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Теоретический и научно-практический журнал

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ИСПОЛЬЗОВАНИЕ ХВОЙНЫХ РАСТЕНИЙ В ТИПОВЫХ ЛАНДШАФТНЫХ ПРОЕКТАХ[1]

Т. Ю. Аксянова, О. М. Ступакова, Е. А. Усова, М. В. Филина, А. А. Горошко

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В работе приведены тезисы об актуальности разработки типовых ландшафтных проектов с участием хвойных растений для использования в благоустройстве различных категорий объектов урбанизированного ландшафта на примере Красноярска. Актуальность обусловлена одной из важнейших задач ландшафтного проектирования – создание гармоничной среды и снижение влияния ряда факторов, негативно воздействующих на состояние здоровья человека. Показаны факторы, с учетом которых подбирается каждый элемент при создании типового ландшафтного проекта. К ним относятся масштабность, цветовые решения, соотношение форм и фактур ландшафтных и архитектурных элементов композиции.

Предлагается проектировать типовые ландшафтные композиции с участием хвойных растений, как четко продуманные схемы – модули, которые можно брать за основу и строго следовать им при проектировании озеленения. Используя типовые ландшафтные проекты как основу, на каждом объекте можно добавлять индивидуальности путем внесения дополнительных смысловых декоративных элементов, используя разные сочетания растений и материалы оформления.

В статье приводится информация о том, что все озелененные территории, входящие в планировочную структуру города, классифицируются по категориям и типам. Показана необходимость учитывать требования по благоустройству различных категорий объектов городского ландшафта. При формировании ландшафта приоритетным является экологический принцип подбора растений. Также необходимо учитывать природно-климатические условия региона, конкретного места посадок. Кроме того, необходимо брать во внимание экологические показатели территории, особенно в урбанизированном ландшафте.

Приводятся краткие данные об особенностях климата и экологических условиях Красноярска, следствием чего является необходимость использования хвойных растений в озеленении сибирских городов. Перечисляются проблемы и пути решения, связанные с участием хвойных растений в городском благоустройстве. В статье приводятся иллюстрации примеров типовых ландшафтных композиций с участием хвойных растений.

Ключевые слова: *хвойные растения, типовой ландшафтный проект, ландшафтные композиции, озеленение, благоустройство, антропогенный ландшафт, урбанизированная среда.*

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USE OF CONIFEROUS PLANTS IN TYPICAL LANDSCAPE PROJECTS

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The paper contains theses on the relevance of developing typical landscape projects with the participation of coniferous plants for use in the improvement of various categories of urbanized landscape objects using the example of Krasnoyarsk. Relevance is due to one of the most important tasks of landscape design – creating a harmonious

[1] Работа поддержана Красноярским краевым фондом науки в рамках реализации проекта «Разработка типовых проектов благоустройства территорий общего пользования с учетом экологического потенциала, устойчивости и восприимчивости экосистем районов г. Красноярска к возможным антропогенным и техногенным нагрузкам».

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environment and reducing the influence of a number of factors that negatively affect the state of human health. The factors from which each element is selected when creating a typical landscape project are shown. These include scale, color solutions, the ratio of forms and textures of landscape and architectural elements of the composition.

It is proposed to design typical landscape compositions with the participation of coniferous plants as well-thought-out schemes – modules that can be taken as a basis and strictly follow them when designing landscaping. Using typical landscape projects as a basis, you can add personalities to each new object by adding additional semantic decorative elements using different combinations of plants and design materials.

The article provides information that all landscaped territories included in the planning structure of the city are classified into categories and types. The need to consider the requirements for the improvement of various categories of objects of the urban landscape is shown. When forming the landscape, the ecological principle of plant selection is a priority. It is also necessary to consider the natural and climatic conditions of the region, the specific place of planting. In addition, environmental indicators of the Territory should be considered, especially in the urbanized landscape.

Brief data are given on the features of the climate and environmental conditions of Krasnoyarsk, as a result of which it is necessary to use coniferous plants in landscaping Siberian cities. Listed are the problems and solutions associated with the participation of coniferous plants in urban landscaping. The article provides illustrations of examples of typical landscape compositions involving coniferous plants.

Keywords: *coniferous plants, typical landscape project, landscape compositions, landscaping, improvement, anthropogenic landscape, urbanized environment.*

INTRODUCTION

According to government reports "On the state and protection of the environment in the Krasnoyarsk Territory" [1] the air pollution index of Krasnoyarsk for many years has been characterized as "high" and "very high", which is due to stationary (enterprises), mobile (transport) sources of pollution, as well as individual heat supply sources for residential buildings in conjunction with the climatic and orographic features of the city's location. The national project "Housing and the Urban Environment" [5] is designed to solve the problem of improving the quality of the urban environment, which, naturally, is impossible without optimizing the tools for landscaping.

Comfortable human life-sustaining activity depends on the surrounding landscape, which is recommended to be preserved as much as possible, but if necessary, make changes taking into account the data of the pre-design analysis of the object.

A person experiences a feeling of discomfort due to the violation of a certain balance between natural and anthropogenic components of the landscape, this is especially true in an urban environment. The tasks of landscape design include creating a harmonious environment and reducing the influence of a number of factors that negatively affect human health.

When implementing a landscape project, compositional solutions uniting the space in a single style are developed, where they can repeat color schemes, plant types, forms and textures of architectural and planning elements, etc. in order to achieve harmony. The use of such landscape design techniques is necessary when creating standard compositional solutions that will serve as the basis for the reconstruction of existing landscape architecture objects and the design of new objects.

THE MAIN PART

Typical landscape projects are ready-made, clearly thought-out schemes – modules of landscape compositions that can be taken as a basis and strictly followed when performing landscaping.

When developing them, all the basic principles of landscape design of urban environment objects were considered and each element was selected taking into account:

– shape relationships; relationships between linear, volumetric and planar structures (paths, lawns, groups of plants);

– scale; proportional ratio of composition elements in size and volume;

– color solutions; stable decorative effect at different times of the year;

– combinations of textures;

– construction geometry.

To design standard projects involving coniferous plants, Adobe Photoshop CS5 and Procreate software were used.

All landscaped areas included in the city planning structure are classified into categories and types.

According to their functional purpose, intra-city landscaped areas are divided into the following categories:

– limited use and purpose – territories of residential complexes, districts and microdistricts, children's institutions, schools, universities, technical colleges, cultural and educational institutions, sports facilities, health care institutions, areas on the territories of industrial enterprises;

– special use and purpose – landscaped green areas associated with the protection of residential areas from adverse environmental impacts, protective zones between industrial facilities and residential areas, sections of highways and streets; cemetery areas; nurseries;

– public areas (parks, squares, boulevards) [6].

During field surveys and using Sentinel-2 satellite images in the city of Krasnoyarsk, the following categories of public spaces were identified: park, square, boulevard, forest park. The ratio of public spaces in the city of Krasnoyarsk is given in table. 1.

The total area of public spaces of all categories is 27.92 km2, which is 7.39 % of the city's area. The largest area of the city is occupied by parks (6.96 %), other categories of public spaces are represented by significantly smaller areas, a total of 162.5 hectares or 0.43 % of the city's area. The distribution of public spaces across the city's administrative districts is uneven (Fig. 1).

The category of forest parks is present only in the Central district (Yaryginsky drive 2/1). The largest area of parks is in the Oktyabrsky and Sovetsky districts (1751 and 699 hectares, respectively).

The area of public gardens is distributed more evenly across administrative districts; this category of public spaces predominates in the Sovetsky, Tsentralny and Sverdlovsky districts (37, 28 and 20 hectares, respectively). Boulevards occupy the largest area in the Central district – 21 hectares (Fig. 2).

Landscaping is a complex process that is associated with the direct planting of trees, shrubs, flowers, creation of lawns, as well as carrying out work on various types of engineering preparation and landscaping of green areas.

Table 1
Area ratio of public spaces Krasnoyarsk city

Categories of public spaces	Area, hectares	Area, %
park	2 629,4	6,96
square	129,4	0,34
boulevard	29,6	0,08
forest park	3,5	0,01

Vegetation forms a component of the environment that relieves stress from artificial anthropogenic space. Definitely, the decorative abilities of living nature play a significant role, which serve as the basis for creating the most attractive compositions.

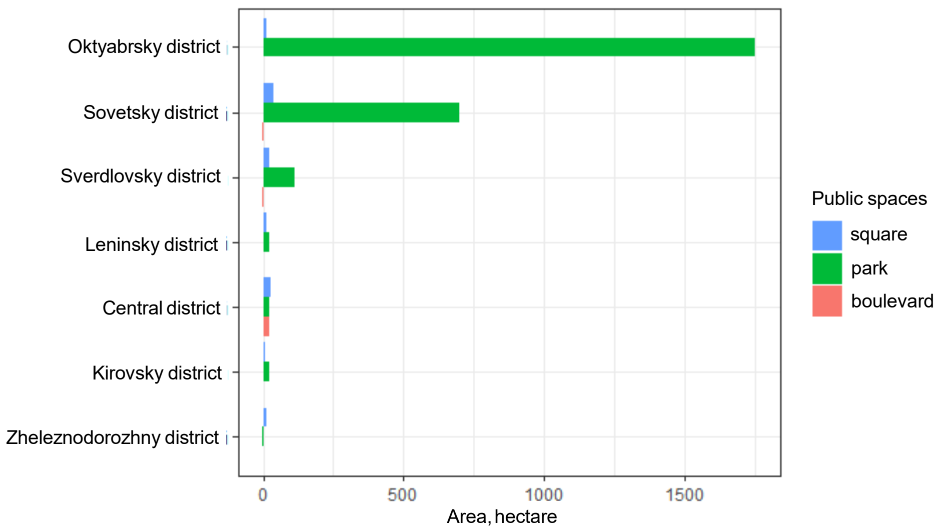

Fig. 1. Chart of distribution of categories of public spaces by administrative districts

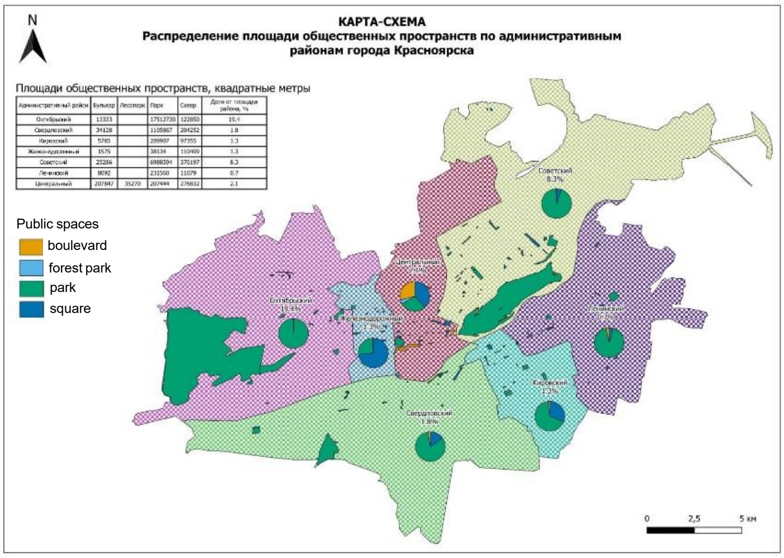

Fig. 2. Distribution of the area of public spaces by administrative districts city of Krasnoyarsk

When creating a landscape, the priority is the ecological principle of plant selection. It is also necessary to take into account the natural and climatic conditions of the region and the specific planting site. In addition, the environmental indicators of the territory are taken into account, especially in an urban landscape.

Three documents were taken as a basis for the analysis of the environmental situation in Krasnoyarsk. They were state report “On the state and protection of the environment in the Krasnoyarsk Territory in 2020” [2]; state report “On the state of sanitary and epidemiological logical well-being of the population in the Russian Federation in 2020” [3]; analytical review of the state of air pollution for 2020 [4].

In 2020 the level of pollution in Krasnoyarsk was characterized as “high”. The main contribution to the level of pollution was made by suspended substances, nitrogen dioxide, ammonia, formaldehyde and benzopyrene [2]. Frequent cases of exceeding the one-time maximum permissable concentration of the following pollutants in the city's atmosphere in 2020 were recorded. Among them were suspended substances; sulfur dioxide; carbon monoxide; nitrogen dioxide and oxide; phenol; hydrogen chloride; ammonia; formaldehyde; xylene; ethylbenzene. Compared to 2019 the level of air pollution in the city as a whole did not change and remained “high” [2]. An unacceptable carcinogenic risk has been recorded in the city [3]. Table 2 was compiled based on the materials of the analytical review of the state of atmospheric air pollution for 2020 [4]. 8 automated stationary sites (ASS) were selected from the report for the quality of atmospheric air in Krasnoyarsk and in adjacent areas (ASS “Krasnoyarsk-Berezovka”). ASS coordinates were obtained from the website of the Ministry of Ecology and Rational Natural Resources Management of the Krasnoyarsk Territory [4]. The table shows the frequency of average daily concentrations above 1 maximum permissable concentration (MPC) for 5 main pollutants: carbon monoxide, sulfur dioxide, nitrogen oxide, nitrogen dioxide, suspended particles (up to 2.5 microns). This indicator allows us to judge the percentage the ratio of days exceeding the daily average higher concentration of pollutant 1 MPC.

Analysis of the resulting table allows us to judge about the heterogeneity of the frequency of atmospheric air pollution in different areas of the city. At the Krasnoyarsk-Berezovka and Krasnoyarsk-Solnechny ASS, the frequency of pollution with nitrogen dioxide predominates (79.5 and 38.4 %, respectively), at the Krasnoyarsk-Pokrovka ASS – with sulfur dioxide (18.1 %), at the Krasnoyarsk-Vetluzhanka ASS – with suspended particles up to 2.5 μm (10.5 %). The frequency of atmospheric air pollution in 2020 above 10% for at least one pollutant was observed at all automated observation points. A map of Krasnoyarsk showing the concentrations of pollutants is shown in Fig. 3.

Table 2
Repeatability of average daily concentrations above 1 MPC

ASS title	PM 2.5	CO	SO_2	NO	NO_2
Krasnoyarsk–Sverdlovsky	10,7	0,3	6,0	0,5	15,1
Krasnoyarsk–Kirovsky	10,6	0,0	4,1	11,0	15,3
Krasnoyarsk–Cheryomushki	11,0	0,0	5,7	4,3	17,1
Krasnoyarsk–Berezovka	11,3	0,0	10,8	8,3	79,5
Krasnoyarsk–Vetluzhanka	10,5	0,0	0,0	0,0	0,0
Krasnoyarsk–Pokrovka	10,1	0,3	18,1	1,7	7,4
Krasnoyarsk–Severny	11,5	0,3	9,5	4,4	20,2
Krasnoyarsk–Solnechny	5,0	0,0	10,4	0,0	38,4

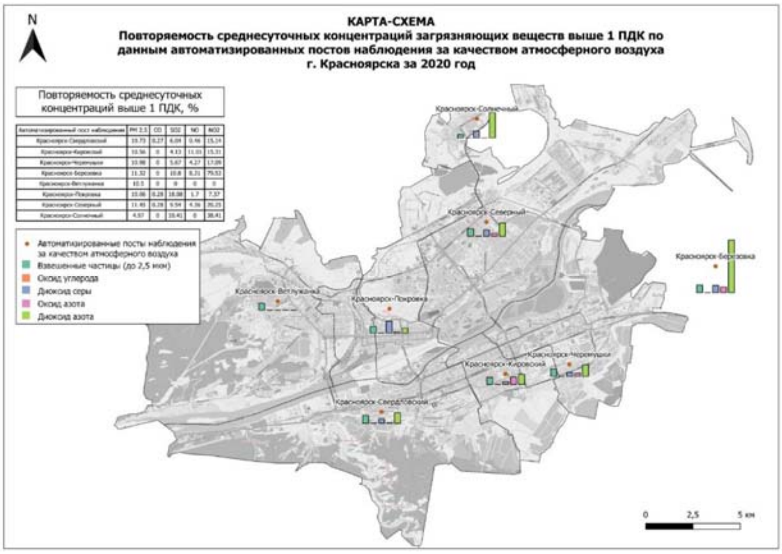

Fig. 3. Repeatability of average daily concentrations of pollutants above 1 MPC

Long winters, late beginnings of the growing season and early defoliation of arboreal trees are among the many reasons why the use of coniferous plants in landscaping Siberian cities is necessary. The participation of coniferous trees and shrubs enhances not only the architectural and artistic function of green spaces, but also improves air quality, which is an important indicator of a comfortable urban environment. However, it is necessary to take into account the frost resistance and winter hardiness of plants; they must be adapted to the natural and climatic conditions of the region and the specific planting site.

Coniferous plant species have different ecological characteristics. *Pinus sylvestris* and *Pinus mugo* are light-loving plants, while *Picea obovata* and *Abies sibirica* are shade-tolerant, preferring moist, shaded places. *Picea pungens* can grow well in an open, sunny location with insufficient soil fertility. *Juniperus horisontalis* and *Juniperus sabina*, *Microbiota decussata* can grow in both full sun and partial shade.

At the same time, when planting coniferous plants, it should be taken into account that many of them have a superficial, extensive root system, which, when growing, can damage the paving of areas and sidewalks and destroy the foundations of buildings. The litter of coniferous plants acidifies the soil, which adversely affects the condition of neighboring plants, so it is better to plant coniferous trees with those who prefer acidic soil (hydrangeas, rhododendrons). Coniferous plants, especially in the first 3–5 years after planting, need additional watering and mulching. For some species (spruce, larch) it is recommended to provide structural pruning to maintain harmony in adulthood.

Since the needles remain on the shoots of coniferous plants (except larch) for several years, In urban plantings, soot, dust and dirt accumulate on the needles. Therefore, it is necessary to provide such type of care as regular (twice during the growing season) washing of the crown of coniferous plants.

Evergreen woody plants that retain their needles for many years have different crown shapes and different shades of needle color. The green cone of fir or spruce and the spreading crown of Scots pine create vertical compositional constants, which is especially important in winter.

Many coniferous species change the nature of their crown shape with age; for example, the ovoid crown of a young Scots pine can become spreading and umbrella-shaped over the years. However, this depends on the type of planting, soil conditions, lighting and other factors. In any case, there is dynamics in plant compositions, which contributes to the diversity of landscape paintings.

Coniferous plant species can be used in various types of landscape gardening (hereinafter referred to as TLG). These are row plantings, alleys, hedges, groups, ordinaries (single plantings). As a result of the analysis of the participation of species in various types of landscape gardenings (TLG), different occurrences of species of the pine family were noted (Table 3).

During field surveys, a census of woody vegetation was carried out and the category of condition was determined (Table 4).

In quantitative terms, the leading species on public landscaping sites in Krasnoyarsk is Siberian larch.

It was noted that Colorado spruce is in good condition, since specimens in unsatisfactory condition were not identified.

Scots pine has the worst adaptation to urban environmental conditions. The remaining species have a distribution of the number of specimens between the first and second categories of condition; we can conclude that they have good adaptive ability in an urban environment.

Table 3
Family and species composition of various TLGs in Krasnoyarsk

Species	Total	TLG		
		solitaire	group planting	row planting
Colorado spruce	7	2	5	0
Colorado spruce (blue form)	78	2	0	76
Norway spruce	18	1	17	0
Siberian spruce	148	38	56	47
Siberian larch	357	13	188	156
Scots pine	115	7	67	41

Table 4
Enumeration of arboreal vegetation by model areas indicating the category of condition

Species	Condition category, score*	Share of the total quantity corresponding to the condition category, pcs./%
Colorado spruce	2	7/100
Colorado spruce (blue form)	1	1/1
	2	77/99
Norway spruce	1	6/33
	2	10/56
	3	2/11
Siberian spruce	1	64/43
	2	62/42
	3	22/15
Siberian larch	1	69/19
	2	265/74
	3	23/7
Scots pine	1	23/20
	2	53/46
	3	39/34

* According to [1].

The main factors for the unsatisfactory condition of the plantings are:

– lack of systematic care for both young plantings and older plantings;

– lack of an ecological approach to design, which leads to the depressed state of plants and degradation of plantings;

– lack of tiering of phytocenoses, which leads to low resistance of the plant community to a complex of unfavorable factors of the urban environment.

These problems arise in practice due to the large volume of work on the design of landscape architecture objects (this applies to both newly created objects and reconstructed ones) in an extremely short time. The creation of standard projects for landscaping and landscaping modules will allow you to achieve the stated goals with a minimum of time.

Typical landscape compositions with coniferous plants can be used in urban landscape areas of any category. However, each project requires an individual approach and model standard design solutions should be adapted taking into account the specific situation, the environmental characteristics of both the territory and the plants themselves. Fig. 4–6 show examples of typical landscape compositions of various TLGs with the participation of conifers.

Companions of coniferous plants can be not only other conifers, but also deciduous trees and shrubs, and herbaceous plants. In mixed compositions, evergreen elements can play the role of background plants for trees and shrubs that bloom in spring and summer. In mixed compositions, it is recommended to select plants with similar requirements for soil, moisture and light. If necessary, individual environmental conditions can be created in accordance with the requirements of certain types of accompanying plants. For example, roses go well with conifers, but for better flowering they will require additional feeding and care.

Groups containing coniferous plants can be designed based on the contrast of color and crown shape. The pyramidal and cone-shaped crown shapes of many spruce and fir trees combine perfectly with the round or spreading crown shapes of some types of spirea (Japanese spirea, dense-flowered spirea, gray spirea, etc.). It is recommended to complement the fine branching texture of many types of coniferous plants with more textured types of deciduous trees, shrubs (pear, apple, linden, hydrangeas, etc.) and perennial herbaceous plants (bergenia, hostas, peonies, etc.).

a *b*

Fig. 4. Ordinary plantings of different species:
a – typical row planting; *b* – alley

a *b*

Fig. 5. Landscape groups:
a – all-round visibility; *b* – one-sided view

Fig. 6. Regular peer review group

It is recommended to design a typical planting scheme depending on the chosen style direction and the purpose of the object. For example, symmetrical compositions are more suitable for areas near administrative buildings with strict forms, asymmetry is closer to objects with natural, natural lines.

Depending on the functional purpose of the object, typical landscape compositions with coniferous plants can be supplemented with sculpture, small architectural forms (SAF), fills, and water features. To enhance the architectural and artistic function of the created compositions with the participation of coniferous plants, it is recommended to place artificial lighting elements.

CONCLUSION

Ready-made versions of landscape compositions open up a wide field for experimentation. Using them as a basis, you can add individuality to each landscape architecture project by introducing additional decorative elements, using different combinations of plants and design materials. However, it is necessary to take into account the requirements for the improvement of various categories of urban landscape objects.

The use of standard landscape projects – modules will allow you to more accurately calculate the budget and control it when implementing the proposed project, since it is no longer necessary to develop a complete project for each new object; it is proposed to use a standard, pre-developed solution, only slightly changing it to the conditions of each specific object.

The development of standard landscape projects with the participation of coniferous plants contributes to the uniqueness and recognition of our city through the creation of a landscape brand of Krasnoyarsk.

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ВЛИЯНИЕ СУБСТРАТА НА РОСТ И РАЗВИТИЕ СЕЯНЦЕВ СОСНЫ КЕДРОВОЙ СИБИРСКОЙ С ЗАКРЫТОЙ КОРНЕВОЙ СИСТЕМОЙ

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Приведены сравнительные данные развития и роста, формирования фитомассы сеянцев сосны кедровой сибирской с закрытой корневой системой в течение первого года выращивания в оранжерее Сибирского государственного университета науки и технологий имени академика М. Ф. Решетнева. Для выращивания сеянцев использовались субстраты разного состава, основой которых служил нейтральный торф (pH = 7) или кокосовый субстрат. В субстраты добавляли вермикулит и/или перлит в концентрациях 5 и 12 %. Семена сосны кедровой сибирской были собраны в Емельяновском лесничестве Красноярского края, подвергнуты траншейной стратификации. Посев произведен в июне 2021 г.

В течение первого вегетационного сезона были изучены длина семядолей, первичной хвои всходов, сформированных верхушечных почек сеянцев, высота и диаметр стволика у шейки корня и фитомаса сеянцев.

В результате проведенных исследований установлено, что на линейные размеры и фитомассу надземной и подземной частей растений оказывает влияние состав субстрата. Большие размеры стебля отмечаются на субстратах из чистого нейтрального торфа, смесей торфа с перлитом 5 % и вермикулитом 5 % и кокосовом субстрате с вермикулитом 12 %. Отставание линейных размеров выявлено у сеянцев, выращиваемых на чистом кокосовом субстрате и торфяной смеси с добавлением 12 % перлита. Сеянцы, растущие на торфяных субстратах, формируют к концу первого вегетационного сезона корневую систему меньших размеров и массы, чем на субстратах, основным компонентом которых является кокос.

Ключевые слова: *сосна кедровая сибирская, всходы, семядоли, первичная хвоя, сеянцы, корневая система, фитомасса, субстрат.*

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THE EFFECT OF THE SUBSTRATE ON THE GROWTH AND DEVELOPMENT OF SEEDLINGS OF SIBERIAN CEDAR PINE WITH A CLOSED ROOT SYSTEM

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The article presents the comparative data of development and growth, formation of phytomass of seedlings of Siberian cedar pine with a closed root system during the first year of cultivation in the greenhouse of Reshetnev Siberian State University of Science and Technology. Substrates of different composition, the basis of which was neutral peat (pH = 7) or coconut substrate, were used for the cultivation of seedlings. Vermiculite and/or perlite were added to the substrates in concentrations of 5 and 12 %. Seeds of Siberian cedar pine were collected in the Yemelyanovsky forestry of the Krasnoyarsk Krai, subjected to trench stratification. Sowing was carried out in June 2021.

During the first growing season, the length of cotyledons, the primary needles of seedlings, the formed apical buds of seedlings, as well as the height and diameter of the stem at the neck of the root of seedlings and their phytomass, were studied.

As a result of the conducted research, it was found that the composition of the substrate influences the linear dimensions and phytomass of the aboveground and underground parts of plants. Large stem sizes are noted on substrates of pure neutral peat, peat mixtures with 5 % perlite and 5 % vermiculite, and coconut substrate with 12% vermiculite. The lag of linear dimensions was revealed in seedlings grown on a pure coconut substrate and peat mixture with the addition of 12 % perlite. Seedlings growing on peat substrates form by the end of the first growing season a root system of smaller size and weight than on substrates, the main component of which is coconut.

Keywords: *Siberian cedar pine, seedlings, cotyledons, primary needles, seedlings, root system, phytomass, substrate.*

INTRODUCTION

Currently, using the planting material with a closed root system is one of the promising areas of reforestation.

This type of planting material started to be used in Russia in the middle of the 20th century, but its use was limited by various limiting factors. Nowadays, technology to grow the planting material with a closed root system are improved; a large number of research has been conducted to select the optimal composition of the substrate, sizes and materials of cassettes, and others [12].

Despite modern successful experience, in different regions of the Russian Federation there are contradictory opinions on the advantages and disadvantages of the technology for growing planting material with CRS. The high efficiency of the applied technology to grow the planting material, both with open and closed root systems, has been established in different experimental variants under the conditions of Altai, Voronezh, Omsk, Leningrad regions, Mari El, Krasnoyarsk Territory [1; 3; 6; 7; 8; 9]. No so many research papers are devoted to growing Siberian pine seedlings with a closed root system [2; 13].

V. P. Besschetnov et al. [3] noted that standard seedlings of Scots pine, grown in open ground for two years using traditional technology, are more developed and more prepared for transplantation to a permanent place in artificial plantings. They are characterized by a more developed aerial part and its balanced development relative to the root system. Seedlings with an open root system, grown in the soil of greenhouses for one year, noticeably lag behind standard planting material in their development, although they are close to it due to morphometric parameters. One-year seedlings with a closed root system were the least developed. This circumstance may be due to the limited volume of the root sphere they occupy and an imbalance in the development of the above-ground part and root system.

Many factors affect the success of growing planting material with a closed root system, one of the factors is the composition and quality of the substrate. Peat is most often used as a substrate. High-moor peat is noted more preferable compared to lowland. Lately, the number of experiments on the selection of mixtures has increased, which in the future may be a full-fledged replacement. In recent years, in many countries, there has been an increase in the number of studies on the selection of substrates that are a complete replacement for peat, which is used in most mixtures to grow seedlings with a closed root system. One of the popular substrates to replace peat mixtures is coconut fiber. The main characteristics of a coconut substrate are considered to be the optimal ratio of moisture and air in its volume and cation exchange capacity (buffering capacity) [14].

A positive effect of mycorrhization of seedling root systems is noted on the survival rate and safety of forest crops. With mycorhization, an increase in plant growth is observed already in the second or third year after planting. The more unfavorable the edaphic conditions, the more strongly mycorhization can affect the sustainability of forest crops [4].

A. V. Zhigunov considered growth energy, being a derived parameter from the height and diameter of the seedling stem, to be the optimal indicator characterizing the growth of seedlings with a closed root system [5].

OBJECTS AND RESEARCH METHODS

The object of research is Siberian pine seedlings grown in the greenhouse of Reshetnev University on substrates of different compositions. Mixtures were used as substrates, based on coconut and peat to be the main components. Substrate variants: 1 – coconut substrate without additives, 2 – coconut substrate with 12 % perlite, 3 – coconut substrate with 12 % vermiculite, 4 – coconut substrate with peat in a 50/50 ratio, 5 – coconut substrate with 5 % perlite and vermiculite 5 %, 6 – neutral peat (pH = 7) without additives, 7 – peat with 12 % perlite, 8 – peat with 12 % vermiculite, 9 – peat with 5 % perlite and 5 % vermiculite.

Seeds of Siberian cedar pine were collected in the Emelyanovsky forestry of the Krasnoyarsk krai and subjected to trench stratification. Sowing was in June 2021.

During the 2021 growing season, we studied the length of cotyledons, primary needles of seedlings, formed apical buds of seedlings, as well as the height and diameter of the stem at the root collar of seedlings. At the end of the growing season, model seedlings were selected in each variant to determine their phytomass.

RESULTS AND DISCUSSION

The average stem length of Siberian cedar pine seedlings at the end of the first growing season, depending on the experimental variant, varied from 2.4±0.15 to 3.8±0.20 cm. The average length of cotyledons ranged from 3.1±0.12 cm to 3.7±0.14 cm. The length of the primary needles ranged from 9.7±0.52 mm to 13.6±0.93 mm.

