Assessment of biological productivity of modal spruce forests in the taiga zone based on modeling the growth of stands

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Abstract. The article provides information on the biological productivity of spruce stands of the Siberian green-moss group of forest types in the taiga zone (Southern ecoregions), which reflects the dynamics of the phytomass fractional composition and the carbon stock in them. The normative reference tables are developed on the basis of mathematical modeling of growth processes in combination with the conversion-volume method for determining the volume of phytomass and its fractional composition based on deposited carbon. Tables of biological productivity of spruce forests in the taiga zone are proposed, which give a quantitative characteristic of the age dynamics of changes in phytomass and the carbon contained in it. The range of phytomass changes in stands of spruce of the green-moss group of forest types over the entire age range in the conditions of the III bonitet class is from 11 to 166.5 t m⁻³, for the IV bonitet class is from 8.6 to 142.5 t m⁻³. Carbon pools in quantitative equivalent in spruce forests of the III bonitet class concentrate from 4.0 to 72.5 t C·ha⁻¹, for the IV bonitet class is from 5.6 to 60.8 t C·ha⁻¹. The obtained results complement the existing database on the biological productivity of taiga forests and can be used in the organization of forest monitoring, implementation of environmental programs at the regional level, including calculations of the carbon cycle.

1. Introduction

In recent decades, the world's forest ecosystems have undergone a significant transformation due to global climate changes, anthropogenic impact, large-scale fires and outbreaks of harmful insects [1, 2]. At the same time, all factors are mutually dependent and together give an obvious negative effect on the productivity and biosphere function of forest ecosystems.

In this respect, dark coniferous forests of the taiga zone are no exception. Having a significant resource potential, the Northern forest territories have long been intensively developed for timber harvesting, but recently there has been a significant reduction in forest productivity due to frequent periods of mass reproduction of the Siberian silkworm, which is favored by the average annual temperature increase and drought that has been forming for several years in the Northern territories. Dark coniferous forests are the food base of a dangerous pest, which is why they experience a huge load, with a negative effect in the accumulation of phytomass and reducing the carbon-containing function of taiga forests.
Trees that make up the upper tier of forest phytocenoses perform an edifying role, ensuring the existence of plants of the lower tiers. Edifiers bear the brunt of negative natural and man-made impacts, which primarily affects the level of their productivity: there is a decrease in growth processes, a decrease in the photosynthetic surface, and as a result, the increase in height and diameter decreases. All this allows us to use biological productivity as an indicator of the state of forest ecosystems, and gives researchers another tool for determining the limits of pressure on forest ecosystems, beyond which their irreversible degradation is possible [3].

The modern management system of Russian forests is based on international conceptually new principles focused on sustainable development. As one of the solutions to the problem, we suggest methods for increasing forest productivity [4] by intensifying forestry [5, 6], as well as improving the regional system of forest and environmental monitoring, which requires expanding the information and regulatory framework on the basis of which it is possible to predict the dynamics of phytomass reserves and carbon sequestration.

Currently, research on bio-productivity and phytomass accumulation, as a starting point for studying carbon deposition in forest ecosystems, is conducted by individual scientists, as well as in the framework of numerous national and international projects [1, 7, 8, 9, 10, 11]. One of the results of the work of domestic researchers is the electronic database “Productivity of ecosystems in Northern Eurasia”, which is freely available on the website http://www.biodat.ru/db/prod/index.htm. The database contains information about the phytomass and productivity of each type of zonal and intrazonal ecosystems [12].

However, this direction requires additions and specification of information primarily related to the large scale of forest areas, as well as the fact that some of the collected data is not linked to the taxational characteristics of stands and has a diverse approach to determining the biological productivity of plantations. Many of the tables are incomplete and do not contain data on total plant productivity, which is the most important indicator for assessing the biosphere role of forests, in particular the carbon cycle. At the same time, to obtain an objective picture and the possibility of regulating the processes of forest productivity, a unified methodological approach to determining the amount of phytomass within a certain forest zone is necessary at the state level.

The high labor intensity and length of time of the measuring stage in the research of forest bioproductivity naturally leads to the need to use a huge array of quantitative information about the forest Fund, accumulated in the process of forest management [12, 13, 14].

