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Taxonomic and interpretation links in coniferous and mixed larch forests of the Altai-Sayan region

**A A Wais, P V Mikhailov, S L Shevelev, S M Sultson, L I Romanova,
T V Batvenkina and I A Vorobyeva**

Institute of Forest Technology, Reshetnev Siberian State University of Science and Technology, Krasnoyarsk, Russia

E-mail: vays@sibsau.ru

Abstract. Currently, methods for interpreting various indicators of plantings by aerial and satellite images based on GIS technologies have gained significant development. They actively implement regression relationships between taxation indicators of stands. The object of the study are modal larch stands of the Altai-Sayan region, which are characterized by both coniferous and mixed forests with larch (*Larix Sibirica* L.) fraction from 40 to 90 % and an admixture of birch (*Betula pendula* R.), aspen (*Populus tremula* L.), fir (*Abies sibirica* L.) and cedar (*Pinus sibirica* D.). Comparison of coniferous and mixed forests did not reveal significant differences in the growth lines. Based on paired and multiple linear regression equations for coniferous and mixed modal larch forests, a set of taxation interpretation models is obtained with the aim of approximating the average diameter, age and standing volume of stands according to such interpretation indicators as average height, completeness, bonitet class and larch fraction in the composition. Thus, a number of equations have been developed for modal larch forests, which are recommended for remote sensing of larch forests in the Altai-Sayan region.

1. Introduction

Currently, methods for interpreting various plantation indicators by aerial and satellite images based on GIS technologies have gained significant development [1–4]. At the same time, the volume of full-scale work is reduced, which disables the interpretation accuracy to be properly verified. It should be noted that in recent years (60–70 years) considerable material in the taxation description of plantations has been accumulated, which allows establishing the necessary taxation-interpretation relationships to determine the main indicators of forest stands [3], minimizing field work.

On the basis of modern means V.I. Arkhipov et al. [1] proposed a technology for taxation of forests by interpretation. The dissertation by I.M. Danilin [2] notes the possibility of using traditional interpretation links (between the average diameters, heights and completeness of stands, as well as their connection with the crown density) for taxation of Siberian forests.

V.I. Sukhikh, M.D. Giryayev, E.M. Atamankin [3] noted that the use of materials from previous forest management and the updating of taxation indicators of plantings according to the models of growth and development of forest ecosystems can significantly reduce the costs of forest inventory.

E.A. Kurbanov et al. [4] point to the possibilities of Landsat satellite imagery during forest inventory. These images allow interpreting with sufficient accuracy the average age, height, density, canopy closeness and completeness of stands [5, 6].



V.F. Kovyazin, V.L. Bogdanov, V.V. Garmanov [7] propose using unmanned aerial vehicles to monitor green spaces and determine the main taxation indicators (age, density, average diameter, average height, fullness and reserve), as well as morphological characteristics of individual trees (tree height, diameter and volume).

O.S. Ozhich [8] has developed a methodology for evaluating interpretation and taxation indicators of forest stands of Belarus using modern software products and GIS technologies.

I.V. Tolkach and O.S. Bahur [9, 10] used GIS ("QuantumGIS") programs and freely accessible space images (maps.google.com) for measuring interpretation of the forests of Belarus.

Recently, methods for interpreting taxation parameters of forest stands based on laser data have been improved [11].

N.D. Skorobogatko [12] notes that in modern conditions the need for field work and the laying of taxation-interpretation trial plots have not lost their relevance for studying the features of the canopy of pine and spruce stands in the Perm Region.

Thus, the analysis of the state of the issue shows that when using various methods of remote sensing of forests, regression relationships between taxation indicators of stands are actively used.

2. Methods and materials

The object of the study was modal larch stands of the Altai-Sayan region, which are characterized by both coniferous and mixed composition with larch fraction (*Larix Sibirica* L.) from 40 to 90 % and an admixture of birch (*Betula pendula* R.), aspen (*Populus tremula* L.), fir (*Abies sibirica* L.) and cedar (*Pinus sibirica* D.). The young growth is quite scarce: 2 thousand pcs/ha on average with group accommodation. Spirea (*Spiraea*), acacia (*Acacia*), less often mountain ash (*Sorbus aucuparia*), and bird cherry (*Prunus padus*) are represented in the undergrowth. The soils are mainly loamy and fresh. Plantations of bonitet class III prevail; on poorer gravelly soils grow stands of bonitet class IV. Larch trees develop in mountainous conditions on the slopes of various exposures [13].