Tables 1 and 2 demonstrate the growth and development indicators of seedlings depending on the predominant component of the mixture. Thus, the length of the stem of seedlings grown on substrates based on coconut mixture averaged from 2.4 ± 0.15 cm to 3.4 ± 0.16 cm by the end of the growing season. The longest stem length characterized seedlings growing on substrates with an admixture of vermiculite (variants 3 and 5). Plants grown on a clean coconut substrate were characterized by smaller length and diameter of the stem at the root collar (variant 1). The reliability of the differences is confirmed by mathematical processing (Table 1).

Based on the totality of the studied indicators, we can conclude that the growth and development of seedlings of the third variant using a coconut mixture in combination with 12 % vermiculite as a substrate is better. First-year seedlings grown on coconut substrate without additives lag behind in terms of growth and development.

Seedlings grown on substrates where peat was used as the main component had an average stem length from 2.5±0.25 to 3.8±0.20 cm. The diameter of the stem at the root collar varied from 1.3±0.06 to 1.9±0.06 mm (Table 2).

Table 1
Indicators of seedlings growing on coconut mixture substrates

Variant	X_{av}	±σ	±*m*	*P*, %	*V*, %	$t_ф$ if t_{05} = 2,04
Stem length, cm						
1	2,4	0,59	0,15	6,1	24,3	4,44
2	2,9	0,76	0,17	5,9	26,6	2,43
3	3,4	0,71	0,16	4,7	20,9	–
4	2,9	0,82	0,22	7,6	28,4	1,85
5	3,3	0,74	0,14	4,4	22,4	0,51
Stem diameter at root neck, mm						
1	1,4	0,25	0,06	4,4	17,5	7,17
2	1,5	0,21	0,05	3,3	14,6	7,90
3	1,9	0,16	0,04	1,9	8,4	–
4	1,9	0,33	0,09	4,6	17,1	0,29
5	1,7	0,2	0,04	2,3	11,9	5,44
Cotyledon length, cm						
1	3,3	0,43	0,11	3,2	12,8	2,00
2	3,4	0,45	0,10	2,9	13,0	1,39
3	3,7	0,61	0,14	3,7	16,6	–
4	3,5	0,85	0,23	6,4	24,1	0,50
5	3,7	0,71	0,14	3,8	19,3	0,00
Length of primary needles, mm						
1	9,7	2,09	0,52	5,4	21,5	2,82
2	12,2	2,71	0,61	5,0	22,3	0,67
3	13,0	4,56	1,02	7,9	35,2	–
4	12,2	2,15	0,58	4,7	17,6	0,63
5	10,8	2,61	0,51	4,7	24,1	1,88

Table 2
Indicators of seedlings growing on peat-based substrates

Variant	X_{av}	±σ	±*m*	*P*, %	*V*, %	$t_ф$ if t_{05} = 2,04
Stem length, cm						
6	3,8	0,89	0,20	5,4	23,7	–
7	2,5	0,88	0,25	10,0	35,7	4,06
8	3,1	0,70	0,17	5,5	22,8	2,67
9	3,4	0,86	0,20	5,9	25,1	1,41
Stem diameter at root neck, mm						
6	1,7	0,45	0,10	6,3	27,4	1,71
7	1,3	0,22	0,06	5,0	17,3	7,07
8	1,9	0,26	0,06	3,3	13,4	–
9	1,6	0,26	0,06	3,9	16,7	3,54
Cotyledon length, cm						
6	3,5	0,7	0,16	4,5	19,7	–
7	3,1	0,43	0,12	4,1	14,1	2,36
8	3,4	0,47	0,11	3,3	13,8	0,59
9	3,5	0,61	0,14	4,1	17,4	0,20
Length of primary needles, mm						
6	13,6	4,06	0,93	6,9	29,9	–
7	10,5	2,62	0,76	7,2	25,1	2,60
8	11,5	4,14	1,00	8,7	35,9	1,49
9	13,4	2,45	0,58	4,3	18,3	0,17

Due to table 2 data, we can conclude that the growth and development of seedlings is better on a substrate of pure neutral peat (variant 6). Plants grown in mixtures with the addition of vermiculite (variants 8 and 9) also reveal good size indicators for the above-ground parts of seedlings. Seedlings on a peat substrate with the addition of pure perlite lag behind in terms of growth and development (variant 7). The differences are confirmed by mathematical processing.

In autumn, 2021, root growth and the formation of phytomass of the above-ground and underground parts of the model seedlings were compared (Fig. 1, 2).

The average length of the above-ground part of the seedlings was 5.6 ± 0.10 cm, the roots – 9.1 ± 0.62 cm. Despite the large linear dimensions of the root system of annual Siberian cedar pine seedlings grown with a closed root system, the mass of the roots is on average 2.6 times less than the mass of the above-ground parts of the plants (Table 3).

It has been established that in variants using coconut mixtures, larger roots are formed than when growing plants in peat substrates (Figure 3). Thus, the length of the root system of annual seedlings exceeds the length of the aboveground part of plants in variants 1, 2, 3 and 5 by 1.8–2.3 times. In variants using peat, this excess is 1.1–1.7 times (variants 6, 8 and 9). When using a peat mixture in combination with 12 % perlite (variant 7), the length of the roots is less than the length of the above-ground part of the seedling. There is a greater excess in the length of the underground part of the plant over the above-ground part in variant 4 in the combination of peat and coconut in equal proportions (2.3 times) (Fig. 3).

Depending on the composition of the substrate, the above-ground part accounts for 0.29-0.41 g, and the roots – from 0.07 to 0.17 g of fresh phytomass (Fig. 4).

Fig. 1. Seedlings of variant 1

Fig. 2. Seedlings of variant 7

Table 3
Indicators of one-year seedlings with a closed root system

Indicator	X_{av}	±σ	±m	P, %	V, %
Length of the above-ground part, cm	5,6	0,67	0,10	1,8	12,0
Root length, cm	9,1	4,14	0,62	6,8	45,3
Weight of the above-ground part, g	0,34	0,07	0,01	3,0	20,2
Root weight, g	0,13	0,05	0,01	5,5	36,7

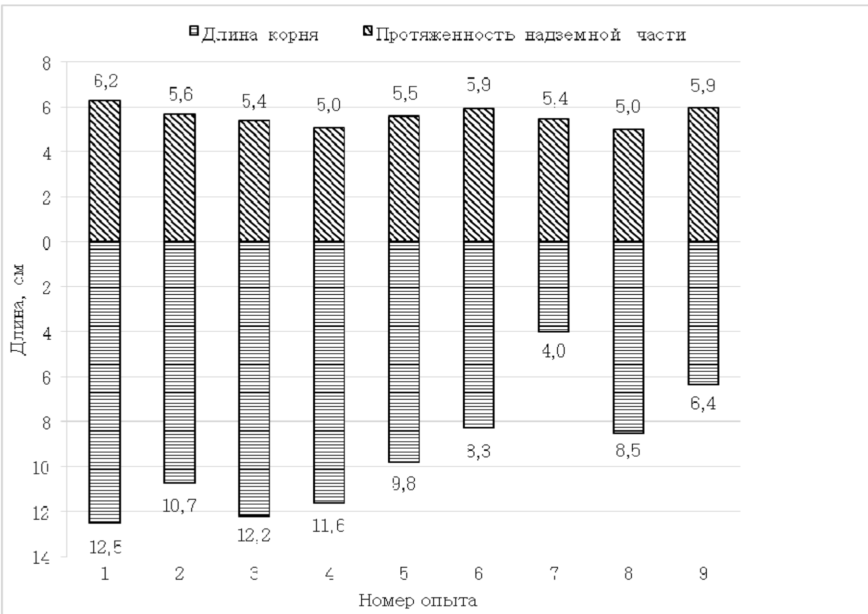

Fig. 3. Dimensions of model annual seedlings with CRS depending on the substrate composition

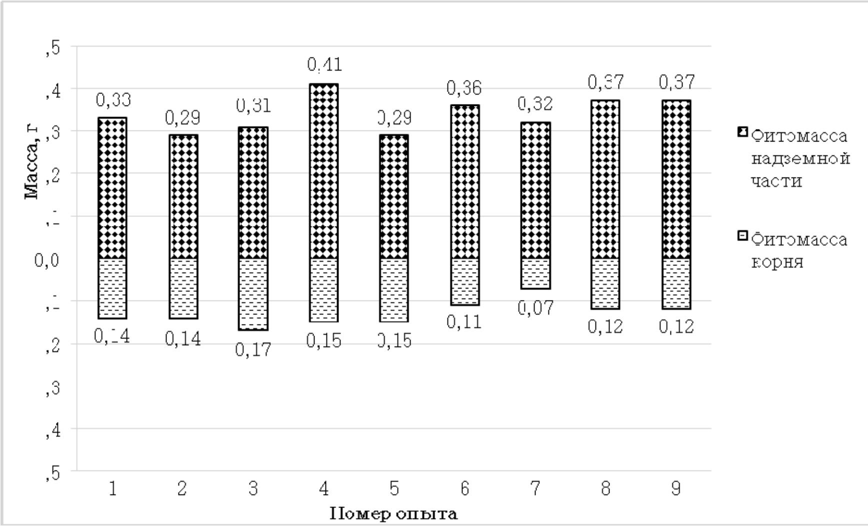

Fig. 4. Phytomass of model one-year seedlings with CRS depending on the substrate composition

CONCLUSION

As a result of studies of the growth and development of one-year Siberian pine seedlings grown with a closed root system, it has been established that the linear dimensions and phytomass of the above-ground and underground parts of plants are influenced by the composition of the substrate. Large stem dimensions are observed on substrates made of pure neutral peat, mixtures of peat with 5 % perlite and 5 % vermiculite, and coconut substrate with 12 % vermiculite. A lag in linear dimensions is detected in seedlings grown on pure coconut substrate and peat mixture with the addition of 12 % perlite. Seedlings growing on peat substrates form, by the end of the first growing season, a root system of smaller size and mass than on substrates with coconut as the main component.

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РОСТ ЛЕСНЫХ КУЛЬТУР ЕЛИ ЕВРОПЕЙСКОЙ СОЗДАННЫХ СЕЯНЦАМИ С ЗАКРЫТОЙ КОРНЕВОЙ СИСТЕМОЙ

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Проведена оценка сохранности и роста культур ели, созданных сеянцами с закрытой корневой системой, а также изменчивости роста их апикального побега. Объектом исследований являются культуры ели европейской в Грязовецком районе Вологодской области в кисличных условиях местопроизрастания. Лесные культуры созданы в 2014 и 2017 году одно- и двухлетними сеянцами ели европейской с закрытой корневой системой с улучшенными наследственными свойствами при одинаковой технологии обработки почвы. Состав исследуемых насаждений включает от 2 до 4 единиц культивируемой породы. Исследуемые культуры ели отличаются интенсивным ростом и хорошей сохранностью, что предопределяет эффективность использования данной технологии. Для всех обследуемых участков характерно снижение уровня вариации прироста апикального побега с возрастом. Корреляционное отношение (η = 0,93) указывает на очень высокую зависимость флуктуации прироста от возраста растений. Снижение уровня изменчивости прироста в фазе индивидуального роста обусловлено, прежде всего, отсутствием затенения древесной и травянистой растительностью, что, в свою очередь, обусловлено и высокой интенсивностью роста культур в сочетании со своевременными уходами. Данные исследования позволяют рекомендовать активизировать переход лесовосстановления на технологию создания культур ели с закрытой корневой системой.

Ключевые слова: *ель европейская, лесные культуры, сеянцы с закрытой корневой системой.*

*Conifers of the boreal area. 2*023, Vol. XL, No. 7 (special), P. 566–569

GROWTH OF EUROPEAN SPRUCE FOREST CROPS CREATED BY SEEDLINGS WITH A CLOSED ROOT SYSTEM

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The assessment of the preservation and growth of spruce crops created by seedlings with a closed root system, as well as their intraspecific variability of apical shoot growth, was carried out. The object of research is the European spruce crops in the Gryazovetsky district of the Vologda Oblast in acidic conditions of the place of growth. Forest crops were created in 2014 and 2017 by one- and two-year-old seedlings of European spruce with a closed root system with improved hereditary properties with the same tillage technology. The composition of the studied plantings includes from 2 to 4 units of cultivated rock. The studied spruce crops are characterized by intensive growth and good preservation, which determines the effectiveness of using this technology. A decrease in the level of variation in the growth of the apical shoot with age is characteristic for all the surveyed areas. The correlation ratio (η = 0.93) indicates a very high dependence of the fluctuation of growth on the age of plants. The decrease in the level of variability of growth in the phase of individual growth is primarily due to the absence of shading by woody and herbaceous vegetation, which, in turn, is also due to the high intensity of crop growth in combination with timely care. These studies allow us to recommend activating the transition of reforestation to the technology of creating spruce crops with a closed root system.

Keywords: *European spruce, forest crops, seedlings with a closed root system.*

INTRODUCTION

Successful reforestation requires quality planting material with optimal growth potential. In this regard, nurseries need to produce seedlings with such characteristics that ensure successful root growth after planting on the forest area [1]. Reforestation in the taiga zone of the European North of Russia in recent years has reached a qualitatively different level due to the introduction of technology of growing seedlings with closed root system (CRS), the effectiveness of which is recognized worldwide. This type of planting material, as a rule, is grown for one year [2]. Planting of such seedlings can be carried out throughout the growing season, which is associated with a reduction in the level of post-planting stress [3; 4]. The root systems of containerized seedlings are surrounded by a nutrient medium that protects them from damage during transplanting. These seedlings have a well-developed root system with a large number of absorptive roots that facilitate the absorption of nutrients and water after transplanting, which increases the growth and establishment of seedlings [5; 6]. Under drier soil conditions, container-grown seedlings have higher rooting rates, primarily because the substrate surrounding the root system of container-grown seedlings may contain a significant amount of moisture. In addition, containerized seedlings usually have a lower ratio of aboveground organs to roots, which predetermines rapid root growth after planting [7; 8].

At the same time, the cost of seedlings with a closed root system is significantly higher than with an open one. In this regard, when creating crops with seedlings with closed root system to minimize costs, their planting density is reduced to 2.0 thousand pieces/ha. The use of this technique, as well as efforts to increase the volume of cultivation of such seedlings in the Vologda Breeding Center allowed to significantly increase the share of crops with seedlings with CRS (18 % of the annually cultivated area) and the total volume of artificial reforestation in the Vologda Oblast. In addition, the use of point seeding in the cultivation of such seedlings contributed to an increase in the share of planting material with improved hereditary properties, the use of which is necessary to improve the productivity and sustainability of forest crops [9]. The use of selective planting material, maximally corresponding to local forest conditions to create plantations of artificial origin is one of the ways to preserve the gene pool and increase the biological diversity of forest ecosystems [10]. A significant area of forest plantations created by this technology and reaching the age of 5–7 years allows for a detailed assessment of this experience. In this regard, it is relevant to assess the growth and safety of crops created by seedlings with a closed root system.

MATERIALS AND METHODS OF RESEARCH

The aim of the present research is to evaluate the growth and condition of European spruce cultivars created by seedlings with closed root system.

The object of research is European spruce crops in the Gryazovetsky district of the Vologda Oblast in acidic conditions.

Forest crops were established in 2014 and 2017 with one- and two-year old seedlings of European spruce with closed root system with improved hereditary properties. The soil was mechanically tilled in a continuous manner. Plowing was carried out with the help of a forest two-tillage plow PL-1 in aggregate with tractor TDT-55. The distance between the rows is: 4.5 m (plot No. 1), 3.5 m (plot No. 2) and 3 m (plots No. 3 and No. 4). The distance between planting (sowing) places along the row line is 1.4, 1.6 and 2.1 m respectively. The planting of European spruce seedlings with CRS was carried out manually with a planting pipe "Pottiputki".

In order to measure the taxation parameters of forest crops, sample plots were planted. The size of the sample area was determined in such a way that at least 400 plants of the main forest element were represented in the study area. In addition to the current plants, the height of self-seeded and undergrowth of spruce and pine trees were measured in the sample plots and accounted for in the stand composition. In addition, the heights of deciduous woody plants were measured on 10 m^2 survey plots.

The following guidelines were used to determine the viability of cultivated plants. Plants with dense needles, green or dark-green coloration of them, marked whorls, island-shaped or cone-shaped symmetrical crown, the length of not less than one third of the trunk length in groups and one second - in individuals, as well as the growth of the apical shoot not less than the growth of lateral branches of the upper half of the crown were considered as reliable plants.

RESULTS AND THEIR DISCUSSION

In artificial plantations of seven years old the share of spruce reaches four pieces, and in five-year old cultures the composition of the plantation varies from 2 to 4 pieces. Natural regeneration of deciduous species is mostly located in the inter-rows and, by now, does not shade the cultivated plants (Table 1).

One of the main quality indicators is the safety of forest crops [1]. On the temporary sample plots a complete enumeration of plants was carried out, as a result of which it was found that the preservation of forest crops varies from 68 to 98 %. The highest preservation was observed in five-year old crops on plot No. 4 (98 %). The lowest was observed in seven-year old spruce crops on plot No. 1 (68 %).

The average height of seven-year old crops is 139 cm and the average diameter is 2.2 cm. Artificial plantings reached a height of more than 1.2 m, which corresponds to the first level of quality determined at the age of 8 years (Table 2).

The highest average height of five-year old forest cultures was observed on plot No. 3 (84 cm) and the lowest on plot No. 4 (57 cm). The value of plant diameter varies from 1.0 to 1.4 cm. The highest value of average diameter was observed on plot No. 2 (1.4 cm) and the lowest on plot No. 4 (1.0 cm). In the surveyed plantations, there is a tendency of increasing annual apical shoot growth, indicating the absence of difficulties in the growth of cultivated plants. The highest growth values are observed in 2021, and the lowest in 2017.

The studied crops were evaluated according to their viability (Fig. 2).

The number of viable plants varies from 88 to 100 %. The highest number of viable specimens was observed in seven-year crops and the lowest in five-year crops. Plant viability was determined by the intensity of crop height growth. In general, the data on the increase in the reliability of cultivated plants with age are confirmed by the assessment of variability in their height and diameter, as well as apical shoot growth (Table 3).

The highest variation in plant height was observed in seven-year crops (C = 36 %), and the lowest in five-year crops - on plot No. 2 (C = 32 %). In general, the level of variability on A. Mamaev scale is high. On plot No. 1, the highest variability in forest crop diameter is observed (C = 37 %), and the lowest (C = 20 %) - on plot No. 2. It should be noted that at the highest fluctuation of plant height and diameter on plot No. 1 there is low preservation (68 %) and, on the contrary, there is high preservation (82 and 98 %) on plots No. 2, 4.

The highest variation of apical shoot height growth for 2017 in plants is expressed on plot No. 3 (C = 57 %), and the lowest on plot No. 4 (C = 32 %). The maximum variability in height growth for 2018 in forest crops on plot No. 2 (C = 50 %) and the minimum variability on plot No. 4 (C = 36 %). The highest variability in growth for 2019 is also on plot no. 2 (C = 45 %), and the lowest on plot No.1 (C = 41 %). On the contrary, in 2020, the maximum value of this indicator is characteristic on plot No. 1 (C = 43 %), and the minimum - on plot No. 2 (C = 26 %). The highest variability of growth for 2021 of forest cultivars is observed on plot No. 1 (C = 41 %), and the lowest on plot No. 4 (C = 26 %). The variation of growth intensity indicates a significant influence of the conducted clearcutting, as well as the successful adaptation of the planted forest cultures on the forest area.

All studied plots are characterized by a decrease in the level of fluctuations of apical shoot growth with age. The effect of age on growth variability was evaluated using analysis of variance (Table 4).

Table 1
Characteristics of European spruce plantings

№ p/p	Year of creation of forest crops	Plot area, ha	Age of seedlings at planting, years	Initial density, thou. pcs/ha	Composition of plantation
1	2014	8,6	1	2000	4Sp3As2Ald1B
2	2017	8,7	2	2042	4Sp1Sp*1P3As1B +W
3	2017	14,8	2	2081	2Sp1Sp*5B1W1Ald
4	2017	15,0	2	2081	4Sp5W1B

Note. * – spruce of natural origin (self-seeding;Sp – spruce; As – aspen; Ald –alder white; B – birch; W – willow.

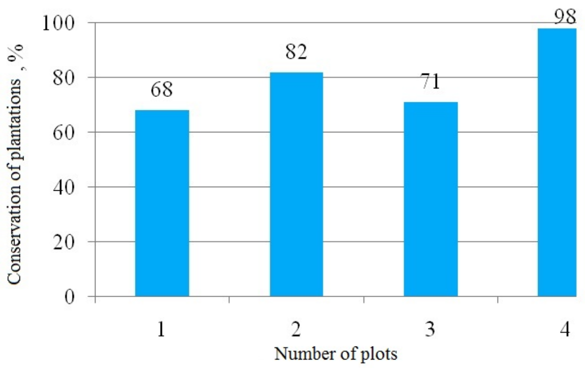

Fig. 1. Preservation of plants in the studied plantations

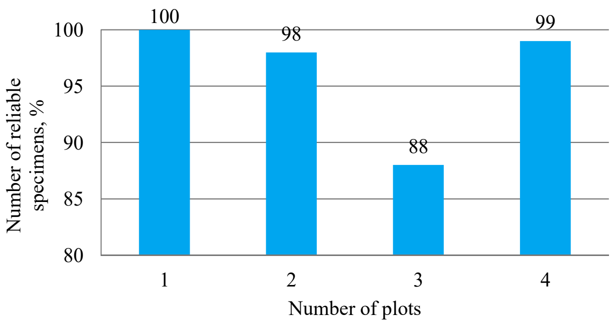

Fig. 2. Spruce viability in cultures

Table 2
Biometric indices of spruce in crops

№ p/p	Age of forest crops, years	Averages		Plant height growth by years, cm				
		trunk height, cm	trunk diameter, cm	2017	2018	2019	2020	2021
1	7	139±3	2,2±0,2	14,1±1,4	17,6±1,7	20,3±1,7	26,5±2,4	32,5±2,7
2	5	79±1	1,4±0,1	8,5±0,7	11,7±0,8	15,8±1,0	25,8±1,0	24,4±1,2
3	5	84±2	1,3±0,1	6,9±0,8	11,1±0,8	14,9±1,2	23,3±1,7	27,4±1,8
4	5	57±1	1,0±0,1	3,8±0,3	7,0±0,5	9,7±0,8	17,3±1,0	18,3±1,0

Table 3
Variability of biometric parameters of forest crops created with seedlings with closed root system (C, %)

Number of plots	Average trunk height	Trunk diameter at root neck	Variability of growth in height by calendar years				
			2017	2018	2019	2020	2021
1	36	37	48	46	41	43	41
2	32	24	53	50	45	26	36
3	34	29	57	37	42	37	34
4	33	20	32	36	42	29	26

Table 4
Effect of plant age on trunk height growth variability

Source of variation	Sum of squares of deviations, SS	Degree of freedom, df	Variance, MS	Fisher's criterion	
				F_{05}	$F_{crit.}$
Between the groups	5258,71	5	1051,74	23,34	2,77
Within the groups	811,25	18	45,07	–	–
Totals	6069,96	23	–	–	–

The influence of the age factor on variability is reliable (F05 > $F_{crit.}$), and its share in the total variation of the index is 87 % (η2 = 0.87). The correlation relation (η = 0.93) indicates a very high dependence of growth fluctuation on plant age. The decrease in the level of growth variability in the individual growth phase is primarily due to the absence of shading by woody and herbaceous vegetation, which, in turn, is also due to the high intensity of crop growth in combination with timely maintenance.

CONCLUSION

The studies of growth and condition of spruce cultivars created by seedlings with a closed root system allow us to conclude that some decrease in the safety of cultivars by the age of seven years is compensated by an increase in the reliability of cultivated plants. The decrease in the variability of the growth value indicates that the post-planting stress has been overcome by the age of 5-7 years.

Thus, the studied spruce crops, created by seedlings with closed root system, are characterized by intensive growth and good safety, which predetermines the effectiveness of using this technology, which also provides for reducing the planting density to 2.0 thsd. pcs./ha. These studies allow us to recommend to intensify the transition of reforestation to the technology of creating spruce crops with seedlings with closed root system.

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ИЗУЧЕНИЕ ПРОЦЕССОВ РОСТА ЛИСТВЕННИЧНЫХ НАСАЖДЕНИЙ С ПОМОЩЬЮ РЕТРОСПЕКТИВНОГО МЕТОДА

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Рассматривается методология построения таблицы хода роста для отдельного древостоя, относящегося к категории одновозрастных и высокопродуктивных. Обычные методы изучения хода роста в этом случае нельзя применить. Исключение составляет исторический метод. При отсутствии многолетних наблюдений использован дендрохронологический метод. По анализу возрастных кернов был восстановлен ход роста по диаметру. Через диаметр и число стволов определена сумма поперечных сечений. Число стволов рассчитано через постоянную изреживания. Для лиственницы она определена по таблицам хода роста нормальных лиственничных насаждений, для ели – еловых. Видовое число взято из справочника таксатора Дальнего Востока. Этот показатель характеризуется не высокой изменчивостью. Ход роста по высоте определен по анализу ствола на ход роста двух модельных деревьев. Остальные показатели находились по общеизвестным лесной таксации формулам. По кернам определена связь радиального прироста в 30 лет с радиальным приростом в других возрастах. На одной пробной площади эта связь прослеживается до 90 лет, на другой – до 60 лет. После 110 лет прирост по диаметру у ели выше, чем у лиственницы. В перспективе возможен переход насаждения в темнохвойную формацию. По другой пробной площади особенности роста не изучены в связи с не высоким возрастом насаждения. Первая структурная перестройка у лиственницы произошла в 20-летнем возрасте. Причиной послужило активное естественное изреживание отставших в росте и развитии деревьев лиственницы. Косвенно это подтверждается сменой знаков асимметрии у лиственницы после этого возраста. Ель в процессе оптимизации численности стволов лиственницы принимала косвенное участие, находясь в стадии подроста. У нее такого перехода не наблюдалось. Максимальной продуктивности древостой достиг благодаря сохранению продолжительное время строения древостоя по диаметру, близкое к оптимальному. Максимальный средний прирост в древостое отмечен в возрасте 90 лет. В год прирастало до 9,3 м^{3}га$^{-1}$. Количественная спелость по лиственнице наступила в возрасте 90 лет, по ели – в 130 лет. Для двух пород максимум среднего прироста по общей продуктивности наблюдается в 90 лет, а отдельно по лиственнице – в 70 лет. Для древостоя характерна тенденция изменения породной структуры в сторону темнохвойной тайги. На это указывает и отсутствие подроста лиственницы. Повышенная сомкнутость в древостое сохранялась до возраста количественной спелости. После этого возраста древостой перешел в стадию климакса, которая завершится разрушением для лиственницы в 210 лет.

Ключевые слова: *возрастной керн, прирост по диаметру, таблица хода роста древостоя, состав, лиственница, ель, асимметрия, количественная спелость.*

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STUDY OF LARCH PLANT GROWTH PROCESSES USING RETROSPECTIVE METHOD

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The methodology of construction of the growth progress table for a separate tree stand belonging to the category of single-age and highly productive is considered. The usual methods of studying the course of growth in this case cannot *be applied. The exception is the historical method. In the absence of long-term observations, the dendrochronological method was used. According to the analysis of age cores, the growth course in diameter was restored. Through the diameter and number of barrels, the sum of the cross sections is determined. The number of barrels is calculated through a cutting constant. For larch, it is determined from the tables of the growth of normal larch plantations, for spruce. The species number is taken from the directory of the taxator of the Far East. This indicator is not characterized by high variability. The height growth course is determined by the analysis of the trunk for the growth course of two model trees. The remaining indicators were calculated according to commonly known formulas of forest taxation. For cores, the association of radial growth of 30 years with radial growth at other ages is determined. On one trial area, this connection can be traced to 90 years, on the other – to 60 years. After 110 years, the diameter increase in spruce is higher than in larch. In the future, it is possible to change the plantation to the dark coniferous formation. For another trial area, growth features were not studied due to the not high age of planting. The first structural restructuring of the larch occurred at the age of 20. The reason was the active natural decimation of lagging larch trees. Indirectly, this is confirmed by the change of asymmetry signs in larch after this age. Spruce in the process of optimizing the number of larch trunks took an indirect part, being in the stage of undergrowth. It did not have such a transition. Due to the preservation of the long building time, the tree has achieved maximum productivity in diameter, close to the optimal. The maximum average growth in woodland was recorded at the age of 90 years. Per year, it grew to 9.3 m^3ha^{-1}. Quantitative ripeness in larch occurred at the age of 90, in spruce – at 130. For two breeds, the maximum average increase in total productivity is observed at 90 years, and separately for larch – at 70 years. The woodland is characterized by a tendency to change the rock structure towards the dark-tailed taiga. This is also indicated by the lack of undergrowth of larch. Increased closeness in the woodland was maintained until the age of quantitative ripeness. After this age, the tree moved to the climax stage, which for larch will end at 190 years old.*

Keywords: *age core, diameter increase, tree growth progress table, composition, larch, spruce, asymmetry, quantitative ripeness.*

RELEVANCE OF THE PROBLEM

It is not customary in forest inventory to make tables of growth progress for an individual stand. If the goal is to develop such a standard, it is necessary to measure taxation parameters over a long period of growth of the stand. But there are not many such permanent objects, where long-term monitoring has been and is being carried out. Therefore, if such a goal is set, there are two options. The first one is to use growth indices, which can be used to restore the chronology of events in the plantation [2; 3; 6; 12] and the second one is the dendrochronological method [7–9]. In this case, calculations are based on the results of analyzing cores of model trees. We used these two approaches to retrospectively assess the growth progress of reference larch stands in order to understand the reasons for achieving high productivity in the green-moss forest type.

MATERIALS AND METHODS OF RESEARCH

The object of the study was two trial areas. One was established in stands of coastal larch (Larix miritima) on the coast of the Tatar Strait (Sovetsko-Gavansky District). Stand composition – 6L4Sp, age 170 years, height of larch – 30.8 m, spruce – 24.3 m, diameter – 43.0 cm and 30.0 cm, absolute completeness – 50.7 m^2, growing stock – 603 m^3 , dead wood – 12 m^3, dry wood – 17 m^3, forest type – green-moss larch. 87 cores of larch and 54 cores of Ayan spruce were taken on the sample area by age drill. Cores were taken at a height of 1.3 m. The two model trees with the highest height were taken on the height growth course. This trial area has previously attracted our attention when studying the growth of reference stands of larch [1].

