FORESTRY

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EVALUATION OF MAIN PARAMETERS FOR THE GROWTH MODEL OF PINE CROPS IN THE EUROPEAN NORTH OF RUSSIA

Research article

Abstract

This article presents the results of assessing the main growth parameters of Scots pine crops planting in the European North of Russia. Considering biological growth, three key phases of growth and development for Scots pine forest crops of the European North of Russia have been identified and described. Time limits of the phases of growth and development of pine crops were determined. Taking into account the dynamics of change in diameter helped in the analysis of Scots pine crops. On the basis of the analysis, systems of equations were obtained for each phase of growth and development of Scots pine crops, and the resulting graphs of functions made it possible to visually assess the change in parameters with age. It was established that the differentiation of crops according to the growth and development phases must be carried out in terms of height and diameter. The results obtained complement the existing database on the biological growth of Scots pine crops for the European North of Russia and can be used in the organization of forest monitoring and implementation of environmental programs at the regional level.

Keywords: forest crops, Scots pine, phases of growth and development, *s*–shaped character of growth, parameters of height and diameter, dependence on age.

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ОЦЕНКА ОСНОВНЫХ ПАРАМЕТРОВ МОДЕЛИ РОСТА ПОСАДКИ СОСНЫ НА ЕВРОПЕЙСКОМ СЕВЕРЕ РОССИИ

Научная статья

Аннотация

В статье представлены результаты оценки основных параметров роста посадки культур сосны обыкновенной на Европейском Севере России. С учетом биологического роста для лесных культур сосны обыкновенной Европейского Севера России получены и описаны три ключевых фазы роста и развития. Определены временные границы фаз роста и развития культур сосны. Учет динамики изменения диаметра оказывает помощь в анализе культур сосны. На основе проведенного анализа, получены системы уравнений для каждой фазы роста и развития культур сосны, а полученные графики функций позволяют наглядно оценить изменение параметров от возраста. Установлено, что дифференциацию культур по фазам роста и развития необходимо производить по высоте и диаметру. Полученные результаты дополняют существующую базу данных по биологическому росту культур сосны обыкновенной для Европейского Севера России и могут быть использованы при организации мониторинга лесов, реализации экологических программ на региональном уровне.

Ключевые слова: лесные культуры, сосна обыкновенная, фазы роста и развития, ход роста культуры, s–образный характер роста.

1. Introduction

The doctrine of the biological growth of living organisms has been conducted since the XIX century. In the most general form, the growth of living organisms is described by a sigmoid curve, in other words, an *S*–shaped curve [1], [2], [3], [4]. This graphical representation allows describing the dynamics of the measured indicators depending on time.

The *S*–shaped curve describes the stages of biological growth of various organisms, including trees [5]. As a rule, these are three stages: the stage of slow growth, the stage of rapid growth and the third stage – the final slow growth [6]. The *S*–shaped curve shows the general pattern of growth. Based on the general regularity, many models of sigmoidal growth are proposed, presented using a mathematical apparatus.

In the history of the development of mathematical modeling of plants, the first research dates back to the 30s of the XX century. And today there are still many attempts to create a theory of plant growth, which are based on various mathematical models describing the dynamics of growth [6], [7], [8], [9]. Thus, knowing the general patterns of growth of a stand, it is possible to study and describe the growth processes of specific plant species.

In forestry practice, a quantitative indicator called a bonus is used to assess the quality of natural objects that determine their economic value. In Russian taxation practice since 1911 [14] 5 bonitet classes has been used, which estimate the average height of the plantings as a basis. In different countries, there are different approaches to determining bonitet classes. So in the UK, the average annual increase in full normal plantings is used as basis of assessment. In the USA, Finland and Canada, based on the typology of Kayander, bonitet classes are determined by ground cover and differences in soils. As a rule, bonitet classes are compiled for each tree species and, taking into account its place of growth [15], researchers usually use uniform bonitet classes. However, it is necessary to take into account the conditions of the place of growth [16]. Thus, the dynamics of the biological growth of forest stands for various growing conditions should be studied in conjunction with indicators of stand productivity [17].

