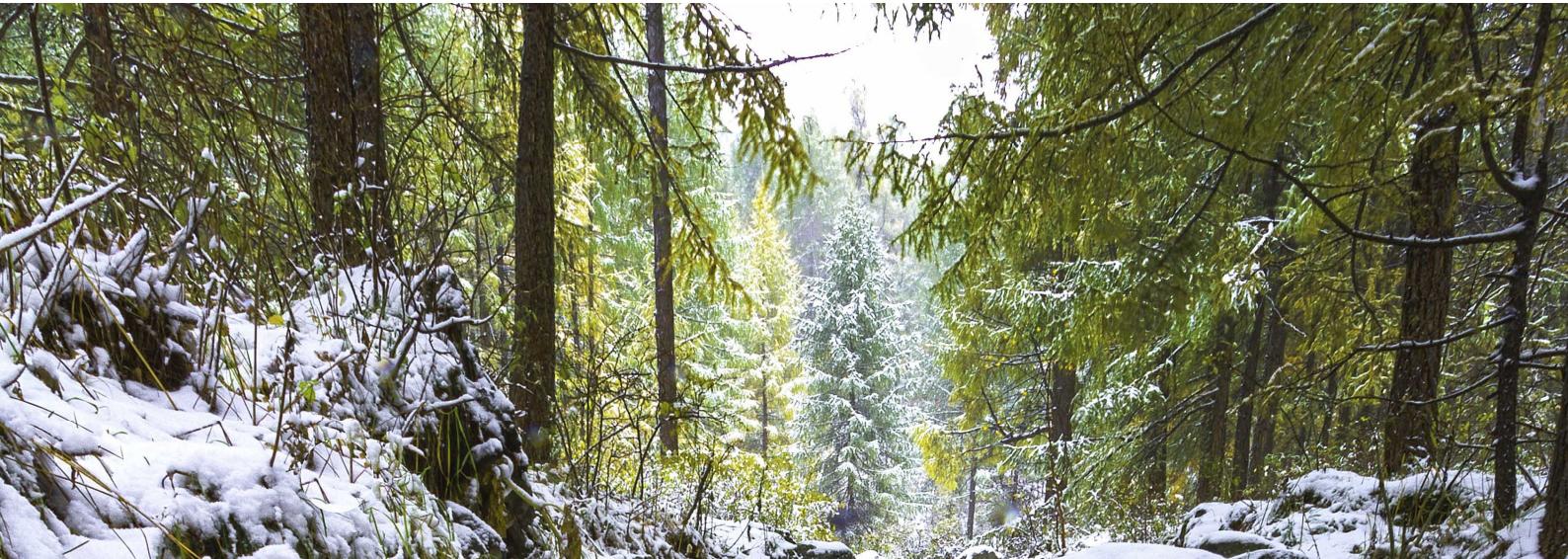




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МОНГОЛ ОРНЫ UN-REDD ҮНДЭСНИЙ ХӨТӨЛБӨР
ХӨТӨЛБӨР ХЭРЭГЖҮҮЛЭХ НЭГЖ



Allometric Model Development for Above Ground Biomass of Saxaul (*Haloxylon ammodendron* (C.A.Mey.) Bunge)

Research Report of Institute of General and Experimental Biology, Mongolian Academy of Sciences

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INTRODUCTION

Mongolia supports 17,9 M ha of forest area, including 10.4 M ha of closed forest which accounts for approximately 11.45 and 7.86 % of the country land area, respectively. The forest area of Mongolia consists of two major forest biomes, namely the northern boreal forests (73.8 % of the forest area) and the southern saxual forests (26.2 %, FRDC, 2017).

The saxaul forests of Mongolia formed by *Haloxylon ammodendron* (C.A. Mey) Bunge. Saxaul forests usually grow in the arid and semi-arid regions of Asia and the deserts of Mongolia, where they are the dominant endemic brush type plant. In Mongolia, the saxaul forest grows in an area within the Gobi approximately 1650 km wide and 360 km in diameter from north to south. There are 7 provinces and 39 sub-provinces where Saxaul forests are thought to grow in Mongolia (Suvdantsetseg et al. 2008). Saxaul forest area take the place of 4,7 M ha or 26.2 % of Mongolian forest area, including 1,9 M ha (15.4 %) of closed forest (FRDC, 2017). *Haloxylon ammodendron* (Saxaul) is a plant species with a broad ecological range. Communities of this species mainly inhabit the following habitats: 1) stony deserts, or hamadas, 2) dried beds of temporary rivers (sairs), 3) sandy deserts, 4) depressions, or takyrs (Kazantseva, 2014).

The southern saxual forests consist of scattered shrubs/trees of *Haloxylon ammodendron* (C.A. Mey) Bunge which is a perennial, xeric, desert shrub or tree that occurs in a wide range of habitats. and are rarely over 5 m in height, the biomass is reported as being very low, volume approximately 1m³ per hectare. Consequently, they are not deemed as likely to be important from a REDD context (in terms of contribution to substantial greenhouse gas emission abatement or increased removals) and are therefore not included in Multipurpose National Forest Inventory, which was successfully conducted in Northern Boreal Forest of Mongolia in 2014 (UN-REDD, 2016). Due to the extreme environmental conditions much time and money would be required to conduct such a regular census of the Saxaul forest (Suvdantsetseg et al. 2008).

The importance of the saxaul forest to Mongolia is that they help to stabilize the active sand dunes and reduce the effects of sand storms. A decrease in the area of saxaul forests from logging and firewood gathering is one probable cause for why sand storms are becoming more harmful in Mongolia. The Saxaul forest is uniquely related to the overall area of Mongolian forests and therefore should be studied and be the subject of the National Forest Monitoring System (NFMS) going forward.

In semi-arid areas Saxaul vegetation influences environmental processes, such as the hydrological cycle, soil erosion and degradation. Biomass is an important ecological variable for understanding the responses of vegetation to the climate system and currently observed global change. It is therefore essential to develop accurate above ground biomass models of Saxaul shrubs/trees and transferable methods for biomass estimation in these areas. The quantification of biomass for large areas and long time periods is necessary to identify and monitor those areas under high risk of degradation and desertification.

There are some published papers and research works on the stem volume equations for Siberian larch, Scots pine and Asian white birch trees, and the assessment of the above-ground biomass of larch forests of Siberia and north-eastern Mongolia and Altai Mountains of Mongolia (Tsogt, 1993; Danilin 1995, 2003; Chuluunbaatar, 2005, Battulga et al., 2013).

Researches of the Forest Research Laboratory of Institute of General and Experimental Biology, Mongolian Academy of Sciences carried out field surveys and measurement of stem volume and above ground biomass of 8 tree species _Siberian larch-*Larix sibirica* Ldb., Scots pine-*Pinus Sylvestris* L.

Siberian stone pine-*Pinus sibirica* Du Tour., Siberian spruce-*Picea obovata* Ldb., Siberian fir-*Abies sibirica* Ldb., Asian white birch-*Betula platyphylla* Sukach., Mongolian Poplar-*Populus suaveolens* Rehd. and Aspen - *Populus tremula* L._in 2013 and 2016 and developed allometric biomass models for the these species. But so far no equations have been developed to estimate shrub/tree biomass and tree and stand biomass of *Haloxylon ammodendron* (C.A. Mey) Bunge in Desert Regions of Mongolia.

To address this gap in knowledge, an agreement between The Food and Agriculture Organization of the United Nations ("FAO") under the UN Collaborative Programme on Reductions of Emissions from Deforestation and Forest Degradation (UN-REDD) and Institute of General and Experimental Biology ("IGEB"), Mongolian Academy of Sciences was signed for the provision of "Saxaul-specific Allometric Model Development based on Above ground biomass sampling".