Another trial area was established in Chumikansky forestry, Khabarovsk Krai. Here larch was also predominant: composition – 7L3Sp; age – 90 years; absolute completeness – 39.3 m^2/ha; stock – 353 m^3/ha; forest type – green-moss larch. 120 drillings were taken to analyze the growth course in diameter (60 – larch, 60 – spruce), and 2 trees were taken to analyze the growth course in height. Measurements and subsequent calculations were carried out on this trial area in order to construct a growth progress table. The plantations of both trial areas are of pyrogenic origin.

The growth rate in diameter and number of trunks are essentially indicators of intracenotic features of stand productivity formation on the one hand, and the direction of forest formation process on the other hand. They are related by the ratio [15]:

$$C = Nd\sqrt{d}, \qquad (1)$$

where C – some thinning constant; N – number of trunks, pcs; d – diameter, cm.

This ratio is implied in the sum of cross-sections, and taking into account species height – the stock of the plantation. It was used in determining the optimal intensity of thinning [15] and modeling the growth course of cedar stands [16].

RESULTS OF RESEARCH

The distribution of trunks by diameter in a mixed stand of larch and spruce (the first trial area) is shown in Fig. 1. The amplitude of reduction numbers by diameter in larch is from 0.3–1.5, in spruce – 0.3–2.0. Values of radial growth in thickness stages correspond to a generalized normal distribution (a = –0.24; +0.32). The variability of ages of larch and spruce of different diameters is not high – 12–14 %, which indicates that the analyzed stand belongs to the same-age stands.

Trees belonging to different thickness stages had the same character of growth in diameter. Consequently, any model trees can be used to determine the age changes in the plantation. They differ significantly in absolute values, but not in indices. The critical situation in the plantation occurred at the age of 20 years. During this period, the number of large and small trees in larch trees equalized [13]. The asymmetry from negative in 20 years became positive in 30 years and did not change its sign (Table 1). The change of asymmetry sign occurred as a result of elimination of lagging trees and subsequent increase in diameter growth of the remaining trees.

The obtained results are consistent with the conclusions of other researchers [5], who noted at this age the appearance of groups of trees that cannot move to the category of larger trees, i.e., change their status (rank) in the stand, and, as a consequence, pass over time into the category of "decay". Perhaps, if the most developed trees were removed, they would have been preserved, but such forest management measures were not planned 150 years ago.

Optimization of larch trunk abundance occurred in 20 years due to natural thinning of "trees not successful in competition" [5]. The asymmetry of rows became positive and small in absolute value, indicating that favorable (optimal) conditions for larch growth were formed in the plantation and that it will probably retain the formed type of structure by diameter up to destruction [7; 13]. There is another point of view on this issue. B. V. Kuzmichev [10] believes that pure pine stands cannot remain in the state of increased closedness (normality) for a long time. Having reached the maximum value, they begin to reduce it and do not return to it anymore.

Comparing the absolute sizes of diameters, it can be seen that before 110 years of age they are larger in larch than in spruce. After 110 years, the opposite picture is observed – the size of radial growth is greater for spruce, it has increased the growth rate in diameter and has overtaken larch. Considering the life cycle of spruce, in the future it is likely to become the dominant species in the plantation, with little participation of larch. But so far there are no obvious signs of destruction in the series of trunk diameter distribution in larch as the main forest-forming species. Stem diameter distribution of both species is close to normal.

Characterizing in general the growth process of mixed stands, we note that no special fluctuations of radial growth on model trees were found. The asymmetry coefficient of both larch and spruce is positive and small in absolute value, which indicates that the distribution series correspond to the generalized normal distribution and that the stands belong to the same type of structure by diameter.

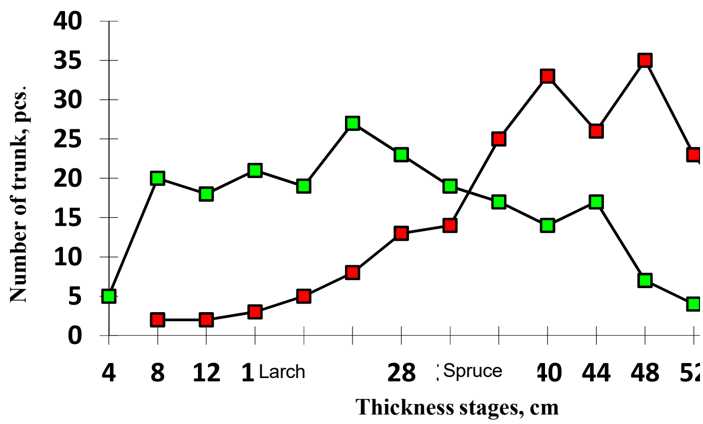

Fig. 1. Distribution of larch and spruce trunks by thickness stages

Table 1
Statistics of radial growth of larch and spruce trees

Statistical values	Age, years						
	30	50	70	90	110	130	150
Larch							
X	6,8	9,8	11,5	13,1	14,3	15,3	16,7
s	1,72	2,42	2,85	3,08	3,11	3,30	3,49
A	0,602	0,387	0,524	0,454	0,354	0,366	0,526
E	–0,061	–0,747	–0,669	–0,794	–0,849	–0,906	–0,933
V	25,9	24,7	24,7	23,6	21,8	21,6	21,8
Ayan spruce							
X	4,0	7,8	10,4	12,4	14,0	15,8	17,3
s	0,98	1,40	2,03	2,12	2,22	2,24	2,32
A	0,558	0,598	0,827	0,601	0,670	0,414	0,313
E	–0,289	–0,377	0,574	0,004	0,096	–0,188	–0,361
V	24,4	18,0	19,4	17,2	15,8	14,1	13,0

Note. *X* – average value of radial growth by diameter without bark, cm; *S* – standard deviation; *A* – asymmetry; *E* – excess; *V* – coefficient of variability.

The asymmetry of both distribution series is characterized by synchronous changes with age, which indicates the consistency of processes occurring in the stand. Spruce has higher peaks of rise above the abscissa axis at 70 and 90 years and some lagging up to 50 years. With a twofold lag at 20 years, diameters of larch and spruce equalized by age 110 years, and then spruce overtook larch. The average diameter values at 150 years of age are higher in spruce than in larch.

Assuming that each tree growing in a stand "records" intracenotic information about the growth peculiarities of the stand with the help of annual rings, the variability of indices over the whole age interval was analyzed. For this purpose, absolute values of radial growth were transformed into indices using the ratio [2; 6]:

$$I = T_i / T_6, \tag{2}$$

where I – index value of a taxation feature; T_i – absolute value of a taxation feature at the i-th age; T_b – absolute value of a taxation feature at the base age (100 years).

After transformation, the radial growth indices grouped into a narrow bundle of lines crossing at 100 years of age (Table 2).

The maximum value of the coefficient of variability of radial growth indices in larch was observed at 30 years, in spruce – at 30 and 170 years. Taking into account insignificant variability of indices, they were represented by two lines. Comparing them with the larch type scale [2; 3; 12], we found that up to 100 years the indices corresponded to growth type 1. After 100 years, the growth rate started to decrease and at 170 years of age the larch indices already corresponded to growth type 6 (the typical scale has 12 growth types by diameter).

Spruce has a somewhat different picture of changes in the indices of model trees. For this species, V. V. Zagreev constructed a scale of 25 growth types [6; 12]. Spruce indices of model trees of the trial area at 30 years corresponded to the 11th growth type, at 50–90 years – to the 9th type, at 110 years – to the 11th type, at 130 years – to the 14th type, at 150–170 years – to the 12th type. In spruce, there is an insignificant deviation of growth indices by diameter from the indices of V. V. Zagreev's type scale. This comparison showed that the forest formation process in the mixed plantation was actively influenced by spruce. This process is consistent with the studies of other researchers who noted the activity of spruce after 100 years in stands mixed with larch [11].

It is believed that only large trees retain the highest rank throughout their life. These are used to select natural growth series. In order to compile growth progress tables, to predict current growth in diameter and stock, it is important to know how far radial growth in the initial growth period (10–20 years) correlates with radial growth at other ages, irrespective of tree diameter size. In other words, how far the diameter rank of a tree, e.g. at 20 years of age, maintains its rank in the long term.

The pair correlation analysis of absolute values of radial growth at 20 years (by decades) with radial growth at other ages showed that there is a reliable relationship between them up to 90 years of age. After this age, the correlation is unreliable. The performed analysis allows us to conclude that in the interval 30–90 years in the stand there were favorable (optimal) conditions for larch growth. After the age of 100 years, the stand underwent a structural change due to the introduction of spruce into the main canopy (before that, it played the role of an understorey, being in the second layer and having the same age as larch). These changes were confirmed by the type scale. After 100 years, the diameter index series of larch began to shift from one growth type to another, i.e. larch significantly decreased its growth rate in diameter. At 170 years of age it already corresponded to growth type 6 of the type scale.

Thus, at 90 years of age, another structural change occurred in the stand due to spruce entering the first layer, which significantly affected the growth rate of larch in diameter. This is confirmed by the parameters of the linear equation describing the correlation between radial growth at 20 years and with radial growth at other ages (Table 3).

Parameters a and b in larch decrease with age along a certain pattern and unsystematically in spruce. On this basis, it is concluded that due to spruce, the optimal conditions for larch diameter growth ended at 90 years of age. Spruce began to regain its status in the possession of the area it previously owned before the fire.

This pattern was confirmed in another high-bunching stand, also dominated by larch. As in the previous case, the amount of radial growth achieved by 10 years of age had a long-lasting influence on the absolute value of diameter or tree rank. This correlation was statistically confirmed for larch in the interval of 20–70 years, and for spruce – 20–60 years (Table 4).

Table 2
Statistical values of radial growth indices

Statstical indices	Age, years							
	30	50	70	90	110	130	150	170
Larch								
X	493	721	845	954	1038	1120	1189	1272
s	61	54	36	17	17	42	57	82
V	12,4	7,5	4,3	1,9	1,6	3,8	4,8	6,0
Spruce								
X	296	588	789	938	1064	1197	1263	1310
s	43	44	49	26	26	96	124	206
V	14,5	7,5	6,2	2,8	2,4	8,0	9,8	16,.0

Methodologically, the construction of the growth progress table for mixed stands was as follows.

The change in heights with age was determined using model trees for the growth course, average values of diameters – according to Table 1, number of trunks – using the formula [15]:

$$N_{opt} = \frac{10000}{0{,}164 d\sqrt{d}} = \frac{60975}{d\sqrt{d}},$$

where d is the average stand diameter, cm; N_{opt} is the optimal number of trunks per 1 ha, pcs.

The volumes of larch and spruce trunks were calculated using the formulas in the Far East Taxator's Handbook [14]:

$$V_l = 9{,}1 \cdot 10^{-5}\, dh + 331 \cdot 10^{-7}\, d^2 h,$$

$$V_{sp} = 10{,}5 \cdot 10^{-5}\, dh + 361 \cdot 10^{-7}\, d^2 h.$$

The same formulas were used to calculate the volumes of fallen trunks. Other indicators were determined using formulas commonly known in forest inventory. These include average stock change and average growth in the stock. Current growth was not determined in the growth progress table. When calculating the total productivity of the stand, the accumulated amount of fall for each tree species was taken into account. Interrelated values of taxation indices of larch and spruce are given in Table 5.

Table 3
Parameters of the linear equation of the correlation between radial growth at age 20 with radial growth at other ages

Age, years	Equation parameters		Correlation coefficient (r)	Reliability indicator (t)
	a	b		
30	0,887 0,164	0,406 0,772	0,60 0,77	6,7 8,9
40	0,719 0,286	0,276 0,787	0,52 0,73	5,1 8,1
50	0,716 0,353	0,146 0,848	0,38 0,69	3,1 7,3
60	0,513 0,558	0,095 0,756	0,29 0,60	2,2 6,5
70	0,510 0,464	0,070 0,806	0,29 0,58	2,0 5,4
80	0,540 0,605	0,052 0,424	0,29 0,21	2,1 2,0
90	0,407 0,906	0,078 0,128	0,38 –	3,1 0,7

Note. Above the line are the parameters of the equation describing the relationship of radial growth of larch, below the line - of spruce.

Table 4
Parameters of the linear equation of the correlation between radial growth at 10 years of age with radial growth at other ages (Chumikan Forestry)

Age, years	Larch				Spruce			
	Equation parameters		Correlation coefficient	Reliability indicator	Equation parameters		Correlation coefficient	Reliability indicator
	a	b			a	b		
20	0,22	0,91	0,88	12,1	0,26	0,82	0,88	11,6
30	0,32	1,12	0,83	8,2	0,29	0,86	0,82	8,0
40	0,65	0,82	0,73	6,8	0,75	0,70	0,65	6,0
50	1,38	0,52	0.42	3,2	0,12	0,47	0,40	3,0
60	1,88	0,90	0,47	3,8	0,14	0,49	0,45	3,1
70	2,62	0,61	0,24	1,9	–	–	–	–

Table 5
Growth progress of green-moss larch forests

A	Composition	H	D	N_{gt}	G	M	$\Delta_{av.change}$	V_f	$\sum V_{saf}$	TP	$\Delta_{av.growth}$
30	8,8 л	9,7	14,2	1140	18,0	113	3,8	28	28	141	4,7
	1,2E	4,0	7,4	3033	13,0	65	2,1	14	14	79	2,6
				4173	**31,0**	**178**	**5,9**	**42**	**42**	**220**	**7,3**

End of table 5

A	Compo-sition	H	D	N_{gt}	G	M	$\Delta_{\text{av.change}}$	V_f	$\sum V_{saf}$	TP	$\Delta_{\text{av.growth}}$
50	8,4Л	18,0	24,2	559	25,7	231	4,6	46	74	305	6,1
	1,6Е	9,1	13,2	1270	17,4	102	2,1	18	32	134	2,7
				1829	**43,1**	**333**	***6,7***	**64**	**106**	**439**	**8,8**
70	7,8 Л	23,3	31,0	353	26,6	282	4,0	86	160	442	*6,3*
	2,2Е	13,6	18,2	786	20,4	155	2,2	24	56	211	3,0
				1139	**47,0**	**437**	**6,2**	**110**	**216**	**653**	**9,3**
90	7,3Л	26,5	35,4	289	28,4	335	3,7	52	212	547	6,1
	2,7Е	17,3	22,4	575	22,6	202	2,2	34	90	292	3,2
				864	**51,0**	**537**	**6,0**	**86**	**302**	**839**	***9,3***
110	6,8Л	28,2	38,3	257	29,6	364	3,3	27	239	603	5,5
	3,2Е	20,4	25,9	462	24,3	243	2,2	32	122	365	3,3
				719	**53,9**	**607**	**5,5**	**59**	**361**	**968**	**8,8**
130	6,5Л	29,1	40,2	239	30,3	384	3,0	23	262	646	5,0
	3,5Е	22,8	28,5	401	25,6	286	2,2	27	149	435	*3,3*
				640	**55,9**	**670**	**5,2**	**50**	**411**	**1081**	**8,3**
150	6,3Л	30,8	43,0	216	31,4	420	2,8	20	282	702	4,7
	3,7 Е	24,5	30,1	370	26,3	308	2,0	22	171	479	3,2
				586	**57,7**	**728**	**4,8**	**42**	**453**	**1181**	**7,9**

Note. A – age of years; D – diameter at the height of 1.3 m, cm; H – height, m; Ngt – number of growing trunks, pcs. ha^{-1}; G – sum of cross-sections, m^2 ha^{-1}; M – stock of growing plantation, m^3 ha^{-1}; $\Delta_{\text{av.change}}$ – average stock change, m^3 ha^{-1}; V_f – volume of fall, m^3 ha^{-1}; $\sum V_{saf}$ – sum of accumulated fall, m^3 ha^{-1}; TP – total productivity, m^3 ha^{-1}; $\Delta_{\text{average growth}}$, m^3 ha^{-1}.

The retrospective method of assessing age-related changes in the taxonomic indicators of the stand allows for certain errors with the depth of retrospection, but they can be corrected with the help of standard scales and general growth patterns identified. The developed table is also interesting in that it defines decay for each species and provides calculations of total stand productivity for the whole analyzed period. According to these data, the age of quantitative ripeness onset was determined both for individual species and for the stand as a whole. It should also be noted that the total productivity of the stand is very high for this forest type. At 150 years of age it is equal to 1181 m^3 ha^{-1}. Of this mass, 453 m^3 ha^{-1} is attributed to the fall, or 3 m^3 per year. The total productivity corresponds to highly productive cedar stands [16].

CONCLUSION

Analysis of the growth progress table allows us to draw several important conclusions.

1. The retrospective method can be used to construct growth progress tables for assessing the productivity of single-age stands. Adjustment of the growth of individual indicators can be carried out with the help of standard growth scales. They are developed practically for all forest-forming species. Model trees for coring can be selected from different thickness stages.

2. The first structural transformation of larch stands in terms of diameter occurred at the age of 20 years. The reason for this was active natural thinning of larch trees that had lagged behind in growth and development. The transformation resulted in the change of asymmetry signs in larch from negative to positive. No change of asymmetry signs was observed in spruce. Spruce took passive part in the process of optimization of larch trunk abundance, being in the second layer.

3. Total stand productivity at 150 years of age reached 1181 m^3 ha^{-1}. Quantitative ripeness in larch was reached at the age of 70 years and in spruce at 130 years. The maximum average growth in total productivity was observed at 90 years of age. After this age, the stand entered the climax stage, which can last up to 220 years and more.

4. The stand is characterized by a tendency to change the species structure towards dark coniferous taiga. This is also indicated by the absence of larch undergrowth. The results of the study are confirmed by the findings of other researchers [11], who noted high productivity of such stands and subsequent replacement of larch by spruce. Signs of deceleration of larch trees in the trial area were established after 100 years. The growth indices of model trees changed from the first type to the sixth type by 150 years of age.

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СРАВНИТЕЛЬНАЯ ОЦЕНКА ТАКСАЦИОННЫХ ПОКАЗАТЕЛЕЙ ПЛЮСОВЫХ ДЕРЕВЬЕВ СОСНЫ ОБЫКНОВЕННОЙ НА ЛЕСОСЕМЕННОЙ ПЛАНТАЦИИ

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В базовых документах общегосударственного формата селекционное совершенствование лесов определено важным вектором развития лесного хозяйства страны на период до 2030 г., что обусловливает актуальность научных работ в указанном направлении. Первостепенное значение это имеет для основных лесообразующих пород, к числу которых отнесена сосна обыкновенная (Pinus sylwestris L.), широко распространенная в северном полушарии и являющаяся представителем аборигенной флоры в Среднем Поволжье и Нижегородской области. Исследовали таксационные показатели плюсовых деревьев сосны обыкновенной, клоны которых сосредоточены на лесосеменной плантации № 36. Её территория входит в район хвойно-широколиственных (смешанных) лесов европейской части Российской Федерации (зона хвойно-широколиственных лесов), а по лесосеменному районированию включена во второй лесосеменной район указанной породы. Методика выдержана с соблюдением принципа единственного логического различия, построена на требованиях к типичности, пригодности, надежности, оптимальности и целесообразности опыта. Работы проведены полевым стационарным методом со сплошным подеревном перечетом таксационных показателей. Установлена выраженная фенотипическая неоднородность клонового состава плюсовых деревьев, которая проявилась как между их вегетативными потомствами, так и внутри последних. По высоте ствола средние величины принимали значения от 103,02±7,26 см до 151,90±7,24 см, а обобщенное среднее составило 129,29±1,12 см. По диаметру ствола наибольшее средние было 32,84±2,14 мм, наименьшее – 19,07±1,37 мм, обобщенное среднее составило 28,04±0,30 мм. Высота ствола в большей степени коррелирует с его диаметром у шейки корня: $r \pm mr$ = $= 0,891 \pm 0,010$ при $tr = 90,70$, что соответствует положительной, достоверной и высокой тесноте связи по шкале Чеддока. Однофакторный дисперсионный анализ подтвердил существенность обнаруженных фенотипических различий между плюсовыми деревьями. Эффект влияния меж-клоновых различий слабо выражен, его наибольшая величина (3,33±2,27 %) отмечена по напряженности роста дерева, а наименьшая (3,13±2,28 %) зафиксирована по высоте ствола.

Ключевые слова: *сосна обыкновенная, селекционная оценка, плюсовое дерево, клоны, лесосеменные плантации.*

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COMPARATIVE ASSESSMENT OF THE TAXATION INDICATORS OF PLUS TREES OF SCOTS PINE ON A FOREST SEED PLANTATION

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In the basic documents of the national format, the selective improvement of forests is defined as an important vector of the development of the country's forestry for the period up to 2030, which determines the relevance of scientific work in this direction. This is of paramount importance for the main forest-forming species, which include the Scots pine (Pinus sylwestris L.), which is widespread in the northern hemisphere and is a representative of the native flora in the Middle Volga region and the Nizhny Novgorod region. The taxational indicators of plus trees of Scots pine were studied, the clones of which are concentrated on the forest seed plantation No. 36. Its territory is included in the area of coniferous-broadleaf (mixed) forests of the European part of the Russian Federation (the zone of coniferous-broadleaf forests), and according to forest-seed zoning it is included in the second forest-seed area of the specified breed. The methodology is maintained in compliance with the principle of a single logical difference, based on the requirements for typicality, suitability, reliability, optimality and expediency of the experience. The work was carried out by a field stationary method with a continuous sub-tree list of taxation indicators. A pronounced phenotypic heterogeneity of the clone composition of plus trees was established, which manifested itself both between their vegetative offspring and within the latter. In terms of trunk height, the average values ranged from 103.02±7.26 cm to 151.90±7.24 cm, and the *generalized average was 129.29±1.12 cm. By trunk diameter, the largest average was 32.84±2.14 mm, the smallest was 19.07±1.37 mm, the generalized average was 28.04±0.30 mm. The height of the trunk is more correlated with its diameter at the root neck: r±mr = 0.891±0.010 at tr = 90.70, which corresponds to a positive, reliable and high closeness of the connection on the Cheddock scale. Univariate analysis of variance confirmed the significance of the detected phenotypic differences between the plus trees. The effect of the influence of inter-clones differences is weakly expressed, its largest value (3.33±2.27 %) is marked by the intensity of the growth of the tree, and the smallest (3.13±2.28 %) is fixed by the height of the trunk.*

Keywords: *Scots pine, selection evaluation, plus tree, clones, forest seed plantations.*

INTRODUCTION

The Strategy for the Development of the Forestry Sector of the Russian Federation for the period until 2030, adopted by the Government of the country, anticipates a consistent transition to intensive forms of forestry based on its innovative character, sustainable forest management, and continuous and non-destructive management of forests. In this context, priority is given to the main forest formers, among which we can reasonably include the common pine (Pinus sylwestris L.) [17–19], which is actively used for economic purposes not only in our country [35; 51], but also abroad [58; 62; 63]. Due to its unique complex of useful features and properties, it is constantly studied by domestic [1–5; 33; 34] and foreign [51–65] researchers. Its breeding potential, intraspecific variability and polymorphism in a wide range of features of economic, adaptive and identifying importance are analyzed in details [6; 8; 10; 27; 28; 30; 31; 46; 47; 50]. The subjects of thorough research are its biology and general physiological state [25; 34; 36; 37], ability to resist water evaporation and resistance to atmospheric and soil moisture deficit [14; 29], pigment composition that determines photosynthesis regimes, which largely affects gross productivity and reproductive potential [11; 48; 53; 59], size and structure of needles [19; 21; 42; 51; 52; 55-57; 61; 65], parameters of seeds and cones [3; 17; 20; 30; 39; 45], content of nutrients [2; 12; 13; 15], peculiarities of xylem development [4; 9], and other no less important and sometimes complicated aspects [3; 5; 7; 17–19].

The aim of the research is comparative assessment of taxation indices of plus trees of common pine, vegetative progeny of which are located in the composition of forest seed plantations.

MATERIALS AND METHODS

The object of the study was clones of 50 plus trees of common pine introduced into the first-order forest seed plantation (FSP I) No. 36. It is located in forest unit No. 7 of forest area No. 139 of Semyonovsky district forestry of Nizhny Novgorod region and has geographic coordinates N 56.74161° E 44.35436°. According to the current official zoning, its territory is included in the area of coniferous-broadleaved (mixed) forests of the European part of the Russian Federation (zone of coniferous-broadleaved forests), and according to the forest-seed zoning it is included in the second forest-seed area of the common pine. Climatic and soil conditions for this species are quite favorable for its growth and seed production [40], as evidenced by the large-scale artificial reforestation works carried out over vast areas and the successful establishment of numerous objects of permanent forest seed base and unified genetic and breeding complex [21–23; 32; 38; 41; 43; 44]. This FSP was established in 2016 with grafted seedlings, which were 2 years old at the time of planting. The source of grafts was the clone archives, which are part of the unified genetic and breeding complex in the same region, and the grafting itself was performed by specialists of the State Autonomous Institution of Nizhny Novgorod region "Semenovsky Spetsemleskhoz". Planting sites were 6×8 m, clone mixing scheme was block, with an initial repeatability of each orthet with 50 ramets. The producing area amounted to 12.44 ha, the type of forest conditions on it was B_2 category.

The methodology of works provided for strict observance of the principle of a single logical difference, as well as their compliance with all requirements for typicality, suitability, reliability, optimality and expediency of experience. The field stationary method was implemented in the course of continuous tree counting, when the height of plants was fixed with a measuring rod with an accuracy of 1 cm, and the diameter at the root neck was determined with an electronic caliper (Electronic Digital Caliper – G06064731) with an accuracy of 0.1 mm. The previously accumulated experience in taxation of similar breeding and seed production facilities was taken into account [22; 23; 32]. The beginning of field surveys was preceded by revision of the purity of the forest-seed plantation composition and detection of its compliance with the designed mixing schemes by the criterion of similarity of the branch-to-trunk attachment angle value in clones of the same name [18; 24; 26].

RESULTS AND THEIR DISCUSSION

A marked phenotypic heterogeneity of the clonal composition of plus trees was established, which was observed both between their vegetative progenies and within the latter (Table 1). Thus, in terms of trunk height (see Table 1), the average values ranged from 103.02±7.26 cm (clone K-107) to 151.90±7.24 cm (clone K-118), which formed an excess of 1.47 times or by 48.88 cm. The average summarized for the whole massif was 129.29±1.12 cm. At the same time, the ratio of limits amounted to 17.94 and their range reached 271 cm. The character of distribution of trunk diameter values of the same plus trees was adequate in the main features to the situation formed in the course of statistical analysis of their heights. In this case, the highest average was 32.84±2.14 mm (clone K-118), and the lowest was 19.07±1.37 mm (clone K-107). Such estimates formed an excess of 1.72 times or 13.77 mm, while the generalized average for the whole massif was 28.04±0.30 mm. The range of limits reached 68.90 mm, and their ratio was 18.23.

Stem cross-sectional area, as one of the most important taxation indices, had more contrasting phenotypic differences, while maintaining the previously observed tendencies in the distribution of values of its linear parameters in the compared clones. The highest average (9.91±1.17 cm^2), which was observed in clone K-118), exceeded the corresponding minimum (3.45±0.48 cm^2) recorded in clone K-107 by 2.78 times or by 6.46 cm^2. The range of absolute values was even more noticeable: their difference was 41.61 cm^2, and the ratio reached the level of 332.15. At the same time, the generalized average value was estimated at 7.63±0.15 cm^2.

A quite adequate indirect estimate of the volume and full woodiness of the trunk part of plants at FSP No. 36 can be the volume of the cone built on the area of the trunk cross-section. Its application is especially relevant when working with trees that have not exceeded the range of the juvenile phase of ontogenesis. These are the trees located on the FSP studied in this work. Both plant height and diameter are involved in the calculation of this integral by its structure indicator. The vegetative progenies of plus trees with indices K-117 and K-118 were close in magnitude and exceeded all other values: 596.30±131.18 cm^3 and 594.20±92.58 cm^3, respectively. They exceeded the minimum established for this species (161,03±32,14 cm^3), observed in clones of plus-tree K-107, by 435,27 cm^3 or 3,70 times. The balance of limits of the studied indicator is the most contrasting, their range amounted to 3076.16 cm^3, and the ratio was 2160.94.

An objective characteristic of the biological state of plants on the FSP is the indicator of tree growth intensity proposed by L. F. Semerikov [49], which is the ratio of its height to the cross-sectional area of the trunk and reflects not only the area of the life space of an individual, but also carries information about the internal growth processes, the character of the distribution of substance and energy flows between organs. In this context, the estimates of plus trees are also very heterogeneous. The highest of them (0.57±0.12 cm/mm^2) observed in clone K-322 exceeded the lowest (0.24±0.02 cm/mm^2), which occurred in clone K-105, by 0.33 cm/mm^2 or 2.42 times. The excess of the absolute maximum over the absolute minimum here reached 4.01 cm/mm^2 or 113.01 times. The generalized average, to which the other estimates approached to a greater or lesser extent, reached 0.35±0.01 cm/mm^2.

The other features of the clonal composition of plus trees at FSP No. 36 had their own specificity in the formation and distribution of their values. It can be stated that estimates of statistical reliability of the obtained results in the vast majority of cases are close to critical for the 5% significance level accepted in silvicultural research. Exceeding of relative error thresholds in a number of cases of analysis for individual clones is caused by a high level of variability of linear parameters of the trunk and their related features. In general, it is characteristic of the juvenile phase of vegetative progeny ontogenesis of plus trees on large-sized FSPs, which includes the studied FSP No. 36. It is clear that in order to achieve the required accuracy of the experiment, the high level of dispersion could be compensated by a large number of surveys and observations.

Table 1
Characteristics of above-ground parts of plus trees of Scots pine[1, 2, 3]

Features	M	STD	max.	min.	Δ_{lim}	± m	Cv, %	t	P, %
h	129,29	51,99	287,00	16,00	271,00	1,12	40,21	114,93	0,87
$D_{1.3}$	28,04	13,64	72,90	4,00	68,90	0,30	48,66	94,98	1,05
h/d	4,99	1,36	13,57	1,31	12,26	0,03	27,20	169,93	0,59
S	763,71	676,63	4173,93	12,57	4161,36	14,64	88,60	52,16	1,92
g	0,21	0,05	0,76	0,07	0,69	0,00	24,55	188,23	0,53
K	0,35	0,38	4,04	0,04	4,01	0,01	108,16	42,73	2,34
Vc	426,13	477,51	3077,59	1,42	3076,16	10,33	112,06	41,23	2,43
Vcyl	1278,94	1432,62	9232,76	4,27	9228,49	31,01	112,02	41,24	2,42

[1] Indicators: M – average; STD – standard deviation; max. – maximum value; min. – minimum value; Δlim – range of variability; ±m – absolute error; Cv – coefficient of variation, %; t – Student's criterion; P – relative error, %.