In this work, we proposed a different approach to the study of the biological growth of pine forests in the European North of Russia, based on the growth phases of the stand associated with the sigmoidal curve of biological growth of living organisms. The coupling of the biological growth of a stand with a sigmoidal curve is based on the application of mathematical regularities in the course of growth. Differentiation of productivity indicators of pine stands takes into account the type of forest and the conditions of crop growth.

Therefore, for further study of the stand, it is necessary to determine the appropriate stages of biological growth. The boundaries of the stages of biological growth depend on the location of the stand, the type of objects of research and methods of their creation. It should be noted that the stages of biological growth of stands created naturally have differences from the stages of growth of stands created artificially, since the creation of crops is accompanied by a set of measures necessary to optimize the growth of plantings [18].

In the literature, there are various approaches to the differentiation of artificially created stands by phases of growth and development [18]. Therefore, based on the *s*–shaped nature of the growth of forest stands by stages of their development, in this article an attempt was made to illustrate the methodology of differentiation of Scots pine crops by phases of growth and development based on the obtained parameters.

In this regard, the following objectives were set: to justify the applicability of one of the approaches to differentiation by growth and development phases of pine crops in the European North of Russia; to determine the time limits of the growth and development phases of pine crops in the European North of Russia.

2. Methods

The area of our scientific research is the northern taiga subzone of the Arkhangelsk region. The predominant crop for renewal is Scots pine, which occupies more than 30% of the area of the Arkhangelsk region [19]. The paper presents experimental taxation materials on the actual measurement of Scots pine crops in the Arkhangelsk region. The volume of initial data, taking into account the current growth of model trees created by the planting method, for the northern taiga subzone is 325 objects, for the middle subzone – 1354 objects, for the southern subzone – 1264 objects.

The study of the dynamics of stands was carried out on forest management trial areas laid by the taxators of the Arkhangelsk forestry enterprises using the static–dynamic research method of N.P. Kobranov (1930). The measurement of stands was taken with the help of the methods used in forest taxation according to the industry standard (Industry standard 56–69–83: Forest management trial areas. Methods of laying). Data collection and analysis on permanent test areas was carried out taking into account the phase of growth and development of forest crops [20].

3. Results and Discussion

The important parameters of the study of the course of growth and characterizing the dynamics of planting were the average diameter and height. The forecast of the growth of a stand is simplified if a number of observations are made at different age periods, while the stand is examined under the same conditions and the observation periods are carried out for 10–20 years. The collected data also allowed us to obtain information about the growth of the stand, for earlier ages and to make a forecast for the future.

3.1 Investigation of the growth and development phases of Scots pine crops in the context of its life cycle

For natural stands, the first fracture (Figure. 1) occurs at the age of 30–35 years, then intensive growth is observed. This is the second phase of growth, which occurs at the age of 100–105 years. The next phase of growth (the third phase) is the transition to the phase of slow growth. However, for crops there is a shift in time intervals due to the fact that for a stand created artificially, it is necessary to take into account the phase of survival of crops when changing the habitat, in the case of creating crops by planting. Thus, for crops created by the planting method, there is a shift of the first fracture for a period of 40–45 years, based on the subzone of the growth of Scots pine in the taiga of the European North of Russia. The second phase of growth of pine crops is usually 46–80 years, when intensive growth in height is observed. Then the stand goes into the third stage of growth. The same conclusions were obtained by V.I. Levin [19], who asserted that the increase in growth in the period from 46–80 years is intense and on average is 45% of the increase in the first phase. Further, there is a slowdown in height growth. However, it is worth noting that in this period there is a maximum increase in diameter, simultaneously with an increase in height, which has a lower growth rate. This period is also characterized by an increase in the stock of wood.

It was found that the growth of Scots pine crops growing in the taiga of the European North of Russia can be well described by the system of equations (3.1)

$$\begin{cases} y = ax^b \\ y = c \ln x - d \end{cases}, \tag{3.1}$$

where x is the age of the model tree, a, b, c, d are the growth constants of the model tree. The system of equations (3.1) is represented by an *s*–shaped curve that describes the growth of Scots pine crops growing in the taiga of the European North of Russia.