Objective. The Services will contribute to the Organizational objective "Policy and practice affecting forests and forestry are based on timely and reliable information for national and international reporting". The Institute of General and Experimental Biology will help FAO to develop emission and removal factors for REDD+ related activities and build national capacities on forest measurement and allometric equation development. The Services were specially targeted to develop a national allometric model for Saxaul forest in Mongolia (*Haloxylon ammodendron*).

Outputs/Outcomes:

- i. A database of biomass sample measurements for 40 tree/vegetation samples of *Haloxylon ammodendron*, including the following measurement for each tree/vegetation sample: ID, GPS coordinates, Collar diameter, H, H of the first branch, Volume of the stem, species scientific name, fresh mass of trunk, branches and leaves, Wood basic density (WD) of trunk and branches, fresh-to-dry ratio for the three compartments, dry mass of the three compartments, Biomass Expansion Factor (BEF);
- ii. A report on AGB allometric equations to be developed to improve biomass estimates of Saxaul forest in Mongolia.

MATERIALS AND METHODS

Field study locations

A field study and laboratory biomass measurements and data processing were conducted by the researchers of the Institute of General and Experimental Biology, MAS:

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The Field study of the above ground biomass of the *Haloxylon ammodendron* (C.A.Mey.) Bge. was carried out from 22 June to 27 September 2018 in most typical saxaul forest habitat types in the Southern Gobi of Mongolia. Starting from the Erdene soum of Dornogovi aimag which is the most eastern distribution of the *Haloxylon ammodendron*, and the to Bayan-Undur soum of Bayankhongor aimag in the West (the Transaltai Gobi), we selected five study site points. Geographical locations of

the site points is shown in Fig 1. Each study site point is presenting the main habitat type of the given study region.

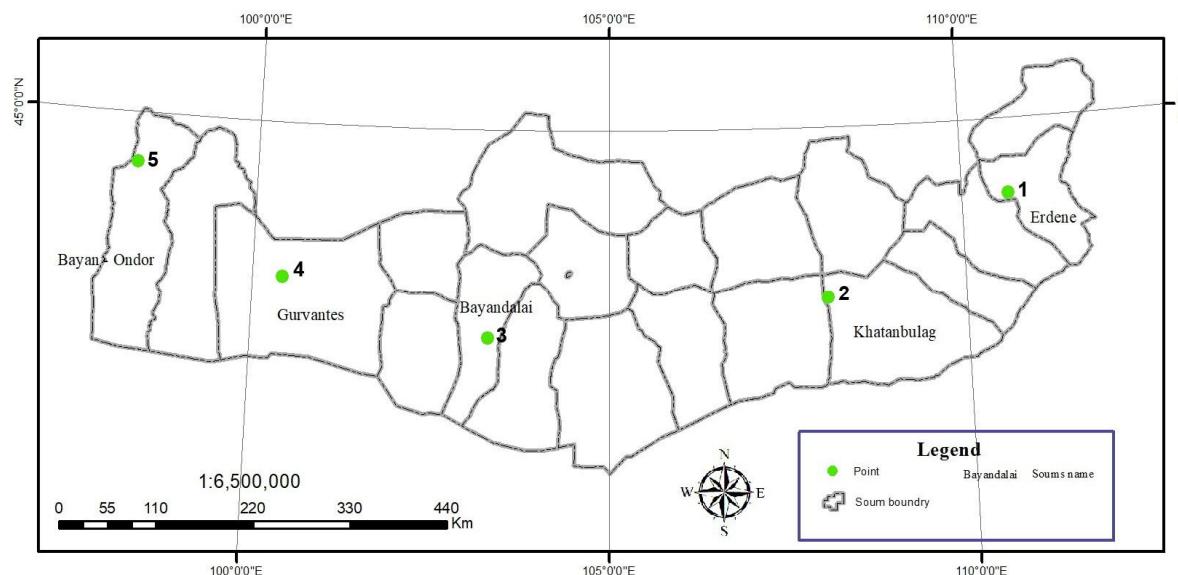


Fig. 1. Study site points. Point1. Study site in Dulaan zag place of Erdene soum of Dornogovi aimag (depression, or takyr habitat). Point 2. Gurvan Tsavchir place of Khatanbulag soum of Dornogovi aimag (sandy desert habitat). Point 3. Zuun Bukhtiin khoooloi place of Bayandalai soum of Umnugovi aimag (sandy desert habitat). Point 4. Naran daatsiin bulag place of Gurvantes soum of Umnugovi aimag (dried beds of temporary rivers). Point 5.Dund toli bulag place of Byan-Undur soum of Byankhongor aimag (stony desert, or Hamada habitat).

The study methodology

During the field study, a total of 20 circle sample plots of 0.15 ha were established to assess quantitative characteristics of the *H. ammodendron* population. In total 46 individuals of the *H. ammodendron* were harvested for the development of volume and biomass allometric equations.

For the measurement of simple plots we used the Manual for the Field Assessments of Multipurpose Forest Resources Inventory of Mongolia (GIZ, 2013) with interpretation. The selection of the five study sites was carried out on the basis of a reconnaissance survey of the given study region. We chose four circle simple plots at each study site in as much as possible homogeneous forest areas. Plot 1 lies in the centre, plots 2, 3 and 4 are located 100 m from plot 1 at azimuths of 0, 120, and 240 degrees (Fig. 2). In total, 20 circle plots of 21.85 m radius (1500 m^2) were established at the five study sites covering the different ecological habitats. *Haloxylon* shrubs/trees were counted for their population size and measured for top height (H, m), crown (Dcr) and collar or basic diameter (at above the soil surface) in perpendicular directions (Do, cm). For the multi-stem shrubs the average collar diameter of the multi-stems was measured. For all of the shrubs/trees the distance from center of the sample plot to shrubs/trees and the azimuths were measured with a Vertex IV ultrasonic clinometer and T3 transponder. A description of the vegetation was made for each simple plot.

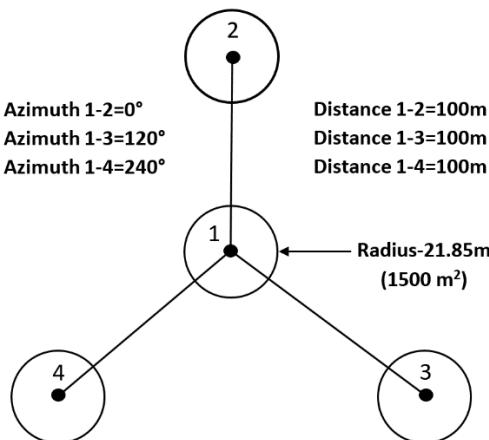


Fig. 2. Sample plots design.

The dichotomous nature of branching of saxaul shrub/tree determines the forks or divarication. The number of forks corresponds to the number of years. Therefore, saxaul shrub/tree age was determined by the number of forks (Fig.3.).



Fig. 3. Forked branch of the five years old saxaul.

The measurements of shrub/tree volume and biomass in the field and the establishment of the appropriate equations were conducted according to the manual for building tree volume and biomass allometric equations (Picard et al., 2012) and also to the methodologies of other researchers who carried out studies on tree and shrub biomass and modeled the above ground biomass of *Haloxylon* species in desert regions in Central Asia (Usoltsev, 1988, Buras et al. 2012, Eisfelder, 2013), and in shrub species of arid zones (Navar et al., 2004, Singh, Singh, 2017).

In total 46 individuals of *Haloxylon ammodenron* were selected at 4 different ecological habitat type sites, in order to represent different tree/shrub-size categories ranging from small to large, i.e. from 0.2 m to 5.7 m of growth height. Height, collar diameter and crown diameter of the selected trees were measured before felling. All selected shrubs/trees were felled and separated into main stem(trunk), branches and leaves (annual green shoots). The trunk of the trees was divided into sections, the volume of each section can be calculated from their length and diameters.