[2] Characteristics: h – height; d – trunk diameter; h/d – height to diameter ratio; S – trunk cross-sectional area; g – trunk taper; K – tree growth intensity; Vc – volume of an inscribed cone; Vcyl – volume of a cylinder built on the cross-sectional area of the trunk;

[3] The number of parameters taken into account (primary sampling elements) for each taxation indicator is 2136 pieces.

Table 2
Correlation between trunk characteristics of plus pine trees[1, 2]

Features	Criterion	Features							
		h	$D_{1.3}$	h/d	S	g	K	V	V
h	r	1,000	0,891	–0,247	0,827	0,170	–0,561	0,837	0,837
	±mr	0,000	0,010	0,021	0,012	0,021	0,018	0,012	0,012
	tr	999(9)	90,70	11,75	68,08	7,97	31,35	70,73	70,68
$D_{1.3}$	r	0,891	1,000	–0,568	0,969	0,550	–0,664	0,928	0,928
	±mr	0,010	0,000	0,018	0,005	0,018	0,016	0,008	0,008
	tr	90,7	999(9)	31,89	182,49	30,41	40,97	114,97	115,00
	r	–0,247	–0,568	1,000	–0,506	–0,893	0,815	–0,406	–0,407

End of table 2

Features	Criterion	Features							
		h	$D_{1.3}$	h/d	S	g	K	V	V
h/d	±mr	0,021	0,018	0,000	0,019	0,010	0,013	0,020	0,020
	tr	11,8	31,89	999(9)	27,08	91,82	65,07	20,54	20,56
S	r	0,827	0,969	–0,506	1,000	0,529	–0,536	0,981	0,981
	±mr	0,012	0,005	0,019	0,000	0,018	0,018	0,004	0,004
	tr	68,1	182,49	27,08	999(9)	28,78	29,31	230,54	230,61
g	r	0,170	0,550	–0,893	0,529	1,000	–0,613	0,413	0,413
	±mr	0,021	0,018	0,010	0,018	0,000	0,017	0,020	0,020
	tr	8,0	30,41	91,82	28,78	999(9)	35,86	20,92	20,93
K	r	–0,561	–0,664	0,815	–0,536	–0,613	1,000	–0,465	–0,465
	±mr	0,018	0,016	0,013	0,018	0,017	0,000	0,019	0,019
	tr	31,3	40,97	65,07	29,31	35,86	999(9)	24,26	24,26
Vc	r	0,837	0,928	–0,406	0,981	0,413	–0,465	1,000	1,000
	±mr	0,012	0,008	0,020	0,004	0,020	0,019	0,000	0,000
	tr	70,7	114,95	20,54	230,48	20,92	24,26	999(9)	999(9)
Vcyl	r	0,837	0,928	–0,407	0,981	0,413	–0,465	1,000	1,000
	±mr	0,012	0,008	0,020	0,004	0,020	0,019	0,000	0,000
	tr	70,6	114,95	20,55	230,50	20,92	24,25	999(9)	999(9)

[1] Indicators: r – Pearson's pairwise correlation coefficient; ±mr – error of the correlation coefficient; tr – criterion for the validity of the correlation coefficient (t_{05} = 1.96).

[2] Characteristics: h – height; d – trunk diameter; h/d – height to diameter ratio; S – trunk cross-sectional area; g – trunk taper; K – tree growth intensity; Vc – volume of an inscribed cone; Vcyl – volume of a cylinder built on the cross-sectional area of the trunk.

However, in our case, this approach was impossible to realize due to the limited number of clones representing each of the plus trees in the FSP: the quantitative representation was limited by the planned assortment composition.

It was possible to identify the fact, scale and form of correlation between the taxation indicators of plus-tree clones of Scots pine trees, used in the formation of FSP No. 36 (Table 2).

Correlation analysis revealed the general situation, determining the unequal level of estimates of the connection between the values of the analyzed features in their pairwise comparison. In particular, trunk height (feature 1) depended to the greatest extent on its diameter at the root neck (feature 2): r±mr = 0.891±0.010 at tr = 90.70. Such closeness of the connection was characterized as positive, reliable and high on the Cheddock scale. The connection of trunk height with the features in the formation of which its diameter was involved, namely, the cross-sectional area at the root neck (feature 4), the volume of the cone (feature 7) and cylinder volume (feature 8), made on the cross-sectional area of the trunk, had similar values and the same focus, which is quite logical. The height of the trunk was related to the other features to a lesser extent, with the ratio of height to diameter (feature 3) and with the indicator of growth intensity (feature 7) is negatively correlated: r±mr = –0.247±0.021 at tr = 11.75 and r±mr = –0.561±0.018 at tr = 31.35.

The interrelation of the diameter at the root neck (feature 2) with the other features also has differentiated values. The largest ones were observed in the interaction of this feature with the cross-sectional area (feature 4) and the volumes of the cone and cylinder built on it (features 7 and 8). Reaching values of r±mr = –0.969±0.005 at tr = 182.49 (feature 4) and r±mr = –0.928±0.008 at tr = 114.97 (features 7 and 8), the values corresponded to very high power of correlation. In general, all the considered features, having both positive and negative values of correlations, confirmed their statistical relevance.

The established phenotypic differences between plus-trees (according to their vegetative progeny) were observed on a leveled background of ecological conditions, which can serve as a basis for recognizing the hereditary character (genotypic nature) of the reasons for their occurrence. The analysis of variance carried out according to the single-factor scheme confirmed the relevance of the detected differences (Table 3).

For most of the features (6 out of 8), with the exception of height-to-diameter ratio (feature 3) and trunk taper (feature 5), the interclonal differences were observed to be significant at the 5 % confidence level: the calculated Fisher's criteria exceeded the threshold values for the number of degrees of freedom specified in the experiment. In variants with confirmed significant differences, they reached values from 1.38 (feature 1) to 1.47 (feature 6) with the critical threshold of 1.36. This result allowed us to continue the analysis of variance to assess the percentage of influence of differences between plus trees on the formation of the general background phenotypic variance. This effect turned out to be weakly evident and in calculations by Plokhinsky's algorithm its highest value (3.33±2.27 %) was recorded for tree growth intensity (feature 6), while the lowest (3.13±2.28 %) was recorded for trunk height (feature 1). The other estimates were located in the specified interval, if they were reliable. The use of the Snedekor algorithm to calculate the same indicators gave a noticeably smaller, but quite adequate result. In the variants of the analysis with confirmed significant differences between the compared plus trees, the obtained estimates of the share of influence of interclonal differences are statistically reliable. This is indicated by the calculated values of the reliability indices of the estimates of the factor influence strength (F_h^2), which exceeded the tabulated values. The fact that for a number of derived features, such as the ratio of height to diameter (feature 3) and trunk taper (feature 5), the differences were small and did not reach the level of significant ones, testifies to the stability of correlations between height and diameter of all studied plants.

Estimates of significance of differences (see Table 3) between the compared plus-trees by the analyzed features made it possible to establish the limit, after which the actual difference of average values acquires the status of significant. Thus, in terms of trunk height (feature 1), the plus tree K-107 in LSD estimates at the 5 % significance level had significant deviations to the lesser side from thirty-five other trees included in FSP No. 36, and plus-tree K-118 – to the greater side from twenty-four. The plus-tree K-97 had 12 recorded differences; the plus-trees K-118, K-212, K-96, K-168, K-305 each had 10; the plus-trees K-105 and K-308 each had 9; the plus-trees K-299, K-208, K-306 each had 7; and the plus-trees K-119 and K-213 each had 6. At the same time, most of the other plus trees had significant differences with only one or two others, and the positions of the trees numbered No. 1, No. 3, No. 4, and No. 5 in the statistical complex are such that they formed no significant differences with any of the other sites in the comparison complex. When evaluated more rigorously in the Tukey test (D_{05}), no significant differences were established in the majority of cases. Only clone K-107 showed a significant deviation to the smaller side from the other two, and clones K-97 and K-118 showed a significant deviation to the larger side from one.

A similar picture was observed for other stem characteristics of the studied plants, while each of them showed its own specificity in this respect. The dominant (up to 96.87 %) influence of environmental factors on the formation of the general background of phenotypic dispersion of taxation indices in vegetative progeny of plus trees growing on FSP No. 36 was found.

In conclusion, it should be noted that the forest seed plantation No. 36 created in accordance with the current regulations and standards (OST 56-74-96; Order of the Ministry of Natural Resources of Russia No. 438 dated 20.10.2015) contains vegetative progeny of plus trees of Scots pine, which significantly differs at the interclonal level by the main taxation indicators. Growing together within the borders of one plot on the ecological background equalized by basic parameters, representatives of differently named clones showed phenotypic heterogeneity, the cause of which is largely related to the specificity of their genotypes. This corresponds to the ideas about the scale of hereditary conditioning of phenotypic dispersion of taxation indices of many conifer species and was confirmed by the results of dispersion analysis.

Table 3
Significance of differences between plus trees by trunk parameters [1, 2]

Plots, features	$F_{оп}$	Percentage of factor influence ($h^2 \pm s_h^2$)						Criteria of differences	
		by Plokhinsky			by Snedekor				
		h^2	$\pm s_h^2$	F_h^2	h^2	$\pm s_h^2$	F_h^2	$НСР_{05}$	D_{05}
h	1,38	0,0313	0,0228	1,3754	0,0087	0,0233	0,3741	21,956	39,605
$D_{1,3}$	1,44	0,0328	0,0227	1,4416	0,0102	0,0232	0,4402	5,758	10,386
h/d	1,29	0,0294	0,0228	1,2910	0,0068	0,0233	0,2900	0,573	1,034
S	1,37	0,0311	0,0228	1,3679	0,0085	0,0233	0,3667	285,769	515,483
g	1,00	0,0231	0,0229	1,0045	0,0001	0,0235	0,0045	0,022	0,040
K	1,47	0,0333	0,0227	1,4666	0,0108	0,0232	0,4650	0,159	0,286
Vc	1,41	0,0320	0,0227	1,4075	0,0095	0,0233	0,4062	201,628	363,705
Vcyl	1,41	0,0320	0,0228	1,4054	0,0094	0,0233	0,4040	605,08	1091,47

[1] Indicators: F_{op} – Fisher's experimental criterion; F_{05}/F_{01} – tabulated values of Fisher's criterion at 5 % and 1 % significance levels, respectively – $F_{05/01}$ = 1.36 and 1.52; h^2 – indicator of the power of factor's influence; $\pm_{Sh}^2$ – error for the indicator of the power of factor's influence; F_h^2 – reliability indicator of the power of factor's influence; LSD_{05} – the smallest significant difference at 5 % significance level; D_{05} – Tukey's criterion at 5 % significance level.

[2] Features: h – height; d – trunk diameter; h/d – height to diameter ratio; S – trunk cross-sectional area; g – trunk taper; K – tree growth stress; Vc – volume of an inscribed cone; Vcyl – volume of a cylinder built on the cross-sectional area of the trunk.

CONCLUSSION

1. Plus trees of common pine represented by their vegetative progenies at the forest seed plantation No. 36 in Semyonovskaya district forestry of the Nizhny Novgorod region differed markedly from each other in the main taxation indicators of the trunk: height, diameter at a height of 1.3 m, run off, as well as in the ratio of trunk height to cross-sectional area, which is an indicator of tree growth intensity.

2. The recorded phenotypic differences between the plus trees appeared within the boundaries of one plot on the leveled ecological background under the same forest conditions and common schemes of agrotechnical and silvicultural care, which can serve as a basis for recognizing the hereditary nature of the established variability.

3. Taxation indices of vegetative progeny of plus pine trees in the juvenile phase of development are character-

ized by a significant dependence on the environmental factors that have a differentiating influence on them.

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ЭСКИЗ ТАБЛИЦЫ ХОДА РОСТА МОДАЛЬНЫХ СОСНОВЫХ НАСАЖДЕНИЙ НА ОСНОВЕ ПРИНЦИПОВ ДИНАМИЧЕСКОЙ ТИПОЛОГИИ

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Для изучения динамики таксационных показателей выбран типологический метод, при этом данный подход основан на принципах динамической типологии. Материал подбирался по типам леса, на основе которых вычислялись усредненные характеристики динамики таксационных признаков с возрастом, пользуясь графической или аналитической интерпретацией.

Объектом исследований являлись сосновые модальные древостои, произрастающие в Караульном участковом лесничестве учебно-опытного лесничества СибГУ.

Исследования проводились в двух типах леса:

– сосняк зеленомошный, представляющий коренной тип леса;

– сосняк осочково-разнотравный, представляющий условно-коренной тип леса.

В результате проведенных исследований изучены и проанализированы как данные лесоустройства, так и материалы, собранные во время исследования. Установлено, что с течением времени коренной тип леса – зеленомошный – переходит в условно-коренной тип леса – осочково-разнотравный. Вследствие этого данные типы леса были объединены, и для них, как для одного единого типа леса составлена таблица хода роста. В процессе анализа динамики основных таксационных показателей, таких как высота, диаметр, запас, установлено, что данные по Караульному лесничеству превосходят значения по известным нормативам таблицы Н. Е. Суприяновича. Это свидетельствует о том, что исследуемые древостои более продуктивные, чем древостои Приангарского района.

Составленная таблица может служить исходной основой для характеристики роста, прироста и производительности сосновых лесов для лесорастительных условий прибрежной части р. Енисей.

Ключевые слова: *таблица хода роста, динамический типологический метод, сосновые насаждения.*

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THE SKETCH OF THE YIELD TABLE OF MODAL PINE STANDS BASED ON THE PRINCIPLES OF DYNAMIC TYPOLOGY

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To study the dynamics of taxational specifications, a typological method was chosen; this approach was based on the principles of dynamic typology. The material was selected according to forest types, on the basis of which the averaged characteristics of the dynamics of taxational characters with age were calculated with the use of graphical or analytical interpretation.

The study object is pine modal stands growing in the in the Karaulnoye district forestry of the training and experimental forestry at Reshetnev Siberian State University of Science & Technology.

The study was conducted in two types of forest:

– greenmoss pine forest representing a primary forest type;

– sedge-grass pine forest representing a nominally primary forest type.

As a result of the conducted research, both data of forest management and the materials collected through studies have been elucidated and analyzed. It is established that over time the primary type of forest (greenmoss) transitions into a nominally primary forest type (sedge-grass). As a result, these types of forest were combined, and for them, as for one single type of forest, a yield table was compiled. In the course of the analysis of dynamics of the basic taxational specifications, such as height, diameter and standing volume, it is established that the data on Karaulnoye forestry surpass the values on known standards of the table by N. E. Supriyanovich. This indicates that the stands being studied are more productive than the stands of the Angara region.

The table can serve as an initial basis for the characteristics of growth, increment and productivity of pine forests for forest conditions of the riparian part of the Yenisei River.

Keywords: *yield table, dynamic typological method, pine stands.*

INTRODUCTION

In Siberia, in order to calculate yield, the method of age classes is used, which, as an organizing principle of forest management, is unable to provide a strict scientific justification. The only possible alternative is not formal, but real transition to forest-typological principles of forest management organization. A number of scientists note that taking into account the peculiarities of the forest formation process is an indispensable condition for the reproduction of forest resources. "In the presence of this classification, in the strata of which evolutionary and natural-historical regularities truly reliably work, we can recognize that all without exception economic activity in the forest will have to be carried out on a typological basis" [7].

Forest type is understood as a silvicultural classification unit that unites forests with similar forest growth conditions of a certain type, with the corresponding species composition of stands, other vegetation and fauna. The type of forest conditions is understood as a classification unit that unites similar forest conditions of forested and non-forested lands, providing the growth of forest vegetation of a certain composition and productivity [1].

The founder of scientific typology is G. F. Morozov who first proposed the doctrine of a stand type. He formulated the definition of a stand type as a set of stands united into one vast group by the commonality of growing conditions or soil conditions [2].

The typological method was developed by I. Ilvessalo [2]. The data are selected on an ecological basis by forest types, within which the averaging of the characterization of the dynamics of taxational characters with age is obtained with the use of their graphical or analytical interpretation [4].

The dynamic typology of forest development was presented by I. S. Melekhov [2]. According to this approach, a forest type is an elementary natural-historical unit being studied not only in space, but also in time; and the time factor is becoming increasingly important. I. S. Melekhov proposed a general conceptual flow chart of the formation of forest types in connection with anthropogenic impact. This flow chart reflects the essence of dynamic forest typology. A number of researchers present dynamic typology as genetic typology. Nevertheless, I. S. Melekhov suggested that "dynamic typology" reflects the essence of the issue better than "genetic typology". Genetic typology limits the study of age and regeneration stages within one forest type, while dynamic typology is characterized by a broader approach, including anthropogenic influence [2]. Primary forest types develop in nature without human influence or natural disasters. Secondary forest types replace primary forest types as a result of these factors. Primary and homonymic secondary types form a series of forest types [5].

Summarizing all of the above, one can conclude that forest type is one of the most important factors of forest ecology. A forest type determines the following: species composition of animals; species composition of the berry world; phytomass of plants; taxational specifications of a stand. The main factor in changing the life cycle of a forest is the change from primary to nominally primary or secondary forest types, in other words, dynamic forest typology.

RESEARCH METHODOLOGY

The present study is based both on experimental data collection and on processing of forest inventory materials.

The material for studying the nature and dynamics of the ground cover was collected by laying sample plots of 1×1 m in size. The distance between the sample plots was 20 meters. They were located on the ground in the form of a grid (3×5 sample plots). Processing of taxation materials was based on the data of the forest inventory of 2002.

The typological method based on the principles of dynamic typology was chosen to study the dynamics of taxational specifications. The material was selected on an ecological basis by forest types with further calculation of averaged characteristics of the dynamics of taxational characters with age, with the use of graphical or analytical interpretation. At the beginning of the study, the prevailing species in the forest division was determined (in this case it is pine) for which regression modeling is performed. Then, after selecting the species, the main forest types were selected according to their qualitative and temporal characteristics: primary forest type and nominally primary forest type. Greenmoss pine forest was selected as a primary forest type; sedge-grass pine forest was selected as a nominally primary forest type. For each age class, 20–25 cards were collected. Divisions were chosen by random selection. All the calculated parameters were summarized in a table according to the age class. The statistical parameters were further analyzed.

RESULTS AND DISCUSSION

The study object is pine modal stands growing in the Karaulnoye district forestry of the educational and experimental forestry at Reshetnev Siberian State University of Science & Technology.

Two forest types were chosen for the study:

– greenmoss pine forest representing a primary forest type;

– sedge-grass pine forest representing a nominally primary forest type.

In order to obtain the most complete picture of the flora of the field layer, 15 plots were established in the territory of the forest division. The Drude scale was used for visual categorization of abundance. When estimating the scale abundance, the following notations were used [3]:

– Un (unicum) – projective cover of the species occupies less than 1 % of the plot;

– Sol (solitaria) – projective cover of the species occupies 3–5 % of the plot;

– Sp (sparsae) – projective cover of the species occupies 10–20 % of the plot;

– Cop (copiosae):

- Cop1 – projective cover of the species occupies 30–40 % of the plot;
- Cop2 – projective cover of the species occupies 50–60 % the plot;
- Cop3 – projective cover of the species occupies 70–90 % of the plot;

– Soc (socialis) – projective cover of the species occupies more than 90 % of the plot.

The plots were established in pine-dominated stands. The dominance of the Carex macroura at all sites allowed us to state the prevalence of pine forests of the sedge-grass forest type in the territory of the forest division.

On the basis of graphical analysis, taxational specifications (changes in height and diameter with age) of pine stands of greenmoss and sedge-grass forest types were compared. It was found that these forest types are identical in terms of growth intensity, as the trend lines practically coincided (Fig. 1). Consequently, it can be noted with full confidence that greenmoss pine forest (primary forest type) in course of time and external factors transitions into sedge-grass pine forest (nominally primary forest type) (Fig. 2). This allowed uniting them into one group.

In order to model the yield of the main taxational specifications, standard functions of the program “Curve Expert” were used.

The yield is described by a set of functions that must be compatible with the following requirements:

– The graph must pass through the origin of coordinates, $f(x) = 0$, at $x = 0$.

– The growth function must be increasing at $x > 0$, and $f(x) \geq 0$.

– The limit of function with unbounded increasing argument must tend to the asymptote: lim f(x) = max x→ to infinity.

– The graph of the current growth must start from the origin of coordinates, $f(x) = 0$, at $x = 0$.

– Growth function must have an inflection point.

With the coefficient $R > 0.95$ the equation is considered adequate.

As a result, three functions were selected.

Exponential Association:

$$y = a * (1 - \exp(-b*x)), \tag{1}$$

Logistic Model:

$$y = a / (1 + b * \exp(-c * x)), \tag{2}$$

where x is a stand age, years; a is a peak value; b, c are function coefficients reflecting the shape of the curve.

MMF Model:

$$y = (a * b + c * x ^\wedge d) / (b + x ^\wedge d), \tag{3}$$

where x is a stand age, years; a, b, c and d are function coefficients.

The analysis of function parameters showed that only one function was compatible with all the criteria, namely MMF Model, which was used for growth approximation (Fig. 3).

The diagrams showed stable growth of stands of average diameters with increasing age, as no external and internal factors influenced the stand development both negatively and positively. The adequacy ratio of the equation is below 0.95. This can be explained by the large variation in the data (Fig. 3). The stands actively grow up to 60–70 years old, which can be explained by a number of factors (climate, former old arable lands, high density), then the height increment decreases, but the stands continue to steadily increase in height. The adequacy ratio of the equation is greater than 0.95 (Fig. 3). The volume increases sharply up to 65–70. After 70 years, the growth decreases. This is associated with the full formation of stands; and the volume increases steadily. The adequacy ratio of the equation is more than 0.95 (Fig. 3).

Based on the obtained models and empirical taxation formulae, the sketches of the yield tables of modal pine stands (see the table) were constructed for the riparian part of the Yenisei River. These norms show that the sum of cross-sectional areas increases from 16.25 to 24.49 m^2/ha, the maximum value is reached at the age of 70 years, then the decline begins. The number of trunks per hectare at the age of 20 years is 818 pcs/ha, then the number of trunks decreases, having a minimum value of 412 pcs/ha. The species number as well as the number of trunks has the maximum value at 20 years, and with increasing age, the species number decreases to the minimum value of 0.447. The total standing volume increases with age. The minimum standing volume at 20 years of age is 47 m^3/ha, and the maximum standing volume is recorded at the age of 140 years and is equal to 258 m^3/ha. The average changes of the standing volume increase from 20 to 60 years of age; at 60 years of age the change of the standing volume has a maximum value of 3.56 m^3/year. Then the values decrease. The minimum change of the standing volume is reached at 180 years and is 1.44 m^3/year. The current change of the standing volume varies from 5.67 m^3/year (50 years) to 0.01m^3/year (170–180 years).

For the comparison of the developed norms, the yield table by N. E. Supriyanovich [6] was used (Fig. 4).

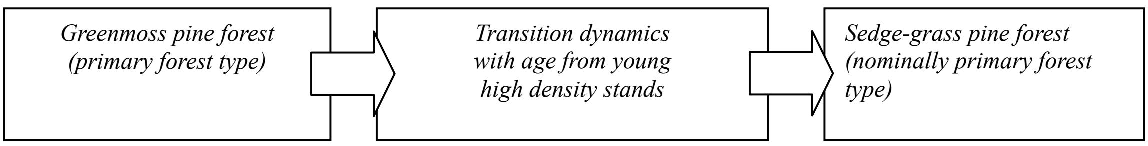

Fig. 2. Scheme of dynamics of transition of a greenmoss pine forest to a sedge-grass forest type

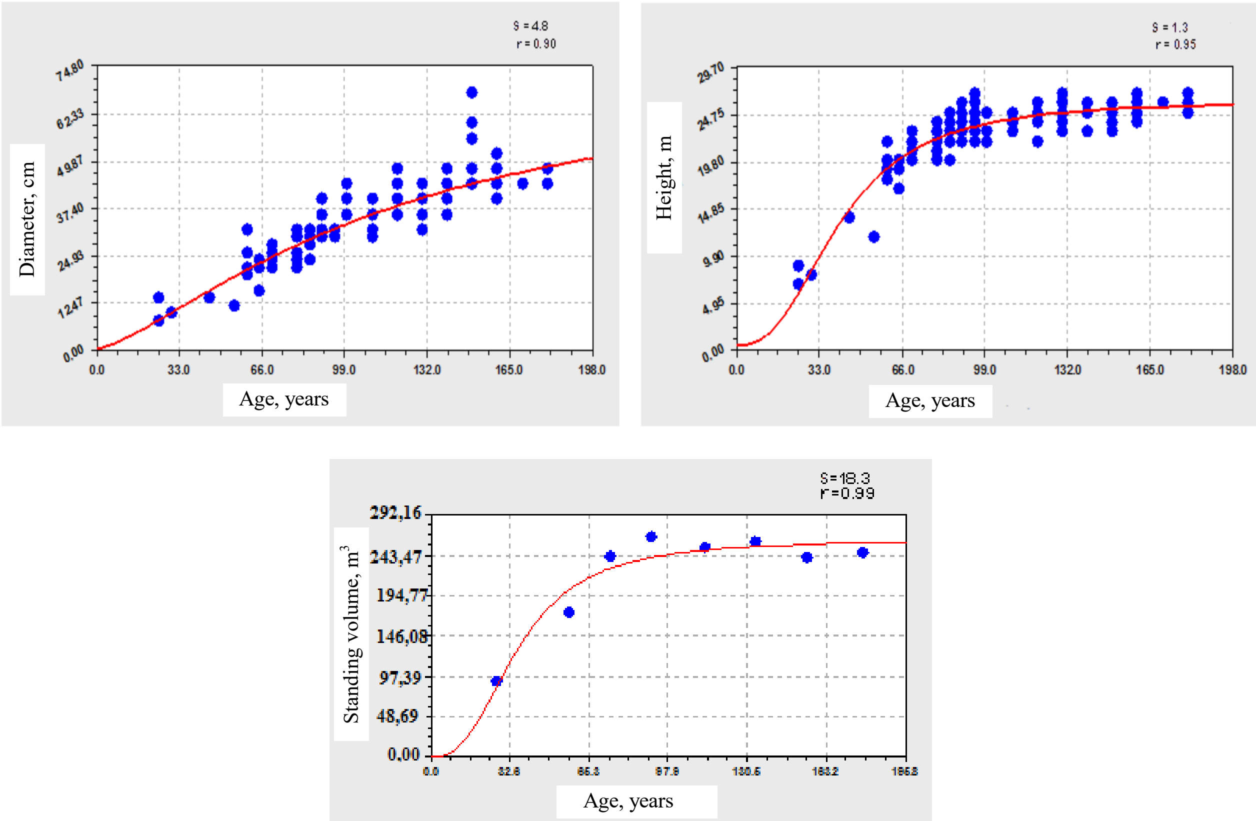

Fig. 3. Relation of main taxational specifications and age of pine stands

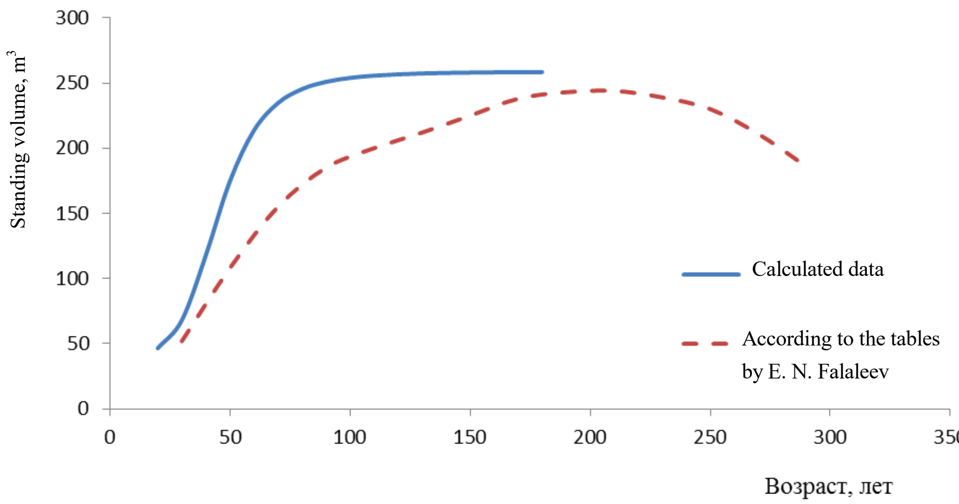

Fig. 4. The comparison of the standing volume of pine stands with the data from the table by N. E. Supriyanovich

The yield table of pine stands of green-moss-mixed herbs forest type

Age, years	Average		Σg, m^2/ha	N, pcs/ha	f	M, m^2/ha	Standing volume changes, m^3/ha	
	height, m	diameter, cm					average	current
20	4.2	6.4	16.25	818	0.688	47	2.33	–
30	8.5	10.2	14.72	588	0.541	68	2.27	2.14
40	13.0	14.1	18.47	628	0.493	118	2.95	4.99
50	16.5	17.8	22.36	675	0.473	175	3.49	5.67
60	19.1	21.4	24.13	665	0.463	214	3.56	3.90
70	21.0	24.8	24.49	627	0.457	235	3.35	2.11
80	22.2	27.9	24.30	586	0.454	245	3.07	1.08
90	23.2	30.8	23.99	550	0.452	251	2.79	0.56
100	23.8	33.5	23.67	521	0.450	254	2.54	0.30
110	24.3	36.0	23.42	497	0.449	256	2.32	0.17
120	24.7	38.2	23.20	478	0.449	257	2.14	0.10
130	25.0	40.3	23.02	462	0.448	257	1.98	0.06
140	25.2	42.2	22.88	448	0.448	258	1.84	0.04
150	25.3	44.0	22.76	437	0.447	258	1.72	0.03
160	25.5	45.6	22.67	428	0.447	258	1.61	0.02
170	25.6	47.1	22.59	419	0.447	258	1.52	0.01
180	25.7	48.5	22.53	412	0.447	258	1.44	0.01

Comparing the calculated indicators with the indicators from the table by N. E. Supriyanovich, one can say that the average diameter of the stand increases more intensively than according to the tables by N.E. Supriyanovich. This may be due to soil fertility, external climatic and anthropogenic factors of influence on stands. The dynamics of the volume of pine stands of the Karaulnoye forestry sharply increases up to 50–60 years; this is due to the fact that young stands grow much more intensively than the ripening ones, mature and overmature ones. Further the change of growth in the volume decreases, which is caused by the entrance of stands to the age of ripeness. The standing volume change according to the tables by N. E. Supriyanovich does not have discontinuities: at first the standing volume change increases up to 70 years, then the increment decreases (Fig. 4).

