Modeling of age dynamics of mean height stands *Haloxylon aphyllum* given the level of groundwater in Ile-Balkhash region

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Abstract. Taking into account severe climatic conditions of the desert and influence of the intense human impacts (grazing, cutting down trees to get fuel, etc.), the actual *Haloxylon* (further-saxaul) forest area is lessening significantly. Herewith, the classification of the experimental materials enabled to design models of age dynamics of growth of black saxaul in Ile-Balkhash region. The implementation of the task is carried out by elaborating the models of black saxaul alteration taking main morphometric parameters: root collar diameter, height and diameter of the crown. As a consequence of the statistical modeling of the investigated relationships, multiple regression equations for the each level of groundwater occurence were obtained.
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Introduction

In regard to physiognomic-ecological, phytocenotic, landscape and household categories saxaul deserts are common type of plant communities of the Sahara-Gobi desert region. The saxaul is represented by three species, two of which are black saxaul and white saxaul which are spread along the extensive area in the deserts of Iran-Turanian region and the Arabian Peninsula. The third type is saxaul Zaysanskiy. It can be found only in eastern Kazakhstan and Junggar province [1].

In Kazakhstan, saxaul plantations cover 6.1 million hectares, where black saxaul grows on 4.4 million hectares, white saxaul – on 1.7 million hectares and saxaul Zaysanskiy - on several thousand hectares [2].

After the 90s of the 20th century, we have seen the significant increase of cases of cutting the saxaul. As a result, the whole massives of most valuable and productive plantations were destroyed and what is left are only damaged and impaired ones.

Unfortunately, the restoration of saxaul plantings following the large-scale destruction is taking place only 30-40 years later [3], but they can reach their former state only after a few hundred years [4].

It is known that carbon stocks and carbon storage in drylands of the world gained special attention in recent years [5].

In fact, saxaul forests are fixers of the significant part of carbon in drylands. The scholars report that up to 36 % of global carbon stored in dryland ecosystems of Central Asia [6].

As a consequence of the human impact, nowadays only 25% of the potential distribution area of saxaul has been recorded in Kazakhstan. About three quarters of the potential dissemination areas of saxaul forests were ruined or degraded compared to the inherent distribution area [7].

Besides of systematic and frequent unsanctioned loggings, which lead to the decrease of forested land, there are also other reasons like ongoing natural processes. In particular, we can emphasize the changing soil conditions. As a rule, saxaul are ubiquitously spreaded in the desert of modern and ancient alluvial river valleys. In these conditions, it is possible to observe the process of soil change-soil salinization and leaching, decrease or increase in the groundwater level [1].

According to different authors, the key performance indicators of natural regeneration of saxaul are a soil (salinity, alkalinity) and a groundwater (level and salinity) [8].

Thus, the main objective of our study - is modeling regularities of relationship of black saxaul stand height with main taxational indicators depending on the level of groundwater to determine the carbon content in desert ecosystems.

Materials and methods

1. Investigated species.

As objects of study, there have been used black saxaul plantings. Saxaul – is presented in arid and strongly salinited areas, distinct xerophytic and classic halophytes habitating in conditions of extreme dryness and extreme salinity [9].

In its turn, saxaul generates significant impact on the soil properties, including the accumulation of organic matter, the change of acidity, phosphorus and potassium. Moreover, it is proved that saxaul increases organic matter content and soil nutrients and improves the soil structure in the long term [10].

The black saxaul has exceptional ecological plasticity – is able to grow on soils "from deep sands to heavy desert soils (takyr)". The poweful root system (up to 1.5 meters in the first year) gives it the opportunity in scorching and using moisture from deep layers during dry summer. Depending on the conditions of ecotype of the roots, 5-10 year aged saxaul penetrate to a depth of 8-16 meters, extending horizontally from 2.5 to 3.5 meters. However, seed germination of saxaul decreases with increasing soil salinity and temperature [11].

2 . The research territory.

The studies were conducted in the Ile-Balkhash region, located within the Almaty oblast, covering the Balkhash-Alakolsky hydroecological region (Figure 1).

The work was carried out in the summer of 2013 in the valley of river Ily. There have been laid two sites: one in the area of village Kuiygan where were laid in total 3 transects, the second - in the area of village Bakanas (3 transects).