E.N. Falaleev [14] noted the following features of larch forests in this region: low natural pruning is due to the low density of the canopy and poor regeneration under the canopy of plantations.

In order to study the growth, the task was to compile sketches of the growth progress tables of pure modal larch trees. All work was carried out in accordance with the methodology of V.S. Moiseev, A.G. Moshkalev, N.A. Nakhabtsev (1968) [15]. At the same time, the initial stands were sections of various types of forest of bonitet class III (more than 400 pieces). Within the age classes, a rather high variability was observed in terms of the main taxation indicators (a height of 1.9 had 42.2 %, a diameter of 6.9 had 34.6 %, standing volume of 13.9 had 69.4 %). Nevertheless, for most age periods, an acceptable accuracy of the experiment on the standing volume is less than 10 %, and the diameter and height are less than 5 %.

Taxation-interpretation regression equations were calculated in the statistical package "STATGRAPHICS". Growth functions were selected using the Excel and Curve Expert programs.

3. Results

To approximate the main taxation indicators of pure larch stands $H=f(A)$, $D=f(A)$ and $M=f(A)$, exponential equations were used:

$$y=a*(1-e^{-bx}), \quad (1)$$

where y is taxation indicator;

a is asymptotic coefficient (maximum value of the sign y);

b is growth curve shape coefficient;

x is age (years).

Table 1 presents the parameters of the growth curves for the main taxation indicators of larch forests.

Table 1. Equation parameters

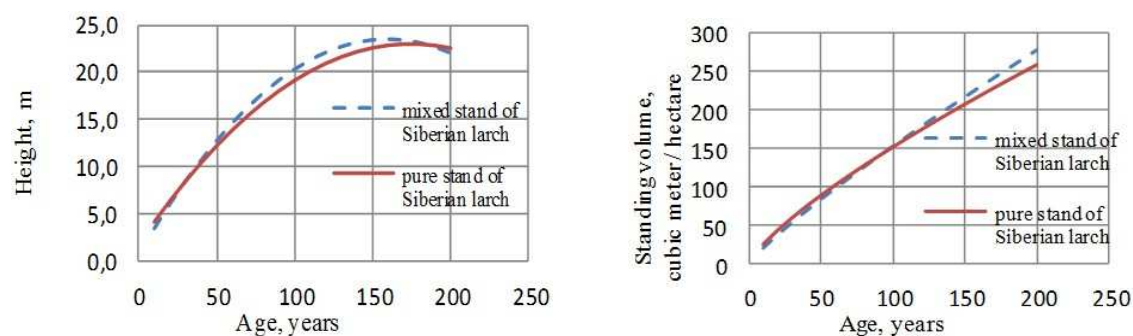
Correlation	Coefficients		Alignment ratio	Basic error
	a	b		
Height-age	27.631	0.01156	0.99	1.1 m
Diameter-age	239.425	0.00111	0.99	1.9 sm
Standing volume load-age	242.069	0.01308	0.97	19 m ³

Based on the obtained middle lines (Figure 1) and a number of standard formulas [15], sketches of the growth progress tables were compiled (Table 2).

Table 2. Sketch of growth progress tables of coniferous modal larche forests of bonitet class iii of the Altai-sayan region

Age, year	Average		$\Sigma G_{1.3}$, m ² /he	N	f	M, m ³ /he	Standing volume change	
	H, m	D, sm					Medium	Current
20	5.7	5.3	16.09	7298	0.611	56	2.80	–
40	10.2	1.4	18.75	2208	0.518	99	2.48	2.15
60	13.8	15.4	19.64	1055	0.487	132	2.20	1.65
80	16.7	20.4	19.92	610	0.472	157	1.96	1.25
100	18.9	25.2	20.21	405	0.463	177	1.77	1.00
120	20.7	29.9	20.25	289	0.458	192	1.60	0.75
140	22.2	34.5	20.14	216	0.454	203	1.45	0.55
160	23.3	39.0	20.15	169	0.452	212	1.33	0.45
180	24.2	43.4	20.13	136	0.450	219	1.22	0.35
200	24.9	47.7	20.07	112	0.448	224	1.12	0.25

Note: D is average diameter at a height of 1.3 m (cm); H is average height (m); $\Sigma G_{1.3}$ is the sum of the cross-sectional areas of trees at a height of 1.3 m (m²/ha); N is the number of trees (pcs/ha); f is the species number; M is standing volume (m³/ha).



a) relationship of average height and age

b) relationship of standing volume and age

Figure 1. Dependence of the main taxation stands of modal larch on age.