Based on the analysis of the initial data, taking into account the current growth of model trees for each taiga subzone, systems of equations (3.2–3.4) were found describing the *s*–shaped character of growth:

– for the northern taiga subzone

$$\begin{cases} y = 0{,}0518x^{1{,}3728} \\ y = 8{,}971 \ln x - 23{,}959 \end{cases}; \tag{3.2}$$

– for the middle taiga subzone

$$\begin{cases} y = 0{,}0605x^{1{,}441} \\ y = 12{,}283 \ln x - 32{,}72 \end{cases}; \tag{3.3}$$

– for the southern taiga subzone

$$\begin{cases} y = 0{,}0776x^{1{,}3589} \\ y = 11{,}84 \ln x - 31{,}96 \end{cases}. \tag{3.4}$$

Calculations of growth parameters in equations (3.2–3.4) were carried out for each growth period and correlated with the measured observation data. In the dynamics of time, the average heights of the predicted growth aligned with the average height of the model trees. The obtained average heights for the three subzones were graphically aligned and graphs of the *s*–shaped curve of the course of growth in height were obtained (Figure. 1).

The obtained equations are adequate and work in a wide age range from 0 to 150 years for each studied taiga subzone of the European North of Russia, which expands the possibilities for predicting the course of growth of Scots pine crops. Also, the results obtained are consistent with the initial data, taking into account the current growth of model trees.