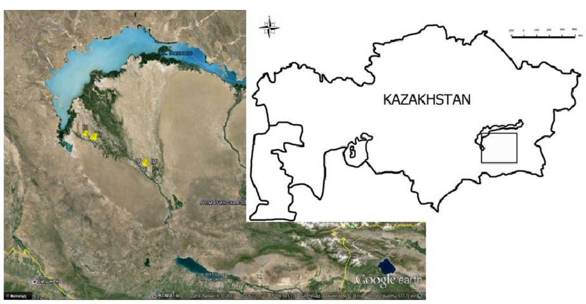

Figure 1. Location of the research territory

The trial plots were located between coordinates: 45 ° 02.096 'N, 74 ° 46.066' E and 44 ° 56'51 .93 N, 75 ° 53'25 .97 E (Table 1).

The study territory in regard to its soil, geomorphological, climatic and geo-botanical terms refers to the 2 areas: the coastal Solonchak plain (sites I, II, III) and Bakanas takyr plain (IV, V, VI).

The Bakanas plain is characterised by peculiar dry river and drainage basins [12]. By soil-geographic regionization the area belongs to the zone of gray-brown soils, which in turn relate to the modern desert soils [13].

Table 1. Coordinates, ground water level and type of wood studied transects

Site	Transect	Coordinates	GWL, m	Forest type	Underwood	Constant species
Kuiygan	I	45°02´096N 74°46´066E	4.6	Black saxaul riverbed sand and loamy plains	Chingil Teresken, Tamarix, Salsola, Artemisia	Teresken, gray, white wormwood
	II	45°02´11.78N 74°43´53E	3.7			
	III	45°31´31.84N 74°33´43.73E	4.0			
Bakanas	IV	44°55´46.68N 75°55´44.11E	5.5	Takyr black saxaul ancient- alluvial plains	Djuzgun, chingil, Salsola, Artemisia	Keyreuk (Salsola orientalis), white wormwood
	V	44°56´3.43N 75°54´30.96E	6			
	VI	44°56´51.93N 75°53´25.97E	6			

The black saxaul (*Haloxylon aphyllum (Minkw.))* is a dominant type among species of vegetation. Amidst other tree and shrub species there found following types: chingil (*Halimodendron halodendron*), turanga (*Populus deversifolia*), djuzgun (*Calligonum aphillum*), krascheninnikovia (*Eurotia ceratoides*), astragalus (*Astragalus ammodendron*) and others [1].

3 . Collection of materials.

There were selected model tree on each plot. The location of trees of black saxaul was determined using the PSQ (Point Centered Quarter method) [14].

There have been measured the following taxational indicators:

- Height (H);
- Diameter of the crown (D.c.);
- The diameter of the root collar (D.r.c.);
- Age of the tree (A) [15].

The diameter of the root collar of the tree is measured by dimensional fork. The tree height was measured by basic altimeters .

As known, Artsikhovsky V.M. [16] after a special study of the biology of saxaul, proposed a method for determining the age of saxaul through the nature of its branches. Annually at the end of each shoot there appears one new fork (whorl) in saxaul; so in this way, through the number of forks or whorls, one can determine the age of saxaul.

There had been used hand sampler (drill) to determine the level of groundwater level (further - GWL).

And dumpy level was employed to determine the level of groundwater that are less than 3 meters. Here dumpy level enabled to determine the height difference between the points of the level of the water table that came to the surface (groundwater level on the surface and a portion of the relief, where saxaul grows).

The main part

1. Statistics and modeling. The methods of mathematical statistics and spreadsheet editor Microsoft Excel were used for processing statistical data of the taxational measurements.

Depending on the depth of groundwater, we investigated the status and growth of the saxaul. To achieve the goals set in the research program, there were laid series of taxational plots (6 transects) and stands of black saxaul were selected with different levels of groundwater [17].

The sophisticated areas are represented by the following features of the groundwater levels: 2-3 m; 4-6 m; stands of 3 -20 -year-olds; with average heights starting from 0.5-2.6 m (Table 2). In overall, total 4 values of variables were employed in the analysis: A- age, H-height , D.r.c. - The diameter of the root collar , D.c. - diameter of crown.

