Phyto mass accumulation and the carbon potential of modal fir stands determination in the conditions of the Krasnoyarsk-Kansk podtaezhno-forest-steppe region

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Abstract. The research paper presents two stages of the study. At the first stage, table sketches of the growth progress of modal fir plantations for the mixed and green-moss type forests of the Kansk forest district and the mixed and fern-mossy groups of the Biryusinsk precinct of the Minino forest district were developed. At the second stage, using the conversion method, the conversion coefficients of the fractions of branches, needles and roots were calculated and the age-related dynamics of the phytomass of modal fir plantations of various typological-territorial groups, with its division into fractions, was determined, and the carbon stock was calculated. As a result of the studies, it was found that a high level of phytomass accumulation and carbon reserve are characterized by fir plantations of the fern-moss type of the forest of the Krasnoyarsk subtaiga region. The total phytomass of the trees of the age being up to 150 years was 205.7 t · m⁻³, and the carbon stock was 102.8 t / ha. The lowest indices for the mixed grass firs of the Kansk forest-steppe were established; according to the data obtained, the total plant phytomass was 123.9 t / ha by 160 and carbon 62 t / ha.

1. Introduction
Currently, the problem of forecasting and assessing the effect of the greenhouse effect as a result of increasing anthropogenic impact on the biosphere is relevant. The main element of organic matter involved in the cycle of matter and energy of the ecosystem is the chemical element carbon [1].

The main source of high organic matter are forest communities. Therefore, carbon reservoirs of tree communities are a defining characteristic of the flow movement in the cycle of biocenosis. The leading pool of woody vegetation with a high content of carbon element is the phytomass of forest stands [2].

The biological productivity of phytomass is largely determined by the course of planting growth, and, therefore, depends on the dynamics of taxation indicators: average height, average diameter, and average reserve per 1 ha. In forest taxation, it is the growth progress tables that reflect the biological productivity of stands development [3].

From the point of view of forest management, simple, but the most informative models of the dynamics of the main taxation indicators with age are used for forestry activities [4]. Currently, in the Russian Federation, it has been the practice to use regional growth progress tables, with an internal division into forest zones, certain forest stands with their closeness, and subsequently with division by class of bonitet and type of forest.
Therefore, an objective methodological direction in determining the dynamics of biological productivity is the transition to the age dependence of taxation indicators of stands.

The following scientists made a scientifically significant contribution to the study of estimating the reserve and flow of forest carbon: D.G. Zamolodchikov, A.Z. Shvidenko, D.G. Schepashchenko, V.A. Usoltsev, S.I. Chumachenko [5, 6, 7, 8, 9, 10, 11].

In order to increase carbon accumulation in forests, according to the authors [12], it is necessary: to protect forests from fires, pests and diseases; reduce the area of timber harvesting; to control the forest roads, skidding and storage; to strengthen the object approach to preparing the soil for planting; to increase the area of forest planting; to develop rational and timely fertilizer application; apply thinning (thinning).

Based on the foregoing, it follows that the determination of the phytomass of the aboveground and underground parts of the plantation with the accumulation of carbon stock using traditional tables of growth progress allows us to determine the value of forest plantations using measures to accumulate and circulate the total phytomass and carbon potential of forest plantations.

Thus, the goal of this research was to determine the age-related dynamics of the accumulation of phytomass of modal fir plantations, divided by fractional components, and carbon stock, based on local sketches of growth tables, divided by territorial affiliation and typological isolation.

2. Materials and methods

The object of the study was the modal fir plantations of two types of forests in the territory of Kansk forest district (Central Siberian sub-taiga-forest-steppe region) and Biryusinsk precinct forestry of the Minino forest district (foothill part of the Eastern Sayan).

The typological structure of fir wood in the conditions of the Central Siberian sub-taiga-forest-steppe region is mainly represented by a mixed-grass and green-moss group of forest types, and in the foothills of East Sayan a fern-mossy type and forbs.