CONCLUSION

As a result of the conducted research, both documentary data of forest management and materials collected during field studies were elucidated and analyzed. By analyzing the growth of pine forests of greenmoss and sedge-grass forest types, their identity was established. Over time, a primary forest type (greenmoss) transitions to a nominally primary forest type (sedge-grass). As a consequence, these forest types were united and a general yield table was compiled.

In the process of analyzing the dynamics of the main taxational specifications, such as height, diameter, and standing volume with age, it was revealed that the yield of pine forests in the Karaulnoye forestry exceeds the data of the tables by N. E. Supriyanovich. This indicates that the stands being studied are more productive.

As a result, on the basis of the identified regularities of pine forest yield, a local yield table of pine stands of greenmoss and sedge-grass forest types was compiled. The presented table can serve as an initial basis for characterizing the growth, increment and productivity of pine forests for forest conditions of the riparian part of the Yenisei River.

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ИССЛЕДОВАНИЯ ПО ВЫРАЩИВАНИЮ СОСНЫ КЕДРОВОЙ СИБИРСКОЙ ЗА МНОГОЛЕТНИЙ ПЕРИОД

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Приведены результаты многолетних исследований по выращиванию сосны кедровой сибирской: хранение, предпосевная обработка семян микроэлементами и стиумуляторами роста, их облучение лучами Ренгена, дополнительное освещение сеянцев, черенкование, создание плантаций клонами, полусибами, потомством разного географического происхождения. Полученные результаты использованы при разработке ГОСТов, ОСТов, РТУ, рекомендаций, создании баз данных. Исследования проведены на опытных участках в Учебно-опытном лесхозе СибГУ, Ермаковском лесничестве Красноярского края, а также других лесничествах Сибири на основании общепринятых в лесокультурном производстве методик. Выявлены оптимальные условия для длительного хранения семян, применения стимуляторов, микроэлементов при выращивании посадочного материала. Предложено дополнительное освещение сеянцев, использование светофильтров определенного спектрального состава. Проанализирована агротехника выращивания посадочного материала в питомниках Сибири, влияние размеров посадочного материала на приживаемость и рост растений в лесных культурах. Испытан рост сосны кедровой сибирской на подвое сосны обыкновенной и сосны кедровой сибирской. Изучена изменчивость рамет и полусибов плюсовых деревьев, аттестованных по семенной и стволовой продуктивности. Установлено влияние облепихи крушиновой на рост и семеношение сосны кедровой сибирской разного географического происхождения, отселектировано потомство популяций, отличающихся интенсивным ростом и ранним репродуктивным развитием.

Ключевые слова: *сосна кедровая сибирская, семена, сеянцы, лесные культуры, плантации.*

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RESEARCH ON THE CULTIVATION OF SIBERIAN CEDAR PINE FOR A LONG PERIOD

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The results of many years of research on the cultivation of Siberian cedar pine are given: storage, pre-sowing treatment of seeds with trace elements and growth stimulants, their irradiation with Rengen rays, additional lighting of seedlings, cuttings, creation of plantations with clones, half-siblings, offspring of different geographical origin. The obtained results were used in the development of GOST, OSTs, RTS, recommendations, creation of databases. The research was carried out at experimental sites in the Educational and Experimental Forestry of SibSU, the Yermakovsky Forestry of the Krasnoyarsk Territory, as well as other forestries in Siberia on the basis of generally accepted methods in forestry production. Optimal conditions for long-term storage of seeds, the use of stimulants, trace elements when growing planting material were revealed. Additional illumination of seedlings, the use of light filters of specific spectral composition are proposed. The agricultural technique of growing planting material in nurseries of Siberia, the influence of the size of planting material on the survival rate and growth of plants in forest crops are analyzed. The growth of Siberian cedar pine on the root of Scots pine and Siberian cedar pine was tested. The variability of ramets and semi-siblings of plus trees certified by seed and trunk productivity was studied. The influence of buckthorn buckthorn on the growth and seed production of Siberian cedar pine of different geographical origin was established, the offspring of populations characterized by intensive growth and early reproductive development were selected.

Keywords: *Siberian pine, seeds, seedlings, forest crops, plantation.*

INTRODUCTION

Siberian pine (*Pinus sibirica* Du Tour), or Siberian cedar, is a forest-forming species of Siberia, the pride of the taiga zone. The wealth of the cedar taiga is well known: nuts, wood, soft resin, furs, etc. Its durability, water protection, water regulation, soil protection and other environmental functions are of great importance. The boundary of the range of this species runs in the west from the upper reaches of the Vychegda River (northeast of the European part of Russia) to Blagoveshchensk in the east (127°20`E). The northern border goes through the lower reaches of the Ob, Yenisei, and the upper reaches of the Aldana River (68°30`N). The southern border of the range, crossing the Urals at 57°N, descends to Altai to 48°N. and to Mongolia to the sources of the Orkhon River (46°30`N), where the southernmost point of the range is located. This biological species is quite demanding on soil fertility, preferring rich loams with moderate moisture; nevertheless, it can grow on rocky and heavily swampy areas [3; 23; 25]. Many authors note the increased requirements of Siberian pine pine for air humidity. However, according to V.V. Protopopov [24], Siberian pine also grows in conditions where the average monthly relative air humidity at 1 p.m. during the growing season can drop to 40 %, and on some days – to 12–15 %. Siberian pine seeds are a valuable balanced nutrition, since they contain vitamins, microelements, and essential fatty acids. They are a source of biologically active substances necessary for human life [2; 10; eleven].

Siberian pine reproduces by seed and vegetative methods. Considering the frequency of seeding, it is necessary to have a reserve fund of seeds for sowing in lean years. When storing seeds for a long time over several years, it is necessary to develop methods to ensure their high viability, which depends on the species, hereditary properties, collection time, and seed storage regimes [7; 20].

RESULTS AND ITS DISCUSSION

The features of long-term storage of Siberian pine seeds were studied at Siberian State University from 1980–2000. As a result of the research, the following conclusions were made: for long-term storage of seeds, it is recommended to collect them in years of copious crop. Seeds must be of first-class quality. Indicators are no less than: seed purity – 96 %, viability – 85 %, weight 1000 pcs. – 230 g. Before long-term storing seeds should be dried at a temperature of 30–35 ° C to a humidity of 5–6 % and placed in disinfected glass bottles. They are tightly closed with stoppers, the edges of which are lubricated with Vaseline, and the joints are filled with paraffin. Store at temperature not lower than minus 11 ° C and not higher than plus 8 °C. Seed storage has proven effective with the addition of activated carbon (5 % by weight of the seeds) or quicklime (10 %), or chloramine (1 %) [6]. Planting material was grown from long-term storage seeds and planted at the test plot of Reshetnev Siberian State University of Science and Technology [15]. Trees from seeds after long-term storage did not have significant differences in growth rates from the control.

To increase seed germination and accelerate the growth of planting material, pre-sowing seeds were soaked in aqueous solutions of microelements and growth stimulants. The most effective were solutions containing H_3BO_3 in concentrations 0.01–0.005 % and $CuSO_4$ 0.001–0.005 %, gibberellin concentration 0.0001–0.001 % heteroauxin – 0.0005–0.0007 %, which contributed to an increase in soil germination of seeds and the performance of three-year-old seedlings. The seedlings in the listed variants were large in size and weight. Solutions containing gibberellin contributed to an increase in the length of the cotyledons and a decrease in their thickness. When seeds were soaked in a 0.0005 % heteroauxin solution, the total photosynthetic surface of the seedlings was 12.7 % larger compared to the control. The seedlings of this variant have 40.8 % more chlorophyll than the control, with an increased ratio of chlorophyll “a” to “b” [6].

We studied the effect of X-rays on Siberian pine seeds in a dry, swollen, sprouted and germinated state. Irradiation of seeds was carried out in the laboratory of light culture of the Institute of Biophysics SB RAS. The seeds were irradiated in doses of 400 and 5000 R within 12 minutes. It was found that when seeds were irradiated with a dose of 5000 R, single shoots appeared, which soon died. A dose of 400 R also had a negative effect on seed germination, and seedlings were characterized by slow growth. At the age of 35, the Siberian pine, which grew from irradiated seeds, did not enter the reproductive stage of development, while in the control variant some trees formed cones and pollen. However, it is possible that single specimens that grew from irradiated seeds will be more environmentally stable in areas with increased radioactivity [6].

Experiments were carried out on the influence of the duration of illumination and the spectral composition of light on the growth of Siberian pine. The photoperiodic response of seedlings was studied by isolating the crops from natural light for a 6–9 hour period and applying additional lighting for 18, 22, and 24 hours. Plywood boxes with air holes were installed above the experimental crops, ensuring the same temperature conditions in the experiment and in the control. The illumination under the box without a lighting source, determined by the LM-3 lux meter, was zero. Seedlings grown under conditions of natural photoperiod duration served as control. To select effective light sources based on their spectral composition, seedlings were grown under films of different colors: red, yellow, blue, green and transparent (wavelength 380–800 nm). Fluorescent lamps (LDS-40) and incandescent lamps (150 watts), providing illumination up to 300–1100 lux, were used as light sources for additional lighting. Long-term illumination was one of the determining factors in regulating the growth processes of Siberian pine seedlings. Seedlings of this species were of better quality when grown under yellow and red light filters and with additional night lighting with incandescent lamps. With additional night lighting during the period of growth of the central shoot, the current growth of seedlings increased; during the period of growth of the central shoot, the initiation and formation of terminal buds of seedlings, not only the current growth of the shoot increased, but also Lammas shoots were formed.

The most effective was the use of additional lighting for 40 days on Siberian pine seedlings of northern origin (Salekhard). All one-year-old seedlings had two growths during the growing season and did not differ in size from two-year-old ones. The next year, the seedlings formed larger growths and at the age of three they were all classified as first grade [6].

An assessment of the patterns of growth of seed product in various ecological and geographical conditions and an analysis of agricultural technology for their cultivation were carried out in accordance with the Russian Research Institute for Silviculture and Mechanization of Forestry methodology (1972) in 21 forestry enterprises of Eastern Siberia [5]. The influence of calibration of planting material, the growth pattern of seedlings in the transplant section of the nursery farm and forest crops was established, depending on the quality indicators of seedlings in various soil and climatic conditions. On test plots the best in terms of biometric indicators were seedlings grown from seedlings selected by diameter. Early flowering (at age 15–20) was noted in some specimens that had the largest stem diameter (8–10 mm) at age 5.

Sustainable and fast-growing forest crops are created on the basis of geno- and phenotypic diversity of populations and the selection of productive ones for specific growing conditions [4]. The state of forest crops created by calibrated seedlings and saplings in the Achinsky, Kozulsky, Kansky, Mansky, Mininsky, Educational and Experimental Forestry Enterprises of the Krasnoyarsk Territory, as well as the Anzhersky, Krapivinsky Forestry Enterprises of the Kemerovo Region was analyzed. The best quality was found in experimental forest crops created with large-sized planting material, which emerge from under the grass canopy earlier and are characterized by increased preservation and growth energy. When creating forest crops, it is advisable to use fast-growing, selected planting material that, under identical growing conditions, has a diameter or height (depending on the density of crops) greater than the average value and is productive – accelerated development, established by the formation of leaf bundle in the first year of cultivation or the ability to form two shoot growths during the growing season [5].

Within its area, Siberian pine has many valuable forms, which can be preserved through asexual propagation. The most common methods of propagation are grafting and cuttings. During asexual propagation, the genetic characteristics and properties of the mother plants are completely preserved. One of the most promising, but little studied methods of propagation of this species is cuttings, with the help of which it is possible to grow own-rooted plants from specimens selected for speed of growth and other valuable traits. Cuttings do not depend on the periodicity of the harvest, which is strongly expressed in Siberian pine, and eliminates the discrepancy in the growth rate of the scion and rootstock in diameter, which is inherent in propagation by grafting. However, Siberian pine is a tree species that is difficult to root, which is confirmed by many years of research [8]. It has been established that callus and root formation of cuttings of coniferous species depends on the age of the mother plants, the use of growth stimulants, growing conditions, etc. Cuttings of Siberian pine was carried out in cold-type greenhouses covered with polyethylene film. The greenhouses had a height of 170–210 cm, a length of 300–400 cm, and a width of 100–120 cm. The roof is gable, removable, the side walls of the greenhouses are covered with plastic film. The greenhouse was placed at a height of 30–40 cm, the base was lattice to provide air access. Initially, river pebbles were laid in a layer of 10 cm, then a mixture (20 cm) of soil from under cedar plantations (humus-accumulative horizon), sand and birch leaves were made in equal proportions (20 cm). The top layer (3 cm) consisted of coarse-grained, well-washed and calcined river sand. Previously, 1–2 days before planting the cuttings, disinfection was carried out by watering the substrate and the internal walls of the greenhouses with a 0.5 % solution of potassium permanganate. Air humidity was maintained within 80–100 % by systematic watering using fine-droplet hand sprayers and containers filled with water. On days with high air temperatures, the greenhouses were ventilated, shaded with gauze (cloth), and the outside was doused with water.

The cuttings were taken at several times from mother plants growing in the arboretum of the Siberian State University of Science and Technology, of different morphological and phenological forms, of geographical origin at the age of 6–30 years. Cuttings 5–10 cm long were cut at different phenological periods from the upper, middle and lower parts of the crown from the lateral branches of the first and second orders, using shoots 1–2 years old. The cuttings were soaked in solutions containing physiologically active substances, concentrations from 0.0001 to 0.1 % for 1, 10, 20, 30 hours. Treatment of cuttings with stimulants was carried out by immersing their basal parts in aqueous solutions. In order to clarify the influence of the age of mother plants on the rooting of Siberian pine cuttings in the suburban area of Krasnoyarsk, several experiments were carried out. Thus, in the first experiment, 6-, 15- and 20-year-old mother plants were used for cutting. Cuttings were cut from lateral one-year-old branches of the first order. The process of callus formation was more intense in cuttings cut from 6-year-old mother plants. By September 13, buds had formed in single cuttings, but roots had not formed during the growing season.

In cuttings from 20-year-old plants using the same harvesting method, the process of callus and root formation was delayed; by this time, even root base was not formed on them. In the second experiment, when cutting 7-year-old seedlings, similar results were obtained. In 63 % of the cuttings, at the end of the first growing season, root rudiments appeared, 16 % – roots. As a result of the research, it was revealed that cuttings of Siberian pine from mother plants under the age of 15 years take root more successfully. Subsequently, the ability to propagate by cuttings sharply decreases. Among 17–23-year-olds, only a few cuttings of different geographical origins were selected. Callus and root formation in Siberian pine occurs better when using winter cuttings with buds (closed), harvested while they are in the phase of swelling of buds from the lateral shoots of the first and second orders of branching. Callus of larger diameter and thickness was noted in cuttings treated with a heteroauxin solution at a concentration of 0.001 %. In the same variant, the cuttings formed a well-developed root system within three years.

A comparison of survival rate and growth was carried out 8-year-old (3+5) plants of cuttings and seed origin. After five years of growing seedlings of cuttings origin in the transplant section, their height was 19.3 cm, seedlings – 33.0 cm. The cuttings were planted in the arboretum of Siberian State University of Science and Technology and on the plantation "Izvestkovaya". By the biological age of 30–33, the height of the Siberian pine, propagated by cuttings, averaged 5.6 m. All cuttings have a vertical position, a straight trunk. No tree death or anomalies in their development were observed. At the age of 27, 14 % of specimens entered the reproductive stage, forming 2–8 cones on central and lateral shoots [8; 9].

When creating forest plantation, much attention is paid to the geographic origin of seeds, which affects the growth of crops up to the age of ripeness and is often a decisive factor in creating sustainable, highly productive plantations [1].

Assessing the growth and sustainability of populations allows for each specific region to identify ecotypes, the use of which will give the greatest silvicultural effect [21; 22; 26]. The "Meteo-station" plantation in the Karaulny district forestry of the Training and Experimental Forestry Enterprise of Reshetnev Siberian State University University of Sciencw and Technology (green zone of Krasnoyarsk) was created by planting plants grown from seeds of different geographical origins (populations of the Krasnoyarsk Territory, the Altai Republic, Kemerovo Region, Kazakhstan), differing in the conditions of growth of parent plantings in height above sea level (from 700 to 1700 m), geographic latitude (from 50 to 63°N), longitude (from 83°56` - Leninogorsk ecotype to 90°EL). As a local ecotype (control), the progeny was taken from the Biryusinsky forestry of the Educational and Experimental Forestry Enterprise of Reshetnev Siberian State University of Science and Technology of the Krasnoyarsk Territory [14; 18]. At the 40-year biological age, the height of plants of various ecotypes reached 5.6–7.7 m. The leadership belonged to the Atushken ecotype of Gorno-Altai origin. At this plantation, an experiment was carried out with planting common sea buckthorn between the rows of Siberian pine as a species that supplies the soil with nitrogen. It was established that, starting from the age of 31, the plants in the area with common sea buckthorn overtook in growth were control plants planted in the neighboring section, but without sea buckthorn. The differences in height were in some years up to 11.1–13.4 %, but no significant differences were found in diameter. However, the percentage of productive trees in the first years of their reproductive development was higher in the area without common sea buckthorn.

The "Izvestkovaya" pine plantation was established by planting Siberian pine plants grown from seeds of different geographical origins. The plantation presents seed progeny of Siberian pine from plantations in the Krasnoyarsk Territory, Irkutsk, Chita regions, Altai, and Khakassia [14]. Trees at 47–48 years of biological age of different geographical origin had a height of 10.8–11.3 m. The first cones formed on single trees of Al-Tai (Kurli tract), Cheremkhovo and Chita origin in 21–24 years of biological age. In the first years of reproductive development, 1–3 cones were formed. The offspring of the Biryusa, Altai, and Cheremkhovo populations were more productive (20–24 % of trees) for this period.

When creating the grafting hybrid seed plantation, cuttings were prepared from Siberian pine plants grown from seeds sown in 1960–1964 of different geographical origins: Kemerovo, Sverdlovsk, Tomsk, Tyumen, Chita regions; Krasnoyarsk Territory (Biryusinsky, Yartsevo forestry enterprises); Republic of Altai, Buryatia, Komi, Tyva, Sakha-Yakutia, Khakassia). Grafting was carried out in 1976–1982. The grafting method is "pith-to-cambium" on Scots pine undergrowth [12; 13; 17]. After five years, the growth of the grafted plants was analyzed. The highest scion indicators were when using 9–10-year-old rootstock. By the age of 24, the grafted plants had reached an average height of 7.5 m. The scions of the Altai (Kurli harvesting) variant were characterized by intensive growth (the scion height was 10.8–64.0 % greater). At this age, 89 % of trees had overgrowths in places where Siberian pine and Scots pine grow together. There is mainly a loss of trees that have large influxes in places where they grow together. More durable specimens have better fusion scion with rootstock, but less intensive growth. Eight years after grafting, massive staminate "blooming" was observed on grafted trees Altai (12-18-3), Biryusa (9-25-1), Komi (3-7-2), Khanty-Mansi (15-34-2) and Yakut (1-2-5) origin. Cones in the amount of 3–127 pcs. were on trees of nine clones at age 24.

A plantation of Siberian pine using half-sibs and ramets from plus trees growing on the territory of the Novosibirsk (Kolyvan forestry) and Irkutsk (Slyudyansky forestry) regions was created in the Western Sayan experimental forestry (Tanzybey forestry of the Ermakovsky forestry) Krasnoyarsk Territory with planting material grown in the conditions of the Training and Experimental Forestry Enterprise of Reshetnev Siberian State University of Science and Technology Siberian State University of Science and Technology. As a scion, cuttings from plus trees selected for seed and stem productivity were used; the rootstock was Siberian pine seedlings of Biryusinsky origin (Biryusinsky forestry of the Educational and Experimental Forestry Enterprise of Reshetnev Siberian State University of Science and Technology). The biological age of trees of Novosibirsk origin, taking into account the age of the rootstock and scion, in 2008 was 24 years (6+18 years) [16; 17]. In terms of seed productivity, clones have an average height of 2.8 m, varying from 2.5 to 3.2 m according to experimental variants. Clones 89/53, 97/61, 100/64, 112/76 had the best growth in the group in terms of seed productivity. The maximum height (4.7 m) was for ramet No. 34-26 of clone 100/64. The average height of 24-year-old grafted clones based on stem productivity on the plantation was 3.0 m. The maximum height was observed in clones 17/17, 13/13, 141/105, 147/111, selected for stem productivity. Some specimens (No. 14-24, 22-14) of clones 17/17 and 141/105 reached a maximum height in this group of 4.2 m. At the age 35, the trees had an average height of 6.2 m. In 1995 cones have formed on some ramets of clones 18/18, 91/55, 92/56, 100/64. In 2008, in the group according to trunk productivity, cones and macrostrobili were formed up to 10.0–34.4 % in ramets of different clones and microstrobili – 10 % ramet clone 13/13.

Trees of seed origin at the age 25 had the greatest height (4.2 m) in families 89/53 and 90/54. A single entry into the seed production stage was noted from the age of 21. Cones in the amount of 1–12 pcs. were formed in five half-sibs aged 24–25 years. At the age 35, the trees reached an average height of 6.9 m [11].

CONCLUSIONS

The results of many years of research were put into practice and included in GOST standards for seedlings: 3317–77, 33-17–90, seedlings: 24835–81; method for long-term storage of seeds: RTU 56-84; "Forest crops. Quality assessment": OST 56-92–87, into databases on growth and productivity indicators of Siberian pine on mother-tree archive [17; 19], plantations were created using seed and vegetative planting progeny of plus trees in the Ermakovsky forestry on an area of 25 hectares and experimental plots in the Educational and Experimental Forestry Enterprise of Reshetnev Siberian State University of Science and Technology – 20 hectares.

The application of scientific research results will help improve the quality of Siberian pine planting material and solve many issues of silvicultural production.

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ПРОГРАММНО-АППАРАТНЫЙ КОМПЛЕКС И МЕТОДИКА СБОРА ПЕРВИЧНЫХ ДАННЫХ О ГОРОДСКИХ НАСАЖДЕНИЯХ НА ОСНОВЕ КАРТОГРАФИЧЕСКИХ ВЕБ-СЕРВИСОВ, МОБИЛЬНЫХ УСТРОЙСТВ И ПРИЛОЖЕНИЙ

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Представлены программно-технические и методические решения, рекомендуемые к применению при сборе первичных данных о городских насаждениях в рамках исследований в области изучения распространения, состояния, роста и ландшафтно-декоративных свойств растений в урбанизированной среде. Предлагаемая методика основана на использовании возможностей картографических веб-сервисов, многофункциональных мобильных устройств и приложений для получения данных о местоположении и таксационных характеристиках насаждений в применении к различным типам объектов озеленения. Выдвинут тезис о достаточности информации, имеющейся на фотоизображениях, для первичной таксационной оценки городских насаждений в целях планирования детальных исследований. Обоснованы возможности предлагаемых методики и программно-аппаратного комплекса для повышения производительности процесса сбора данных, точности и объективности информации, снижения затрат на этапах полевых и камеральных работ.

Ключевые слова: *методы таксации, городские насаждения, картографические веб-сервисы, мобильные устройства, мобильные приложения, геопозиционирование, наземные дистанционные съемки.*

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SOFTWARE AND HARDWARE COMPLEX AND METHODOLOGY FOR COLLECTING PRIMARY DATA ON URBAN PLANTINGS BASED ON CARTOGRAPHIC WEB SERVICES, MOBILE DEVICES AND APPLICATIONS

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The article presents software-technical and methodological solutions recommended for use in the collection of primary data on urban plantings in the framework of research in the field of studying the distribution, condition, growth and landscape-decorative properties of plants in an urbanized environment. The proposed method is based on the use of the capabilities of cartographic web services, multifunctional mobile devices and applications to obtain data on the location and taxation characteristics of plantings in application to various types of landscaping objects. The thesis about the sufficiency of the information available on the photo images for the primary taxational assessment of urban plantings in order to plan detailed studies is put forward. The possibilities of the proposed methodology and software and hardware complex for improving the productivity of the data collection process, the accuracy and objectivity of information, and reducing costs at the stages of field and desk work are substantiated.

Keywords: *methods of taxation, urban plantings, map web services, mobile devices, mobile applications, geopositioning, ground remote surveys.*

INTRODUCTION

The study of biological and ecological properties, environment-protective and landscape-decorative characteristics, taxation parameters of individual plant species in urban landscaping, if we are not talking about studies on experimental plantings or permanent monitoring objects, is usually associated with the following factors:

– stochastic character of plantation allocation and lack of preliminary information on the growing of plants of the species under study, requiring a preliminary search for the objects of study over large areas;

– diversity of urbanized environment conditions affecting the condition, growth and development of plants, implying the use of pre-planned multifactor experiments (observations, measurements) and, as a consequence, the need for significant volumes of statistical samples with a sufficient amount of data in the cells of the experimental plan.

Conducting studies under such conditions requires the use of data collection methods combining the necessary completeness, accuracy, maximum objectivity of information and high productivity, minimum labor intensity and cost of work. This problem is partly solved by the application of a two-stage method of data collection arrangement, when at the first (preliminary) stage the places of plant growth of the studied species are identified and primary information on plantations, necessary and sufficient for planning the experiment and forming representative samples, is obtained; at the second stage detailed taxation of sample objects is carried out in accordance with the research program.

Currently, to identify the place of plant growth of the studied species in urban plantings, methodological approaches are used, which with some generalizations can be grouped into the following three groups:

– surveys of territories of individual objects of urban landscaping with different functional purpose and located in zones with different levels of anthropogenic pollution [3; 7; 8, etc.];

– route surveys in different districts and territorial zones in most of the urban area to identify plantings of different volume-spatial structure and functional purpose [10; 11; 15, etc.];

– continuous survey of the entire urban area, which is used for relatively small areas and the study of plant species rarely found in a given locality [13].

Obviously, in all cases it is more appropriate to use a two-stage method, which involves a preliminary (reconnaissance) survey of the urban area and obtaining primary information on plantations of the species under study. In this case, at the first stage, as a rule, two sets of data are obtained: coordinates of geographical location and survey taxation characteristics.

Realization of the task of increasing the productivity of work with simultaneous improvement of accuracy, completeness and objectivity of the data obtained at the preliminary survey stage can also be carried out through the use of electronic multifunctional mobile devices (smartphones, pads, etc.) and mobile software applications. They have become generally available and widespread, providing the ability to work on digital platforms of web mapping services, as well as obtaining high-quality photo images with the geographical information. Examples of such use are available in studies in related fields [4].

OBJECTS AND METHODS OF RESEARCH

As an elementary object for obtaining primary data at the preliminary survey stage, a plantation is accepted, which in the system of urban landscaping is understood as a set of woody, shrub and herbaceous plants in a certain area [5]. Thus, the population of plants of the studied species from one individual and more for the purposes of the study, can be considered conditionally, as a plantation. The number of plants in each particular plantation is determined on place visually according to the principle of biogrouping or other criteria, depending on the objectives of the study.

The following functions of mobile devices are proposed to be used for data collection:

– Internet communication providing online access to web mapping services (Google Maps, Yandex Maps, Map World, etc.);

– determination of the device location by means of the built-in GPS-sensor with the option of coordinates correction according to the parameters of cellular mobile communication and Wi-Fi;

– taking photos using the built-in camera with options to record geographic coordinates in the metadata (EXIF tags) of the photo.

According to the obtained geographic coordinates, in addition to the location of plantations, using web-mapping services or GIS-systems, it is possible to obtain data on transportation routes, industrial enterprises, large green areas, water areas of rivers and lakes located in the area of the studied plantations, as well as other information that allows to differentiate data on the spectrum of conditions of local growth.

On the basis of photo-images it is possible to determine a number of taxation characteristics of stands and individual plants [2], as well as data relevant for the organization of detailed taxation works, such as:

– plant species, species composition (for mixed plantings);

– age group;

– life state, presence of major defects and damages of crown and trunk;

– volumetric and spatial structure of plantations, type of planting;

– number of individuals;

– surrounding situation, accessibility for detailed taxation;

– others.

Some of the characteristics to be defined may be differentiated into categories adopted temporarily for preliminary groupings of data, some of which may need to be specified at a later date.

The given list of parameters, determined directly or indirectly on the basis of data obtained through mobile devices and applications, for the task of collecting primary information about plantations can be considered, if not exhaustive, then at least sufficient, containing the core information on the basis of which samples can be formed when planning an experiment and organizing detailed taxation works. Thus, obtaining primary data can be summarized:

– to determine geographical coordinates of plantation locations;

– obtaining photographic images of plantations.

The initial information for primary data collection are:

– boundaries of the surveyed area (route maps);

– information for identification of research objects (morphological features of plants, image samples, etc.).

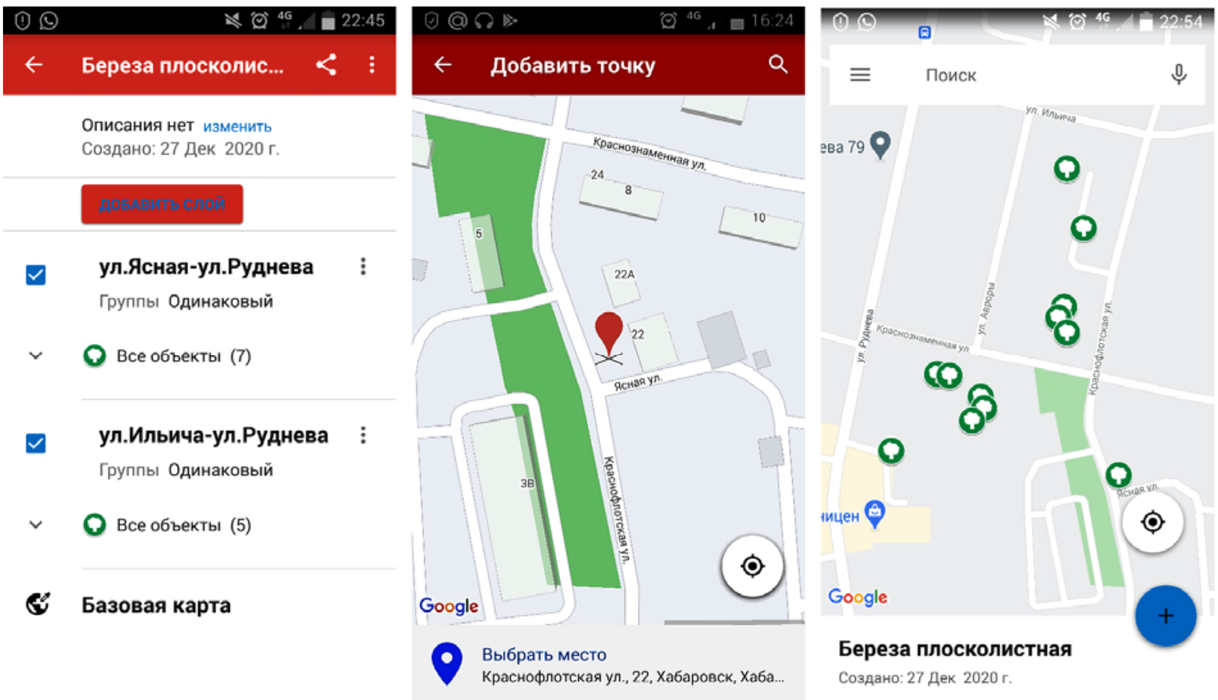
Google cloud elements are proposed for storing raw data and primary survey data, as well as for operational information management.