Empirical modeling of growth and productivity of stands is one of the methods of cognition and identification of the regularities of functioning of these complex biological systems. It allows us to predict their development and the limits of their possible economic use with some caution. Knowledge of the general regularities of the forest formation process, the dynamics of productivity of forest phytocenoses is based on the assessment of taxational indicators of stands in the study of their growth, structure and structure [13]. Empirical models of these processes are not only of general theoretical significance, but also allow us to obtain a wide range of practical applications, in particular, to provide forest management with the necessary and extremely relevant forest taxational standards for the transition from assessing the raw functions of forests to determining indicators of their biological production process.

To assess the biological productivity of plantings at the regional level, the most acceptable information on the amount of produced phytomass and carbon stocks is the tables of the growth of modal stands, which represent a certain average characteristic of homogeneous groups of plantings in a particular region [12]. Their advantage is that they describe the dynamics of real stands that are often objects of economic activity, and with a high probability, are exposed to fires and mass exposure to pests and diseases of the forest.

Thus, a universal approach in this case is the development of models linking taxational and bioproductivity indicators of stands intended for assessing the dynamics of phytomass, which are necessary as a source material for designing the full and rational use of forest vegetation resources, planning fire prevention measures, forecasting the number of pests and tracking the carbon cycle at the regional level.
The object of this work was to study the regional features of phytomass accumulation based on modeling the age dynamics of the modal spruce stock as the basic forest ecosystems of the taiga zone, which play an important resource and environment-forming role in the research area.

2. Research objects and methods

The area of observation was the Yenisei forest area located within the boundaries of the taiga zone (the South ecoregion). The climate of the territory is sharply continental, with an average annual temperature of -2.0 °C, with severe long winters and short relatively humid summers. The length of the growing season in the Yenisei forest area is 145 days. The total amount of annual precipitation is 497 mm, the main part of it (60 – 70 %) falls during the warm season [15].

The object of study was the modal stands of Siberian spruce (Picea obovata) of the green-moss group of forest types, widely represented in the research area. Stands mixed with a share of participation in the composition of fir, cedar, birch, less often aspen. They grow on loamy soils of varying degrees of salinity, preferring gentle slopes, low terrain areas, river and stream valleys [16, 17].

Since within a group of forest types, the variability of growth and productivity of stands is often significant and the use of data in accounting for forests can lead to errors, when considering the methodological approach to choosing the basis for classifying growth standards for modal spruce forests, we have combined the forest type with the bonitet class, which makes the developed standard universal and more accurate. In the research area, spruce forests are represented by stands of the III and IV bonitet class, which served as an additional classifying indicator in the development of tables of growth and biological productivity of modal spruce forests of the green-moss group of forest types.

The table method of development of the growth progress was based on the research of N. V. Tretyakov, supplemented by I. V. Semechkin [18]. The work is based on the materials of mass taxational of 4719 allotments. The “derived” indicators of the growth progress table (species number, trunk volume, number of trunks, current and average stock increments) were calculated using well-known forest taxational formulas [12].

When assessing the biological productivity of stands, the conversion-volume method or “Ph/M-conversion” was used, as the simplest of the existing methods for assessing plant phytomass. The assessment is carried out using conversion coefficients that represent the ratio of phytomass (Ph, t·ha⁻¹) of individual fractions to the wood stock (M, m³·ha⁻¹). For Russian forests, it is successfully applied at the federal, large-regional, zonal and regional levels, on the basis of which the materials of the state forest accounting are maintained [14]. The conversion coefficients recommended in the works of D. G. Zamolodchikov and A. I. Utkin [19, 20] were used for the transition from the stand stock to the general phytomass and its fractional composition, and for the calculation of the carbon stock.

3. Research results and their discussion

The work is based on the materials of mass taxation of 4669 allotments, with 2877 allotments belonging to stands of the III bonitet class, and 1792 allotments to the IV bonitet class. In the process of sampling, the allotments with a predominance of the spruce element of the forest with a share of Siberian spruce (Picea obovata) of at least three units in the total composition of the plantation. Such stands growing on the territory of the research area are characterized by average taxational indicators shown in table 1.

| Bonitet class | A, years | H, m  | D, cm | P   | M, m³/ha |
|---------------|----------|-------|-------|-----|----------|
| III           | 144 ± 0.4| 23.3 ± 0.1| 26.7 ± 0.1| 0.58| 221 ± 1 |
| IV            | 145 ± 0.5| 20.7 ± 0.1| 23.6 ± 0.1| 0.58| 187 ± 1 |

The stability of the natural environment of forest regions can be assessed by the state of productivity of coniferous native forests within one or more close forest conditions [13]. The formation of modal plantings is mainly determined by the local specifics of growing conditions and the corresponding
characteristics of external factors. Based on the data of forestry research, the studied stands are represented mainly by stands previously defoliated by the Siberian silkworm, post-harvest and post-fire spruce forests, which are at different stages of natural succession, and have emerged from the preserved undergrowth of pre-generation or after the natural decay of birch and aspen trees [16, 17].