The methodology of the study at the first stage with the construction of sketches of the growth progress tables was carried out according to the methodological recommendations of V.S. Moiseeva and I.V. Semechkina [13, 14]. At the second stage, the method of information and analytical assessment of the carbon budget of forest stands at the local level was used to determine biological productivity. To transfer the stock of standing wood to the phytomass by fractional composition and carbon stock, conversion coefficients were used and calculated based on the scientific works of D.G. Zamolodchikova, A.I. Utkina, G.N. Korovin [15].

3. Results and discussion

At the first stage of the study, from the materials of the 1978-1979 eye-measuring taxation of the Kansk forest district and 2001 of the Minino forest district (Biryusinsk precinct forestry), 443 selected modal fir plantations of 3-4 growth class, with their forestry division, age classes and typological affiliation.

Further selected data on the corresponding age classes: average height, average diameter, average reserve per 1 ha, were subjected to statistical processing.

As a result, it was found that the accuracy of the experiment for the average height varies from 1.6 to 7.0%, the average diameter is from 1.2 to 7.7%, and the average reserve per 1 ha is from 4.8 to 11.3%. The obtained indicators of the accuracy of the experiment and the coefficient of variation indicated in most cases a sufficient amount of data, with the exception of young (1-2 grades of age) and old-aged (8-9 grades of) firs.

Subsequently, the average main taxation indicators were approximated by age in CurveExpert 1.3, using the Exponential Association function for average height and average diameter, and with respect to the average reserve per 1 ha by the Gompertz Relation function.

In accordance with the proposed regression models, the determination coefficients were in the range of 0.72 - 0.96.
Based on the calculated equations, the dynamics of taxation indicators of the modal groups of fir plantations, the corresponding forestry and the type of forest is constructed (is not presented in this article).

After that, the transition from the stock of planting to the phytomass and the assessment of the carbon stock took place. At this stage, in order to achieve the task, the conversion method was used, using coefficients for various fractions. The conversion coefficient of the stem fraction for all age stages was 0.455. The conversion coefficients of branches, needles and roots were calculated by the method of D.G. Zamolodchikova, A.I. Utkina, G.N. Korovin [15].

In accordance with the conversion coefficients obtained, the phytomass was calculated according to the fractional composition, with the subsequent determination of the total phytomass and the carbon potential in the age dependence was calculated (table 1).

Phytomass and carbon stock are concentrated in ripe and mature stands, while the type of forest and the conditions of habitat significantly affect their accumulation. The total phytomass of modal fir in the conditions of the Kansk forest district varies by age stages from 13.8 to 123.9 t · m⁻³, carbon - from 6.9 to 62.0 t / ha, for the green grass group, the total phytomass ranges from 13, 9 to 170.3 t · m⁻³, and carbon - from 7 to 89.2 t / ha (table 1).

On the territory of the Birysinsk precinct forestry of the Minino forest district, there is a significant difference in the accumulation of total phytomass and carbon and modal fir trees relative to fir trees under the conditions of the Kansk forest district, here the phytomass of fir forbs is distributed in age from 5.7 to 178.4 t · m⁻³ and the carbon stock in the range from 2.9 to 85.2 t / ha. Fern-mossy fir trees distinguished themselves by significant accumulation, according to which the total phytomass of fractions increased by 150 years to 205.7 t · m⁻³, and in turn, the carbon potential by this age amounted to 102.8 t / ha.

Active growth, in both typological groups of two forest districts, in the phytomass of branches and needles lasts up to 100-110 years, after which the growth of fractions decreases and the variation over decades is from 0.1 to 0.5 t · m⁻³, the growth of root phytomass increases up to 130 years, and subsequently decreases, and further changes are in the range from 0.1 to 0.6 t · m⁻³.