RESULTS AND THEIR DISCUSSION

Different field and desk work technology options are available for different types of landscaping objects.

Identification of intra-block plantations and obtaining primary data on them is carried out in the course of field works on the landscape. The search and identification of plantations is carried out by walking around and visual inspection of the territories in accordance with the route plan, and photography and determination of geographical coordinates is carried out with the help of mobile software and hardware. In order to determine the coordinates of plantations, accurate enough for their subsequent detection, it is proposed to use the method of geo-labeling on electronic maps of mobile web-services. Location of intra-block plantings on the territories of residential and public-business zones, next to buildings, in close proximity to the road-trail network makes it possible to use these objects as bases, relative to which the location of plantings on the map is determined. The mobile application "Google My Maps" [16] allows you to create and edit user geoinformation layers on the basis of Google maps, including in the form of point objects (geotags) with assigned numbers and, if necessary, combined into groups (Fig. 1, *a*). Installation of a geotag is preceded not by adjusting its location to the map, but by adjusting the map to the tag's sight (Fig. 1, *b*), which allows to achieve positioning accuracy up to 3–5 m relative to buildings and eliminates the need to use a stylus. The mobile application "Google My Maps" is second in capabilities to the full-featured cartographic web service "Google Maps", in particular, it does not contain the function of saving the created layers with tags to a separate file. However, since this application uses a Google account, the created layers automatically become available on all devices connected to the user's account. This makes it possible to save the layers created on a desktop computer or laptop using the Google Maps web service (Fig. 1, c) into a separate kml-file for further independent use, e.g. in GIS systems.

Unfortunately, the Google My Maps mobile application also does not allow to geotag photo images (as is possible with the full-function web service Google Maps) or to write geographic coordinates obtained by specifying geotags on maps automatically into photo metadata. The last task, geotagging of photo images, is usually solved with the help of special programs that use the correspondence between the time of photo shooting and the time of geotrack point recording obtained with the help of GPS-tracker for synchronization of photo images and geographic coordinates. "Google My Maps" does not record the time of geotagging on the map automatically, therefore it is not possible to use geotagging directly with the help of synchronizing programs. However, the principle of correspondence in time can be used indirectly by creating two temporal sequences of data, the synchronization of which is based on the mutual ordering of their elements. The first sequence is a set of geotags on Google maps, the numbering of which is required to be strictly in ascending order over time. The second sequence is a set of photo images, which can be organized by time using the automatic recording of the time of photo creation in the metadata of the image file, which is performed during digital photography. The relative ordering of the elements that make up these sequences is achieved by the fact that only one geotag is created per plantation and only one photograph is taken, and the photograph is created only after the geotag is placed on the map. Thus, we obtain two time series in which each pair of data (geotag – photograph) corresponds to only one plantation.



a *b* *c*

Fig. 1. Interface of the mobile application "Google My Maps":
a – structure of geoinformation layers on the user map "Flat-leaved Birch";
b – installation of geotag by adjusting the map to the tag sight; *c* -- set of created geotags

To create a table with the data of plantation numbers, their geographic coordinates and hyperlinks to the corresponding photo images, the information obtained during field work is prepared as follows: 1) kml-file with geotags is reformatted into a csv-file, in which tag names, latitude and longitude of their locations are batch distributed (simultaneously the whole set) into separate columns by text separation, e.g. using Excel's “Text by Column” tool, and sorted in ascending order of tag number (which will correspond to the specified temporal sequence); 2) files with photo images are renamed in such a way that the file name contains the date and time when the photo was created – many photo editors allow you to do this in batch (from free ones: Adobe Bridge, Namexif). After changing the name of the photos, they will be automatically arranged in the file folder in chronological order, which will correspond to the temporal sequence of geotags and will allow creating hyperlinks to the photo images for the corresponding plantation numbers. This procedure can be implemented programmatically to speed up the process and to avoid errors possible when creating hyperlinks manually. The proposed method is quite simple, allows to ensure data synchronization, but has a disadvantage – the possibility of errors when creating a temporary sequence of geotags manually in the field, which is associated with the influence of the human factor. These errors, however, are successfully mitigated by observing the following rules: a) the numbering of geolabels in the Google My Maps mobile application should be created strictly in ascending order over time, ignoring possible cases of missing numbers and regardless of the layer in which the geotags are located; b) a photo should always be created only after the geotag has been placed on the map; c) regular checks should be made to ensure that there are no repeating numbers and that the number of photos corresponds the number of geotags in individual groups (for example, when moving to another work area, when creating a new layer with geotags, etc.).

Identification of park and natural plantings and their initial assessment is also carried out on the ground during field work. In some cases, the methodology for collecting primary information for this type of landscaped area may be identical to that for intra-block landscaping. However, park and natural plantings are often large; plantings with the desired species may be located at a considerable distance from buildings, structures and other objects suitable as geopositioning bases; the road and path network is not always well developed and not all its elements are shown on Internet maps accurately enough. Therefore, using the method of geotagging on electronic maps of mobile web services to determine the location of plantations can give very approximate results in such conditions. It is proposed to determine the geographical coordinates of plantations in such cases by means of a GPS module on a mobile device, which is currently equipped with almost all modern models of smartphones and pads.

It is known that the accuracy of geopositioning using GPS-sensors is determined by the quality of the satellite signal received by the receiving device, which in turn depends on a number of factors, the key of which are: the number and geometric location of satellites with which the device is connected at a given time; the presence of obstacles in the signal path or objects shielding and reflecting the signal (multi-storey buildings in the immediate vicinity of the measurement point, closed canopy of trees, sharply rugged topography, etc.) [1]. The GPS system provides location of objects with an error of 10-15 m, GLONASS system - with an error of 10–20 m [14]. The minimum recommended number of simultaneously involved satellites is not less than 5. The joint use of GPS and GLONASS satellite systems allows to reduce the error of positioning by about 3–5 m. In addition, in city conditions, the additional number of satellites that can be used creates a reserve for cases of signal blocking by high-rise buildings and other obstacles [14]. Using mobile applications that allow to control the quality of the signal received on the smartphone and diagnose related software and hardware problems, for example: GPS Test [17], you can programmatically check the number of satellites connected to the device (GPS, GLONASS, etc.), the geometry of their mutual location relative to the device, SNR (signal-to-noise ratio, showing the strength and quality of the received signal), as well as the approximate accuracy of geopositioning (Fig. 2).

Moreover, in modern smartphone models in addition to data received by the device directly from satellites, it is possible to include corrections using information about the distance to cell towers and Wi-Fi signal, which significantly increases the accuracy of geographic coordinates [1]. To enable this function in the smartphone menu “Location – Mode” select the option “By all sources” (by the example of the Android operating system).

After you turn on and configure the GPS sensor to the currently available satellite grouping, you can take photos and add the geographic coordinates of the photo location to the photo metadata. The function of adding geotag to the photo image is activated on the smartphone by selecting the corresponding option in the photo mode settings. Thus, using this approach we get one set of data as a result of fieldwork – photo images with geotags.

To create a table with the data of plantation numbers, their geographical coordinates and hyperlinks to the corresponding photos, the information obtained during field work is prepared as follows: 1) a vector layer is created in QGIS environment on the basis of geotagged photos (for QGIS 2.* – using ImportPhotos module, for QGIS 3.* – using Import geotagged photos tool), which is saved in csv-file; 2) file names of photo images, latitude and longitude of the place of shooting in the structure of csv-file are batch separated by certain columns and sorted by file name. Creation of hyperlinks to the photo images is performed by the correspondence of the file name of the photo images, which similar to the one shown for intra-block plantings can also be implemented programmatically.

From the organizational moments it should be noted that operation of GPS-module, especially in the “All sources” mode, is associated with significant power consumption, which leads to a rather fast discharge of the mobile device battery. In this regard, if there are significant areas of surveyed territories and large volumes of field work, the set of auxiliary equipment should include a spare battery for a smartphone and a charger that works from the car power grid.

The identification of street plantings and obtaining primary information about them is proposed to be carried out in the laboratory conditions through the Google Maps web mapping service. There is a possibility to view spherical photopanoramas of the territories in the street view mode adjacent to the road network of large cities, including with green plantings growing on them (Fig. 3). Search and identification of plantings of the studied plant species is carried out by means of virtual movement along the road axis and inspection of the surrounding space available in the visual range. The geographic coordinates of the observer's location are included in the URL, which can be copied. To ensure the accuracy of the coordinate values, the observer should stop in front of the plantation, if possible on a line perpendicular to the road axis. Batch extraction of geographic coordinates from the entire set of copied URLs is performed by text separation. The result is a data set with geographic coordinates of plantation locations, each of which is assigned an identification number. A copy of the original URLs is saved to create a column with active web links for further viewing of selected plantations in Google Maps, their initial taxation assessment, control and correction of work results. As Google changes the Google Maps web service data over time, some of the saved URLs may no longer be valid. Therefore, in order to ensure the long-term relevance of the obtained information, it is recommended to duplicate the web links with URLs with screenshots of plantation images and create separate hyperlinks for them. We have been using the proposed approach since 2015 on the example of landscaping the streets of Khabarovsk to study the distribution and initial assessment of various morphological characteristics of tree species – conifers, broad-leaved, small-leaved (10 species in total at the moment), as well as shrubs, and it has shown good results [6; 9; 12, etc.]. It should be noted that when planning further studies, it is necessary to take into account the date of creation of the Google photo-panoramas (date of survey) and, in this regard, the corresponding changes in the stands at the time of the start of detailed taxation. In addition, the data on the location of plantations obtained by the proposed method need some correction due to the fact that the geographical coordinates extracted from the URL actually correspond to the point on the road from where the Google photo panoramas were taken. The location of plantations can be corrected on any GIS platform by shifting the geotags to the required side of the roadway and then overwriting the geographic coordinates. The errors arising in this process, related to the glance estimation of the distance from the plantation to the edge of the roadway, are insignificant for the purposes of the study.

a *b* *c*

Fig. 2. Interface of the GPS Test mobile application:
a – average SRN value on the scale, SRN histogram for each of the connected satellites, accuracy (±m);
b – location of satellites in the sky relative to the device; *c* – satellite filter

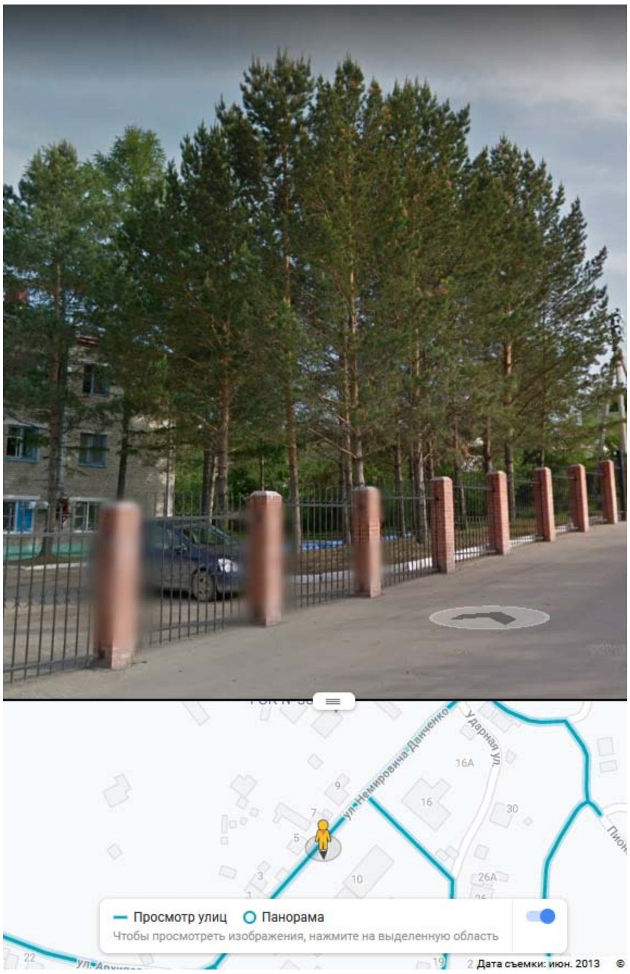


Fig. 3. Google Maps photopanorama (plantation of common pine; Nemirovicha-Danchenko str., Khabarovsk)

CONCLUSION

The proposed version of the hardware-software complex and methodological support for the collection of primary data on urban plantations meets the following criteria:

1) decrease in the cost of field work and post-processing of information due to:

– use of common and accessible equipment that is available to almost everyone and does not require separate purchase costs (smartphones, cell phones, pads);

– use of free software (web mapping services; mobile software applications available for free download in Google Play Store, etc.);

– simplicity of the methodology of data collection and primary data processing, which does not require highly qualified personnel and allows for extensive use of student resources.

2) reduction of labor intensity and increase in productivity of field works due to:

– minimizing the set of collected data – two sets of data: geographic coordinates (in different formats) and photo-images; for park and natural plantations – one set of data: photo-images with geotags;

– transfer of a part of field works (on street plantings) to the format of virtual survey on spherical photopanoramas of Google Maps in the laboratory.

3) reduction of labor intensity and increase in productivity of desk works due to:

– exclusion of digitization of field materials on paper (route maps, record cards, forms, etc.);

– minimizing the volume of manual operations through batch automatic processing of data sets;

– using cloud-based elements of the Google Maps web service, which eliminates the need for additional data copying and transferring activities.

4) ensuring the necessary completeness, accuracy and objectivity of data by:

– use of a non-contact method of one-step fixation of the entire volume of available visual information – photography, which excludes subjective judgments regarding the characteristics of plantations and accidental loss of some data;

– the possibility of repeated and low-cost return to the original field survey data (photographic materials) to check the correctness of the made taxation estimates (if there are suspected errors, there is no need for verification visits to the location of plantations);

– reducing the frequency of losses and errors caused by the human factor by automating the processes of data collection and post-processing.

Additional features of the mobile devices and applications used include the function of saving Google map fragments and using them through the mobile application in off-line mode in situations of poor or no internet connection. It can also sometimes be useful to create an audio file associated with a photo to record individual voice comments.

The hardware-software complex and methodology have been tested in real field conditions for a number of years and proved its effectiveness. The data obtained as a result of preliminary survey of urban plantations are in the format of the electronic tables with geographical coordinates of plantations (in WGS 84 coordinate system), their primary taxation characteristics, hyperlinks to photo images, and can be exported to database management systems and geo-information systems.

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ПРИНЦИП ПРОСТРАНСТВЕННО-ВРЕМЕННÓГО ЗАМЕЩЕНИЯ В ЭКОЛОГИИ И ПРОГНОЗИРОВАНИЕ БИОМАССЫ *Picea* spp. ПРИ ИЗМЕНЕНИИ КЛИМАТА*

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Человеческое общество столкнулось сегодня с проблемами глобального масштаба, вследствие чего приоритеты экологических исследований сдвигаются на макроуровень, экология вступает в эпоху «больших данных». Авторами сформирована база данных в количестве 1550 модельных деревьев Picea spp. с замеренными показателями высоты дерева, ширины кроны и надземной биомассы, произрастающих на территории Евразии. Рассчитаны регрессионные модели для компонентов надземной биомассы, включающие в качестве независимых переменных ширину кроны, высоту дерева и два климатических показателя. На основе теории пространственно-временнóго замещения полученные закономерности изменения надземной биомассы в территориальных климатических градиентах Евразии использованы для прогноза изменений биомассы вследствие климатических сдвигов. В соответствии с законом лимитирующего фактора Либиха установлено, что в достаточно влагообеспеченных климатических поясах повышение температуры на 1 °С при неизменном количестве осадков вызывает увеличение биомассы, а во влагодефицитных поясах – ее снижение; в теплых климатических поясах сокращение уровня осадков на 100 мм при неизменной средней температуре января вызывает снижение биомассы, а в холодных климатических поясах – ее увеличение.

Ключевые слова: *гидротермические градиенты, компоненты биомассы, лидарное зондирование деревьев, аллометрические модели, средняя температура января, годовые осадки.*

*Conifers of the boreal area. 2*023, Vol. XL, No. 7 (special), P. 603–608

THE PRINCIPLE OF SPACE-FOR-TIME SUBSTITUTION IN ECOLOGY AND THE PREDICTION OF *Picea* spp. BIOMASS WITH CLIMATE CHANGE

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Today, human society is faced with problems of a global scale, as a result of which the priorities of environmental research are shifting to the macro-scale level, and ecology is entering the era of "big data". The authors have created a database of 1550 model Picea spp. trees with measured indicators of tree height, crown width and aboveground biomass growing in the territory of Eurasia. Regression models for aboveground biomass components are calculated, including crown width, tree height, and two climate indicators as independent variables. Based on the theory of space-for-time substitution, the obtained patterns of changes in aboveground biomass in the territorial climatic gradients of Eurasia are used to predict changes in biomass due to climate shifts. In accordance with the law of the limiting factor by Liebig, it is established that in sufficiently moisture-rich climatic zones, an increase in temperature by 1°C with a constant amount of precipitation causes an increase in biomass, and in water-deficient zones – its decrease; in warm climatic zones, a decrease in precipitation by 100 mm at a constant average January temperature causes a decrease in biomass, and in cold climatic zones – its increase.

Keywords: *hydrothermal gradients; biomass components; tree lidar sensing, allometric models; mean January temperature; annual precipitation.*

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INTRODUCTION

Most of the environmental problems facing human society today can only be solved on a global scale, and the priorities of environmental research are shifting to the macro level. Ecology has entered the era of "big data", "big science" and "big theories" [17]. In the context of global climate shifts, understanding the development of forest ecosystems in terms of their capacity to absorb atmospheric carbon is of increasing interest. Changes in the biological productivity of the vegetation cover occur in localized gradients of natural zones formed as a result of long-term evolution of vegetation [9; 14]. These climate-related spatial gradients of tree and stand productivity can be used to prospectively predict its changes over time under anticipated climate shifts based on the theory of space-for-time substitution. Space-for-time substitution means using current patterns observed in spatial gradients to understand and model the same patterns in prospective time gradients that are currently unobservable [7]. Methods based on space-for-time substitution have been applied in various fields. In particular, to study long-term nutrient cycling and plant succession [12] or in biodiversity prediction [10], with encouraging results [7; 19].

A comparative analysis of the accuracy of different methods for determining the biological productivity of tree species has shown that models performed at the tree level give a smaller error in estimating biomass per unit area compared to models performed at the stand level [28]. Allometric models of tree biomass are particularly relevant for estimating biomass in stands of mixed species composition [20]. The inclusion of territorial values of temperature and precipitation as additional independent variables in allometric models of tree biomass has improved the accuracy of estimates and made it possible to predict biomass changes in Chinese forests under climatic shifts [11; 27]. It has been shown that a 1 °C warming leads to a 0.9 % increase in aboveground tree biomass and a 2.3 % decrease in root biomass; a 100 mm increase in precipitation causes a 1.5 and 1.1 % decrease in aboveground and belowground biomass, respectively [27]. In these studies, regional climate differences are extrapolated to projected climatic shifts in time in accordance with the principle of space-for-time substitution [11; 27].

Aboveground biomass of trees is most often estimated using allometric dependence on height and trunk diameter at breast height. Having analyzed the world data of aboveground biomass of stands on 640 sample plots, M. Cannell [8] found that for the same dimensions of trunk diameter and tree height, aboveground biomass in tree species with developed crowns is significantly underestimated. Key pantropical equations that include height but do not consider crown size underestimate tree biomass by 11–14 %, primarily due to undercounting the largest trees.

Airborne laser scanning (ALS) technology has a huge advantage over traditional ground-based taxation because of the sharp reduction of labor-intensive field work [2; 13]. Since trees of different tree species have a specific configuration of the vertical profile, this specificity is now successfully recognized using onboard laser sensors [15].

In this study, we intend to (a) identify at the transcontinental level, using spruce trees as an example, how aboveground tree biomass is related not only to morphometric tree indices obtained by airborne laser scanning, but also to spatial averages of temperature and precipitation in Eurasia, and (b) apply the obtained patterns to predict biomass changes due to climatic shifts based on the theory of space-for-time substitution.

Table 1
Sample statistics of model trees *Picea*

Statistics [a]	Analyzed indicators [b]					
	H	*Dcr*	*Ps*	*Pb*	*Pf*	*Pa*
Mean	13,8	2,7	136,4	20,4	12,6	168,1
Min	0,43	0,25	0,005	0,001	0,004	0,011
Max	44,8	10,9	4122,0	1259,6	305,0	5089,0
SD	9,3	1,5	337,7	59,3	26,1	413,0
CV.%	67,6	55,8	247,6	291,0	206,9	245,7
n	1550	970	1330	1550	1550	1330

Note. [a] Mean, Min and Max – average, minimum and maximum values, respectively; SD – standard deviation; CV – variation coefficient; n – number of observations. [b] *H* – tree height, m; *Dcr* – crown width, m; *Ps, Pb, Pf* and *Pa* - biomass of trunk in bark, branches, needles and aboveground in absolutely dry state, kg.

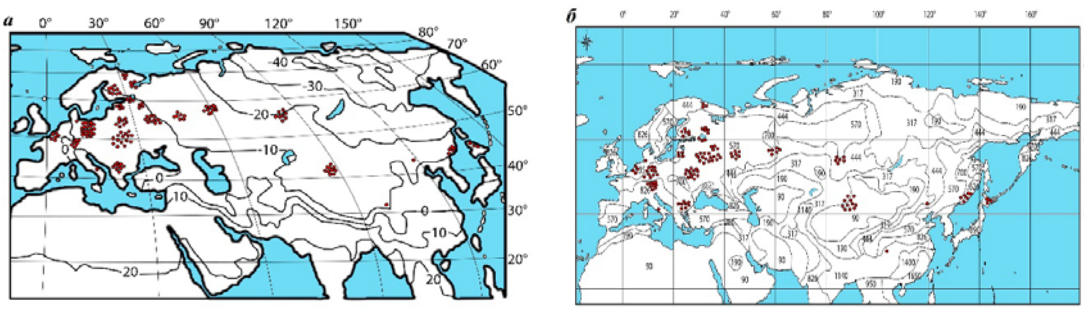

Fig. 1. Position of empirical data of 2030 model trees on the maps of mean January temperature, °C (a) and mean annual precipitation, mm (b) [26]

MARETIALS AND METHODS OF RESEARCH

To solve the set tasks, we used a database on the biomass of forest-forming species of Eurasia in the amount of 15200 trees [22]. From it, 1550 model trees of *Picea* spp. with measured indices of tree height, crown width and biomass of needles and branches, 1330 trees with indices of trunk and aboveground biomass and 970 trees with indices of crown width were selected (Table 1). The genus *Picea* spp. is mainly represented by species of *Picea abies* (L.) H. Karst. and P. *obovata* Ledeb.) and in smaller numbers species of *P. schrenkiana* F. *et* M.., *P. ajanensis* (Lindl.*et* Gord.) Fisch. *ex* Carr., *P. koraiensis* Nakai. and *P. purpurea* Mast.

Available data of geographic coordinates of model trees were plotted on maps of mean January temperature (https://store.mapsofworld.com/image/cache/data/map_2014/currents-and-temperature-jan-enlarge-900x700.jpg) and mean annual precipitation (http://www.mapmost.com/world-precipitation-map/free-world-precipitation-map/) [26] (Fig. 1) and are combined with morphometric indices of model trees [23]. The rejection of the use of mean annual temperature in favor of mean January temperature has been justified previously [23; 24]. The obtained table of initial data was included in the regression analysis [24].

RESUTS AND THEIR DISCUSSION

Allometric models for the correlation of aboveground biomass with tree height and crown width have been previously proposed [21].

$$\ln Pa = a_0 + a_1 \ln H + a_2 \ln Dcr, \quad (1)$$

where *Pa* – aboveground biomass, kg. As a result of regression analysis of empirical continental-level data, we propose a model of aboveground biomass combining tree morphometric indices (model (1)) and climatic variables:

$$\ln P_i = a_0 + a_1(\ln Dcr) + a_2(\ln H) + a_3[\ln(T + 40)] + $$
$$+ a_4(\ln PR) + a_5[\ln(T + 40)]\cdot(\ln PR), \quad (2)$$

where P_i – biomass of i-th tree component (respectively *Ps, Pb, Pf* and *Pa* – trunk in bark, branches, needles and above-ground in absolutely dry condition), kg; *T* – mean January temperature, °C; *PR* – mean annual precipitation, mm; $[\ln(T+40)]\cdot(\ln PR)$ – is a combined variable characterizing the joint effect of temperature and precipitation. Most regression coefficients are significant at the $p < 0.05$ level. Since the mean January temperature in high latitudes has a negative value, for its logarithmization in model (2) it is reduced to the form (T+40).

The results of calculation of models (2) are shown in Table 2.

The geometric interpretation of models (2) is obtained by substituting into (2) the mean values of *Dcr* and *H* taken from Table 1.

As we can see in Fig. 2, the dependence of aboveground biomass of equal-sized spruce trees on temperature and precipitation is described by 3D propeller-shaped surfaces. In cold regions, biomass decreases with increasing precipitation, but as we move to warm regions, it is characterized by the opposite trend. Biomass increases with increasing temperature in humid regions, but begins to decrease as we move to dry conditions. A similar pattern is characteristic of trunk biomass, but it is not so obvious for branch and needle biomass.

Let us consider the described regularities from a different perspective, realizing the concept of space-time substitution and the principle of "What would happen if...?". In other words, how will tree biomass react if, given constant spatial gradients of temperature and precipitation, we assume a 1 °C change in temperature over time or a 100 mm change in annual precipitation. Taking the first derivatives of the two-factor surfaces shown in Fig. 2, we obtained the patterns of biomass change under given changes in temperature and precipitation.

Figure 3 shows the change in tree biomass (Δa, %) with a 1 °C temperature increase in different climatic zones characterized by different temperature and precipitation ratios. It is assumed that precipitation changes only spatially, and temperature increases by 1 °C as a result of the assumed climate change at different spatial temperature levels, denoted as -30Δ...+10Δ. For stem and aboveground biomass, a general Eurasian-scale pattern was obtained: in sufficiently humid climatic belts, temperature increase with unchanged precipitation causes its increase (red areas of surfaces in Fig. 3), and in moisture-deficient belts it causes its decrease (blue areas of surfaces in Fig. 3 *a, b, d*). At the same time, minus values of branch biomass are observed only in extremely dry conditions (at annual precipitation of 300 mm). Obviously, the change in needle biomass does not go "into the minus" even in extremely dry conditions, and only approaches the zero level (Fig. 3, *c*).

Table 2
Calculation results of models (2)

$\ln(Y)^{(1)}$	$a_0^{(2)}$	ln*Dcr*	ln*H*	ln(*T*+40)	ln*PR*	[ln(*T*+40)]× (ln*PR*)	$adjR^{2(4)}$	$SE^{(5)}$
ln(*Ps*)	91,3762	0,6862	2,1229	–27,1626	–15,0636	4,3568	0,974	0,39
ln(*Pf*)	27,4702	1,2380	0,9116	$–6,8624^{(3)}$	–5,0223	$1,2126^{(3)}$	0,848	0,66
ln(*Pb*)	30,2767	1,6641	1,0806	–7,9246	–5,5036	1,3599	0,908	0,61
ln(*Pa*)	73,9962	0,9059	1,7195	–21,4481	–12,2168	3,4829	0,960	0,44

Note. (1) Dependent variables; (2) correction for logarithmic transformation of the model was applied [4]; (3) – regression coefficients not significant at the level of $p < 0,05$. (4) $adjR^2$ – coefficient of determination adjusted for the number of variables; (5)SE – standard error of equation (2).

