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Article

Forecast of growth and development of modal fir stands in the lower Angara region

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Abstract: The paper presents an assessment of the growth dynamics of the modal fir plantations in the Lower Angara region. At present, a vast area of fir forests in the Lower Angara region is characterised by a significant decrease in sustainability due to periodic forest fires, insect pests outbreaks and diseases, which lead to their natural degradation and death. However, the intensity of coniferous stand growth in certain forest site characteristics persists in the long term. Therefore, creating regression models of forest growth and development involving the identification of site conditions is very important both from a practical point of view and for environmental monitoring. The materials of the mass inventory of 3491 stands served as the initial data for studying the processes of fir plantations natural growth. The *Hoerl Model* function is suitable for the best approximation of stand growth since it is characterised by high levelling factor (from 0.970 to 0.987) and a small standard error (not exceeding 7%). As a result of the research, there have been constructed sketches of the growth rate tables for the modal Siberian fir stands of the third bonitet class of the forb and mossy groups of forest types.

Keywords: Siberian fir, regression model, forest type group, bonitet, growth rate table

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1. Introduction

The Lower Angara region is one of the major reserves of Russia's forest resources. However, there still occurs natural forest degradation considering extensive forestry model, combined with climate change, fires, periodic massive pests impact and diseases. In most regions of Russia, there is an insufficient amount of sanitary and health-improving forestry activities aimed at developing dead forest stands which leads to a negative tendency towards the accumulation of standing dead trees. Thus, forests are losing their important ecological and economic components.

Many researchers had scientifically proved the fact that dark coniferous forest formation is more vulnerable to adverse impacts than the light coniferous forests [1, 2, 3, 4, 5, 6]. At present, the impact of the factors mentioned above affects a vast territory of fir and cedar forests sustainability in the Lower Angara region. As practice shows, most of these forests will be left for natural growth and self-restoration, since the modern forest management system does not allow the timely implementation of sanitary and recreational activities properly.

It is common knowledge that succession often occurs through the change of species (which takes decades) or through successful coniferous species natural renewal with no period of replacing a forest space with birch and aspen. However, in both cases, the development patterns and the intensity of coniferous stand growth in certain forest site conditions persist in the long term. Therefore, creating regression models of forest growth and development involving the identification of site conditions is very important from a practical point of view and for environmental monitoring as well.

Studying the course of site growth, one can trace the pattern of taxation indicators changes throughout its life or to a specific (depending on the study purpose) age [7]. Growth rate tables (GRT) are the most straightforward and informative models of taxation parameters dynamics over time [8].

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There are various approaches to growth rate tables building and their classification basis. Recently, considering mass inventory materials availability and climatic processes, the typological approach to the study of plantations growth and development has received additional interest [9, 10, 11].

V.B. Kozlovsky and V.M. Pavlov [12, p. 23] pointed out that the main difficulty in using growth rate tables based on forest type is the change in environmental conditions and consequently, the forest type itself. At the same time, according to the authors, such tables represent the unique shape of the growth curve, in contrast to the bonitet curve. N.N. Svalov [13, p. 28] noted, "One should resolve the issue of choosing the type of tables and classification criteria for grouping material specifically, considering the economic goals and taxation objects". N.P. Anuchin [7] called for broader use of forest inventory materials (tables of age classes, bonitet, density and stocks; inventory descriptions) to compile growth rate tables for modal plantations. At the same time, V.B. Kozlovsky and V.M. Pavlov [12] believed that the practical use of tables for modal stands is somewhat limited. They make it possible to obtain a generalised idea of the studied area forests age dynamics and to substantiate the cutting age. However, in recent years, the problems of updating taxation indicators have become increasingly important, and a constant decrease in forest density makes such stands more common [9, 14]. Thus, the statistical approach to the taxation indicators determination based on age classes makes it possible to estimate mean forest stand attributes reliably.