After harvest, fresh aboveground parts of shrubs/trees were separately weighed with an RS232 scale (precision: 5 g, range 0-30kg). Three till five wood and foliage sub-samples were taken from each individual for the laboratory measurement, the subsamples were oven-dried for 7 days with a constant temperature at 70 °C, to avoid the loss of essential oils (Kalra, 1998) and then reweighed to determine the water content of fresh samples (i.e. the difference between fresh weight weight after oven-

drying). The derived moisture loss of these sub-samples was then considered as representative for the whole above ground parts, respectively, and used for calculation of above ground dry biomass.

Equations and methods of parameter estimation

The different allometric equations could be calculated using above ground biomass crown and collar diameters of the harvested trees/shrubs. Following allometric models were applied to trees to estimate above ground biomass for *Haloxylon ammodenron*.

First, we have tested the following biomass equations, which are widely used to estimate the volume and above ground biomass of *Haloxylon* (Usoltsev, 1988, Buras et al., 2012) and shrubs species in arid zones (Navar et al., 2004, Singh & Singh, 2017).

$$\begin{aligned}y &= a(Dcr^2 H)^b & (1) \\y &= aH^b Dc^c & (2) \\y &= aH^b Dcr^c & (3) \\y &= aH^b Dc^c Dcr^d & (4)\end{aligned}$$

where y is tree biomass in kg, and a , b , c , and d are the parameters to be estimated. H is height (m), Dc is collar or basic diameter of stem (cm), Dcr is crown diameter (m).

The regression analyses showed that the most significant model for estimating the volume and above-ground biomass is the Eq (3, 4) for the volume and Eq (4) for the above-ground biomass which also proposed by Usoltsev (1988) and Buras et al. (2012) for *H. aphyllum* and *H. persicum* in Central Asia.

Because of the assumed violation of heteroscedasticity in nonlinear regression models with original scales of measurements, it is convenient to use logarithms for the fitting model (Overman et al. 1994, Packard et al. 2011). Therefore, Eqs (3) and (4) were linearized using logarithms and log transformed as follows:

$$\ln y = \ln a + b * \ln H + c * \ln Dcr \quad (5)$$

$$\ln y = \ln a + b * \ln H + c * \ln Dc + d * \ln Dcr \quad (6)$$

where \ln is the natural logarithm, v is volume of stem, y is tree above ground biomass and a , b , c , and d are the parameters to be estimated.

The parameters $\ln a$, b , c and d in the models were calculated with Minitab software (ANNEX I) using ordinary least square regression (N) and weighted least square regression (W). The accuracy of the volume and different biomass estimates from ordinary and weighted equations was validated against the measured volume and biomass data using the coefficient of determination (R^2), the adjusted coefficient of determination (R_{adj}^2), the estimated standard deviation of the error in the model (S)

$$R^2 = 1 - \left(\frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \right) \quad (7)$$

$$R_{adj}^2 = 1 - \left(\frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \right) \left(\frac{n-1}{n-p-1} \right) \quad (8)$$

$$S = \sqrt{\sum_{i=1}^n ((\ln y_i - \ln \hat{y}_i)^2 / (n - p - 1))} \quad (9)$$

where: \ln is the natural logarithm, y_i - i^{th} observed response value, \bar{y} - mean response, \hat{y} - i^{th} fitted response, n - number of observations, p - number of terms in the model

RESULT

The allometric model development for volume and above-ground biomass estimation of saxaul (*Haloxylon ammodendron* (C.A.Mey) Bge.)

The regression analyses showed that the most significant model for estimating the volume and above-ground biomass are linearized log transformed equation (4) and (5). For the weighted analysis we tested weight terms: 1/Do², 1/Dcr², 1/H²; and 1/Do² was selected as most significant weight (ANNEX I). Weighted regression reduced the standard error of the parameter estimates (Table 1.). Therefore, the parameters from the weighted regressions were selected for the allometric model development.

Table 1. The ordinary and weighted regression equations for modeling the volume, the stem, branch and foliage, biomass of *Haloxylon ammodendron* with shrub height (H), basic diameter (Do) and crown diameter (Dcr)

Type ¹	Model	Log-transformed equation and parameters	R ²	R ² _{adj}	R ² _{pred}	S
Volume						
W	$Y=aH^bDo^cDcr^d$	Ln V = -7.966 + 1.055 Ln H + 0.499 Ln Do + 0.816 Ln Dcr Lna= -7.9664 b= 1.0547 c= 0.4992 d=0.8155 a= 0.000347	89.2%	88.4%	83.0%	0.2478
N	$y=aH^bDo^cDcr^d$	LN Volume = -8.113 + 1.059 Ln H + 0.694 Ln Do + 1.066 Ln Dcr Lna= -8.1132 b= 1.0588 c= 0.6940 d=1.0664 a= 0.0003	87.2%	86.3%	85.2%	0.8064
W	$Y=aH^bDcr^c$	Ln V = - 7.601 + 0.446 Ln H + 1.614 Ln Dcr Lna=-7.6007 b= 0.4461 c= 1.6143 a= 0.0005	87.8%	87.3%	78.59	0.2598
N	$Y=aH^bDcr^c$	Ln V = - 7.19 + 1.79 Ln H + 0.951 Ln Dcr Lna=-7.1901 b= 1.7902 c= 0.9513 a= 0.0007	83.7%	82.9%	81.7%	0.9000
Total biomass (AGB)						
W	$y=aH^bDo^cDcr^d$	LN Biomass = 0.711 – 0.375 Ln H – 0.135 Ln Do + 3.26 Ln Dcr Lna= 0.7115 b= -0.3753 c= -0.1346 d=3.2614 a= 2.037045	98.1%	98.0%	93.9%	0.1422
N	$y=aH^bDo^cDcr^d$	LN Biomass = 0.359 + 0.795 Ln H + 0.122 Ln Do + 1.69 Ln Dcr Lna= 0.3595 b= 0.7948 c= 0.1221 d=1.6935 a= 1.432613	95.3%	95.2%	93.7%	0.4439

Stem							
W	y=aH^bDo^cDcr^d	Ln Stem = - 0.492 + 0.129 Ln H + 0.118 Ln Do + 2.39 Ln Dcr Lna= 0.4919 b= 0.1292 c= 0.1183 d=2.3932 a= 0.611464		95.9%	95.6%	92.7%	0.1882
N	y=aH^bDo^cDcr^d	LN Stem = - 0.582 + 1.21 Ln H + 0.174 Ln Do + 1.43 Ln Dcr Lna= - 0.5815 b= 1.2138 c= 0.1742 d= 1.4327 a= 0.559059	92.8%	92.3%	90.6%	0.5926	
Branch							
W	y=aH^bDo^cDcr^d	LN Branch = 0.251 – 1.68 Ln H – 0.467 Ln Do + 4.92 Ln Dcr Lna= 0.2511 b= -1.6816 c= -0.4668 d= 4.9242 a= 1.285439		97.1%	96.8%	87.4%	0.2019
N	y=aH^bDo^cDcr^d	LN Branch = - 0.479 – 0.061 Ln H + 0.082 Ln Do + 2.28 Ln Dcr Lna= -0.4786 b= -0.0607 c= 0.0817 a= 0.619650	89.3%	88.5%	86.2%	0.6404	
Foliage							
W	y=aH^bDo^cDcr^d	LN Foliage = - 1.33 + 1.88 Ln H – 0.454 Ln Do + 1.70 Ln Dcr Lna= -1.3261 b= 1.8812 c= -0.4538 d= 1.6989 a= 0.265511		96.4%	96.2%	90.9%	0.2069
N	y=aH^bDcr^c	LN Foliage = -1.89 + 1.27 Ln H + 1.37 Ln Dcr Lna= -1.8899 b= 1.2667 c= 1.3657 a= 0.151087	90.5%	90.0%	89.1%	0.6413	

Note: W, weighted least square regression. N, ordinary least square regression. The most significant models were printed in bold. The all of tested biomass equations were shown only for stem volume.