The discreteness of forest vegetation conditions determines the feature of forest ecosystems associated with their stability over time, that is, the ability to restore to the original or close to the original state, which is very important when organizing forestry, environmental forecasts and timely correction of monitoring data, including tracking the carbon cycle. Since the influence of external factors on growth processes is probabilistic and at the same time integral in the course of the development of natural plantations, this study is based on a one-factor regression analysis related to the study of the dynamics of growth processes and productivity of modal spruce forests, as a homogeneous population, depending on the time factor (the age of stands). This approach has an important advantage in that the process of modeling the biological productivity of modal spruce forests represents a general picture of a natural dynamic system that changes over time. If additional experimental material is available, it is possible to update models of growth and data on phytomass, changing the coefficient matrix as new empirical information is accumulated [13].

As a result of regression analysis of experimental data, it was found that the functional dependence of age dynamics on the height, diameter and stock of modal spruce forests is reflected by the Hoerl Model equation (1):

\[ y = ab^x \cdot x^c \]  

where \( X \) is the age of stand, years; 
a, b, c are coefficients of the equation;

Table 2 shows the parameters of the mathematical model.

**Table 2. Coefficients of the equation of age dynamics of taxational indicators of spruce forests of green-moss forest type of the III and IV bonitet class.**

| Taxational indicator | Coefficients of the equation | S  | R²  |
|----------------------|-----------------------------|----|-----|
|                      | a      | b   | c      |     |     |
| III bonitet class    |        |     |        |     |     |
| H, m                 | 0.0873 | 0.9920 | 1.3603 | 0.92 | 0.62 |
| D, cm                | 0.0266 | 0.9911 | 1.6542 | 2.30 | 0.42 |
| M, m³/ha             | 0.1931 | 0.9893 | 1.7329 | 14.99 | 0.42 |
| IV bonitet class     |        |     |        |     |     |
| H, m                 | 0.0835 | 0.9923 | 1.3345 | 0.93 | 0.72 |
| D, cm                | 0.0503 | 0.9923 | 1.4650 | 1.75 | 0.59 |
| M, m³/ha             | 0.1576 | 0.9902 | 1.7151 | 16.05 | 0.50 |

The resulting equation is adequate and works in a wide age range from 10 to 200 years, which expands the possibility of predicting the productivity and stability of the state of the studied woodlands. Regression coefficients are statistically significant at a confidence level of 0.95. Considering the obtained coefficients of determination (\( R^2 \)), it should be noted that the complex dependence of growth processes on many factors is obvious in nature. For the studied stands within the group of forest types, the probability of variability in the average height of the stand due to the age factor is from 62 to 72 %, in diameter is from 42 to 59 %, in stock is from 42 to 50 %. In other cases, these taxational indicators are affected by the density, shape of the stand, and other internal and external processes and influences.
The correlation of experimental data with the results of regression analysis of the growth of spruce forests for the selected group of forest types according to the main taxational characteristics of the III and IV bonitet classes is clearly shown in figures 1 and 2, respectively.

**Figure 1.** Growth rate of spruce forests of green-moss type of forest of the III bonitet class: a) by height, b) by diameter, c) by stand stock.

**Figure 2.** Growth rate of spruce forests of green-moss type of forest of the IV bonitet class: a) by height, b) by diameter, c) by stand stock.
The result of modeling growth processes is the developed table of the growth rate of spruce forests of the green-moss group of forest types (table 3).