The study of the growth rate of the most common fir formation forest types, growing within the boundaries of the Yenisei forestry of the Krasnoyarsk Krai, was carried out in frames of the present research. On the mathematical analysis basis, regression models of growth processes have been developed, which can be useful for adjusting and improving forest inventory standards and diverse environmental monitoring activities.

2. Materials and Methods

Bonitet was taken as the basis for identifying forest growing conditions as a universal indicator of a habitat quality [7]. The object of the study was Siberian fir stands of the third bonitet class, growing in the conditions of the West Siberian southern taiga plain forest area of the Lower Angara region on the territory of the Yenisei forestry of the Krasnoyarsk Krai [15]. These plant communities occupy 36.3% of coniferous plantations of the forestry and are considered modal forest stands. Within given productivity of forest stands, the most common types of forest are mossy and forb groups.

The research methodology is based on the developments of N.V. Tretyakov, supplemented by I.V. Semechkin [14]. The study is based on the materials of the mass inventory of 3491 stands (1367 stands belonged to the forb group of forest types, and 2124 stands belonged to the mossy group of forest types). Stands with a predominance of the fir element (proportion of fir of at least three units in the total composition of the stand) were selected for sampling. Such stands, growing on the study territory, are characterised by the mean taxation indices shown in Table 1.

Table 1. Mean taxation indices of the fir stands of the third bonitet class.

Forest type group	Age, years	Height, m	Diameter, cm	Density	Stock, m^3/ha
Forb	103 ± 1,2	18.4 ± 0,2	20.0 ± 0.2	0.62	177 ± 2
Mossy	99 ± 0,9	18.7 ± 0,1	20.2 ± 0.1	0.67	201 ± 1

Primarily, the initial data of mass inventory materials by the following indicators: age, height, diameter, stock, density were subjected to statistical processing. The processing formulas follow standard statistical approaches. The selection of regression models was carried out using the «Curve Expert 1.3» curve fitting system.

3. Results and Discussion

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In the absence of stress factors (fire, pests, weather conditions) leading to the mass death of trees, fir stands naturally develop as uneven-aged stands. There are all transition stages from self-seeding and undergrowth to overmature trees. When overmature trees reach the age of natural death, young ones developed from the undergrowth under the maternal canopy replace them. The forest-forming process occurs continuously in fir stands, but its intensity changes over time since it depends on many constantly changing factors. Thus, fir forests structure is also continually changing: at some stages, relatively young trees (under the age of 50-60 years) prevail in a stand, at others – older ones (up to 80-120 years). At the same time, the taxation indicators of the stand change, which affects other components of the plantation. Therefore, fir stands undergo certain development stages [16].

Although one fir stand can include several generations of trees, its main parameters (development pattern, productivity and taxation characteristics) do not change much over time, since they are determined by the quality of forest growing conditions.

It can be assumed based on the data of various sources [16, 17, 18] that the studied fir stands formed by previous generations of undergrowth which survived logging or after the natural decay of birch and aspen forests.

According to the results of the study, the statistical analysis of the main taxation characteristics showed a specific pattern for naturally developing forest stands; namely, more aged stands demonstrate the decrease in indicators variability and the increase in experiment accuracy.

Initially, a forecast of age-related changes in mean height, diameter and stocks values in modal fir stands was carried out. It was established that the studied correspondences reach a high degree of approximation using the Hoerl Model function (Equation 1):

$$y = ab^x \cdot x^c , \tag{1}$$

Table 2 shows the coefficients of the equations and indicators of their approximation.

Table 2. *Hoerl Model* regression function parameters

Parameters	Equation coefficients			Levelling factor	Standard error
	a	b	c		
		Forb group of forest types			
Height, m	0.127	0.993	1.266	0.987	0.855
Diameter, cm	0.068	0.992	1.429	0.971	1.674
Stock, m^3/ha	0.090	0.988	1.954	0.972	16.332
		Mossy group of forest types			
Height, m	0.196	0.994	1.148	0.989	0.652
Diameter, cm	0.158	0.995	1.188	0.970	1.433
Stock, m^3/ha	0.186	0.989	1.783	0.967	16.509

Figure 1 shows the age-related change in taxation parameters of modal Siberian fir stands in the Lower Angara region.