Table 2. Sophisticated material subject to classification

Transect	Model number	Age, years			Diameter of root collar , cm			Height, m			Crown's diameter, m		
		max	min	aver	max	min	aver	max	min	aver	max	min	aver
I	28	15	3	9.7	14	2	6.6	2.1	0.5	1.3	2.2	0.5	1.3
II	25	18	5	10.1	15	2	7.5	2.2	0.7	1.6	2.2	0.5	1.4
III	32	15	5	8.7	14	2	6.7	2.6	0.6	1.4	1.9	0.5	1.2
IV	18	20	10	15.7	16	6	11.9	2.2	1.3	1.9	2.3	1.3	1.9
V	29	25	10	15.8	14	4	10.5	2	1	1.7	2.2	0.8	1.6
VI	18	25	12	17.7	18	8	12.6	2.3	1.2	1.9	2.4	1.4	1.9

On the basis of experimental data, the correlation matrix has been constructed. As a result of the correlation analysis, there was confirmed the close relationship between the variables in all test areas (Table 3).

Table 3. Correlation of major taxational indicators

	A						D.r.c.					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI
D.r.c.	0.923	0.955	0.858	0.923	0.693	0.797						
H	0.909	0.954	0.877	0.909	0.617	0.472	0.945	0.949	0.875	0.945	0.872	0.838
D.c.	0.904	0.943	0.912	0.903	0.506	0.424	0.950	0.939	0.816	0.951	0.855	0.774

	H					
	I	II	III	IV	V	VI
D.c.	0.925	0.968	0.870	0.926	0.912	0.712

The critical value of the correlation (r = 0,424) at the five percent level of significance, is possibly due to the fact that the plot stands presented by mainly middle-aged and maturing trees.

2. Results. Modeling the age dynamics of height of stands implemented by regression model including age (A, years), the diameter of the root collar (D.r.c., cm), crown diameter (D.c., m) as an independent variables. As a result of the statistical modeling, there were obtained models for the different depths of groundwater.

The high coefficient of determination model (R^2) and the importance of the numerical coefficients indicate the sufficient accuracy of approximation of the analyzed relationships. The valuation of the multiple regression equation is carried out by testing the hypothesis that the coefficients of determination calculated according to the population: R^2. The F - Fisher test was used to test that output. The table value with degrees of freedom k1=3 and k2 = nm - 1 = 28 - 3 - 1 = 24, Fkp (3.24) = 3.01, since the actual value F>Fkp, the coefficient of determination is statistically significant and equation of the regression is statistically reliable.

Table 4. Age growth dynamics models of black saxaul (R^2 - coefficient of determination, F - Fisher criterion, t - test of significance of the numerical coefficients of the equation)

Transects	GWL	Regression model equation	R^2	t	F
I	4.6	H = 0.44 + 0.0234A + 0.0661D.r.c. + 0.17D.c.	0.91	1.86;0.45;0.84;0.39	78.77
II	3.7	H = 0.31 + 0.0329A + 0.0265D.r.c. + 0.53D.c.	0.96	1.36;0.49;0.36;1.19	152.09
III	4.0	H = 0.25 + 0.0341A + 0.066D.r.c. + 0.33D.c.	0.84	0.87;0.4;1.14;0.72	50.56
IV	5.5	H = 0.7 + 0.0108A + 0.0616D.r.c. + 0.14D.c.	0.87	0.88;0.43;0.4;1.51	57.65
V	6	H = 0.6 + 0.0115 A + 0.0308 D.r.c. + 0.37 D.c.	0.87	2.18;0.4;0.66;0.96	57.03
VI	6	H = 0.85 + 0.0207 A + 0.0318 D.r.c. + 0.14 D.c.	0.74	0.36;0.46;0.42;0.3	13.56

The estimation of the average height of the reliability (adequacy) model is the next element of the age dynamics study.

The evaluation of the adequacy model of the relationship of average height black saxaul with age, root collar diameter and crown diameter is at R^2 = 0.81-0.96, close to the direct reduction (Htheor. = 1.579 m, Hest.=1.45 m), which indicates the adecuacy of the resulting model of average stand heights.

Table 5. Comparison of the effectiveness of using multiple regression equations to determine the height of black saxaul stands

Transects	Quantity of Stands	Average height		Difference of estimated values from initials
		initial	estimated	
I	28	1.326	1.324	0.002
II	25	1.572	4.556	2.984
III	32	1.396	1.405	0.09
IV	18	1.884	3.596	1.712
V	29	1.71	1.704	0.06
VI	18	1.888	2.632	0.744

The results of the comparison of the initial and calculated values of the average heights confirm the high efficiency of the used models (Table 5). The largest deviations are observed on transect II, IV, probably due to the fact that there do not appear large variability of stand ages. So planting in transect II presented the average age - 10.6 years, and in transect IV - 15-16 years. Consequently, the application of this procedure will give satisfactory results for aggregate plantations of highlighted age groups. The deviations are determined by methodological flaws in the original definitions of saxaul age on one hand, and on the other side, with unknown level of anthropogenic influence.

