Carbon-removing ability of fir plantations of the Krasnoyarsk Territory forest-steppe zone

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Abstract. Forest ecosystems play a global role in carbon sequestration and emission processes on a planetary scale. The topic of the functional ecological role of forests is urgent due to the problem of climate warming and an increase in the level of carbon dioxide concentration in the atmosphere. Currently, a differentiated (regional) approach to assessing the biological productivity of stands and their carbon-removing ability is important, which allows a detailed approach to organizing monitoring of the ecological balance and using the resource potential of forest ecosystems of a certain territory. The aim of this work was to assess the carbon-removing ability of modal stands of Siberian fir based on the study of the dynamics of the fractional composition of phytomass in the process of planting development. The studies were conducted in the conditions of the Central Siberian subtaiga forest-steppe region of the Krasnoyarsk Territory (the territory of the Bolshemurtinsky forestry). The object of research was fir stands of the third class bonitet. In the work, materials were used for eye-tracking taxation of 456 sections. The dynamics of the fractional composition was calculated using the conversion-volumetric method (Ph/M conversion) on the basis of the developed table of the growth course, followed by the conversion of the studied fir plantations to the carbon reserves deposited by the tree layer.

1. Introduction

In recent years, Russia, within the framework of the signed environmental Conventions, has taken a number of international obligations in the field of environmental protection. Obligations predetermine the organization of a system of measures aimed at developing and implementing programs to control climate change, protect the ozone layer, assess environmental impacts in a transboundary context, and others [1-3].

Due to the recognition of the global role of boreal forests in climate regulation, an important task has arisen for the numerical determination of the biosphere role of forest communities, which are the main reservoirs of phytomass. No other plant formation can be compared with forest phytocenoses in oxygen-producing and carbon-depleting functions, therefore, an important role in this process is given to boreal (taiga) forests due to their significant role in weakening the greenhouse effect and stabilizing the planet’s climate [2, 4, 5].

Estimating the significant resource role of plantations in the process of forest development, it is important to plan and control the organization of forest management while taking into account the ecological function of forests in terms of carbon depot ability throughout the life of the plantation.
V.A. Alekseev and R.A. Beardsy note that the determination of carbon stocks in plant ecosystems is possible as a result of identifying their phytomass stocks [4]. The solution to this problem requires knowledge of the dynamics of the components of the biological productivity of forest ecosystems that have not traditionally been determined by forest management, in particular, the age-related dynamics of phytomass fractions and estimates of carbon pools [6].

A detailed approach to solving this issue is the development of regional tables of the biological productivity of stands based on a system of models linking taxation and biometric indicators. Such tables are necessary for assessing the dynamics of phytomass and carbon deposition by various components of plantations in the process of their growth under certain forest conditions.

2. Research objects and methods

The research object was fir stands of Siberian third class bonitet growing in the conditions of the Central Siberian taiga-forest-steppe forest region in the territory of the Bolshemurtinsky forestry of the Krasnoyarsk Territory. These plant communities occupy a significant proportion of the area covered by forest and are modal forest stands under local growing conditions. Plantations are post-cutting and post-fire fir trees that are at different stages of natural succession. In the overall composition, the share of participation of fir varies from five to nine units. The rest of the stands is mainly represented by cedar, spruce, birch, and less often aspen. A characteristic habitat is gray forest, heavy loamy fresh and moist soils. The average fullness of fir stands of class III bonitet varies from 0.5 to 0.6 at all age stages. Forest stands are represented by sedge-green-grass, sedge-mixed-grass, reed-large-grass types of forest.

In the work we used materials of eye inventory of 456 sections, on the basis of which, in accordance with the methodological provisions set forth in the works of N.V. Tretyakova [7] developed a sketch of a table of the growth progress of the studied stands. The amount of phytomass produced at different stages of age-related development of stands was determined through conversion factors, which are the ratio of phytomass (Ph, $\text{t} \cdot \text{ha}^{-1}$) of individual fractions to the wood supply (M, $\text{m}^3 \cdot \text{ha}^{-1}$) (Ph/M conversion) [3, 4, 6].

The carbon content in the absolutely dry phytomass of trees was calculated using conversion factors based on the following parameters: 1 kg of absolutely dry mass of dry branches, bark, wood and roots contains 0.50 kg of carbon, 1 kg of absolutely dry needles mass contains 0.45 kg of carbon [1, 2, 8].

3. Research results and their discussion

The growth of natural fir plantations is characterized by a continuous forest-forming process, in connection with which they are characterized by a great diversity of ages. Within the same forest canopy, all transitions from self-seeding and undergrowth to the oldest overripe trees are found. However, the intensity of this process at individual time intervals varies, as it depends on the impact of a number of factors. Hence, the whole appearance of fir forests is also constantly changing: at some stages of development, relatively young trees under the age of 50–60 years predominate in the stands, while older trees predominate at the age of 80–120 [9, 10]. At the same time, the average taxation indicators of the stands are changing, which in turn affects other processes, namely, the intensity of phytomass accumulation, absorption and emission of carbon at a certain age.