At the second stage, sketches of growth rate tables were developed for groups of forest types, using the data obtained by tabbing of the Hoerl Model function. The regression equation works in the age range from 20 to 200 years.

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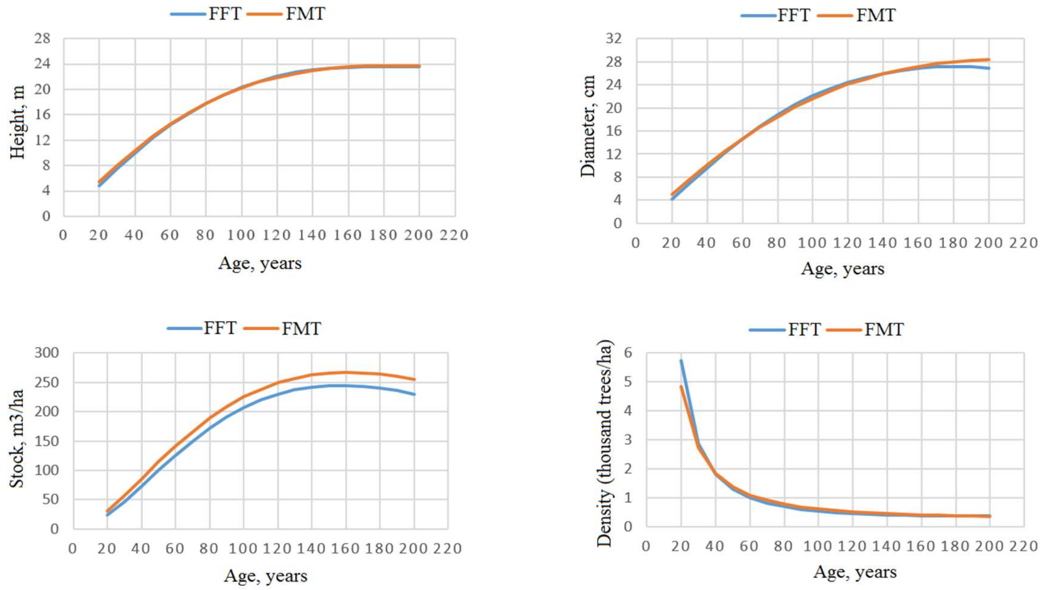

Figure 1. Changes in taxation parameters of the modal Siberian fir stands with age in the Lower Angara region (FFT – fir stand of forb group of forest types, FMT – fir stand of mossy group of forest types)

Other taxation indicators for constructing the studied site standards were calculated using generally accepted taxation formulas of correspondence between them [9, 14]. The results of the forecast of the course of growth for the forb and mossy forest types groups are presented in Tables 3 and 4, respectively.

Table 3. *Sketch of the growth rate table for the modal Siberian fir stands of the forb group of forest types*

Age, years	Mean		Form factor	Tree volume, m³	Density, trees/ha	Stock, m³/ha	Stock change, m³/ha	
	height, m	diameter, cm					mean	current
20	4.8	4.2	0.64	0.0042	5746	24	1.2	–
30	7.5	6.9	0.59	0.0165	2870	47	1.6	2.3
40	10.0	9.6	0.56	0.0406	1803	73	1.8	2.6
50	12.3	12.2	0.54	0.0778	1285	100	2.0	2.7
60	14.4	14.6	0.52	0.1270	992	126	2.1	2.6
70	16.2	16.8	0.51	0.1858	808	150	2.1	2.4
80	17.8	18.8	0.50	0.2508	686	172	2.2	2.2
90	19.2	20.6	0.50	0.3183	600	191	2.1	1.9
100	20.4	22.1	0.49	0.3849	538	207	2.1	1.6
110	21.3	23.4	0.49	0.4475	492	220	2.0	1.3
120	22.1	24.5	0.48	0.5037	457	230	1.9	1.0
130	22.7	25.3	0.48	0.5517	431	238	1.8	0.7
140	23.1	26.0	0.48	0.5905	411	242	1.7	0.5
150	23.4	26.5	0.48	0.6195	395	245	1.6	0.2
160	23.5	26.9	0.48	0.6387	384	245	1.5	0.0
170	23.6	27.1	0.48	0.6486	375	243	1.4	–0.2
180	23.5	27.1	0.48	0.6497	370	240	1.3	–0.3
190	23.4	27.1	0.48	0.6430	366	236	1.2	–0.5
200	23.1	26.9	0.48	0.6296	365	230	1.1	–0.6