Conclusion

The first group of forest – the black saxaul of flat and undulating conditions concentrated along the riverbeds and channels with available groundwater level of 3-4 m. The soils are extremely dry (takyr) and sandy loam. Locating in the zone of intense human influence, these black saxaul are overwhelmingly represented by the second generation of coppice (70-80 %) and with the different density plantings - from 935 individuals per hectare to 2,300 individuals per hectare.

The height of saxaul is reduced by the coppice generation till 1.3 m, trunk diameter - up to 6.6 cm and diameter of the crown - till 1.2 m.

The second group of forests classified as takyr black saxaul. They are confined to a small aligned lowlands of ancient-alluvial valleys. The soil is saline-takyr. The GWL is available starting from 5-6 m.

At age 25, the number of damp growing black saxaul reach 550-610 individuals per hectare. The average height of plantings on takyrs - 1.7-1.9 m; trunk diameter - 10,5-12,6 cm; crown diameter - 1.6-1.9 m; ground cover presented by keyreuk (*Salsola orientalis*) (Table 6).

Table 6. Dependence of density plantings and the average height of the level saxaul form the occurence of groundwater

Transects	GWL	Density of plantings, individuals per hectare	Average height, m
I	4.6	1663	1.3
II	3.7	2500	1.6
III	4.0	950	1.4
IV	5.5	785	1.9
V	6	600	1.7
VI	6	543	1.9

In general, the best growth of black saxaul plantings noticed at GWL at a depth of 3 m. As GWL lowers from 3 to 6 and then to 8 m, average height of saxaul plantings decrease. Despite the close proximity of groundwater along transects I, II, III there observed average height of 1.3-1.4 m which is due to the predominance of the second generation saxaul plantations as a result of human impact (deforestation).

It is found that GWL has the primary influence on the growth of black saxaul plantings. At optimal GWL (3 m) the height of 20-25 year old saxaul are 3.7 m which is significantly higher than at the unavailable GWL (12 or more) [18].

In these circumstances, the state and the growth of young plants in the early years begin to depend on rainfall and only when the root system of the plants reach the capillary fringe, their condition and growth are significantly improved. Otherwise, all are on automorphic soils where the laborious groundwater level and powerful presence of the carbonate horizon contribute to the formation of sparse and stunted vegetation.

With other things the same, the level of groundwater primarily affects to the density of ripe of saxaul.

The collected data indicate that under optimal growth conditions with GWL to 3-4 m, thickness of black saxaul stands on average are 1578 individuals per hectare; in satisfactory conditions with GWL within 5-6 m - 646 individuals per hectare; in harsh environments with GWL 12 or more - 144 individuals per hectare [18].

Thus, GWL affects density and height of the plantings, with decreasing groundwater level decreases the density and height of black saxaul. However, according to the authors, this pattern is evident only in natural forests. In cultural plantations, the higher density stands at 4-6 m GWL are explained by repeated semination of area after stowage of crop [18]. But under these conditionsa, there is a tendency of reduction of the height of the stand.

Summary of the results

In this study, there have been revealed the regularities of changes in indicators of average height of black saxaul depending on age and other taxational indicators. The statistical models of age dynamics of growth of black saxaul have been constructed.

The results were presented in particular allometric formula for determining the height of the stand which can be used as a basis for estimating carbon stocks .

Employing taxational data, and further modeling provides a more detailed spatio-temporal view of the forest plantations compared to material standards of forest taxations of Kazakhstan, as well as determination of the content of carbon in forest ecosystems of the Ile-Balkhash region. The studies and the resulting model will allow more correctly and accurately describe the biological productivity of forest ecosystems, especially stocks of wood phytomass and its carbon equivalent. The research related to the modeling of ground phytomass of black saxaul in the Ile-Balkhash region was conducted, and models determining the carbon stock that can be used in the calculations were obtained. Moreover, our research has been expanded through inclusion of age to the modeling of saxaul that permits to define the biomass with utmost accuracy.

The comparison of trends of age dynamics represented with dotted lines according to the tables of growth of saxaul deserts of Kazakhstan enabled to make conclusion about the appropriateness of the regression equations in the modeling of medium height of stands of black saxaul at different levels of groundwater in Ile-Balkhash region.

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