Table 1. Dynamics of biological productivity of modal fir plantations of various types of forests.

| Age | Volume m³/ha | Phytomass, t m⁻³ | Carbon stock, t/ha |
|-----|--------------|------------------|-------------------|
|     |              | trunk | branches | needles | roots | total |        |        |
|-----|--------------|-------|----------|---------|-------|-------|--------|--------|
| Kansk forest district |
| 10  | 15           | 6.8   | 2.2      | 2.2     | 2.6   | 13.8  | 6.9    |
| 20  | 24           | 10.9  | 3.2      | 2.9     | 4.1   | 21.1  | 10.5   |
| 30  | 47           | 21.4  | 5.4      | 4.6     | 7.6   | 39.0  | 19.5   |
| 40  | 73           | 33.2  | 7.7      | 6.2     | 11.5  | 58.6  | 29.3   |
| 50  | 97           | 44.1  | 9.6      | 7.4     | 14.9  | 76.0  | 38.0   |
| 60  | 118          | 53.7  | 11.0     | 8.3     | 17.9  | 90.9  | 45.4   |
| 70  | 134          | 61.0  | 12.0     | 8.8     | 20.0  | 101.9 | 50.9   |
| 80  | 145          | 66.0  | 12.6     | 9.1     | 21.5  | 109.2 | 54.6   |
| 90  | 153          | 69.6  | 13.0     | 9.3     | 22.5  | 114.5 | 57.2   |
| 100 | 159          | 72.3  | 13.2     | 9.3     | 23.2  | 118.1 | 59.1   |
| 110 | 163          | 74.2  | 13.4     | 9.3     | 23.7  | 120.5 | 60.2   |
| 120 | 166          | 75.5  | 13.4     | 9.3     | 24.0  | 122.3 | 61.1   |
| 130 | 167          | 76.0  | 13.4     | 9.2     | 24.1  | 122.6 | 61.3   |
| 140 | 168          | 76.4  | 13.3     | 9.1     | 24.1  | 122.9 | 61.5   |
| 150 | 169          | 76.9  | 13.2     | 9.0     | 24.2  | 123.4 | 61.7   |
| 160 | 170          | 77.4  | 13.2     | 9.0     | 24.3  | 123.9 | 62.0   |

| F_em  |
|-------|
| 10    | 14   | 6.3  | 2.4   | 2.6   | 2.6  | 13.9  | 7.0    |
| 20    | 32   | 14.6 | 4.3   | 4.0   | 5.5  | 28.4  | 14.2   |

3
The reason for this is the location of plantations in the Kologrivsky forest reserve [16]. Similarly, modal fir plantations of different species in the Kansk forest district and fir forest stand of the III class of growth class of the Bolshemurtinsky forest district [17] in fractional accumulation are in a similar position. The reason for this is the location of plantations in one forest area, as well as the active management of forestry in these territories (figure 1).

| Biryusinsk precinct Minino forest district |
|------------------------------------------|
| F<sub>gm</sub>                           |
| 10 | 6  | 2.7 | 1.0 | 1.0 | 1.1 | 5.7 | 2.9 |
| 20 | 20 | 9.1 | 2.4 | 2.1 | 3.3 | 17.0 | 8.5 |
| 30 | 45 | 20.5 | 4.8 | 3.8 | 7.1 | 36.2 | 18.1 |
| 40 | 77 | 35.0 | 7.4 | 5.6 | 11.8 | 59.8 | 29.9 |
| 50 | 113 | 51.4 | 10.1 | 7.3 | 16.8 | 85.6 | 42.8 |
| 60 | 146 | 66.4 | 12.3 | 8.7 | 21.4 | 108.9 | 54.4 |
| 70 | 175 | 79.6 | 14.1 | 9.7 | 25.2 | 128.7 | 64.4 |
| 80 | 199 | 90.5 | 15.5 | 10.5 | 28.3 | 144.9 | 72.5 |
| 90 | 217 | 98.7 | 16.5 | 10.9 | 30.6 | 156.8 | 78.4 |
| 100 | 230 | 104.7 | 17.1 | 11.2 | 32.2 | 165.0 | 82.5 |
| 110 | 240 | 109.2 | 17.5 | 11.3 | 33.3 | 171.3 | 85.6 |
| 120 | 247 | 112.4 | 17.7 | 11.3 | 34.1 | 175.4 | 87.7 |
| 130 | 252 | 114.7 | 17.8 | 11.3 | 34.7 | 178.4 | 89.2 |

