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Comparative productivity of artificial and natural forest stands in the belt pine forests of Altay

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Abstract. Using the indicator of the initial density G:H, tables of the growth course of natural and artificial self-thinning pine stands growing in conditions such as dry pine forest of gentle hills type were compiled. It was found that the productivity of self-thinning artificial stands is higher than natural ones only up to III-IV age classes, after which their productivity is equal or less than the productivity on natural stands. The most productive artificial stands are those with average density, however, the largest average diameter is possessed by rare tree stands. In the artificial pine forests in the belt pine stands of the Altai Territory, it is necessary to carry out thinning in a timely manner by using a grass-root method. This will get rid of oppressed trees and increase the growth of trees in diameter, that in turn will increase the yield of commercial timber at the ripeness age.

1. Introduction

The area of the belt pine forests of the Altai Territory is about 1.1 million hectares [1]. The share of artificial stands according to our estimation, accounts for 12% and every year this value increases [2]. About 95% of all artificial stands were created by Scots pine plantations, as of the local species, only this breed is able to grow successfully in a dry, hot climate on poor sandy soil. Despite the fact that natural stands in the belt pine forests are also formed mainly by scots pine, between artificial and natural stands there are significant differences in their growth and development [3]. At the same time, all normative documents regulating forestry in the Altai Territory were developed on the basis of data on the growth of natural stands and incapable to give recommendations for the effective cultivation of artificial stands. In the future, when artificial stands will begin massively reach the cutting age (in 30-50 years) this can become a big problem for the Altai Territory, since with the wrong mode of forestry cultivation, the region will receive a tree stands with low productivity. To avoid this, it is necessary to study the differences in the growth and development of pine stands in the belt pine forest in the Altai Territory and adjust the mode of growing artificial stands.

2. Methods and Materials

The research was carried out on the territory of the Rakitovsky forestry in the Barnaul belt forest. In the process of research the method of trial plots (TP) was used [4]. Trial plots (numbered 91) were laid in accordance with well-known tested methods [5], had a rectangular shape and occupied an area of 0.25 hectares. This size of trial plots allowed to cover the required number of trees of the main forest element. Within the trial plot a continuous count of trees was carried out by using a measuring



fork. Trees of all forest elements having six or more centimeters in diameter and having at least 1/4 of the upper canopy height and more than 4 meters were taken into account.

All TP were laid in artificial and natural pine forests growing in the most widespread type of forest within the Rakitovsky forestry (58% from the total area) - dry pine forest of gently hills type (DBH). The studied pine stands are pure in composition, one-aged (artificial pine stands), or conditionally one-aged (natural pine stands), in addition, no economic measures were carried out on their territory. Research covered forest stands at the age from 13 to 121 years.

The compilation of growth course tables (TGC) was carried out according to the methodology described in the paper by Z Ya Nagimov [6]. When compiling the growth course tables for stands of the same origin and the same forest type the G:H indicator (relative cross-sectional area) was calculated. Then, for each set of forest stands a dot diagram was plotted reflecting the dependence of G:H indicator on the age of the stands. For the resulting field of values, an average approximation line was plotted and two lines of deviation limits $G:H \pm 10 - 15\%$ of the aligned central line. In such a way from the data set, stands with a similar initial density were isolated, they belonged to the same density class. When calculating the equations, the method of inverse step regression was used. All coefficients of equations are significant at 5% level.

The process of compiling growth tables consisted of the following steps:

1. Division of forest stands into classes according to initial density using the G:H indicator;
2. Selection of a regression model based on the dependence of G:H on the average age (A) and the class of initial density (K) of forest stands to determine the average indicators of G: H ten-year age intervals;
3. Selection of an equation describing the dynamics of the average height (H) in dependence on the average age and G:H indicator;
4. Selection of an equation describing the dynamics of the average diameter (D) and the average density (N) depending on the average age, the density class and G:H indicator;
5. Selection of an equation describing the dynamics of the species height (HF) depending on the average age and average height;
6. Calculation the sum of the cross-sectional areas for ten-year age intervals TGC by multiplying the calculated G:H indicator on the calculated value of the density and average height;
7. Calculation of species numbers for ten-year age intervals of TGC by dividing the values of the species height by the average height of the stands;
8. Calculation of the growing stock (M) by multiplying the calculated values of the amount of the cross-sectional areas by the corresponding species heights;
9. Calculation of the average and current growth of forest stands by stock.

The accuracy of the equations was estimated by the magnitude of the standard error [7]. The formula for the main mistake finding has the following form:

$$m_y = \left(\frac{\sum (y_i - \tilde{y}_i)^2}{n-e} \right)^{0.5} \quad (1)$$

where, $\sum (y_i - \tilde{y}_i)^2$ –sum of square deviations between actual (y_i) and approximated (\tilde{y}_i) values; n – sample size; e – number of equation coefficients.