Among all taxation indicators, the stand stock is the main one characterizing the accumulation of phytomass per unit area. Its value substantially depends on the forest growing conditions in which the plantation develops. The stock varies significantly from the moment of the stand to the age of natural ripeness. Significant changes in the natural processes occurring in the forest stand can be made by human activities, forest fires, mass reproduction of phylophagous insects, diseases, forest pests and other factors [9].

At the initial stage of the study, an analysis was made of the patterns of growth processes of modal fir plantations and their mathematical interpretation was given. The age-related changes in the stand
stock were established, which are approximated with a high degree of adequacy by the *Hoerl Model* function (1):

\[
M = 0.35 \times 0.99^A \times A^{1.58}
\]

(1)

where \(M\) is stand stock, m\(^3\)/ha; 
\(A\) is the age of stand, years.

This equation is displayed with a high correlation coefficient \((r)\) of 0.989, with a standard error of equation \((S)\) of 6.2. The equation works for an age period of 20 to 180 years, during which the value of the stand stock varies from 33 to 205 m\(^3\)/ha.

When calculating the volume of phytomass and carbon stock, the conversion-volumetric method was used, which provides for the use of conversion coefficients that allow us to go to the desired values based on the stand stock indicator \([2, 3, 4, 6, 8]\). The determination of phytomass in the stands was carried out only for the main structural part of the phytocenosis - the stand.

The results of calculations of the dynamics of the biological productivity of modal fir plantations of class III bonitet are given in table 1.

**Table 1.** Dynamics of biological productivity of modal fir stands of class III bonitet.

| Age, years | Stock, m\(^3\)/ha | overall | Phytomass, ton/cubic meter | fraction aboveground phytomass | total | the tree roots |
|------------|------------------|---------|-----------------------------|-------------------------------|-------|---------------|
| 20         | 33               | 27.7    | tree trunk in bark          | 12.7                          | 21.4  | 6.3           |
| 30         | 56               | 47.0    | 21.6                        | 4.1                           | 28.1  | 10.8          |
| 40         | 79               | 66.4    | 30.5                        | 9.7                           | 40.2  | 15.3          |
| 50         | 102              | 62.7    | 40.0                        | 6.8                           | 46.8  | 11.1          |
| 60         | 123              | 75.6    | 48.2                        | 8.2                           | 56.4  | 13.4          |
| 70         | 141              | 86.7    | 55.3                        | 9.4                           | 64.7  | 15.4          |
| 80         | 158              | 97.2    | 61.9                        | 10.6                          | 72.5  | 17.3          |
| 90         | 171              | 96.6    | 59.5                        | 8.3                           | 67.8  | 22.4          |
| 100        | 183              | 103.4   | 63.7                        | 8.8                           | 72.5  | 24.1          |
| 110        | 192              | 103.5   | 66.4                        | 10.6                          | 77.0  | 19.8          |
| 120        | 198              | 106.7   | 68.5                        | 10.9                          | 79.4  | 20.4          |
| 130        | 200              | 107.8   | 69.2                        | 11.0                          | 80.2  | 20.6          |
| 140        | 202              | 108.9   | 69.9                        | 11.1                          | 81.0  | 20.8          |
| 150        | 204              | 110.0   | 70.6                        | 11.2                          | 82.8  | 21.1          |
| 160        | 205              | 110.5   | 70.9                        | 11.3                          | 82.2  | 21.1          |
| 170        | 206              | 111.0   | 71.3                        | 11.3                          | 82.6  | 21.2          |
| 180        | 204              | 110.0   | 70.6                        | 11.2                          | 82.8  | 21.1          |

The data of the table show that the bulk of the phytomass of modal stands of fir is concentrated in a ripe and mature age state. The change in the stock of total phytomass throughout all age stages in these forest growing conditions varies from 27.7 to 111 t/m\(^3\).

Subsequently, based on the calculated fractional reserves of phytomass, the reserves of carbon deposited by the canopy of the studied modal fir stands of fir were determined (table 2).