**Table 3. Growth rate of spruce stands of the green-moss group of forest types.**

| Age, years | average H, m | D, cm | f | V, m³ | N, th | M, m³/ha | increase in the stock of trees, m³/ha |
|------------|--------------|-------|---|-------|-------|----------|-------------------------------------|
|            | III bonitet class |       |   |       |       |          | average | current |
| 20         | 4.4          | 3.2   | 0.81 | 0.0028 | 10030 | 28       | 1.4      | 1.9     |
| 30         | 7.0          | 5.6   | 0.70 | 0.0123 | 4129  | 51       | 1.7      | 2.3     |
| 40         | 9.6          | 8.3   | 0.64 | 0.0329 | 2283  | 75       | 1.9      | 2.4     |
| 50         | 12.0         | 11.0  | 0.59 | 0.0669 | 1484  | 99       | 2.0      | 2.4     |
| 60         | 14.1         | 13.6  | 0.56 | 0.1145 | 1068  | 122      | 2.0      | 2.3     |
| 70         | 16.1         | 16.0  | 0.54 | 0.1739 | 825   | 143      | 2.0      | 2.1     |
| 80         | 17.8         | 18.2  | 0.52 | 0.2421 | 671   | 162      | 2.0      | 1.9     |
| 90         | 19.3         | 20.3  | 0.51 | 0.3152 | 567   | 179      | 2.0      | 1.6     |
| 100        | 20.5         | 22.0  | 0.50 | 0.3984 | 495   | 193      | 1.9      | 1.4     |
| 110        | 21.6         | 23.6  | 0.49 | 0.4610 | 443   | 204      | 1.9      | 1.1     |
| 120        | 22.4         | 24.9  | 0.48 | 0.5269 | 405   | 213      | 1.8      | 0.9     |
| 130        | 23.0         | 26.0  | 0.48 | 0.5847 | 376   | 220      | 1.7      | 0.7     |
| 140        | 23.5         | 26.8  | 0.47 | 0.6328 | 355   | 225      | 1.6      | 0.5     |
| 150        | 23.8         | 27.5  | 0.47 | 0.6701 | 339   | 227      | 1.5      | 0.3     |
| 160        | 24.0         | 28.0  | 0.47 | 0.6964 | 328   | 229      | 1.4      | 0.1     |
| 170        | 24.1         | 28.3  | 0.47 | 0.7118 | 320   | 228      | 1.3      | -0.1    |
| 180        | 24.0         | 28.4  | 0.47 | 0.7170 | 315   | 226      | 1.3      | -0.2    |
| 190        | 23.8         | 28.4  | 0.47 | 0.7127 | 313   | 223      | 1.2      | -0.3    |
| 200        | 23.6         | 28.2  | 0.47 | 0.7003 | 313   | 219      | 1.1      | -0.4    |
|            | IV bonitet class |       |   |       |       |          |          |         |
| 20         | 3.9          | 3.5   | 0.84 | 0.0031 | 7134  | 22       | 1.1      | 1.5     |
| 30         | 6.2          | 5.8   | 0.72 | 0.0119 | 3354  | 40       | 1.3      | 1.8     |
| 40         | 8.4          | 8.2   | 0.66 | 0.0293 | 2026  | 59       | 1.5      | 1.9     |
| 50         | 10.5         | 10.5  | 0.61 | 0.0561 | 1405  | 79       | 1.6      | 1.9     |
| 60         | 12.4         | 12.7  | 0.58 | 0.0919 | 1062  | 98       | 1.6      | 1.9     |
| 70         | 14.1         | 14.8  | 0.56 | 0.1351 | 853   | 115      | 1.6      | 1.8     |
| 80         | 15.7         | 16.6  | 0.54 | 0.1833 | 716   | 131      | 1.6      | 1.6     |
| 90         | 17.0         | 18.3  | 0.53 | 0.2342 | 621   | 146      | 1.6      | 1.4     |
| 100        | 18.1         | 19.7  | 0.52 | 0.2852 | 554   | 158      | 1.6      | 1.2     |
| 110        | 19.0         | 21.0  | 0.51 | 0.3342 | 504   | 168      | 1.5      | 1.1     |
| 120        | 19.8         | 22.0  | 0.50 | 0.3793 | 467   | 177      | 1.5      | 0.9     |
| 130        | 20.4         | 22.9  | 0.50 | 0.4191 | 439   | 184      | 1.4      | 0.7     |
| 140        | 20.8         | 23.7  | 0.49 | 0.4527 | 418   | 189      | 1.4      | 0.5     |
| 150        | 21.2         | 24.2  | 0.49 | 0.4794 | 403   | 193      | 1.3      | 0.4     |
| 160        | 21.3         | 24.6  | 0.49 | 0.4990 | 391   | 195      | 1.2      | 0.2     |
| 170        | 21.4         | 24.9  | 0.49 | 0.5117 | 384   | 196      | 1.2      | 0.1     |
| 180        | 21.4         | 25.1  | 0.49 | 0.5178 | 379   | 196      | 1.1      | 0.0     |
| 190        | 21.3         | 25.1  | 0.49 | 0.5177 | 377   | 195      | 1.0      | -0.1    |
| 200        | 21.1         | 25.1  | 0.49 | 0.5122 | 377   | 193      | 1.0      | -0.2    |
The obtained results are consistent with the data of the current growth progress table developed by A. Z. Shvidenko, D. G. Shchepashchenko and others for modal spruce stands of the III and IV bonitet classes of the Central Siberia (ecoregions of the Southern and middle taiga) [21]. However, the growth rate table developed by us is based on a forest-typological basis and it provides the appropriate adjustments. In this connection, it should be noted that there are some deviations in the data on changes in the stock of stands, as a source indicator for calculating the biological productivity of plantations. Comparison of the results in percentage ratio showed that within the group of forest types for stands of the III bonitet class, the reserve values with the current table are minus 12%, for the IV bonitet class, the opposite is an excess of 10%. Thus, it should be concluded that the complex characterization of the growth process on a bonitet and forest-type basis provides a more accurate description of changes in taxational characteristics of modal spruce stands.