On the one hand, the applicability of this table raises certain questions, on the other hand, the average parameters of the standard allow comparing and contrasting data, in addition to the traditional use of modal tables of growth.

Comparison of the growth of coniferous and mixed larch forests did not reveal a significant difference in the average lines (Figure 1). The presence of small deviations is due to the lower completeness of the net stands, which is reflected in the growth lines.

As a result, it can be stated that the middle growth lines are quite stable and reflect the history of the development of modal larch forests.

At the next stage, the parameters of the equations were calculated that reflect the taxation-interpretation relationships and allow the taxation characteristics of the pure and mixed larch stands

(Table 3) to be reconstructed from the paired and multiple linear equations from the parameters measured from the images.

It should be noted that in pure larch forests, the average diameter significantly affects the average diameter. Age is interpreted according to the average height, average diameter and density of the stands. The volume is approximated by the average height and density of the stand (Table 3).

The age of mixed larch forest can be determined by bonitet class, average height, average diameter and larch percentage in the composition. The average diameter is reliably determined by the average height value. At the same time, the bonitet class is correlated with height, so it is recommended to adjust the equation by deleting the bonitet class variable. The standing volume depends on the average height, density and proportion of larch in the composition.

Table 3. Taxation and interpretation links in coniferous and mixed larch forests

Type of relationship	Equations with significant coefficients	Coefficient determination, %	Absolute error	Equation validity Fp>Ft
Pure stand of Siberian larch				
Lg D = f(H)	Lg D _{1.3} =0.535+0.0448*H	93.5	1.2 cm	valid
A=f(H, D, p)	A=4,395+1.872*H-35.781*p	98.4	12 years	valid
M=f(H, p)	M=-204+11.464*H+275.335*p	91.8	16 m ³ /ha	valid
Mixed stand of Siberian larch				
Lg D = f(H)	Lg D _{1.3} =0.473+0.0481*H	93.4	1.1 cm	valid
A=f(B, H, D, DS)	A=-	93.4	12 years	valid
M=f(H, p, DS)	57+10.164*B+3,205*H+2.225*D+2.504*DS	88.6	21 m ³ /ha	valid
	M=-143+9.730*H+159.843*p+4.446*DS			

Note: D_{1.3} is the average diameter at a height of 1.3 m, cm; H is average height, m; A is age, years; p is density (densities except light forests); M is standing volume, m³/ha; B is bonitet class (II–IV); DS is the proportion of larch in the composition (3–7 units). The range of equations includes the parameters of larch forests from I to X age classes. All coefficients of the equations are significant, since $p \leq 0.05$.

An important assessment of the models is the magnitude of the random (absolute) error. The presented error values do not exceed the permissible errors for young and ripe plantings for the subzone of extensive forestry and forest management in the forests of the third group [3]: diameter of 15 %, height of 10–12 %; stock of 20–25 % (Table 3).

4. Conclusion

As a result of the research, we can state the following:

- Currently, the process of interpreting images is automated, but in order to increase the accuracy of taxation, it is necessary for local areas to have a set of average regression lines in order to update the taxation parameters of the stands.
- Differentiation of equations by forest type significantly increases the number of regression models. In this case, it is advisable to use the middle line of growth, which in relation to modal larch will be reliable and stable, drawn up on a bonitet basis (bonitet class III).
- Comparison of coniferous and mixed stands did not reveal significant differences in the growth lines.
- To approximate the basic growth functions (average height–age, average diameter–age, stock–age) it is recommended to use exponential equations. Based on these dependencies, a table has been compiled of the growth progress of coniferous larch forests.
- In relation to coniferous and mixed modal larch forests, a set of taxation interpretation models has been obtained with the aim of approximating the average diameter, age and standing volume according to such interpretation indicators as average height, density, bonitet class and larch share in the composition.

Thus, a number of equations have been developed for modal larch forests, which are recommended for remote sensing of forests in the Altai-Sayan region.

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