LAI and the Biomass of Larch wood

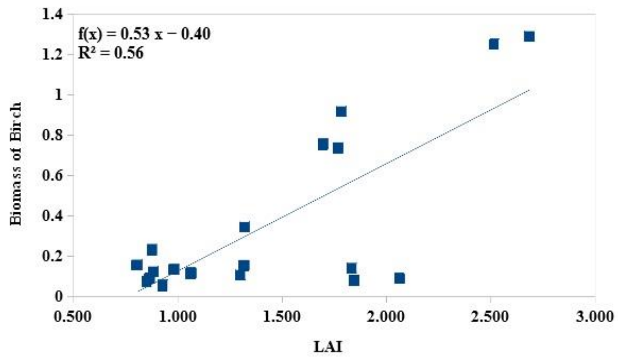

Figure 7. Relationship between the LAI and the Biomass of Birch wood

7. CONCLUSION

Forest research is vital for the Mongolian environment. The forest area accounts for 8 percent of the total territory of Mongolia, out of which 70 percent has deteriorated intensively by ageing, fire and insect infestations (FCRD 2017). The approach developed for this research could be applied to other ecological zones for various wood types.

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