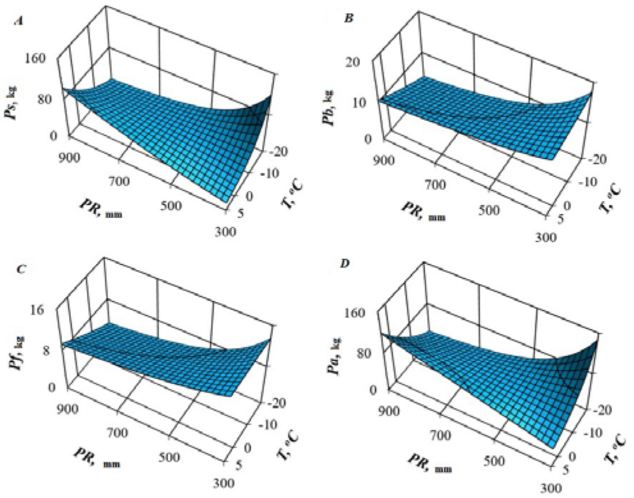

Figure 2. Calculated changes according to model (2) in aboveground biomass of spruce trees in relation to the mean January temperature (*T*) and annual precipitation (*PR*).
Biomass component symbols here and hereafter:
a, b, c, d **- respectively *Ps, Pb, Pf* and *Pa* - trunk in bark, branches, needles and aboveground in absolutely dry condition kg**

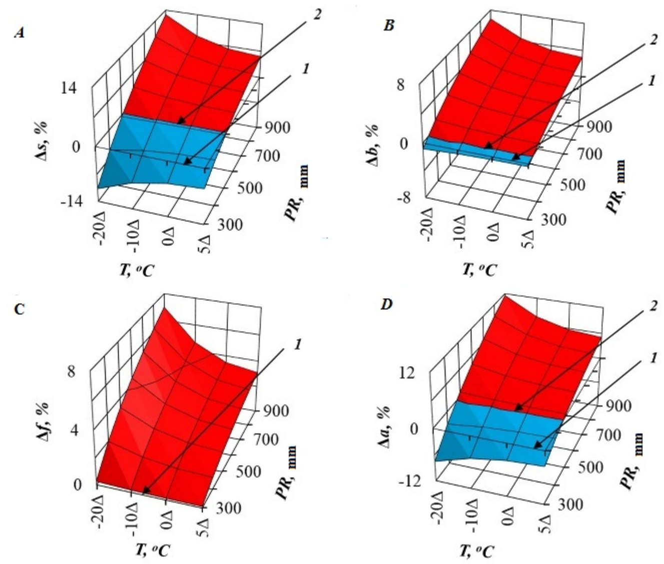

Figure 3. Change in tree biomass at 1 °C temperature increase due to the assumed climate change at different spatial levels of temperature and precipitation:
1 **- the plane corresponding to zero biomass change under the assumed temperature increase by 1 °C;**
2 **- the line distinguishing between positive and negative changes in biomass under the assumed temperature increase by 1 °C**

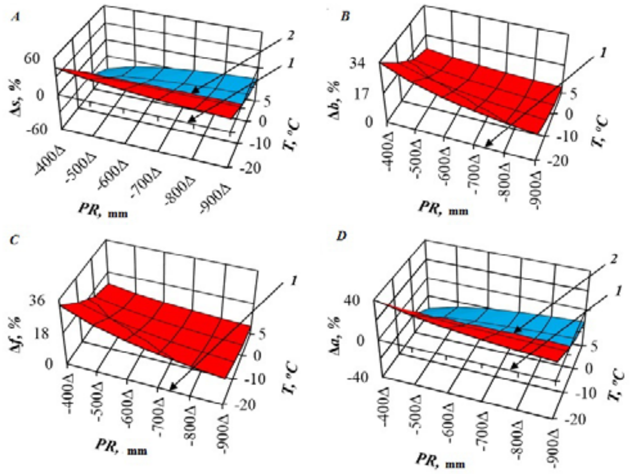

Figure 4. Change in tree biomass with decreasing precipitation due to assumed climate change at different territorial levels of temperature and precipitation:
1 **- the plane corresponding to the zero biomass change under the assumed precipitation decrease by 100 mm;**
2 **- the line of delimitation of positive and negative changes of biomass under the assumed precipitation decrease by 100 mm**

Figure 4 shows the change in tree biomass (Δa, %) when annual precipitation decreases by 100 mm in different climatic zones. It is assumed that the January temperature changes only spatially, and precipitation as a result of climate change decreases by 100 mm at different spatial precipitation levels, denoted as -300Δ...-800Δ. A general transcontinental pattern was established: in warm climatic belts, a 100 mm decrease in precipitation levels at unchanged mean January temperature causes a decrease in stem and aboveground biomass (blue area of surfaces), while in cold climatic belts it increases (red area of surfaces) (Fig. 4 *a, d*). The biomass of needles and branches decreases during the transition from warm to cold climatic conditions, and in the warmest zones (January temperature

5 °C) this decrease approaches zero, but does not go "to minus" (3D surfaces are entirely represented by the red zone (Fig. 4 *b, c*). Thus, the patterns of crown biomass change under shifts in temperature and precipitation are somewhat different from those of stem and aboveground biomass. The reason may be more evident residual dispersion in the crown biomass model due to the fact that interspecific variation of needle biomass and biomass of branches supporting it in space is explained not only by climatic factors, but also by the unrecorded ecological "noise".

Our results on changes in aboveground biomass of trees in two climatic gradients confirm the regularities previously established by Russian researchers at the local and regional levels. A similar regularity was traced earlier at the local level in swamp forests of the Tomsk region in Siberia, when at the maximum sums of temperatures above 10 °C, equal to 2200 °C, when precipitation increases from 400 to 600 mm, radial growth of trunks increases by 30–50 %, and at the minimum sums of temperatures (1600 °C) radial growth decreases by 4-9 % with increasing precipitation in the same range. Correspondingly, at a precipitation level of 400 mm with increasing temperature sums from 1600 to 2200 °C radial growth decreases by 14–20 %, and at a precipitation level of 600 mm in the same temperature range increases by 14–33 % [1]. According to the results obtained by A. A. Molchanov [3], in the conditions of northern Eurasia, air temperature has the greatest influence on the growth of the annual ring, while precipitation plays a dominant role in the conditions of southern forest-steppe.

The above regularities correspond to the principle of the limiting factor of Liebich [16], according to which plant growth is limited by an environmental factor that is minimal in relation to a certain "norm". However, the law of Liebich limiting factor works well under stationary conditions. When the limiting factor (e.g., air temperature or precipitation) changes rapidly, forest ecosystems are in a transient (non-stationary) state, in which some factors that have not yet been of significant importance may come to the fore, and the final result may be determined by other limiting factors [18].

We used existing changes in tree biomass in spatial climatic gradients to predict possible changes in tree biomass in assumed temporal gradients of temperature and precipitation. However, the fundamental assumption that spatial correlation between climate and biomass can be used to predict temporal trajectories of bioproductivity under a changing climate remains largely unproved [25]. The success of applying space-for-time substitution theory in plant ecology depends on the extent to which the ecological conditions that determine plant properties in spatial gradients are consistent with future ecological conditions that determine plant properties in a temporal gradient [5; 6]. Nevertheless, when there is no other possibility to study ecosystem processes in the long term, the method of space-for-time substitution is still an acceptable alternative.

CONCLUSION

A regression model was developed on the basis of the authors' database on aboveground biomass of 1550 trees of *Picea* spp. growing in Eurasia, including as independent variables both morphometric parameters of trees obtained by airborne laser scanning and territorial long-term data on temperature and precipitation.

The obtained trans-Eurasian regularities were used to predict biomass changes due to climatic shifts based on the theory of space-time substitution.

Eurasian scale regularities were obtained: in sufficiently moisture-supplied climatic belts, a 1°C increase in temperature with unchanged precipitation causes an increase in biomass, while in moisture-deficient belts it causes a decrease; in warm climatic belts, a 100 mm decrease in precipitation with unchanged mean January temperature causes a decrease in biomass, while in cold climatic belts it causes an increase.

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ВОСПРОИЗВОДСТВО СОСНЫ КЕДРОВОЙ СИБИРСКОЙ НА ГЕНЕТИКО-СЕЛЕКЦИОННОЙ ОСНОВЕ*

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В статье приведены результаты изменчивости микросателлитных локусов ядерной ДНК клонового потомства плюсовых деревьев сосны кедровой сибирской 91/55, 94/58 и 100/64, произрастающее на прививочной плантации Караульного участкового лесничества Учебно-опытного лесхоза СибГУ им М. Ф. Решетнева (юг Средней Сибири).

По результатам исследований проведен отбор 8 стабильных и надежных праймеров методом полимеразной цепной реакции и электрофореза. Индетифицированы генотипы ДНК образцов сосны кедровой сибирской. Установлена $1{,}5\times10^{-6}$ вероятность случайного совпадения аллелей у неродственных генотипов. Выявлены 4 общих ДНК-профиля.

Ключевые слова: *сосна кедровая сибирская, плюсовые деревья, клоновое потомство, прививочные плантации, микросателлиты ядерной ДНК.*

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REPRODUCTION OF *PINUS SIBIRICA* DU TOUR ON A GENETIC AND BREEDING BASIS

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The article presents the results of variability of microsatellite loci of nuclear DNA of clone progeny of Siberian cedar pine trees 91/55, 94/58 and 100/64, growing on the grafting plantation of the Sentry district Forestry of the Educational and Experimental Forestry of the Reshetnev University (south of Central Siberia).

Based on the research results, 8 stable and reliable primers have been selected by polymerase chain reaction and electrophoresis. DNA genotypes of Siberian cedar pine samples have been identified. The probability of a random coincidence of alleles in unrelated genotypes was 1.5×10^{-6}. 4 common DNA profiles were identified.

Keywords: *siberian cedar pine, plus trees, clone progeny, grafting plantations, nuclear DNA microsatellites.*

INTRODUCTION

Siberian pine *Pinus Sibirica* Du Tour is one of the most important forest-forming species, as well as a valuable nut-bearing species in Russia [12]. Many studies have been performed to research the selection, variability and softening of Siberian pine *Pinus Sibirica* Du Tour in terms of productivity and reproductive development, and subsequently to the cultivation of selective planting material to create genetically valuable high-yielding nut-producing plantations [9; 6–13]. Grafting plantations cre-

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ated by ramets from plus trees certified for seed production are a valuable gene pool to conduct genetic research of selectable traits, which is an urgent task in the field of forest selection based on molecular genetics to create high-yielding industrial plantations [10–12].

Studying the genetic material of the clonal progeny of plus trees of Siberian cedar pine, growing at the educational and scientific places of the Karaulny district forestry of the Educational and Experimental Forestry Enterprise of the Reshetnev University is important for the conservation and rational use of the gene pools of this species.

The accumulated long-term data on the selection of Siberian cedar pine require genetic studies of the results obtained. In recent years, due to the development of specific primers, the SSR method, in which codominantly inherited nuclear microsatellite loci (nSSRs) are used as DNA markers, has become widely used in genetic studies of conifers. High polymorphism of microsatellites makes it possible to identify an organism with high accuracy and reveal biological relationships.

The purpose of the research is to select genetic markers of Siberian cedar pine and test them by carrying out genetic certification of the offspring of plus-trees.

OBJECTS AND RESEARCH METHODS

The research objects were the clonal offspring of three plus-trees 91/55, 94/58 and 100/64, growing on the grafting plantation of the Karaulny district forestry of the Educational and Experimental Forestry Enterprise of Reshetnev University. (southern Central Siberia).

Plus-trees were certified for yield in the Kolyvan forestry enterprise of the Novosibirsk region in 1977. Table 1 provides taxation characteristics of the plus-tree stand, where the studied plus trees grow. Table 2 characterizes the plus-trees at the certification time.

At the time of certification, the plus tree 91/55 was distinguished by a spherical crown with powerful branches with horns. The cones are large and late in maturity. The condition is good. Tree 94/58 had a powerful oval-oblong shape with powerful branches. The needle-foliage is thick. Female type of sexualization. The condition is good. Tree 100/64 had a spherical crown, dense foliage and an early ripening shape. The condition is very good. The survival rate of cuttings 91/55 is 88 %, 94/58 – 90 %, 100/64 – 97 %[**].

In 1988, plus-trees were propagated by grafting using the core method for cambium according to E. P. Prokazin. Siberian pine seedlings of local (Biryusa) origin were taken as a rootstock [1].

In May 2021, an inventory of ramets of plus trees was carried out at the grafting plantation and cuttings were cut for genetic research. Experimental material was collected from 47 clonal trees.

The methodological basis for the work was the microsatellite analysis method based on the polymerase chain reaction (PCR). Microsatellite loci are regions of the genome with repeating short (2–6 nucleotides) sequences called motifs [5]. The number of repeats at each locus varies from organism to organism, so each individual is characterized by a virtually unique multilocus genotype. Using the electrophoresis method gives a possibility to detect the variability of this parameter by determining the molecular weight of the variable fragment in this case the allele. Heavier molecules (with a larger number of repeats) migrate more slowly and polymorphism can be observed in the resulting electropherogram: the presence of different discrete variants in individual individuals, reflecting a different number of repeating motifs.

To study the variability of microsatellite loci of nuclear DNA, we studied pine needles, previously dried in a dry-heat oven at a temperature of +40 ºC for 2–3 days. DNA extraction from needles was carried out according to the standard protocol for plant tissues (CTAB method) using cetyltrimethylammonium bromide [15].

To select nuclear DNA microsatellite loci, developed specifically for studying the variability of Siberian cedar pine, 12 nuclear microsatellite loci were selected for testing [1], the characteristics of which are presented in Table. 3.

When performing PCR, a commercial GenPak®PCR Core kit (scientific manufacturing laboratory "Genlab" LLC, Russia) was used for all primers, according to the manufacturer's instructions.

PCR-amplification of selected microsatellite loci was carried out using the following regime: preliminary DNA denaturation was at 94 °C – 15 min; then 10 cycles, including 1 min of melting at 94 °C, annealing of primers for 1 min at 60–50 °C (–1 °C for each cycle) and 1 min. elongation at 72 °C, the next 25 cycles consisted of 1 min of melting at 94 °C, 1 min of primer annealing at 53 °C, and 1 min of elongation at 72 °C. The final elongation cycle took place at 72 °C for 20 min.

Electrophoretic separation of amplification products was carried out in 6 % polyacrylamide gel (PAGE), using 1xTAE buffer in chambers for vertical electrophoresis (VE-20, LLC "HELICON COMPANY") at a voltage of 200V for 2.5 hours. E. coli plasmid PBR322 DNA treated with HpaII restriction enzyme was used as a standard length marker. The gels were stained with ethidium bromide solution with further visualization of the amplicons in UV-light using the Gel-Imager gel documentation system. The analysis results were read using the PhotoCapt V.12.4 program (Vilber Lourmat). Analysis of the identified genotypes was carried out using the program (macro) GenAlEx, a freely distributed add-in for MS Excel [16].

[1] [**] Data provided upon request in 2021 in the Kolyvan forestry of the Novosibirsk region (condition assessment cards).

Table 1
Taxation characteristics of a positive forest stand

Structure	Age class/years	Average height, m	Average diameter, cm	Bonitet	Stand type	Density	Selection category
9К	4/160	18	52	III	thv	0,6	Plus for seed production
1С	6/110	20	44				

Table 2
Biometric indicators of *Siberian cedar pine*, selected for seed productivity

Number of a plus-tree	Age, years	Height		Stem diameter		Crown diameter, m
		m	% to Xav.	cm	% to Xav.	
91/55	140	19	105	72	138	8,5
94/58	150	23	128	72	138	10,0
100/64	110	17	94	44	84	7,0

Table 3
Characteristics selected for testing the nuclear microsatellite loci of the Siberian cedar pine

№	Locus	Motif	Primer sequence (5'–3')	Number of alleles, pcs.
1	Ps_80612	$(AAG)_{10}$	F:CTTCTAAGTGGGTCATCTTGGC R:CTGTCTAGGCTTTTGGCCTTTA	4
2	Ps_364418	$(TGA)_{10}$	F:TCGGACCTAAAGAAAAGAGGTG R:AAGATTCGTCTGAGTGGACGTT	7
3	Ps_1502048	$(AAT)_{11}$	F:AGATCCATCCCAATCACAGTTC R:AGGGACCTAGCACTTTCATCCT	3
4	Ps_1915155	$(TAT)_{11}$	F:TTGTTGGATTGGCTCATGG R:TCTCCAGTACACACCTCGATTG	4
5	Ps_2040062	$(GAT)_{12}$	F:TGGTATGAAAACCTTCAGCCTC R:TAATGTCGTCTTCGTCGTCGT	2
6	Ps_264432	$(TTC)_{13}$	F: GCATTGTTGATTTGTGTCCCTA R: GAGGCTGAAAAGGAGAAGATGA	4
7	Ps_1375177	$(CAT)_{10}$	F: ATGGGCTAGATGGTAGCAGTTC R: GGTGGTTTGGCTCTCTTAAATG	3
8	Ps_31489	$(AGA)_{6}$	F: CACCCAAACAAGACAAACCTCT R: TTCTTCCTCCTTCCCCTTATTC	2
9	Ps_25981	$(TATT)_{5}$	F: TTGAGTGGGATGGACATAGAG R: TTGCCCCAAGTCTACAAGAT	3
10	Ps_39709	$(ATGT)_{5}$	F: GTTCTCTTAACCTCGAACTTGTGAT R: CTGAAAACCCTGTCAAACAACA	4
11	Ps_718958	$(TAT)_{10}$	F: CTATGTATGGGTCAATGGTGTCC R: GATGCAACAAATGCACATGACT	2
12	Ps_650842	$(TTA)_{11}$	F: ATGCACTCTAACTCCAAGCACA R: ATAATGACCCAAGCATGAAACC	4

RESULTS AND THEIR DISCUSSION

The main criterion to select primers at the stages of PCR and electrophoresis was the stable and reliable manifestation of loci alleles and a sufficiently high level of polymorphism on the tested samples. On DNA preparations isolated from the needles of 47 trees, 12 nuclear microsatellite loci were tested (Table 3). Primary analysis of these loci demonstrated that Ps_650842 and Ps_264432 had 3 amplification zones, which made it difficult to read variants of the variable zone and could lead to future errors when interpreting the data obtained. The Ps_2040062 locus was polymorphic, but it clearly contained "null alleles" (the lack of amplification of some samples may be due to mutations in the "landing" zone of the primer). Another primer (Ps_718958) turned out to be monomorphic (Fig. 1). After excluding the loci described above, 8 loci that demonstrated the most stable interpretable spectra were taken into further work (Fig. 2 and 3, Table 4).

Based on the results of a DNA study of 47 Siberian cedar pine samples for 8 polymorphic nuclear microsatellite loci, data was analyzed in the GenAlEx program to identify genotypes and assess the probability of a random coincidence of multilocus genotypes. The probability of a random coincidence of alleles in unrelated genotypes, calculated for each locus, should not exceed 5 %, and when using the entire set of markers, the probability of erroneously establishing genetic identity should not exceed one millionth of a percent [2]. The probability of a random coincidence of alleles in unrelated genotypes, calculated for each locus, should not exceed 5 %, and when using the entire set of markers, the probability of erroneously establishing genetic identity should not exceed one millionth of a percent [2]. The method is also called population matching probability. It is widely used in DNA forensics as an indicator of the statistical power of a particular set of marker loci [6].

Calculations based on a set of 8 loci showed that the probability of a random coincidence of unrelated genotypes was 1.5×10^{-6}. This value confirms the effectiveness of using this set of microsatellite loci for genetic certification of the offspring of plus Siberian cedar pine trees.

Analysis of multilocus allele combinations by 8 microsatellite loci showed that out of 47 studied samples, 26 belonged to different genotypes (Table 5). Four common DNA profiles were identified: genotype A – samples No. 100/64_21-16 (2) and 100/64_21-16 (4); genotype B – samples No. 100/64_2-19, 100/64_3-19, 100/64_4-17, 100/64_4-18, 91/55_6-17, 100/64_7-18; genotype C – 91/55_3-15, 91/55_3-16, 91/55_5-15a, 91/55_8a-16, 91/55_8-16, 91/55_9a-16, 91/55_10a-16, 91/55_11-16 , 91/55_12-16; genotype D – samples No. 91/55_9-16 (1), 91/55_10-16 (2).

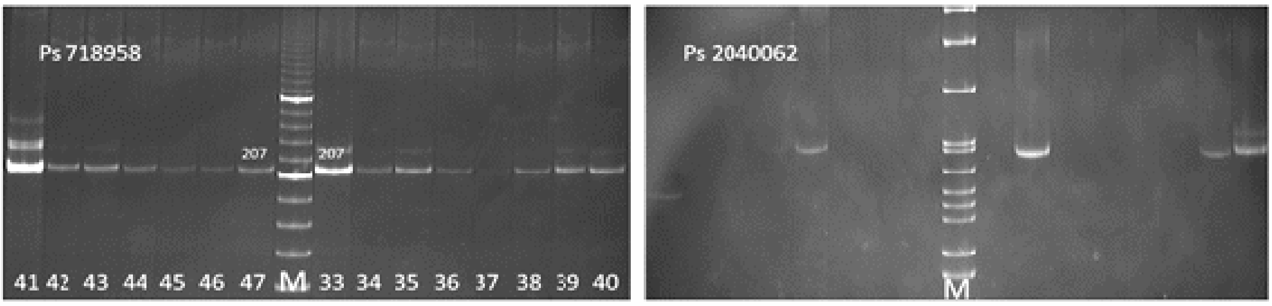

Fig. 1. Electropherograms of loci amplification products of Ps_718958 and Ps_2040062.
33–47 – serial numbers of tree samples. M – standard fragment length marker

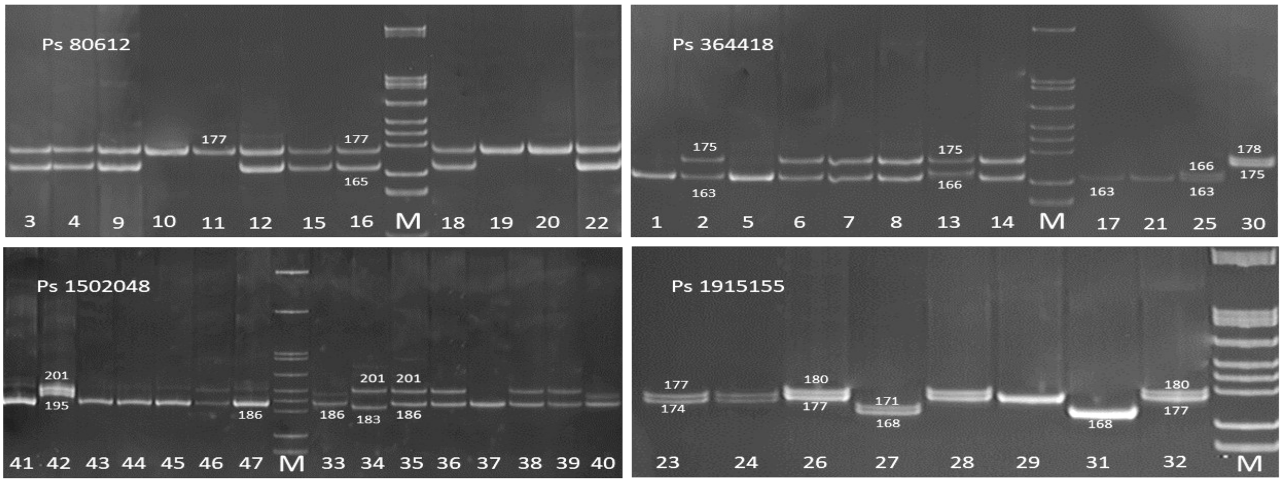

Fig. 2. Electropherograms of loci amplification products of Ps_80612, Ps_364418, Ps_1502048, Ps_1915155.
1–47 – serial numbers of tree samples. M – standard fragment length marker

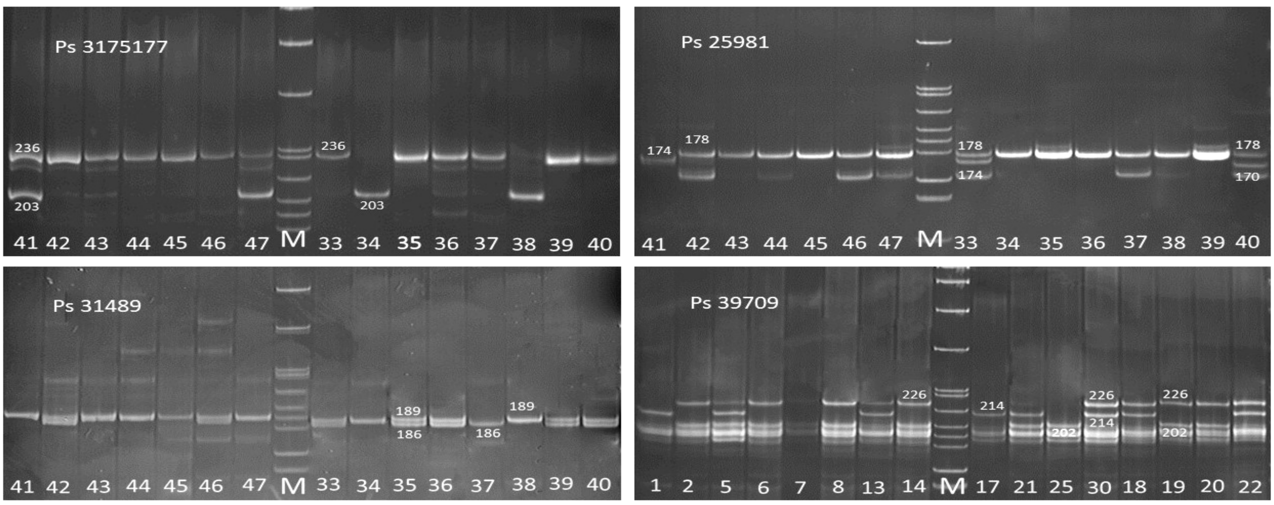

Fig. 3. Electropherograms of loci amplification products of Ps_3175177, Ps_25981, Ps_31489, Ps_39709.
1–40 –serial numbers of tree samples. M – standard fragment length marker

Table 4
Characteristics of nuclear microsatellite loci selected for further researching *Siberian cedar pine*

№	Locus	Motif	Fragment size	Number of alleles, pcs.
1	Ps_80612	$(AAG)_{10}$	162–180	5
2	Ps_364418	$(TGA)_{10}$	163–178	5
3	Ps_1502048	$(AAT)_{11}$	183–201	5
4	Ps_1915155	$(TAT)_{11}$	162–183	7
5	Ps_1375177	$(CAT)_{10}$	203–236	4
6	Ps_31489	$(AGA)_{6}$	186–189	2
7	Ps_25981	$(TATT)_{5}$	170–178	3
8	Ps_39709	$(ATGT)_{5}$	202–226	3

Table 5
Number of genotype matches in samples of progeny of plus *Siberian cedar pine* trees

№	Identification number		Multilocus genotypes	Genotype designation	Number of matches
	clone (plus-tree)	ramet			
1	100/64	21-16 (2)	163163177177189189177177236236186186178178214226g	A	2
2	100/64	21-16 (4)			
3	100/64	2-19	163175180183189189165177236236183192174178202226g	B	6
4	100/64	3-19			
5	100/64	4-17			
6	100/64	4-18			
7	100/64	6-17			
8	100/64	7-18			
9	91/55	3-15	163178177180186189165177236236186186170178214226g	C	9
10	91/55	3-16			
11	91/55	5-15a			
12	91/55	8a-16			
13	91/55	8-16			
14	91/55	9a-16			
15	91/55	10a-16			
16	91/55	11-16			
17	91/55	12-16			
18	91/55	10-16 (1)	166172174177186189165177236236186186170178202214g	D	2
19	91/55	10-16 (2)			
20	91/55	9-16 (1)	175178174183186186177177206236186195178178202226g	E	2
21	91/55	9-16 (2)			
22	100/64	2-18	163163171180186189177177206236183192178178214214g	1	0
23	100/64	3-18	163163177180186189165177206236186201174178202214g	2	0
24	91/55	5-16	163163174174186186177177236236201201170178202202g	3	0
25	91/55	6-16	163178162174186189165177206236186186178178202214g	4	0
26	100/64	6-19	166175174177186189168177206236186201178178214226g	5	0
27	100/64	8-18	163163177177189189168177209236186186178178214214g	6	0
28	100/64	9-18	163163177180189189165165206236186186178178202214g	7	0
29	100/64	10-18	163166177177186189177177206236186186178178202202g	8	0
30	91/55	11a-16	163175168171186186165177206209186186178178202214g	9	0
31	91/55	13-15	163163177177189189177177206236186186178178214214g	10	0
32	100/64	13-17	175178177177186189177180203203186186170178214226g	11	0
33	91/55	14-15	163166168168186189165180236236186186174178214214g	12	0
34	91/55	14-16	163175177180189189177180236236186195170178202214g	13	0
35	94/58	15-14	163163177177186189165174236236186186174178214226g	14	0
36	94/58	16-15 (1)	163178174177189189177177206206183201178178214214g	15	0
37	94/58	16-15 (2)	178178177177186189165177236236186201178178202214g	16	0
38	94/58	17-13	166175177180186189168177236236186201178178202226g	17	0
39	94/58	17-15	163175174174186186162177236236186186178178214226g	18	0
40	94/58	18-13	175175177183189189177180206206186201178178202214g	19	0
41	94/58	18-14	163178177180186189162165236236186201178178202214g	20	0
42	94/58	19-13	163175177180186189177180236236186195170178214226g	21	0
43	100/64	19-18	166172177180189189165177206236186186174174214214g	22	0

End of table 5

№	Identification number		Multilocus genotypes	Genotype designation	Number of matches
	clone (plus-tree)	ramet			
44	100/64	21-16 (1)	163175177180186189177180236236195201178178226226g	23	0
45	100/64	21-16 (3)	175175174180189189177180236236186186178178214226g	24	0
46	100/64	21-16 (5)	163163171180186189165165236236186201178178226226g	25	0
47	100/64	22-17	163175177177189189177177206206186186178178214214g	26	0

To confirm the correspondence of the obtained clone genotypes with the supposed plus trees No. 91/55, 94/58 and 100/64 growing in the Novosibirsk region, it is necessary to select material (needles or wood) from these trees. The authors plan to select control samples from plus-trees to determine their genetic characteristics and more detailed comparison of their genotypes with the genotypes of the clonal offspring.

CONCLUSION

During the research, 8 nuclear microsatellite loci of Siberian pine were selected, demonstrating the most stable interpretable spectra. The probability of a random coincidence of unrelated genotypes at these loci was 1.5×10^{-6}.

Four common DNA profiles were identified: genotype A – samples No. 100/64_21-16 (2) and 100/64_21-16 (4); genotype B – samples No. 100/64_2-19, 100/64_3-19, 100/64_4-17, 100/64_4-18, 91/55_6-17, 100/64_7-18; genotype C – No. 91/55_3-15, 91/55_3-16, 91/55_5-15a, 91/55_8a-16, 91/55_8-16, 91/55_9a-16, 91/55_10a-16, 91/55_11- 16, 91/55_12-16; genotype D – samples No. 91/55_9-16 (1), 91/55_10-16 (2).

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ СВЕРХВЫСОКОЧАСТОТНОГО ИЗЛУЧЕНИЯ НА ПРОНИЦАЕМОСТЬ ДРЕВЕСИНЫ ЛИСТВЕННИЦЫ СИБИРСКОЙ

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Древесина лиственницы сибирской за счет имеющихся в сибирском регионе значительных запасов является перспективным объектом для модификации. Однако из-за низкой проницаемости древесины ее пропитка модифицирующими составами практически невозможна. В работе представлены результаты исследований направленных на повышение проницаемости ядровой древесины лиственницы сибирской за счет воздействия СВЧ-излучения.

Экспериментальные исследования проводились на образцах древесины размерами 50×50×150 мм (последний вдоль волокон) изготовленных из свежесрубленной ядровой древесины лиственницы сибирской с исходной влажностью 55 %. Обработка древесины СВЧ осуществлялась в микроволновой камере при частоте 2,45 ГГц с фиксированной мощностью 0,9 кВт. Продолжительность обработки СВЧ составляла 270 с и 330 с.