The results showed that throughout the entire life cycle (from 20 to 180 years), the studied fir stands absorb carbon from 13.6 to 54.6 t/ha per year. It is obvious that the main carbon pools of fir phytocenoses are connected in the above-ground phytomass and in the mature stage reach up to 81% of its total value. The underground part (tree roots) accounts for 19%, respectively.
Table 2. Carbon detonating ability of fractions of phytomass of modal stands of fir of the third class bonitet, t/ha per year.

| Age, years | overall | tree trunk in bark | aboveground phytomass | total | the tree roots |
|------------|---------|--------------------|-----------------------|-------|---------------|
| 20         | 13.6    | 6.4                | 2.1                   | 10.5  | 3.2           |
| 30         | 23.1    | 10.8               | 3.5                   | 17.7  | 5.4           |
| 40         | 32.7    | 15.3               | 4.9                   | 25.0  | 7.7           |
| 50         | 31.1    | 20.0               | 3.4                   | 25.6  | 5.6           |
| 60         | 37.5    | 24.1               | 4.1                   | 30.8  | 6.7           |
| 70         | 43.0    | 27.7               | 4.7                   | 35.3  | 7.7           |
| 80         | 48.2    | 31.0               | 5.3                   | 39.6  | 8.7           |
| 90         | 48.0    | 29.8               | 4.2                   | 36.8  | 11.2          |
| 100        | 51.4    | 31.9               | 4.4                   | 39.3  | 12.1          |
| 110        | 51.4    | 33.2               | 5.3                   | 41.5  | 9.9           |
| 120        | 53.0    | 34.3               | 5.5                   | 42.8  | 10.2          |
| 130        | 53.6    | 34.6               | 5.5                   | 43.3  | 10.3          |
| 140        | 54.1    | 35.0               | 5.6                   | 43.7  | 10.4          |
| 150        | 54.6    | 35.3               | 5.6                   | 44.1  | 10.6          |
| 160        | 54.9    | 35.5               | 5.7                   | 44.3  | 10.6          |
| 170        | 55.1    | 35.7               | 5.7                   | 44.5  | 10.6          |
| 180        | 54.6    | 35.3               | 5.6                   | 44.1  | 10.6          |

Analysis of the structure of deposited carbon by fractions of the aboveground phytomass shows that in the ripe and mature stages of the stand, the main share (65%) is the trunk wood in the bark, 10% and 6%, respectively, on the branches and needles. However, it should be borne in mind that the presented results are preliminary and may change as a result of the impact on the plantings of various external factors. The most negative impact on the process of phytomass accumulation and carbon deposition is exerted by fires and intensive wood harvesting.

4. Conclusion
As a result of the work, the carbon-releasing ability of fir stands of the third class of bonitet was assessed, which are modal for the research area and, accordingly, perform a significant share of environmental functions along with frequent involvement in forest exploitation. According to observations, the maximum amount of carbon is concentrated in the ripe and mature state of the stand. In the dynamics of passing through the age stages from the young growth stage, the accumulation of carbon stock is from 13.6 to 54.6 t / ha per year. When calculating the fractional carbon-removing ability of the fir phytomass, it was found that the percentage of each fraction accounts for the following amount of carbon: 65% to the trunks in the bark, 10% to the branches, 6% to the needles, 19% to the roots of the trees. Thus, the aerial part of the fir phytomass concentrates the largest reserves of bound carbon - 81%, and the underground part accounts for 19%. The results obtained are important in the organization and conduct of regional environmental monitoring of the state of the environment in the research area and nearby territories. When organizing forest management and involvement of the studied fir forests in operation, one should take into account their most important role in maintaining a favorable ecological balance of the territory.

References
[1] Klevtsov D N and Tyukavina O N 2018 Carbon-releasing ability of the above-ground phytomass of common pine crops (Pinus sylvestris l.) In the middle taiga forest region
Vestnik of KrasGAU Journal 6 221-4

[2] Isaev A S, Korovin G N, Utkin A I et al 1993 Estimation of reserves and annual carbon deposition in the phytomass of forest ecosystems of Russia Forest Science 5 3-10

[3] Zamolodchikov D G, Utkin A I and Korovin G N 1998 Determination of carbon reserves by age-dependent conversion coefficients Forestry 3 84-93

[4] Alekseev V A and Birdsey R A 1994 Carbon in the ecosystems of forests and swamps of Russia (Krasnoyarsk: Forest Institute named after V N Sukachev)

[5] Usoltsev V A et al 2012 Biological productivity of the forests of the Urals under conditions of technogenic pollution. The study of the system of relations and patterns (Yekaterinburg: Ural State Technical University)

[6] Zamolodchikov D G, Utkin A I and Korovin G N 2005 Conversion coefficients phytomass / stock in connection with dendrometric indicators and composition of stands Forestry 6 73-81

[7] Tretyakov N V 1956 Methods of studying the dynamics of stands of this type of forest (Leningrad: LTA)

[8] Kobak K I 1988 Biotic components of the carbon cycle (Leningrad: Gidrometeoizdat)

[9] Falaleev E N 1964 Siberian fir forests and their integrated use (Moscow: Forestry industry)

[10] Falaleev E N et al 1975 The growth progress of the main forest-forming species of Siberia (Krasnoyarsk: STI)