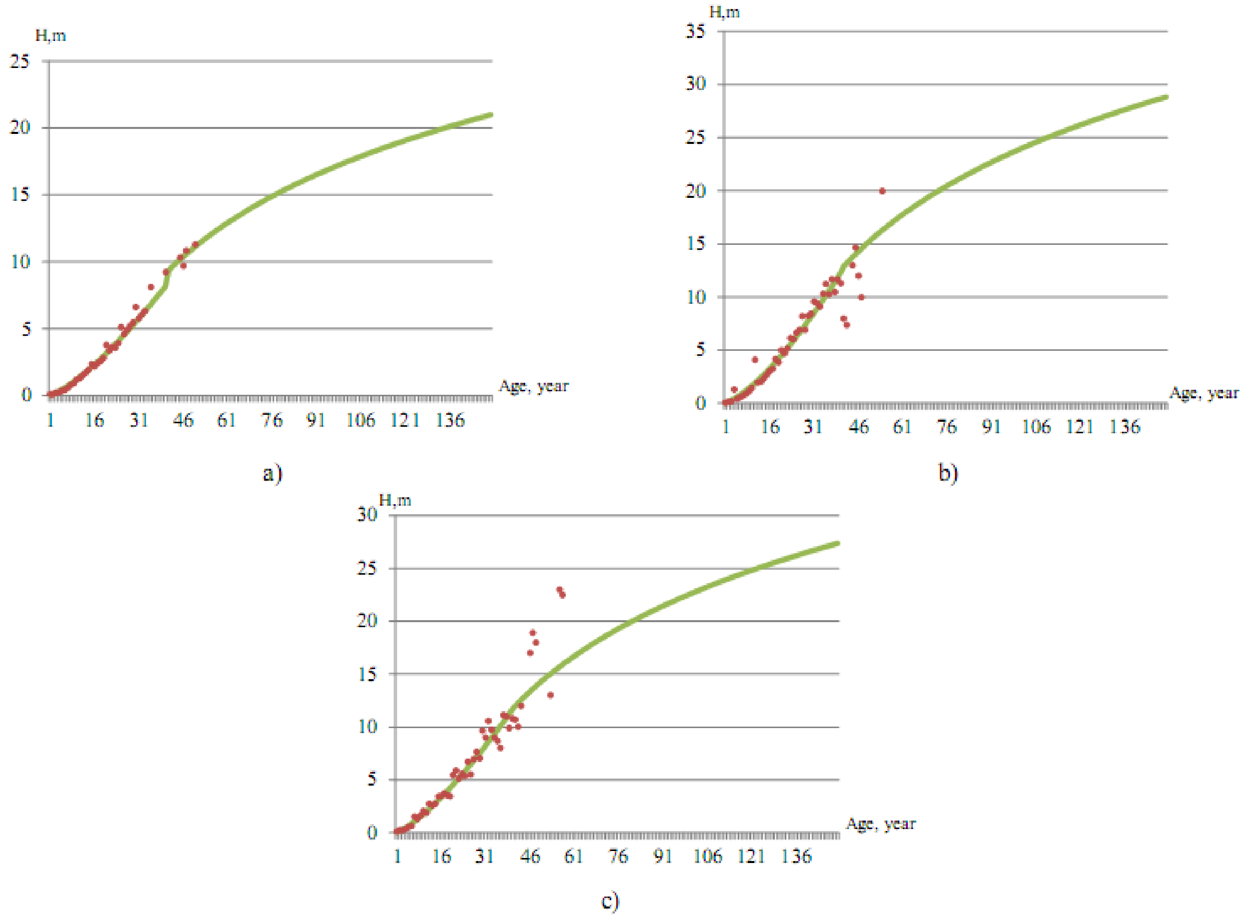

Fig. 1 – S–shaped growth of Scots pine crops growing in the taiga of the European North of Russia, created by planting: *a* – northern taiga subzone; *b* – middle taiga subzone; *c* – southern taiga subzone

The nature of the *s*–shaped curve for each subzone shows that in the northern subzone growing conditions are less favorable for the crop, since the course of growth is less rapid, in contrast to the middle and southern subzones (Figure. 2). This factor is explained by environmental factors affecting the course of crop growth.

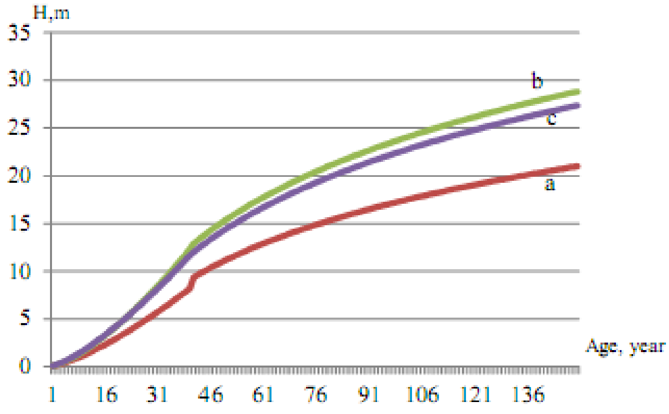

Fig. 2 – Comparative dynamics of the course of growth in height of Scots pine crops growing in the taiga of the European North of Russia, created by the planting method:
a – northern subzone; *b* – middle subzone; *c* – southern subzone

However, comparing the obtained *s*–shaped dynamics of the course of growth of crops in the middle and southern subzones, it can be seen that the growth in height in the middle subzone occurs faster in contrast to the southern subzone. This factor can be explained by the maximum increase in diameter with a simultaneous increase in height for the southern subzone. To explain this factor, the dynamics of growth and development of Scots pine crops in diameter for the middle and southern subzones of the taiga can be considered.

3.2 Investigation of the diameter growth in the context of the phases of growth and development of Scots pine crops

Data collection on the diameter was carried out at a height of 1.3 m. Based on the analysis of data on the course of growth in the height of the Scots pine, it was found that the crops reach a height of 1.3 m by 10–12 years. For the studied crops within the group of growing subzones, the experimental data were correlated with the results of regression analysis of the increase in diameter for the studied taiga subzones of the European North of Russia. As a result of regression analysis of the experimental data, it was found that the functional dependence of age dynamics on the diameter of model pine crops is represented by a system of equations of the form (3.5):

$$\begin{cases} y = a \ln x - b \\ y = c \ln x - d \end{cases}, \tag{3.5}$$

where x is the age of the model tree, a, b, c, d are the growth constants of the model tree. Table 1 shows the parameters of the mathematical model.

Based on the analysis of the initial data, taking into account the current growth of model trees in diameter, systems of equations (3.6–3.7) describing the nature of crop growth were found:

- for the middle taiga subzone

$$\begin{cases} y = 7{,}1679 \ln x - 15{,}576 \\ y = 23{,}673 \ln x - 76{,}409 \end{cases}; \tag{3.6}$$

- for the southern taiga subzone

$$\begin{cases} y = 8{,}5332 \ln x - 18{,}914 \\ y = 33{,}204 \ln x - 110{,}08 \end{cases}. \tag{3.7}$$

The results of the correlation of the initial data, taking into account the current growth of model trees, with the results of regression analysis of the selected groups of late growth in diameter are shown in Figure. 3.