Thus, the following specific weighed allometric models were developed for estimating the volume and above-ground biomass of Saxaul (*Haloxylon ammodendron* (C.A.Mey.) Bge.) based on the field data of 46 shrubs and trees:

1. For volume

$$\ln V = -7.966 + 1.055 \ln H + 0.499 \ln Do + 0.816 \ln Dcr \quad (11a)$$

$$V = 0.0003 * H^{1.055} * \ln Do^{0.499} * \ln Dcr^{0.816} \quad (11b)$$

If basic diameter (Do) was not measured during the field inventory, the following equation could be used for the volume estimation.

$$\ln V = - 7.601 + 0.446 \ln H + 1.614 \ln Dcr \quad (12a)$$

$$V = 0.0005 * H^{0.446} * Dcr^{1.614} \quad (12b)$$

2. For total biomass (AGB)

$$\text{LN Biomass} = 0.711 - 0.375 \ln H - 0.135 \ln D_o + 3.261 \ln D_{cr} \quad (13a)$$

$$\text{Biomass} = 2.037 * H^{0.375} * \ln D_o^{0.135} * \ln D_{cr}^{3.261} \quad (13b)$$

3. For stem

$$\ln \text{Stem} = -0.492 + 0.129 \ln H + 0.118 \ln D_o + 2.39 \ln D_{cr} \quad (14a)$$

$$\text{Stem} = 0.6115 * \ln H^{0.129} * \ln D_o^{0.118} * \ln D_{cr}^{2.39} \quad (14b)$$

4. For branch

$$\ln \text{Branch} = 0.251 - 1.68 \ln H - 0.467 \ln D_o + 4.92 \ln D_{cr} \quad (15a)$$

$$\text{Branch} = 0.251 - 1.68 \ln H - 0.467 \ln D_o + 4.92 \ln D_{cr} \quad (15b)$$

5. For foliage

$$\ln \text{Foliage} = -1.33 + 1.881 \ln H - 0.454 \ln D_o + 1.70 \ln D_{cr} \quad (16a)$$

$$\text{Foliage} = 0.2655 * \ln H^{1.881} * \ln D_o^{0.454} * \ln D_{cr}^{1.70} \quad (16b)$$

An analysis of the field data of 46 trees collected during a field study and a test of the developed allometric models shows that it is necessary to increase the number of model trees in order to develop more accurate biomass according models biomass according to 4 forest habitat types in the future.

The stand characteristics of the studied saxaul forest and a database of the biomass sample measurements

Out of the three species of saxauls as *Haloxylon aphyllum* Minkw., *Haloxylon persicum* Bunge., *Haloxylon ammodendron* (C.A.M) Bge. growing in arid region of the earth, the Gobi desert in Mongolia is a habitat of *H.ammodendron* only which also grows in China. The saxaul shrubs grown scattered in the Gobi desert is called “Saxaul forest” in the Forest Resource Land of Mongolia (Tsogtbaatar et al., 2015).

We selected five study site points in the 4 saxaul forest habitat type, being stony deserts or hamadas, dried beds of temporary rivers or sairs, sandy deserts and depressions or takyrs in the Gobi desert (Fig 1).

The saxaul population characteristics were studied establishing 20 simple plots of 1500 m² (e.g. for hamadas 4 plots, for sairs 4 plots, for sandy deserts 8 plots, takyrs - 4 simple plots were established). *Haloxylon* shrubs/trees were counted for their population and measured top height (H, m), crown (Dcr) and basic diameter (Do, cm) at above the soil surface (Table 2.). For the multy-stem shrubs the average basic diameter of the multy-stems was measured.

The manual of forest management and inventory of *Haloxylon ammodendron* has not yet been developed for Mongolia. Therefore, the Manual of the *Haloxylon persicum* and *Haloxylon aphyllum*

forest inventory of Uzbekistan is applied in the forest management practice of Mongolia (Jalbaa and Enkhsaikhan, 1991). Computation of the saxaul stand volume was carried out:

1. using forest inventory method of Mongolia, the stand volume and relative density of *Haloxylon ammodendron* in sample plots were computed by saxaul stand density reference table (Tabl. 3);
2. using allometric model (11a), the saxaul stand volume of all shrubs in sample plots was estimated. Relative density of the sample plot calculated by volume or number of growing stock per unit area.

Actual stand characteristics of the sample plots are presented in table 4 compared with published volume per unit area (Table 3).

Table 2. Geographical data of sample plots

Sample plot	Aimag	Soum	Coordinates			Type of habitat
			Latitude, N	Longitude, E	Altitude (a.s.l.m)	
1	Dornogovi	Erdene	44°15'13.2"	110°39'47.8"	931	Takyrs
2	Dorngovi	Erdene	44°15'13.5"	110°39'52.2"	910	Takyrs
3	Dorngovi	Erdene	44°15'13.0"	110°39'34.4"	928	Takyrs
4	Dorngovi	Erdene	44°15'12.7"	110°39'58.8"	927	Takyrs
5	Dorngovi	Khatanbulag	43.30171°	108.05927°	841	Sandy desert
6	Dorngovi	Khatanbulag	43.30261°	108.0592°	852	Sandy desert
7	Dorngovi	Khatanbulag	43.30127°	108.06039°	839	Sandy desert
8	Dorngovi	Khatanbulag	43.30120°	108.05818°	857	Sandy desert
9	Umnugovi	Bayandalai	42.92184°	103.31093°	1175	Sandy desert
10	Umnugovi	Bayandalai	42.92310°	103.31118°	1150	Sandy desert
11	Umnugovi	Bayandalai	42.92139°	103.31200°	1170	Sandy desert
12	Umnugovi	Bayandalai	42.92140°	103.30988°	1167	Sandy desert
13	Umnugovi	Gurvantes	43.46645°	100.42686°	1463	Sairs
14	Umnugovi	Gurvantes	43.46735°	100.42686°	1470	Sairs
15	Umnugovi	Gurvantes	43.46601°	100.42793°	1463	Sairs
16	Umnugovi	Gurvantes	43.46600°	100.42580°	1466	Sairs
17	Bayankhongor	Bayan-Undur	44.50596°	098.28436°	1410	Hamadas
18	Bayankhongor	Bayan-Undur	44.50684°	098.28435°	1415	Hamadas
19	Bayankhongor	Bayan-Undur	44.50552°	098.28546°	1410	Hamadas
20	Bayankhongor	Bayan-Undur	44.50550°	098.28328°	1408	Hamadas

Table 3. Saxaul stand density reference (Stand Density=1.0)

Stand height(H), m	Grown area (CA) m ² /ha	Volume (V) m ³ /ha
1.0	1550	0.8
1.5	2200	2.4
2.0	2850	5.0
2.5	3500	8.5
3.0	4150	13.0
3.5	4800	18.0
4.0	5500	22.0

Table 4. Average values of the stand characteristics of the studied saxaul forest