In accordance with the intended purpose of this work, based on the results of the dynamics of stock of spruce modal forest stands and application conversion-volume method there are the obtained results of biological productivity, reflecting the dynamics of the fractional composition of phytomass and carbon stock in them (table 4).

**Table 4.** Dynamics of biological productivity of modal stands of spruce green-moss groups of forest types.

| Age, years | M, m³/ha | overall | tree trunk in bark | Phytomass fraction | carbon stock, tC·ha⁻¹ | the tree roots | the tree total | aboveground phytomass needles | branch | total | III bonitet class | IV bonitet class |
|------------|----------|---------|-------------------|--------------------|----------------------|----------------|---------------|-----------------------------|---------|--------|----------------|-----------------|
| 20         | 19       | 34.4    | 12.7              | 5.1                | 7.2                  | 25.0           | 9.4           | 11.2                        |         |        |                 |                 |
| 30         | 40       | 56.0    | 23.1              | 7.7                | 8.1                  | 39.0           | 17.0          | 20.4                        |         |        |                 |                 |
| 40         | 64       | 69.7    | 34.0              | 9.1                | 8.4                  | 51.5           | 18.2          | 30.1                        |         |        |                 |                 |
| 50         | 90       | 86.2    | 46.4              | 10.2               | 8.5                  | 65.2           | 21.0          | 39.6                        |         |        |                 |                 |
| 60         | 116      | 100.2   | 57.2              | 11.1               | 8.7                  | 77.0           | 23.2          | 41.8                        |         |        |                 |                 |
| 70         | 141      | 112.8   | 67.1              | 11.9               | 8.8                  | 87.7           | 25.1          | 49.4                        |         |        |                 |                 |
| 80         | 163      | 118.9   | 70.8              | 12.5               | 8.9                  | 92.2           | 26.8          | 55.4                        |         |        |                 |                 |
| 90         | 182      | 128.5   | 78.2              | 13.1               | 9.0                  | 100.3          | 28.2          | 60.1                        |         |        |                 |                 |
| 100        | 199      | 141.1   | 87.2              | 13.6               | 9.1                  | 109.9          | 31.3          | 63.7                        |         |        |                 |                 |
| 110        | 212      | 148.9   | 92.2              | 14.5               | 9.1                  | 115.8          | 33.0          | 67.8                        |         |        |                 |                 |
| 120        | 222      | 155.1   | 96.3              | 15.1               | 9.2                  | 120.6          | 34.5          | 68.8                        |         |        |                 |                 |
| 130        | 229      | 159.9   | 99.4              | 15.6               | 9.2                  | 124.3          | 35.6          | 71.0                        |         |        |                 |                 |
| 140        | 233      | 163.6   | 101.7             | 16.0               | 9.5                  | 127.1          | 36.5          | 72.2                        |         |        |                 |                 |
| 150        | 234      | 165.0   | 102.6             | 16.1               | 9.5                  | 128.3          | 36.8          | 72.5                        |         |        |                 |                 |
| 160        | 234      | 166.5   | 103.5             | 16.3               | 9.6                  | 129.4          | 37.1          | 72.5                        |         |        |                 |                 |
| 170        | 231      | 165.8   | 103.1             | 16.2               | 9.6                  | 128.8          | 36.9          | 71.6                        |         |        |                 |                 |
| 180        | 227      | 164.3   | 102.2             | 16.0               | 9.5                  | 127.7          | 36.6          | 70.4                        |         |        |                 |                 |
| 190        | 221      | 162.1   | 100.8             | 15.8               | 9.4                  | 126.0          | 36.1          | 68.5                        |         |        |                 |                 |
| 200        | 214      | 159.2   | 99.0              | 15.5               | 9.2                  | 123.7          | 35.5          | 66.3                        |         |        |                 |                 |
| 20         | 22       | 27.0    | 10.0              | 4.0                | 5.7                  | 19.6           | 7.3           | 13.0                        |         |        |                 |                 |
| 30         | 40       | 40.9    | 18.1              | 6.1                | 6.4                  | 30.6           | 10.3          | 20.4                        |         |        |                 |                 |
| 40         | 59       | 54.4    | 26.7              | 7.3                | 6.7                  | 40.7           | 13.7          | 27.7                        |         |        |                 |                 |
| 50         | 79       | 68.5    | 37.1              | 8.3                | 6.9                  | 52.2           | 16.2          | 34.8                        |         |        |                 |                 |
| 60         | 98       | 80.5    | 46.0              | 9.1                | 7.1                  | 62.1           | 18.4          | 35.3                        |         |        |                 |                 |
| 70         | 115      | 91.0    | 53.9              | 9.8                | 7.2                  | 70.9           | 20.2          | 40.3                        |         |        |                 |                 |
### Table 1: Phytomass Distribution by Forest Ecosystems (t ha⁻¹)