Comparing the obtained results of the dynamics of the growth course in diameter for these taiga subzones (Figure. 4), the predominance of the growth rate in diameter in the southern taiga subzone in comparison with the growth rate in diameter in the middle taiga subzone is observed. This also explains the fact that in the southern subzone there is an increase in diameter with a simultaneous increase in height and a predominance of the growth rate in diameter in comparison with the growth rate in height.

Based on the results of modeling the process of growth of pine crops in diameter, it can be said that the dynamics of growth in diameter is also decomposable into phases of growth and development of crops. Due to the fact that the study of crop growth in diameter begins with the period when the culture can reach a height of 1.3 m, and for the study of the subzone this period begins with a 10–12-year period, the growth phases are defined as follows:

I phase of growth – 10–40 years characterizing intensive growth in height and the beginning of differentiation of the forest stand level growth;

II phase of growth – from 40–45 years to 80 years – the phase of the trunk formation, an increase in the trunk diameter is observed;

III phase of growth – from 80 years – the phase of intensive growth in diameter.

Thus, it should be concluded that complex characteristic of the growth process based on the growth dynamics in height and diameter provides a more accurate description of the changes in the taxation characteristics of model Scots pine crops.

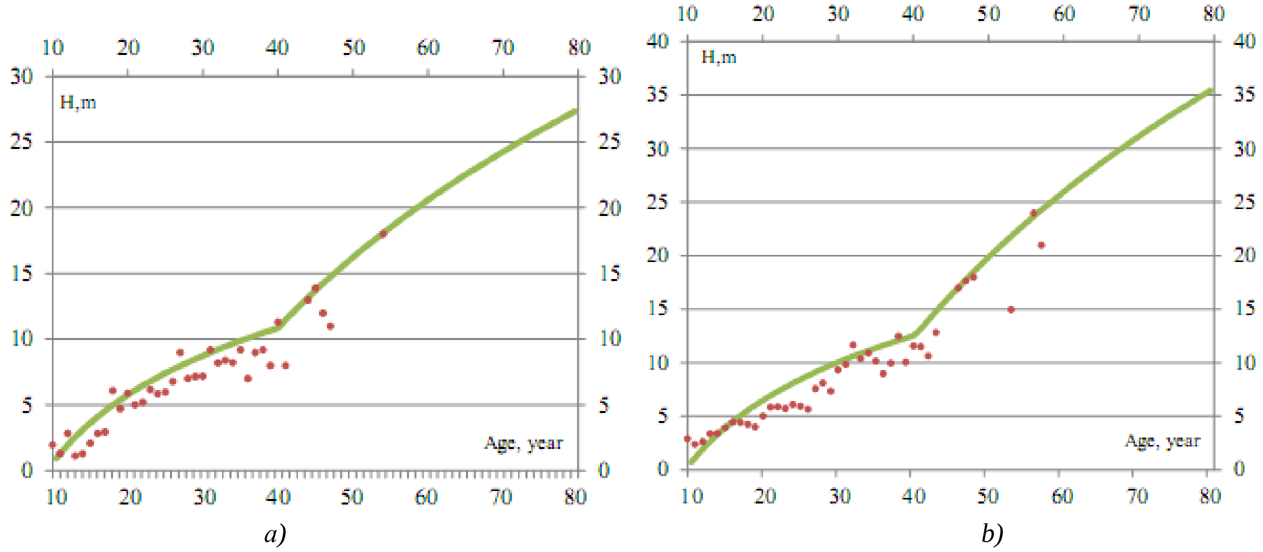

Fig. 3 – Growth of Scots pine crops in the taiga subzones of the European North of Russia in diameter:
a – middle subzone; *b* – southern subzone