Sample plot	H,m	Do, cm	Dcr, m	N, pieces/ha	Crown cover,%	RD	Volume m ³ /ha		Volume of per shrub,m ³	
							by forest inventory manual	by volume equation	by forest inventory manual	by volume of per shrub,m ³
1	1.1	3.1	1.1	660	8.8	0.52	0.4171	0.7176	0.0006	0.0009
2	1.7	4.8	2.3	147	6.8	0.31	0.8298	0.4479	0.0057	0.0031
3	1.3	3.8	2.0	240	9.6	0.62	0.4121	0.5059	0.0017	0.0021
4	0.7	2.1	1.0	373	4.9	0.33	0.2184	0.2398	0.0006	0.0006
5	1.7	6.8	1.3	340	6.7	0.31	0.8162	1.0576	0.0024	0.0031
6	0.9	3.7	0.8	187	1.2	0.08	0.0501	0.1148	0.0003	0.0006
7	1.0	3.4	0.8	407	2.5	0.16	0.1091	0.2933	0.0003	0.0007
8	1.5	5.6	1.1	433	5.4	0.25	0.6569	0.7910	0.0015	0.0018
9	3.7	13.5	3.6	300	35.4	0.74	13.1865	4.3793	0.0440	0.0146
10	3.3	9.9	2.6	627	38.1	0.84	10.9799	5.5414	0.0175	0.0088
11	3.0	10.3	2.1	340	13.5	0.33	4.3455	2.2125	0.0128	0.0434
12	2.4	9.0	1.9	260	9.1	0.32	2.7763	1.2806	0.0107	0.0049
13	0.9	8.7	1.0	93	0.9	0.06	0.0374	0.0914	0.0004	0.0010
14	1.2	4.8	1.3	140	2.2	0.14	0.0939	0.1816	0.0007	0.0013
15	1.2	6.7	1.3	133	2.0	0.13	0.0872	0.2114	0.0007	0.0016
16	1.4	5.2	1.2	67	1.0	0.05	0.3037	0.1304	0.0046	0.0020
17	1.0	3.1	0.4	167	0.3	0.02	0.0132	0.0587	0.0001	0.0004
18	0.5	2.1	0.5	73	0.2	0.01	0.0083	0.0125	0.0001	0.0002
19	0.9	4.0	0.9	167	1.2	0.08	0.0517	0.0994	0.0003	0.0006
20	0.7	3.2	2.0	107	4.3	0.28	0.1864	0.1159	0.0017	0.0011
Mean	1,5	5,7	1,5	263	7,7	0,3	1,8	0,9	0,005	0,005

Note: H is average height, Do- collar diameter, Dcr - crown diameter, N- number of shrubs,

RD - Relative density



Table 5. The characteristics and data of the sample trees

Sample tree #	Do,cm	Dcrown, m	Height, m	Volume, m3	Stem biomass, kg	Branch biomass, kg	Foliage biomass, kg	Above ground biomass, kg	Stem fresh biomass, kg	Branch fresh biomass, kg	Foliage fresh biomass, kg	Above ground fresh biomass, kg	Moisture content of total biomass
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0,71	0,15	0,22	0,000014	0,0048	0,0013	0,0006	0,0067	0,0073	0,0022	0,0020	0,0115	0,42
2	9,60	0,34	0,57	0,000284	0,0128	0,0341	0,0106	0,0574	0,0187	0,0488	0,0370	0,1045	0,45
3	15,25	7,10	2,60	0,030902	28,7507	37,8228	8,8816	75,4551	38,8800	54,4419	24,8581	118,1800	0,36
4	10,00	1,05	2,40	0,002387	2,6082	1,3339	0,2112	4,1532	3,6870	2,1837	0,6893	6,5600	0,37
5	7,50	1,08	1,60	0,004205	1,8703	2,3135	0,5827	4,7665	2,5129	3,1792	2,0079	7,7000	0,38
6	5,50	0,85	0,95	0,000713	0,6565	0,6716	0,2038	1,5319	0,9011	1,0697	0,6292	2,6000	0,41
7	16,20	2,15	3,60	0,032112	29,0206	3,7142	2,7958	35,5306	38,7862	7,1888	9,2251	55,2000	0,36
8	7,33	2,90	2,30	0,006360	8,0590	3,7020	1,6410	13,4020	11,0700	6,1191	6,5109	23,7000	0,43
9	18,50	2,28	3,00	0,024160	12,8685	8,6789	2,7994	24,3468	18,0031	14,8455	11,9514	44,8000	0,46
10	3,56	1,65	1,50	0,001418	2,3556	3,4172	0,5429	6,3157	3,0000	5,1480	2,0520	10,2000	0,38
11	0,89	0,49	0,56	0,000097	0,1827	0,1989	0,0366	0,4182	0,2587	0,2879	0,1534	0,7000	0,40
12	7,50	1,05	1,80	0,000483	0,4530	0,7602	0,2403	1,4535	0,6506	1,2490	0,9172	2,8167	0,48
13	2,08	1,50	1,80	0,003131	4,3141	2,2534	1,1760	7,7435	5,7000	3,4440	4,9560	14,1000	0,45
14	7,40	0,95	1,15	0,001072	2,4012	0,3109	0,1506	2,8627	3,6172	0,4534	0,6294	4,7000	0,39
15	17,70	1,20	2,63	0,007328	7,2371	2,0313	0,7816	10,0499	10,1270	3,0578	3,1152	16,3000	0,38
16	25,50	3,00	4,40	0,043988	31,1313	8,1866	3,3801	42,6980	42,1490	13,1195	12,9315	68,2000	0,37
17	5,50	0,75	0,63	0,001353	0,4143	0,4195	0,1105	0,9444	0,5907	0,6370	0,3721	1,5998	0,41
18	1,00	0,90	1,10	0,000316	0,3903	0,5675	0,2241	1,1818	0,7180	0,8013	1,0177	2,5370	0,53
19	20,00	6,15	5,65	0,079888	68,9507	18,3939	8,3235	95,6681	98,5971	31,9200	31,5880	162,1051	0,41
20	17,00	2,25	3,60	0,084045	18,6288	3,1069	1,7829	23,5186	27,3215	6,8602	7,8738	42,0555	0,44
21	9,00	4,85	3,40	0,019204	22,3530	11,6510	4,8971	38,9011	31,4299	20,6024	22,1966	74,2289	0,48
22	7,00	0,95	1,00	0,000207	0,4118	0,6287	0,2110	1,2515	0,5800	1,1060	0,8870	2,5730	0,51
23	7,80	2,48	3,95	0,014281	17,3097	1,7337	3,8316	22,8750	25,0990	2,5268	16,4052	44,0310	0,48



24	8,40	3,18	2,90	0,018734	25,6381	7,7423	3,9208	37,3012	34,6160	11,4667	18,2363	64,3190	0,42
25	5,10	2,30	2,50	0,004878	5,9505	4,5618	0,7074	11,2198	7,3490	6,7524	2,8476	16,9490	0,34
26	8,40	4,65	3,20	0,022576	19,6167	9,3656	5,3042	34,2866	29,1600	15,3689	23,8121	68,3410	0,50
27	2,33	1,13	1,04	0,000116	0,3582	1,2805	0,4950	2,1337	0,5183	2,1341	2,0311	4,6835	0,54
28	2,60	0,53	0,60	0,000014	0,1759	0,0674	0,0556	0,2989	0,3120	0,1613	0,2492	0,7225	0,59
29	3,80	0,65	0,50	0,000139	0,1811	0,2378	0,1256	0,5445	0,2725	0,3881	0,5242	1,1848	0,54
30	18,50	1,25	1,20	0,006054	3,3783	2,6655	0,2423	6,2861	4,6980	3,5263	0,8631	9,0874	0,31
31	5,80	0,95	0,90	0,000538	0,4725	0,5157	0,2945	1,2827	0,6790	0,6727	1,0823	2,4340	0,47
32	6,00	2,40	2,20	0,005038	4,5625	8,7638	1,4687	14,7950	6,3650	12,2418	4,1582	22,7650	0,35
33	3,40	1,60	1,60	0,001401	1,2408	2,4274	0,8258	4,4939	1,8320	3,4331	2,4949	7,7600	0,42
34	5,50	2,15	1,90	0,004561	3,9642	6,3717	1,0681	11,4040	5,6820	8,9964	3,3546	18,0330	0,37
35	2,60	0,83	0,85	0,000134	0,2367	0,4500	0,1368	0,8234	0,3613	0,6900	0,4238	1,4750	0,44
36	3,30	1,50	1,40	0,002901	2,6731	3,2901	0,6104	6,5735	3,6330	4,1873	1,6357	9,4560	0,30
37	2,10	1,15	1,20	0,001165	1,1114	1,3180	0,3755	2,8048	1,5270	1,7098	0,8532	4,0900	0,31
38	1,10	0,55	0,65	0,000123	0,0728	0,1142	0,0588	0,2458	0,1685	0,1538	0,1752	0,4975	0,51
39	3,70	2,40	1,75	0,005010	5,7608	3,9939	0,4718	10,2265	6,1475	5,5914	1,8211	13,5600	0,25
40	3,30	1,20	1,00	0,001007	1,2034	2,5659	0,0315	3,8009	1,5570	2,9291	0,1139	4,6000	0,17
41	2,20	0,45	0,50	0,000170	0,1420	0,1366	0,0197	0,2983	0,1955	0,1821	0,0734	0,4510	0,34
42	3,27	1,05	0,80	0,000713	0,8822	1,1661	0,0610	2,1094	1,0560	1,3327	0,2113	2,6000	0,19
43	1,60	0,38	0,39	0,000104	0,0586	0,0455	0,0043	0,1084	0,0821	0,0724	0,0131	0,1675	0,35
44	4,08	1,37	1,05	0,003443	3,0273	1,7758	0,2004	5,0035	3,6635	2,4270	0,7095	6,8000	0,26
45	5,53	1,45	1,05	0,005172	1,6251	3,8610	0,0846	5,5708	2,0045	5,2510	0,3445	7,6000	0,27
46	2,50	0,82	0,70	0,000289	0,4229	0,8984	0,0423	1,3636	0,5780	1,2653	0,1567	2,0000	0,32