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Table 4. *Sketch of the growth rate table for the modal Siberian fir stands of the mossy group of forest types*

Age, years	Mean height, m	Mean diameter, cm	Form factor	Tree volume, m³	Density, trees/ha	Stock, m³/ha	Stock change, m³/ha mean	Stock change, m³/ha current
20	5.4	5.0	0.62	0.0064	4837	31	1.6	2.1
30	8.0	7.6	0.58	0.0210	2718	57	1.9	2.6
40	10.4	10.1	0.56	0.0466	1835	85	2.1	2.8
50	12.6	12.5	0.54	0.0832	1370	114	2.3	2.8
60	14.6	14.7	0.52	0.1295	1089	141	2.4	2.7
70	16.3	16.7	0.51	0.1836	905	166	2.4	2.5
80	17.8	18.5	0.51	0.2429	777	189	2.4	2.2
90	19.1	20.2	0.50	0.3049	683	208	2.3	2.0
100	20.2	21.6	0.49	0.3672	612	225	2.2	1.7
110	21.2	22.9	0.49	0.4277	558	238	2.2	1.4
120	21.9	24.1	0.49	0.4845	514	249	2.1	1.1
130	22.5	25.0	0.48	0.5363	480	257	2.0	0.8
140	23.0	25.9	0.48	0.5819	451	263	1.9	0.5
150	23.3	26.6	0.48	0.6207	428	266	1.8	0.3
160	23.6	27.2	0.48	0.6523	409	267	1.7	0.1
170	23.7	27.7	0.48	0.6767	393	266	1.6	–0,1
180	23.7	28.0	0.47	0.6938	380	264	1.5	–0,2
190	23.6	28.3	0.47	0.7041	369	260	1.4	–0.4
200	23.5	28.4	0.47	0.7080	360	255	1.3	–0.5

Analysis of taxation indicators within each group of forest types allows us to conclude that the productivity of mossy fir stands is higher than the productivity of forb fir stands. The stock at the interval from the young growth stage to the overmature stage varies from 31 to 255 m3/ha, while in the forb fir stands its values range from 24 to 230 m3/ha. The values of the mean stock increase also vary. Forest stands are similar in terms of the trees density thinning dynamics. Trees maturity stage begins at the age of 170 years in both stands.

4. Conclusions

As a result of the research regression model of the growth rate has been developed for modal fir stands concentrated in the Lower Angara region (Yenisei forestry of the Krasnoyarsk Krai). The regression model makes it possible to predict the taxation indicators dynamics and reproduce the successional development of forest stands of the third bonitet class of the forb and mossy groups of forest types.

The *Hoerl Model* function approximates the growth rate of the study plantations with high precision. Sufficiently high accuracy is evidenced by the correlation coefficients from 0.97 to 0.99 for mossy and forb groups of forest types, respectively, as well as by a small standard error (not exceeding 7%).

The practical importance of such growth rate tables is indisputably high, which characterise the features of the development of the modal stand in certain forest conditions in mathematical progression. In addition to the advantages mentioned above, such tables make it possible to detail environmental observations data related to the identification of phytomass accumulation per unit area, including forest pathological monitoring of areas where favourable forage base for pests is formed; the dynamics of carbon deposition and emission by fir stands; as well as adjusting a study area taxation standards..

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