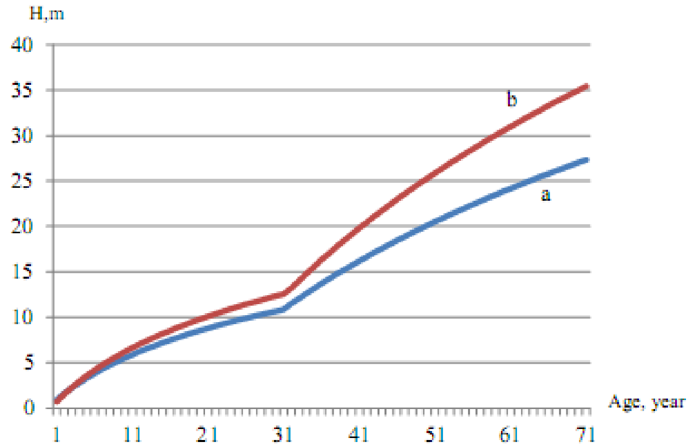

Fig. 4 – The course of growth of the average diameter of Scots pine crops in the middle and southern taiga subzones of the European North of Russia:
a – middle subzone; *b* – southern subzone

3.3 The main phases of growth and development of the life cycle of Scots pine crops

The boundaries of the phases of growth and development of artificial forests are dynamic and depend on various factors, and one of such factors is the conditions of the place of growth. Based on the above data, it can be stated that there is a shift in time intervals in the classifications of growth and development of crops by N.P. Korbanov [21], V.V. Ogievsky and A.A. Hirov [22] for a detailed study of a stand created artificially, it is necessary to dwell on the analysis of the growth phases of crops, based on the conditions of growth, since each zone of growth has its own phase dynamics of growth.

In this regard, we propose the following classification of the phases of growth and development of Scots pine crops for the taiga subzones of the European North of Russia:

I phase of growth – 0–40 years, the phase characterizing the survival of cultures and the phase of individual growth;

II phase of growth – from 40–45 to 80 years – the phase of formation of the stand and the transition to the phase of trunk formation, when there is a decrease in height and an increase in trunk diameter;

III phase of growth – from 80 years – the phase of ripening and ripeness, when there is an intensive increase in diameter, and the rate of growth of crops in diameter depends on the conditions of the place of growth.

The result of modeling the processes of growth and development of Scots pine crops is also a table of growth rates for the northern, middle and southern taiga subzones (Table 1)

Table 1 – Coefficients of the equation of Scots pine crops growth in height and diameter for taiga subzones of the European North of Russia

Taxational indicator	Coefficient of the equation				R^2	R^2
	a	b	c	d		
northern subzone						
H, m	0,0518	1,3728	8,971	23,959	0,9789	0,7806
D, cm	−	−	−	−	−	−
middle subzone						
H, m	0,0605	1,441	12,283	32,72	0,9579	0,6278
D, cm	7,1679	15,576	23,673	76,409	0,8459	0,9952
southern subzone						
H, m	0,0776	1,3589	11,84	31,96	0,9786	0,6873
D, cm	8,5332	18,914	33,204	110,08	0,7839	0,9097

Regression coefficients are statistically significant at a confidence level of 0.95. Taking into account the obtained determination coefficients (R^2), we can say that for the studied pine crops, the probability of variability of the average height depending on age according to the first power equation of the system is from 95% to 97%, according to the second logarithmic equation − from 62 to 78%. Also, the variability of the average diameter depending on age according to the first equation of the system is from 78% to 84%, according to the second equation of the system − from 90 to 99%. When analyzing the growth and development of a stand, the external and internal factors affecting the growth processes should be taken into account. The change in these factors is probabilistic. In this study, we use a one–factor regression analysis based on the dynamics of the growth processes of Scots pine crops, usually as a homogeneous population, depending on time. The advantage of this approach is that it allows us to present a general dynamic picture of the biological growth of Scots pine crops depending on time. In case of accumulation of additional experimental material, it is possible to update the models by changing the coefficients of the obtained growth models in height and diameter.

4. Conclusion

As a result of our research, the need to differentiate crops by growth and development phases was confirmed based on such basic parameters as height and diameter. Using the example of Scots pine crops growing in the taiga subzones of the European North of Russia, it was found that the *s*–shaped growth pattern showed adequate differentiation into three key phases of growth and development. The time limits of the phases of growth and development of Scots pine crops for the taiga subzones of the European North of Russia have also been determined.

The obtained systems of equations are adequate and work in a wide age range from 0 to 150 years for height and from 10 to 80 years for diameter, which makes it possible to predict the dynamics of growth in height and diameter of Scots pine crops for the taiga subzones of the European North of Russia.

Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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