D1.3,cm	Age	Life form	Soum	Sample plot #	Type of habitat	Coordinates		Altitude, a.s.l.m	Dry density, gr/cm ³	Biomass Expansion Factor (BEF)
15	16	17	18	19	20	21		22	23	24
0	8	tree	Erdene	1	Takyrs	44°15'13.2"	110°39'47.8"	931	0,6317	1,3862
0	14	tree	Erdene	1	Takyrs	44°15'13.2"	110°39'47.8"	931	0,9723	4,4888
0	21	shrub	Erdene	3	Takyrs	44°15'09.2"	110°39'48.6"	925	0,7005	2,6245
0	19	tree	Erdene	3	Takyrs	44°15'12.7"	110°39'58.8"	927	0,6417	2,6082
0	14	tree	Erdene	2	Takyrs	44°15'10.9"	110°39'44.6"	928	0,5759	2,5485
0	11	tree	Erdene	2	Takyrs	44°15'10.9"	110°39'46.7"	928	0,7279	2,3335
8,9	23	tree	Erdene	4	Takyrs	44°15'10.1"	110°39'45.1"	933	1,0240	1,2243
0	20	shrub	Erdene	4	Takyrs	44°15'09.9"	110°39'45.7"	911	0,8251	1,6630
6,5	20	tree	Khatanbulag	5	Sandy desert	43.30133°	108.05909°	844	1,4622	1,8920
2	20	shrub	Khatanbulag	5	Sandy desert	43°18'04.9"	108°03'33.5"	844	0,8205	2,6812
0	20	shrub	Khatanbulag	5	Sandy desert	43°18'05.3"	108°03'33.2"	844	0,7930	2,2891
0	20	shrub	Khatanbulag	6	Sandy desert	43°18'05.5"	108°03'33.3"	842	0,8332	3,2083
0	12	shrub	Khatanbulag	6	Sandy desert	43°18'07.0"	108°03'35.3"	841	0,9279	1,7949
0	15	shrub	Khatanbulag	8	Sandy desert	43.30191°	108.05982°	846	1,0542	1,1922
3,5	33	tree	Khatanbulag	8	Sandy desert	43.30156°	108.06001°	840	0,9386	1,3887
11	35	tree	Khatanbulag	7	Sandy desert	43°18'07.4"	108°03'36.1"	827	0,8249	1,3715
0	11	shrub	Khatanbulag	7	Sandy desert	43.30222°	108.05995°	843	1,0198	2,2795



0	10	shrub	Khatanbulag	8	Sandy desert	43°18'06.7"	108°03'35.6"	846	0,8016	3,0280
16,6	20	tree	Bayan-Dalai	10	Sandy desert	42,92275	103,3102	1167	0,8277	1,3875
5,9	23	tree	Bayan-Dalai	10	Sandy desert	42.92276°	103.31031°	1172	0,9107	1,2625
3,5	35	tree	Bayan-Dalai	10	Sandy desert	42.92273°	103.31033°	1175	1,0005	1,7403
0	12	shrub	Bayan-Dalai	10	Sandy desert	42.92302°	103.30930°	1175	1,0075	3,0392
4,2	36	tree	Bayan-Dalai	10	Sandy desert	42.92238°	103.31078°	1175	0,8861	1,3215
4,4	12	Shrub	Bayan-Dalai	10	Sandy desert	42.92233°	103.31074°	1175	0,8422	1,4549
2,5	12	Shrub	Bayan-Dalai	11	Sandy desert	42.92225°	103.31066°	1175	1,0681	1,8855
4,5	9	shrub	Bayan-Dalai	11	Sandy desert	42.92233°	103.31074°	1175	0,7362	1,7478
0	10	shrub	Bayan-Dalai	11	Sandy desert	42.92233°	103.31074°	1175	0,7581	5,9569
0	11	shrub	Bayan-Dalai	9	Sandy desert	42.92225°	103.31066°	1175	0,8333	1,6996
0	11	Tree	Bayan-Dalai	9	Sandy desert	42.92225°	103.31066°	1175	0,7482	3,0058
0	19	shrub	Gurwantes	14	Sairs	42.47008°	100.42702°	1463	0,8877	1,8607
0	18	shrub	Gurwantes	14	Sairs	43.47021°	100.42693°	1463	0,7432	2,7146
2,2	11	shrub	Gurwantes	14	Sairs	43,47017	100,42721	1463	0,9821	3,2428
1	12	shrub	Gurwantes	14	Sairs	43,47017	100,42721	1464	1,0045	3,6219
0,5	11	shrub	Gurwantes	14	Sairs	43.47010°	100.42678°	1464	0,8023	2,8768
0	10	shrub	Gurwantes	14	Sairs	43.47021°	100.42684°	1464	0,7882	3,4788
0	10	shrub	Gurwantes	13	Sairs	43.46977°	100.42741°	1462	0,9441	2,4592
0	11	shrub	Gurwantes	15	Sairs	43.47025°	100.42712°	1461	0,9883	2,5237



0	8	shrub	Gurwantes	15	Sairs	43.47021°	100.42728°	1453	1,0750	3,3763
1	10	shrub	Bayan-Undur	20	Hamadas	44.50582°	098.28395°	1415	1,0489	1,7752
0	9	shrub	Bayan-Undur	20	Hamadas	44.50589°	098.28404°	1410	0,8675	3,1585
0	10	shrub	Bayan-Undur	20	Hamadas	44.50586°	098.28404°	1453	0,8303	2,1007
0	8	shrub	Bayan-Undur	17	Hamadas	44.50591°	098.28381°	1415	0,7860	2,3909
0	8	shrub	Bayan-Undur	20	Hamadas	44.50591°	098.28381°	1408	1,1844	1,8485
0	22	shrub	Bayan-Undur	18	Hamadas	44.50605°	098.28413°	1410	0,9860	1,6528
0	21	shrub	Bayan-Undur	18	Hamadas	44.50606°	098.28419°	1412	0,7930	3,4279
0	22	shrub	Bayan-Undur	18	Hamadas	44.50591°	098.28403°	1410	0,6960	3,2242

CONCLUSION

Country species-specific allometric models for volume and stem, branch and foliage above ground biomasses of *Haloxylon ammodendron* (C.A. Mey) Bunge were developed based on height (H,m) basic diameter (Do) and crown diameter (Dcr, m) relations of 46 model shrubs/trees.

An analysis of the field data of 46 trees collected during a field study and a test of the developed allometric models shows that it is necessary to increase the number of model trees in order to develop more accurate biomass according models biomass according to 4 forest habitat types in the future. However, the current model is the best available model within the country and sufficient to estimate biomass amount for the saxaul forests.