In order to have a general judgment about the quality of the obtained approximation equation, the average approximation error was determined:

$$\delta = \frac{\sum \left| \frac{y_i - \tilde{y}_i}{y_i} \right|}{n} \times 100\% \quad (2)$$

where, y_i – actual value; \tilde{y}_i – approximation value; n – sample size.

3. Results and Discussion

When compiling the TGC of artificial stands of DBH forest type, from the entire data set (57 TP) using the indicator G:H, 51 tree stands were selected and assigned to three density classes. The stands

were divided into three conditional classes by density: I – rare, II-medium, III-dense. The classes of density (K) were denoted by Arabic numerals (1, 2, and 3). The equations obtained by the method of stepwise regression analysis is presented in table 1.

Table 1. Regression equations for compiling tables of growth course tables of self-thinning artificial pine stands of forest type DBH.

Indicator	Equation	R^2	δ , %	No*
Relative cross-sectional area	$G:H = 0.0445 \ln(A) - 0.0821 \sqrt{K} + 0.0298 \ln(K)$	0.994	± 8.3	1
Average stand height	$\ln(H) = -0.0131 A + 1.006 \ln(A) + 0.362 \ln(G:H)$	0.996	± 10.9	2
Average stand diameter	$\ln(D) = -0.0171 A + 1.119 \ln(A) + 0.454 \ln(G:H)$	0.998	± 6.9	3
Stand density	$N = -43907 G:H + 1557.4 \ln(A)$	0.966	± 11.9	4
Species density	$\ln(HF) = -0.0753 \sqrt{A} + 0.245 \ln(A) + 0.421 \sqrt{H}$	0.997	± 5.0	5

where, R^2 – coefficient of determination; δ – average error of approximation; No - equation number; K – density class; A – average age of the stand; $G:H$ – relative cross-sectional area.

The density dynamics of the forests were modelled on the basis of data from the entire set of trial plots, since the intensity of self-thinning of stands in different classes of density in the analyzed forest type turned out to be similar. The age dynamics of the density in addition to the initial density can be influenced by such unaccounted factors as: the ground relief, the exposure of the slope, the planting mode, the row spacing as well as the presence of the technological corridors, weather conditions in the first years after planting and so on. Since over a hundred year period of forest cultural production in belt pine forests the methods, the ways and schemes of planting, the required density of planting (reduction), the average survival ability have changed greatly, even there were some facts of climate changes [8] it is difficult and even impossible practice to draw up the rows of artificial stands taking into account all these numerous factors.

As the most part of regression equations have rather high determination coefficients and are characterized by satisfactory errors, they can be used in the TGC working out.

The growth course table worked out reflects three variants of dynamics (depending on growth density) of the main taxation indicators in artificial pine stands not covered by thinning in condition of DBH forest type (table 2).

At the age of 80 years the largest average diameter is observed in rare stands, while the least - in thick stands. For all this the largest deposit in condition of DBH forest type is accumulated in stands of average thickness. Age related changes in the cross-sectional area sums in stands of various thickness classes is characterized by the following tendency: up to 40 years, rare stands have the large sum of cross – sections, in 50-60 years – stands with medium density, in 70-80 years – the thick stands.

The average height of rare stands during the whole growth period is larger than the one of average thickness or thick. Dense stands are more woody-full.

When compiling the natural stands TGC of DBH forest type from the whole data totality (35 TP) using the indicator $G:H$, 18 forest stands were selected and assigned to one density class.

Regression equations describing the natural pine stands of DBH forest type are represented in table 3. All the equations are characterized by very high determination coefficient and are characterized by satisfactory errors. The elaborated growth course tables of self-thinning natural stands of DBH forest type are shown in table 4.

Natural stands of DBH forest type are inferior to artificial ones in average height and diameter up to III age class, after which the natural stands surpass the artificial ones as concerns the mentioned indicators. Self-thinning in natural pine stands is processing more intensively than in artificial. To 80 years of age the density in natural pine stands becomes less than in rare artificial. The cross-sectional area sum of natural stands over 80 years is somewhat less than an analogous indicator of the average in

density artificial stands, but in 80 years of age the sum of areas becomes equal. The stock in natural stands up to 60-70 years age is lower than that one inartificial stands, in older age natural stands surpass artificial in this indicator.

Table 2. Growth course of self-thinning artificial pine stands of DBH forest type.