| Forest Type | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
|-------------|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Green Hill  | 103.4 | 160.5 | 109.6 | 118.5 | 128.7 | 138.8 | 148.9 | 159.0 | 169.1 | 179.2 | 189.3 | 199.4 | 209.5 |
| Coniferous  | 103.7 | 161.8 | 110.9 | 120.7 | 130.8 | 140.9 | 150.0 | 160.1 | 170.2 | 180.3 | 190.4 | 200.5 | 210.6 |
| Deciduous   | 104.0 | 162.1 | 111.1 | 121.2 | 131.3 | 141.4 | 151.5 | 161.6 | 171.7 | 181.8 | 191.9 | 201.0 | 211.1 |

In general, the range of phytomass changes in spruce stands of the green-moss group of forest types throughout the age range in the conditions of the III bonitet class is from 11 to 166.5 t m⁻³, for the IV bonitet class is from 8.6 to 142.5 t m⁻³. At the same time the main share of phytomass and carbon reserves in the modal stands of spruce are accumulated in the ripe and overgrown age state [12, 22, 23, 24]. It is obvious that the total amount of phytomass naturally increases with an increase in the value of the stock of the stand and then when the trees die off and the stand disintegrates, it decreases along with a decrease in the number of trunks and transfers into the fraction of large wood residues (or wood debris). At the same time, the ratio of fractional composition also changes with increasing age due to natural processes. Generative organs fall off, dead branches, detached fragments of bark, needles, whose life span is from 4 to 6 years, thus form a stream that transfers organic matter from the phytomass to the litter [3, 7, 14, 20]. According to the average data for various forest ecosystems, the carbon stock of vegetation per unit (per 1 ha) of forested area is from 31 to 38 tons. In dry plant biomass (phytomass) it contains from 45 to 53% carbon [19, 24, 25]. The lower tiers of taiga forests are much less developed under closed forests and usually add no more than 3-5% to the carbon reserves of vegetation in the upper canopies [12, 21, 25]. In this case, calculations have shown that carbon reserves in modal spruce forests of the III bonitet class is from the stage of young growth to the overstaying state are concentrated from 4.0 to 72.5 tC·ha⁻¹, for conditions of the IV bonitet class is from 5.6 to 60.8 tC·ha⁻¹.

### 4. Conclusion

The current state of normative and information support of the forest scientific and practical sphere requires a significant expansion of knowledge in the field of individual ecological functions of forests, assessment of their resource potential, which currently makes it difficult to correctly discuss many issues of global and regional ecology.

The proposed tables of biological productivity of spruce forests in the taiga zone provide a detailed quantitative characteristic of the age dynamics of changes in phytomass and carbon contained in it, which is a tool for environmental forecasting and monitoring of taiga forest ecosystems.

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