A database of biomass sample measurements of 46 model trees and 20 sample plots of *Haloxylon ammodendron* was build and delivered to FAO and UN-REDD Mongolia National Programme.

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ANNEX I. THE RESULTS OF THE REGRESSION ANALYSES FOR STEM VOLUME

Regression Analysis: Ln V versus Ln H, Ln Dcr

The regression equation is

$$\text{Ln } V = -7.19 + 1.79 \text{ Ln } H + 0.951 \text{ Ln } Dcr$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-7.1901	0.1460	-49.24	0.000	
Ln H	1.7902	0.4300	4.16	0.000	5.397
Ln Dcr	0.9513	0.4002	2.38	0.022	5.397

$$S = 0.900007 \quad R-Sq = 83.7\% \quad R-Sq(adj) = 82.9\%$$

$$\text{PRESS} = 39.0206 \quad R-Sq(\text{pred}) = 81.72\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	178.582	89.291	110.23	0.000
Residual Error	43	34.831	0.810		
Total	45	213.413			

Source	DF	Seq SS
Ln H	1	174.006
Ln Dcr	1	4.576

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid
3	0.96	-3.477	-3.615	0.466	0.138	0.18 X
27	0.04	-9.062	-7.008	0.150	-2.055	-2.32R
28	-0.51	-11.160	-8.718	0.207	-2.442	-2.79R

R denotes an observation with a large standardized residual.

X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus Ln H, Ln Dcr

Weighted analysis using weights in $1/H^2$

The regression equation is

$$\text{Ln } V = -7.26 + 1.13 \text{ Ln } H + 1.17 \text{ Ln } Dcr$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-7.2618	0.1803	-40.28	0.000	
Ln H	1.1343	0.7362	1.54	0.131	15.481
Ln Dcr	1.1711	0.5906	1.98	0.054	15.481

$$S = 1.03487 \quad R-Sq = 81.5\% \quad R-Sq(adj) = 80.6\%$$

$$\text{PRESS} = 54.4430 \quad R-Sq(\text{pred}) = 78.10\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	202.51	101.26	94.55	0.000
Residual Error	43	46.05	1.07		
Total	45	248.57			

Source	DF	Seq SS
Ln H	1	198.30
Ln Dcr	1	4.21

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St	Resid
1	-1.51	-11.153	-11.201	0.203	0.048	0.47	X
2	-0.57	-8.167	-9.190	0.276	1.023	1.99	X
17	-0.46	-6.605	-8.123	0.202	1.517	2.45R	
28	-0.51	-11.160	-8.596	0.131	-2.564	-4.22R	
29	-0.69	-8.880	-8.553	0.264	-0.328	-0.74	X

Regression Analysis: Ln V versus Ln H, Ln Dcr

Weighted analysis using weights in 1/Dcr^2

The regression equation is

$$\text{Ln V} = -7.33 + 1.99 \text{ Ln H} + 0.416 \text{ Ln Dcr}$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-7.3289	0.1939	-37.79	0.000	
Ln H	1.9895	0.6121	3.25	0.002	14.530
Ln Dcr	0.4158	0.5296	0.79	0.437	14.530

S = 1.13356 R-Sq = 84.5% R-Sq(adj) = 83.8%

PRESS = 67.1319 R-Sq(pred) = 81.14%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	300.73	150.36	117.02	0.000
Residual Error	43	55.25	1.28		
Total	45	355.98			

Source	DF	Seq SS
Ln H	1	299.94
Ln Dcr	1	0.79

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St	Resid
1	-1.51	-11.153	-11.130	0.158	-0.023	-0.37	X
2	-0.57	-8.167	-8.919	0.202	0.753	2.34RX	
17	-0.46	-6.605	-8.368	0.238	1.762	2.16R	
28	-0.51	-11.160	-8.613	0.131	-2.546	-4.39R	

R denotes an observation with a large standardized residual.

X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus LNDcr^2*H

The regression equation is

$$\text{Ln V} = -7.12 + 0.883 \text{ LNDcr}^2*\text{H}$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-7.1181	0.1477	-48.21	0.000	
LNDcr^2*H	0.88261	0.06244	14.14	0.000	1.000

S = 0.935556 R-Sq = 82.0% R-Sq(adj) = 81.5%

PRESS = 41.8728 R-Sq(pred) = 80.38%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	174.90	174.90	199.83	0.000
Residual Error	44	38.51	0.88		
Total	45	213.41			

Unusual Observations

Obs	LNDcr^2*H	Ln V	Fit	SE Fit	Residual	St	Resid

1	-5.31	-11.153	-11.803	0.408	0.650	0.77 X
20	2.90	-2.476	-4.556	0.189	2.080	2.27R
27	0.27	-9.062	-6.876	0.142	-2.187	-2.37R
28	-1.80	-11.160	-8.706	0.215	-2.453	-2.69R

Regression Analysis: Ln V versus LNDcr^2*H

Weighted analysis using weights in 1/H^2

The regression equation is

$$\text{Ln } V = -7.28 + 0.741 \text{ LNDcr}^2\text{H}$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-7.2777	0.1764	-41.26	0.000	
LNDcr^2*H	0.74103	0.05349	13.85	0.000	1.000

S = 1.02645 R-Sq = 81.3% R-Sq(adj) = 80.9%

PRESS = 51.8086 R-Sq(pred) = 79.16%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	202.21	202.21	191.92	0.000
Residual Error	44	46.36	1.05		
Total	45	248.57			

Unusual Observations

Obs	LNDcr^2*H	Ln V	Fit	SE Fit	Residual	St Resid
1	-5.31	-11.153	-11.211	0.201	0.058	0.56 X
2	-2.76	-8.167	-9.322	0.126	1.155	2.04R
17	-1.04	-6.605	-8.046	0.142	1.441	2.28R
28	-1.80	-11.160	-8.611	0.127	-2.548	-4.23R

R denotes an observation with a large standardized residual.

X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus LNDcr^2*H

Weighted analysis using weights in 1/Dcr^2

The regression equation is

$$\text{Ln } V = -7.22 + 0.741 \text{ LNDcr}^2\text{H}$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-7.2199	0.1931	-37.39	0.000	
LNDcr^2*H	0.74060	0.05059	14.64	0.000	1.000

S = 1.17393 R-Sq = 83.0% R-Sq(adj) = 82.6%

PRESS = 66.8292 R-Sq(pred) = 81.23%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	295.34	295.34	214.31	0.000
Residual Error	44	60.64	1.38		
Total	45	355.98			

Unusual Observations

Obs	LNDcr^2*H	Ln V	Fit	SE Fit	Residual	St Resid
1	-5.31	-11.153	-11.151	0.164	-0.002	-0.03 X
2	-2.76	-8.167	-9.263	0.117	1.096	2.92R
28	-1.80	-11.160	-8.553	0.132	-2.607	-4.33R

R denotes an observation with a large standardized residual.

X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus Ln H, Ln Do

The regression equation is

$$\text{Ln } V = -8.08 + 2.14 \text{ Ln } H + 0.637 \text{ Ln } Do$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-8.0826	0.3273	-24.70	0.000	
Ln H	2.1436	0.2671	8.02	0.000	2.198
Ln Do	0.6372	0.2208	2.89	0.006	2.198

$$S = 0.876228 \quad R-Sq = 84.5\% \quad R-Sq(adj) = 83.8\%$$

$$\text{PRESS} = 36.5726 \quad R-Sq(\text{pred}) = 82.86\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	180.398	90.199	117.48	0.000
Residual Error	43	33.014	0.768		
Total	45	213.413			

Source	DF	Seq SS
Ln H	1	174.006
Ln Do	1	6.392

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid
12	0.59	-7.635	-5.539	0.142	-2.096	-2.42R
28	-0.51	-11.160	-8.569	0.198	-2.591	-3.04R

R denotes an observation with a large standardized residual.