| F<sub>fm</sub>                           |
|------------------------------------------|
| 10 | 13 | 5.9 | 2.2 | 2.4 | 2.4 | 13.0 | 6.5 |
| 20 | 30 | 13.7 | 3.9 | 3.6 | 5.1 | 26.2 | 13.1 |
| 30 | 55 | 25.0 | 6.1 | 5.1 | 8.9 | 45.1 | 22.6 |
| 40 | 87 | 39.6 | 8.7 | 6.8 | 13.5 | 68.5 | 34.3 |
| 50 | 122 | 55.5 | 11.2 | 8.4 | 18.4 | 93.6 | 46.8 |
| 60 | 155 | 70.5 | 13.4 | 9.6 | 22.9 | 116.5 | 58.3 |
| 70 | 186 | 84.6 | 15.3 | 10.7 | 27.0 | 137.6 | 68.8 |
| 80 | 213 | 96.9 | 16.8 | 11.4 | 30.5 | 153.6 | 77.8 |
| 90 | 234 | 106.5 | 17.8 | 11.8 | 33.0 | 169.2 | 84.6 |
| 100 | 252 | 114.7 | 18.6 | 12.1 | 35.2 | 180.6 | 90.3 |
| 110 | 266 | 121.0 | 19.2 | 12.3 | 36.8 | 189.4 | 94.7 |
| 120 | 276 | 125.6 | 19.5 | 12.3 | 37.9 | 195.2 | 97.6 |
| 130 | 284 | 129.2 | 19.6 | 12.3 | 38.7 | 199.7 | 99.9 |
| 140 | 291 | 132.4 | 19.7 | 12.2 | 39.4 | 203.8 | 101.9 |
| 150 | 295 | 134.2 | 19.7 | 12.1 | 39.7 | 205.7 | 102.8 |

Note: F<sub>gm</sub> – mixed-grass fir; F<sub>fm</sub> – green-moss fir; F<sub>fm</sub> – fern-mossy fir.

Without regard to the age stage, it follows that the modal fir plantations of the Biryusinsk precinct forestry, the Minino forest district, in their accumulation of phytomass, correspond to the fir forests of the Kologrivsky forest reserve [16]. Similarly, modal fir plantations of different species in the Kansk forest district and fir forest stand of the III class of growth class of the Bolshemurtinsky forest district [17] in fractional accumulation are in a similar position. The reason for this is the location of plantations in one forest area, as well as the active management of forestry in these territories (figure 1).
Figure 1. Comparison of the maximum increase in the phytomass of firs of different age classes.

The increase in the carbon reserve of fir plantations over ten-year periods is intensively increasing under the conditions of the Kansk forest district by the age of 40, so the maximum growth of the herb group is 9.8 t / ha, and that of the green grass is 11.3 t / ha. In the Biryusinsk forest district the maximum growth of the different type of forest is 12.9 t / ha by the age of 50, and in the fern-mossy firs - 12.5 t / ha, after which, under both conditions of the study, carbon accumulation decreases (figure 2).

Figure 2. Increase in carbon stock of firs over decades of different territorial and typological conditions.
The modal fir plantations of the Biryusinsk precinct forestry of the Minino forest district accumulate almost twice as much phytomass, therefore, the carbon stock, as compared to the firs of the Kansk forest district, thereby having a highly marked value in the accumulation of phytomass and carbon.

The results on biological productivity, namely the phytomass and carbon stocks of modal fir plantations of various typological and territorial groups, are not a constant standard and a specific scenario of their accumulation, due to climatic changes. A large and significant role in the accumulation and circulation of carbon stocks is played by anthropogenic impact. As a result of the high recreational burden and the main cutting in the Kansk forest district, the forest carbon potential and phytomass as a whole runoff. Recently, outbreaks of foci of phyto- and entomo pests have been observed in the study area, which lead to the transition of forest carbon through pools and, subsequently, a high carbon sink into the atmosphere.

4. Conclusion

On the results of the study, sketches of the growth progress tables according to typological affiliation for modal fir plantations in the conditions of the Krasnoyarsk-Kansk subtaiga-forest-steppe region were constructed. Based on the constructed regression models of the dynamics of taxation indicators, the conversion coefficients of branches, needles and roots were determined, and subsequently the common phytomass was established with a division by fractional components of carbon reserves by age periods. The obtained standards can be used both to supplement regional tables of growth progress and rational forestry planning in these research areas.

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