Age, years	Average		Density, pcs/ha	Sum of cross-section areas, m ² /ha	Species number	Stock, m ³ /ha	Growth in stock, m ³	
	height, m	diameter, cm					average	current
I density class								
20	5.3	5.3	2420	6.6	0.735	26	1.3	-
30	7.9	8.0	2260	12.3	0.629	61	2.0	3.5
40	9.8	10.1	2146	17.2	0.583	98	2.5	3.8
50	11.2	11.5	2058	21.2	0.557	133	2.7	3.4
60	12.2	12.3	1986	24.2	0.541	160	2.7	2.7
70	12.8	12.7	1925	26.3	0.529	178	2.5	1.9
80	13.1	12.8	1872	27.7	0.521	189	2.4	1.0
II density class								
20	4.8	4.6	3005	5.4	0.778	20	1.0	-
30	7.3	7.3	2845	11.6	0.650	55	1.8	3.4
40	9.2	9.3	2731	17.2	0.596	94	2.4	4.0
50	10.6	10.7	2643	22.0	0.567	132	2.6	3.8
60	11.6	11.6	2571	25.8	0.549	164	2.7	3.2
70	12.2	12.0	2510	28.6	0.536	187	2.7	2.3
80	12.5	12.1	2458	30.6	0.527	202	2.5	1.4
III density class								
20	4.1	3.7	3619	3.5	0.854	12	0.6	-
30	6.6	6.4	3459	9.5	0.681	42	1.4	3.0
40	8.5	8.4	3346	15.5	0.615	81	2.0	3.8
50	9.9	9.8	3258	20.8	0.580	119	2.4	3.8
60	10.9	10.7	3186	25.2	0.559	153	2.5	3.4
70	11.5	11.1	3125	28.6	0.545	179	2.6	2.6
80	11.8	11.3	3072	31.1	0.534	197	2.5	1.8

Table 3. Regression equations for compiling growth course tables of self-thinning natural pine stands of DBH forest type.

Indicator	Equation	R ²	δ, %	No
Relative cross-sectional area	$\sqrt{G:H} = 0.00614 A - 0.0000221 A^2$	0.993	± 10.5	6
Average stand height	$\ln(H) = -0.0103A + 1.012 \ln(A) + 0.401 \ln(G:H)$	0.999	± 5.5	7
Average stand diameter	$\ln(D) = -0.0105A + 1.07 \ln(A) + 0.508 \ln(G:H)$	0.998	± 5.9	8
Stand density	$\ln(N) = 0.95 \ln(A) - 1.488 \ln(G:H)$	0.999	± 11.2	9
Species density	$HF = 0.653\sqrt{A} - 0.951 \ln(A) + 2.382 \ln(H)$	0.997	± 6.6	10

where, R² – coefficient of determination; δ – average error of approximation; No – equation number; K – density class; A – average age of the stand; G:H – relative cross-sectional area.

Table 4. Growth course of self-thinning natural pine stands of DBH forests type.

Age, years	Average		Density, pcs/ha	Sum of cross-section areas, m ² /ha	Species number	Stock, m ³ /ha	Growth in stock, m ³	
	height, m	diameter, cm					average	current
20	3.0	2.2	11052	4.2	0.898	11	0.6	-
30	5.4	4.4	5466	7.9	0.808	35	1.2	2.3
40	7.9	6.9	3449	12.1	0.701	67	1.7	3.2
50	10.4	9.5	2493	16.3	0.624	106	2.1	3.9
60	12.5	12.0	1969	20.6	0.573	148	2.5	4.2
70	14.4	14.2	1657	24.7	0.540	192	2.7	4.4
80	15.9	16.1	1464	28.5	0.519	236	2.9	4.4
90	17.1	17.5	1346	32.0	0.509	278	3.1	4.2
100	17.8	18.6	1279	35.2	0.506	317	3.2	4.0
110	18.3	19.2	1253	38.0	0.510	354	3.2	3.6
120	18.4	19.5	1241	40.5	0.520	386	3.2	3.3

4. Conclusion

1. Natural stands begin to form under larger density as compared with artificial get self-thinning in them proceeds more intensively.

2. Productivity of self-thinning artificial stands are higher than natural one only to III-IV age classes, after which their productivity is equal or less than that of natural stands of the same forest type. It is explained by high density of artificial stands, which in turn comes into existence because of weak differentiation of trees.

3. In conditions of DBH forest type, at 80-year age, the most productive are average in density stands (II density class), however, the largest average diameter have rare stands (I density class).

4. As a result of lesser differentiation of trees in diameter in artificial pine stands at the ripeness age it should be expected a more uniform assortment production than in stands of natural origin, however, the share of bulky wood in pine stands will be larger as compared with artificial stands.

5. In artificial pine stands of the Altai belt pine stands, it is necessary to carry out thinning procedures timely by grass-roots method. This will get rid of oppressed trees and increase the growth of trees in diameter, that in its turn will increase the yield of commercial timber at the ripeness age and increase fire-resistance of stands.

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