Regression Analysis: Ln V versus Ln H, Ln Do

Weighted analysis using weights in $1/H^2$

The regression equation is

$$\text{Ln } V = -8.12 + 1.89 \text{ Ln } H + 0.618 \text{ Ln } Do$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-8.1239	0.3480	-23.35	0.000	
Ln H	1.8891	0.2892	6.53	0.000	2.615
Ln Do	0.6180	0.2138	2.89	0.006	2.615

$$S = 0.989268 \quad R-Sq = 83.1\% \quad R-Sq(adj) = 82.3\%$$

$$\text{PRESS} = 48.1609 \quad R-Sq(\text{pred}) = 80.62\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	206.48	103.24	105.49	0.000
Residual Error	43	42.08	0.98		
Total	45	248.57			

Source	DF	Seq SS
Ln H	1	198.30
Ln Do	1	8.18

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid
1	-1.51	-11.153	-11.196	0.191	0.043	0.41 X
2	-0.57	-8.167	-7.805	0.334	-0.362	-0.81 X

17	-0.46	-6.605	-7.943	0.209	1.338	2.28R
28	-0.51	-11.160	-8.498	0.125	-2.661	-4.59R

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus Ln H, Ln Do

Weighted analysis using weights in 1/Do^2

The regression equation is

$$\ln V = -8.10 + 1.92 \ln H + 0.626 \ln Do$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-8.1030	0.1623	-49.94	0.000	
Ln H	1.9212	0.1761	10.91	0.000	1.903
Ln Do	0.6261	0.1894	3.31	0.002	1.903

$$S = 0.248875 \quad R-Sq = 88.8\% \quad R-Sq(adj) = 88.3\%$$

$$PRESS = 3.19046 \quad R-Sq(pred) = 86.62\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	21.174	10.587	170.92	0.000
Residual Error	43	2.663	0.062		
Total	45	23.837			

Source	DF	Seq SS
Ln H	1	20.496
Ln Do	1	0.677

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid	
1	-1.51	-11.1530	-11.2264	0.1533	0.0734	0.83	X
11	-0.58	-9.2452	-9.2876	0.1122	0.0424	0.22	X
18	0.10	-8.0583	-7.9199	0.1760	-0.1384	-0.79	X
27	0.04	-9.0625	-7.4981	0.1216	-1.5644	-2.76R	
28	-0.51	-11.1595	-8.4862	0.1541	-2.6733	-4.25R	

R denotes an observation with a large standardized residual.
X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus Ln H, Ln Do, Ln Dcr

The regression equation is

$$\ln V = -8.11 + 1.06 \ln H + 0.694 \ln Do + 1.07 \ln Dcr$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-8.1132	0.3014	-26.92	0.000	
Ln H	1.0588	0.4413	2.40	0.021	7.080
Ln Do	0.6940	0.2041	3.40	0.001	2.218
Ln Dcr	1.0664	0.3602	2.96	0.005	5.445

$$S = 0.806444 \quad R-Sq = 87.2\% \quad R-Sq(adj) = 86.3\%$$

$$PRESS = 31.6513 \quad R-Sq(pred) = 85.17\%$$

Analysis of Variance

Source	DF	SS	MS	F	P
Total	45	23.837	0.529	170.92	0.000

Regression	3	186.098	62.033	95.38	0.000
Residual Error	42	27.315	0.650		
Total	45	213.413			

Source	DF	Seq SS
Ln H	1	174.006
Ln Do	1	6.392
Ln Dcr	1	5.700

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid
3	0.96	-3.477	-3.120	0.442	-0.356	-0.53 X
12	0.59	-7.635	-6.041	0.214	-1.595	-2.05R
22	0.00	-8.481	-6.818	0.180	-1.663	-2.12R
27	0.04	-9.062	-7.359	0.170	-1.703	-2.16R
28	-0.51	-11.160	-8.678	0.186	-2.481	-3.16R

R denotes an observation with a large standardized residual.

X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus Ln H, Ln Do, Ln Dcr

Weighted analysis using weights in $1/H^2$

The regression equation is

$$\text{Ln V} = -8.10 + 0.619 \text{ Ln H} + 0.593 \text{ Ln Do} + 1.08 \text{ Ln Dcr}$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-8.0996	0.3372	-24.02	0.000	
Ln H	0.6195	0.7049	0.88	0.385	16.562
Ln Do	0.5931	0.2074	2.86	0.007	2.625
Ln Dcr	1.0750	0.5478	1.96	0.056	15.540

S = 0.958012 R-Sq = 84.5% R-Sq(adj) = 83.4%

PRESS = 55.1263 R-Sq(pred) = 77.82%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	210.019	70.006	76.28	0.000
Residual Error	42	38.547	0.918		
Total	45	248.566			

Source	DF	Seq SS
Ln H	1	198.304
Ln Do	1	8.180
Ln Dcr	1	3.535

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid
1	-1.51	-11.153	-11.280	0.190	0.127	1.40 X
2	-0.57	-8.167	-8.288	0.406	0.121	0.34 X
28	-0.51	-11.160	-8.542	0.123	-2.617	-4.66R
29	-0.69	-8.880	-8.200	0.274	-0.680	-1.73 X

R denotes an observation with a large standardized residual.

X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus Ln H, Ln Do, Ln Dcr

Weighted analysis using weights in $1/Dcr^2$

The regression equation is

$$Ln V = -8.14 + 0.942 \ln H + 0.580 \ln Do + 0.763 \ln Dcr$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-8.1435	0.3029	-26.88	0.000	
Ln H	0.9422	0.6371	1.48	0.147	19.350
Ln Do	0.5799	0.1761	3.29	0.002	2.965
Ln Dcr	0.7626	0.4892	1.56	0.126	15.236

S = 1.02250 R-Sq = 87.7% R-Sq(adj) = 86.8%

PRESS = 65.1730 R-Sq(pred) = 81.69%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	312.07	104.02	99.50	0.000
Residual Error	42	43.91	1.05		
Total	45	355.98			

Source	DF	Seq SS
Ln H	1	299.94
Ln Do	1	9.59
Ln Dcr	1	2.54

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid
1	-1.51	-11.153	-11.216	0.145	0.063	1.26 X
2	-0.57	-8.167	-8.204	0.284	0.037	0.19 X
28	-0.51	-11.160	-8.562	0.119	-2.597	-4.96R

R denotes an observation with a large standardized residual.

X denotes an observation whose X value gives it large leverage.

Regression Analysis: Ln V versus Ln H, Ln Do, Ln Dcr

Weighted analysis using weights in $1/Do^2$

The regression equation is

$$Ln V = -7.97 + 1.05 \ln H + 0.499 \ln Do + 0.816 \ln Dcr$$

Predictor	Coef	SE Coef	T	P	VIF
Constant	-7.9664	0.1994	-39.95	0.000	
Ln H	1.0547	0.7619	1.38	0.174	35.917
Ln Do	0.4992	0.2176	2.29	0.027	2.534
Ln Dcr	0.8155	0.6978	1.17	0.249	42.027

S = 0.247822 R-Sq = 89.2% R-Sq(adj) = 88.4%

PRESS = 4.04429 R-Sq(pred) = 83.03%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	21.2574	7.0858	115.37	0.000
Residual Error	42	2.5795	0.0614		
Total	45	23.8369			

Source	DF	Seq SS
Ln H	1	20.4964
Ln Do	1	0.6771
Ln Dcr	1	0.0839

Unusual Observations

Obs	Ln H	Ln V	Fit	SE Fit	Residual	St Resid	
1	-1.51	-11.1530	-11.2815	0.1597	0.1285	1.74	X
11	-0.58	-9.2452	-9.2160	0.1274	-0.0292	-0.16	X
18	0.10	-8.0583	-7.9518	0.1774	-0.1065	-0.62	X
27	0.04	-9.0625	-7.4067	0.1441	-1.6557	-2.96R	
28	-0.51	-11.1595	-8.5537	0.1640	-2.6058	-4.18R	

R denotes an observation with a large standardized residual.



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