После обработки СВЧ древесина пропитывалась в автоклаве при давлении 0,5 МПа в течение 40 мин. Для моделирования процессов происходящих в сортиментах промышленных размеров, у части образцов производилась герметизация торцов. В качестве пропиточного состава использовался водный раствор FeSO4.

Полученные экспериментальные данные показывают, что СВЧ-обработка древесины лиственницы позволяет эффективно повышать проницаемость древесины как вдоль, так и поперек волокон. В ходе исследований установлено, что СВЧ-обработка обеспечивает увеличение поглощения древесиной пропиточного раствора в 2,5–2,6 раза, а глубины пропитки поперек волокон в 2,3 раза. При пропитке короткомерных сортиментов СВЧ-обработка позволяет добиться сквозного пропитывания древесины. Чрезмерная обработка СВЧ может приводить к образованию разрывов древесины вдоль волокон.

***Ключевые слова**: СВЧ, древесина, модификация, лиственница, проницаемость, повышение проницаемости, пропитка.*

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RESEARCH OF THE INFLUENCE OF MICROWAVE RADIATION ON THE PERMEABILITY OF SIBERIAN LARCH WOOD

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The wood of Siberian larch, due to the significant reserves available in the Siberian region, is a promising object for modification. However, because of the low permeability of wood, its impregnation with modifying compositions is practically impossible. The research presents the results of studies aimed at increasing the permeability of the heartwood of Siberian larch as a result of exposure to microwave radiation.

Experimental studies were carried out on wood samples with dimensions of 50×50×150 mm (the latter along the fibers) made from freshly cut heartwood of Siberian larch with an initial moisture content of 55 %. Microwave wood processing was carried out in a microwave chamber at a frequency of 2.45 GHz with the fixed power of 0.9 kW. The duration of microwave processing was 270 s and 330 s.

After microwave treatment, the wood was impregnated in an autoclave at a pressure of 0.5 MPa for 40 minutes. To simulate the processes occurring in assortment of industrial sizes, the ends of some samples were sealed. An aqueous solution of FeSO4 was used as the impregnating composition.

The obtained experimental data show that microwave processing of larch wood can effectively increase the permeability of wood both along and across fibers. In the course of research, it was found that microwave treatment provides an 2.5–2.6 times increase in the absorption of the impregnating solution by wood, and the depth of impregnation across the fibers by 2.3 times. When impregnating short assortments, microwave processing allows achieving thorough impregnation of wood. Excessive microwave processing may cause the wood to break along the fibers.

Keywords: *microwave, wood, modification, larch, permeability, increased permeability, impregnation.*

INTRODUCTION

Annual consumption of natural wood is constantly growing in the world. This is facilitated by the unique properties of wood, such as relatively high specific strength, environmental friendliness, decorative appearance, renewable resource, etc.

The range of wood on the world market is represented by a very extensive list of different types of tree species. At the same time, wood of certain species is in high demand due to its attractive color, texture or high physical and mechanical properties. This negatively affects the size of populations of this species, contributes to the formation of a supply shortage and, consequently, an increase in the price of such wood.

One of the ways to meet the demand for wood with sought-after properties may be the targeted modification of wood with less valuable species growing in northern latitudes.

A promising species for targeted modification of wood is Siberian larch, widespread in the Siberian region [1]. Larch wood has fairly high physical and mechanical properties, comparable to such species as oak, ash, and beech [2]. And its modification can provide high bio- and fire resistance, increasing physical, mechanical and decorative properties.

Most technologies for direct changing the properties of wood are based on deep or even through impregnation with modifying compounds. At the same time, the permeability of wood to liquids is a prerequisite for the implementation of such technologies. Larch wood is a hard-to-impregnate species. Almost the entire volume of the larch trunk is occupied by heartwood, which has low permeability to liquids and gases [3]. Therefore, without increasing the permeability of wood, it is almost impossible to impregnate it.

A large number of works have been devoted to the study of the reasons for the low permeability of the core part of a coniferous tree trunk in comparison with the sapwood. Low permeability of heartwood is explained by a change in the position of the tori in the pores of vertical tracheids [6], deposition of extractives in the cell walls [3] and clogging of the marginal zones of the pores of ray tracheids with extractives [7].

To date, a wide range of methods have been developed to increase the permeability of wood raw materials: by pricking [4], using variable pressure [7], pre-infection with wood-coloring fungi [8], by burning with a laser beam [9; 10], temperature increases [3], etc. The listed methods have serious disadvantages: they violate the integrity of the wood, are energy-consuming, and technically difficult to implement in industrial conditions, have an unacceptably long process duration, etc.

Recently, methods for increasing the permeability of wood through microwave treatment have been actively developed all over the world. Studies [12; 13; 14; 15; 16; 17; 18; 19] have noted the high efficiency of microwave processing of wood in order to increase permeability with an acceptable decrease in mechanical properties. In the study [12], due to microwave treatment, the absorption of Chinese fir wood increased by 156 % compared to the control untreated wood, and in the work [13] this value was increased to 308 %. An increase in the permeability of hardwood also indicates the effectiveness of microwave exposure. It has been established that microwave treatment of European beech wood provides an increase in permeability along the fibers up to 159 % [15].

In the cited works [20; 21; 22; 23; 24] the mechanism of increasing the permeability of wood when exposed to microwaves is explained primarily by the heating and evaporation of the water contained in it, as a result of which vapor-gas pressure arises and partial destruction of the cell walls of anatomical elements occurs. Moreover, in most of the sources reviewed, the authors focus on increasing permeability along the fibers. While it is the transverse permeability of wood that is decisive when impregnating assortments longer than 0.5 meters [6]. In this regard, the possibility of increasing transverse permeability due to microwave exposure is of no less interest.

Taking into account the available scientific data on the high potential of microwave treatment to increase the permeability of wood and taking into account the preliminary results obtained [11], it was decided to investigate the possibility of increasing the permeability of heartwood of Siberian larch, taking into account structural directions.

MATERIALS AND METHODS OF RESEARCH

For research purposes from freshly cut 120 samples of larch heartwood were made with an oriented arrangement of annual layers relative to the layers, dimensions 50×50×150 mm (the latter along the fibers). The initial humidity of the samples was 55 %.

Microwave processing of wood samples was carried out in a microwave chamber at a frequency of 2.45 GHz with a fixed power of 0.9 kW. Based on the duration of microwave treatment (taking into account the preliminary data obtained [11]), all samples were divided into two treatment groups: microwave 270 s and microwave 330 s. Control samples were not subjected to microwave treatment.

After microwave treatment, all samples were impregnated in an autoclave at a pressure of 0.5 MPa for 40 minutes. Since the permeability of wood along the fibers is many times greater than the transverse one [2], to simulate the processes occurring in industrial-sized assortments, the ends of some samples were sealed. Before impregnation, the samples of the first and second groups were divided into two subgroups. Samples of the first subgroup were impregnated without waterproofing the ends, the second to study transverse permeability with waterproofed ends to prevent longitudinal impregnation. The samples were waterproofed by applying three layers of PPH15 and one layer of silicone sealant. An aqueous solution of FeSO4 was used as an impregnating composition. This solution changes the color of larch heartwood, allowing you to record the depth of the impregnation front. To determine the absorption of the solution, the samples were weighed and the absorption was calculated in kg/m^3. The impregnation depth was determined after splitting the samples along the fibers into four parts.

RESULTS AND DISCUSSION

The results of studies of microwave treatment influence on the longitudinal permeability of heartwood for liquids are presented in Fig. 12.

The data obtained discovered that absorption of samples treated microwaves and impregnated without waterproofing the ends increased in comparison with control samples (Fig. 1) by 1.7–2 times. Moreover, the most significant increase in the absorption rate was observed in samples of the second group that underwent longer microwave treatment. A comparison of the absorption of microwave 270 s and microwave 330 s samples showed an 18 % superiority of the latter.

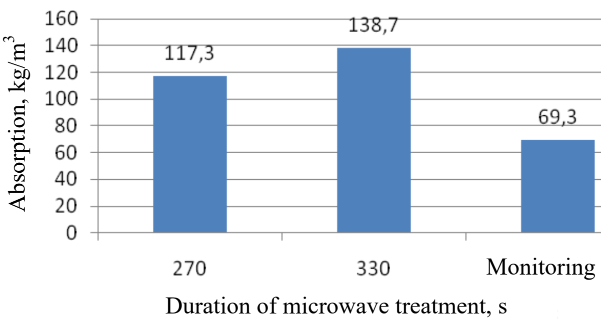

Fig. 1. The effect of microwave processing on the value absorption of samples without waterproofing the ends

When splitting the samples, the following features of the penetration of the impregnating solution were revealed (Fig. 2). All samples treated with microwaves and impregnated without waterproofing the ends showed through penetration of the impregnating solution with local unimpregnated areas (Fig. 2, *a*). While the average depth of penetration of the impregnating solution in the control samples was slightly more than 16 mm (Fig. 2, *b*). In the transverse direction, the depth of penetration of the impregnating solution for samples impregnated without waterproofing was not recorded, since the solution penetrated primarily along the fibers.

Impregnation of wood samples with sealed ends showed the following results (Table 1, Fig. 3). The absorption of the solution by such samples predictably turned out to be 4–6 times lower in comparison with samples impregnated without sealing the ends. At the same time, in the samples treated with microwaves, just as in the previous experiment, there was a significant increase in the absorption of the solution relative to the control samples. The absorption of microwave samples at 270 s exceeded the control by 38.1 %, and at microwave 330 s by 82.5 %. At the same time, the absorption of samples with a microwave treatment duration of 330 s turned out to be 44 % higher than those treated with 270 s.

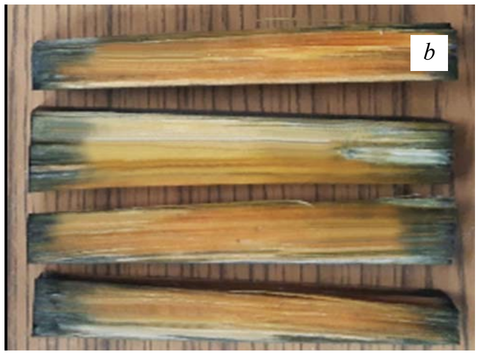

Fig. 2. Samples of wood after impregnation without waterproofing the ends:
a – microwave-treated; *b* – untreated microwave (control)

After assessing absorption, all wood samples impregnated with closed ends were split into four parts to measure the depth of advance of the impregnation front. The measurement results are presented in Table 1 and in Fig. 4.

From the histogram in Fig. 4 it follows that increasing the depth of penetration of the impregnating solution (compared to control samples) is observed only in the radial direction and only in samples treated with microwave 330 s (by 43.5 %). While samples treated with microwave 270 s show only a tendency to increase the depth of impregnation (within the limits of the accuracy of the experiment). In the tangential direction, on the contrary, there was a slight tendency towards a decrease in permeability in samples treated with microwaves. In general, when impregnating in the transverse direction, a greater depth of solution advancement in all cases was observed in the radial direction.

For samples of microwave 270 s, the radial direction exceeded the tangential direction by 2.3 times, and microwave 330 s by 3 times, in control samples the difference was 2-fold. Despite the significant increase in the relative depth of impregnation of samples of the microwave group 330 s in the radial direction, in fact, the depth of advance of the impregnation front was less than 2 mm, which cannot be called a significant result.

Table 1
Results of impregnation of wood with sealed ends

Duration of Microwave processing, s	Absorption, kg/m^3	Depth of impregnation in structural directions, mm	
		radial	tangential
270	22,1±0,86	1,20±0,04	0,52±0,02
330	29,2±1,16	1,65±0,05	0,55±0,02
Control	16,0±0,37	1,15±0,04	0,56±0,027

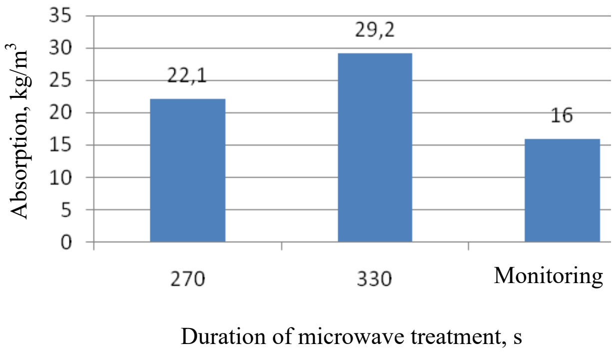

Fig. 3. Influence of microwave treatment on the value absorption of samples with waterproofing of ends

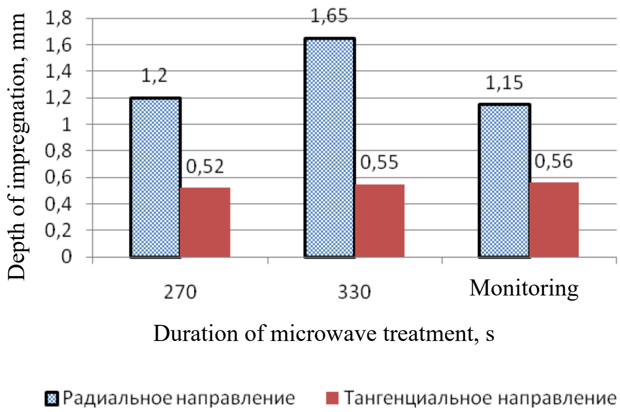

Fig. 4. The influence of microwave treatment on the depth of wood impregnation across the grain

The results obtained showed a significant increase in the permeability of larch heartwood along the fibers and a less significant increase across the fibers. Apparently, the excess pressure generated during microwave treatment (due to its active relaxation along the fibers) turned out to be insufficient to create transport paths across the fibers.

To confirm the hypothesis put forward. A batch of samples was produced in the amount of 60 pcs., similar dimensions and humidity (50×50×150 mm W – 55 %). In this case, unlike the previous experiment, before microwave treatment the samples underwent special preparation, which consisted of multilayer sealing of the end surfaces of the samples. Sealing was carried out to exclude pressure relaxation due to transfer along the fibers, which made it possible to simulate processes occurring in assortments of real sizes. The ends of the samples were covered with a layer of silicone sealant, then plastic plugs with inserted rubber gaskets were put on them. Before being placed in the microwave chamber, the plugs of opposite ends were tightened with a clamp made of heat-resistant plastic (Fig. 5).

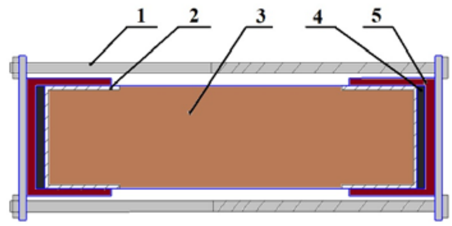

Fig. 5. Sealing the ends of the samples for microwave processing:
1 – plastic clamp; 2 – heat resistant silicone sealant;
3 – wood sample; 4 – rubber gasket; 5 – plastic plug

As in the previous experiment, the samples were divided according to the duration of microwave treatment: 270 s and microwave 330 s. After microwave treatment, the sealing layer was restored at the ends of the samples and then impregnated for 40 min with an aqueous solution of $FeSO_4$ at an excess pressure of 0.5 MPa. After impregnation, the magnitude of absorption and the depth of advance of the impregnation front were assessed. The research results are given in table 2 and in Fig. 6 and 7.

The results obtained show (Fig. 6) that the treatment of samples with microwave 270 s with closed ends made it possible to increase the absorption of wood by 2.1 times and by 2.6 times when treated with microwave 330 s. At the same time, the group that underwent longer microwave treatment had absorption 1.25 times higher than that of the 270 s microwave samples. In comparison with samples processed by microwave without sealing the ends (Fig. 3), the absorption rate increased by 1.6 times for samples of microwave 270 s and by 1.5 times for microwave 330 s.

The difference in solution absorption between samples with different durations of microwave treatment, in the case of sealing the ends during processing, was not as significant – 25 %, as without sealing – more than 44 % (Fig. 3).

Separately, it should be noted that some of the samples that underwent microwave treatment for 330 s were found to have closed cracks that formed during the treatment process. This indicates excessive processing time. The absorption values obtained for cracked samples were not taken into account in the calculation of the average absorption value.

The results of measuring the depth of impregnation of samples treated with microwaves with sealed ends revealed the following features (Fig. 7). The depth of advance of the impregnation front increased for all samples that underwent microwave treatment, both in the radial and tangential directions. Compared to the control, the increase in the depth of impregnation in the radial direction ranged from 74 to 131 %, and in tangential 122–127 %.

The greatest value of the advance of the impregnation front (as in the previous experiment) was noted in the radial direction for samples that underwent a longer microwave treatment of 330 s. 33 % higher than for samples treated with microwave 270 s. In the tangential direction, no significant difference in the depth of impregnation between samples of different treatment durations was established. In general, under the same microwave processing conditions in the radial direction, the depth of advance of the impregnation front exceeded the tangential direction by 59–107 %.

A comparison of the impregnation depth of samples treated with microwaves with open and closed ends showed the following. Under the same processing conditions, samples with ends sealed during microwave treatment showed a depth of impregnation higher than those with unsealed ends. In the radial direction the difference was 65–71 %, in the tangential direction 140–148 %. Typical examples of the advancement of the impregnation front in the radial and tangential directions for microwave samples at 330 s and 270 s are presented in Fig. 8.

Table 2
Indicators of impregnation of wood treated with microwaves with sealed ends

Duration of microwave treatment, s	Absorption, kg/m^3	Depth of impregnation in structural directions, mm	
		radial	tangential
270	34,7±1,08	2,05±0,08	1,29±0,04
330	43,4±1,78	2.73±0,11	1,32±0,05
Monitoring	16,4±0,39	1,18±0,02	0,58±0,015

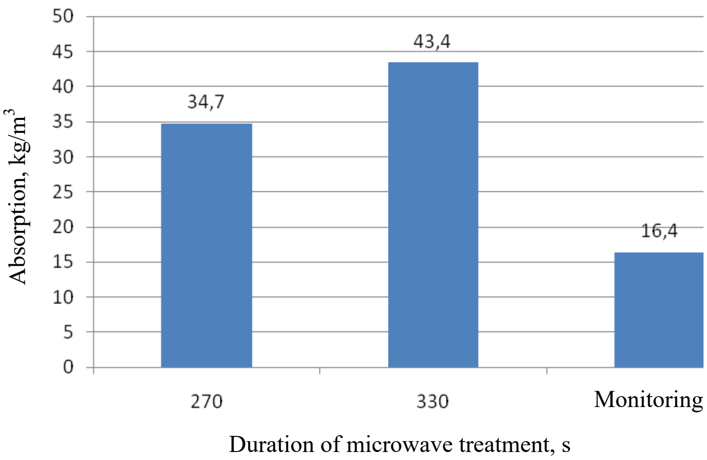

Fig. 6. Influence of microwave treatment on the absorption value of samples with sealed ends during microwave processing and impregnation

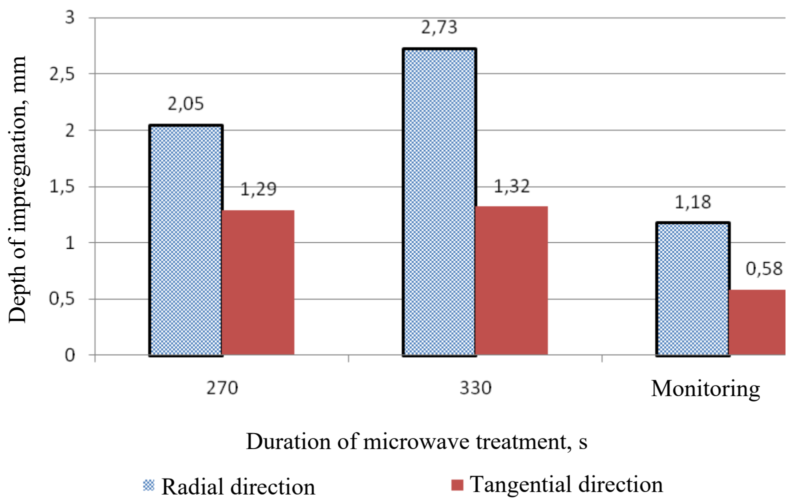

Fig. 7. The influence of microwave treatment on the depth of wood impregnation across the grain with closed ends for microwave processing and impregnation

Fig. 8. Fragments of wood samples treated with microwaves and impregnated with closed ends:
a – radial direction; *b* – tangential direction

CONCLUSIONS

Based on the results of the research, the following conclusions can be drawn:

– Microwave exposure to the heartwood of Siberian larch allows you to increase its permeability, both longitudinally and transversely.

– This is confirmed by a significant increase in absorption and depth of wood impregnation.

– Since microwave treatment allows for end-to-end impregnation of wood along the fibers and a 2.5-fold increase in the absorption of impregnating liquid, this creates good prospects for using microwaves to prepare for impregnation of short-length assortments.

– Increasing the duration of microwave treatment has a positive effect on the results of increasing the permeability of larch heartwood. But excessive microwave treatment can lead to wood ruptures along the grain. Their formation is most likely associated with high vapor-gas pressure arising in the wood.

– When impregnating long assortments, the modeling of which was carried out by sealing the ends of the samples, there is a significant increase in the permeability of larch wood across the fibers. The depth of impregnation increased by 2.3 times, and absorption by more than 2.6 times. This indicates that microwave treatment of long assortments before impregnation also has good prospects for increasing their permeability.

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ИССЛЕДОВАНИЯ ВЛИЯНИЯ НЕУСТАНОВИВШИХСЯ РЕЖИМОВ РАБОТЫ НА ВЫХОДНЫЕ ПАРАМЕТРЫ ДВИГАТЕЛЯ ЛЕСОТРАНСПОРТНОЙ МАШИНЫ

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Представлены результаты исследовательской работы, цель которой – исследовать влияние неустановившихся нагрузочных режимов на динамические характеристики дизельного автотракторного двигателя лесотранспортной машины. В статье предлагается методика полунатурных испытаний дизельного двигателя и лабораторная экспериментальная установка для исследования влияния неустановившихся режимов работы двигателя на его выходные параметры ($M_e(f)$, $\omega(f)$, $h(f)$, $P_м$, $t_{вг}$); приведены результаты исследования влияния неустановившихся нагрузочных и скоростных режимов работы двигателя на выходные параметры; установлено, что для двигателя ЯМЗ-238НБ существует диапазон частот (f = 0,7…0,9 Гц) изменения момента сопротивления M_c на коленчатом валу, в котором возможно максимальное отклонение основных параметров от средних значений их на сопоставимы установившихся режимах; на основании анализа амплитудно-частотных характеристик колебаний рейки топливного насоса установлено, что в данном диапазоне частот (f = 0,7…0,9 Гц) изменения M_c наблюдается совпадение частот вынужденных колебаний с собственной частотой чувствительного органа регулятора, что приводит систему «двигатель-регулятор» в резонансное состояние.

Ключевые слова: *дизельный автотракторный двигатель, неустановившийся режим работы, выходные параметры двигателя.*

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RESEARCH OF THE INFLUENCE OF UNSTEADY OPERATING MODES ON THE OUTPUT PARAMETERS OF A TIMBER TRANSPORTING MACHINE ENGINE

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The paper presents the results of research aimed at investigating the influence of unsteady load conditions on the dynamic characteristics of a diesel automotive engine of a timber transporting machine. The methodology of semi-full-scale tests of a diesel engine and a laboratory experimental installation for studying the influence of unsteady engine operating modes on its output parameters ($M_e(f)$, $\omega(f)$, $h(f)$, P_o, t_{eg}) is offered. The results of researching the influence of the engine unsteady load and speed modes on the output parameters are presented. It is established that for the YaMZ-238NB engine, there is a frequency range (f = 0.7...0.9 Hz) of changes in the moment of resistance M_r on the crankshaft, in which the maximum deviation of the main parameters from their average values in comparable steady-state modes is possible. On the basis of the analysis of the amplitude-frequency characteristics of the fuel pump rack oscillations, it is found that in this frequency range (f = 0.7...0.9 Hz) of the M_r change the frequencies of forced oscillations coincide with the natural frequency of the governor's sensitive organ, which brings the engine-governor system to a resonant state.

Keywords: *diesel automotive engine, unsteady operating mode, engine output parameters.*

INTRODUCTION

Russia has the world's largest reserves of forest resources (22 % of world reserves). In the composition of Russian forests, coniferous tree species amount to more than 80 % (39 % of larch, 17 % of pine, 11 % of spruce, 6 % of cedar), the main reserves of which are located in the northern and eastern regions of Russia, characterized by severe climatic conditions, complex relief and soil composition. For the industrial use of forest resources, logging equipment is now increasingly being used having powerful general-purpose diesel engines, which were designed without taking into account the peculiarities of operation in the conditions of development of forest resources.

Timber transporting and technological machines operating in the forest industry should be considered as an independent class of machines that have their own specific use and their own operating conditions, determined by terrain, climate, time of year, road or drag condition, soil moisture, machines application technology, etc. [2; 3; 7]. The operation of machines under these conditions is characterized by an increased intensity of changes in speed and load conditions in a wide range of amplitudes and frequencies. The forces of resistance to the movement of a machine along a rack or cutting area, rapidly changing over time, have a significant impact on the operation of the engine, its loading, and cause unsteady operating conditions of the engine, which affects its reliability, efficiency and durability.

The most reliable assessment of the reliability of a diesel engine can be made under real operating conditions. But operational tests require a significant amount of time and money, and the results obtained have a wide scatter, which requires simultaneous conducting of a number of tests. In addition, during operational tests it is difficult, and often impossible, to determine the influence of individual factors on engine wear. Therefore, stand laboratory tests of engines for reliability have become widespread. They can significantly reduce the time and material costs of testing, as well as increase the identity of research results. However, stand tests of engines in accordance with GOST 18509–88 do not provide a number of factors affecting the durability of engines under operating conditions, and in the engine passport, the technical characteristics of the engine do not include its dynamic characteristics, which are important for an engine operating under unsteady conditions.

Particular difficulties arise when studying the influence of unsteady conditions on the wear of main engine parts. This is due to the fact that mass-produced test stands do not allow simulating engine operating modes in laboratory conditions, there are no standard requirements for such testing methods, and there is also no consensus on the concept of the "engine unsteady operating mode". This situation forces researchers to independently develop methods and equipment for testing engines in unsteady operating conditions, and to introduce criteria for unsteady operating conditions. The analysis of the methods and installations used for studying engines in unsteady operating modes showed that for the most part they do not allow simulating a wide range of operating loads.

Thus, the methods and installations developed by Kanarchuk V. E. [5] and Khrushkov P. P. [12] make it possible to study unsteady modes and their effect on the wear resistance of automotive engines. The unsteady mode is considered as a set of transient processes of the speed regime, the duration and sequence of which is determined by the imbalances of the engine torques and the power consumer that arise under operating conditions.

However, in order to determine the influence of individual parameters of unsteady modes on the wear rate of the engine, the sources [5; 12] artificially kept one of them (speed or load) constant, which does not reflect the operating conditions, where the load on the engine and the angular velocity of its shaft simultaneously change.

An original way to eliminate the last drawback inherent in the methods listed above was proposed by V. P. Antipin [1]. A load changing according to a harmonic law in the range (0.01…2.0) Hz was created on the crankshaft of the test engine using an electric braking stand STEU-28-1000, in the stator circuit of which a 3-phase magnetic amplifier controlled by a low-frequency generator of periodic oscillations is connected. The disadvantage of the proposed method of reproducing variable loads on the shaft of the tested engine is that with an increase in the power of the braking device above 100 kW, the installation time constant increases, i.e. the braking device does not allow reproducing loads changing with a frequency of more than 1.5 Hz.

From the analysis of existing methods for studying unsteady operating modes of automotive engines it follows that they do not allow solving the above tasks of studying the characteristics of automotive engines with a power of more than 100 kW. This circumstance required the development of a special installation and methodology for studying the amplitude-phase frequency characteristics of the engine and a methodology for studying the influence of unsteady modes on the wear of a diesel engine with a power of more than 100 kW. The development of the methodology was carried out in accordance with the requirements of GOST 18509–88 based on the analysis of the operating conditions of timber transporting machines.

PURPOSE OF THE RESEARCH

1. Develop a methodology for modeling operational load conditions to study the dynamic characteristics of a diesel engine.

2. Create an experimental laboratory installation to conduct research into the influence of unsteady operating conditions on the output parameters (dynamic characteristics) of a diesel automotive engine and to study the effect of unsteady operating conditions on engine wear.

3. Investigate the influence of the amplitude and frequency of load changes on the dynamic characteristics of the YaMZ 238NB engine.

METHOD AND INSTALLATION TO TEST THE ENGINE

Research of operating modes of skidders [2; 3; 8] showed that at any moment in time the current value of the resistance forces is determined by two components: a constant one equal to (0.75–0.85) Mn, and a variable one equal to 0.15 Mn - the rated torque of the engine.

The frequency spectrum of changes in resistance forces can be divided into two zones [7]: the first zone characterizes the slow process with a period of change (T) of more than 10 seconds ≤ 0.1 Hz. Changing forces in this range is available for regulation by the engine governor and by humans. They are determined by changes in macro conditions and are taken into account by the traction balance equation. Their fairly complete characteristic is the mathematical expectation (μ_x) or the average value and dispersion (D_x), since the engine time constant (T_e) is significantly less than the period of change of these forces and the engine's response to their influence is known in advance.

The second frequency zone characterizes fast processes with a period of less than 10 seconds (0.1 Hz), which can only be controlled by the engine governor. These forces are not taken into account by the traction balance equation and can be characterized by spectral density of a random process, describing the microconditions in which the machine operates.

Due to the lack of a consensus on the physical essence of the unsteady operating mode of the engine, it is advisable to take the process of transition from one speed mode to another [11] under the influence of a change in the moment of resistance M_r as the main element defining this operating mode, since it most fully characterizes the work of an automotive engine in operating conditions.

Under operating conditions of machines during logging, unsteady operating modes of machine engines are random in both frequency and amplitude. It is extremely difficult to reproduce the entire range of loads in full in laboratory conditions, therefore, when developing an installation for studying engine wear, it was proposed to load the engine according to the harmonic law, which says, that according to the first theorem of V. A. Kotelnikov [9], any function (including one describing a random process) with a frequency range from zero to maximum can be spread horizontally in a row, and as the harmonic number increases, its frequency increases and its amplitude decreases, which is observed in nature.

The method of harmonic loading of the engine does not contradict the research of academician V.N. Boltinskii [10], where it is indicated that under operating conditions the moment of resistance on the engine shaft changes according to a quasi-harmonic law.

Based on the above, a methodology [4] for semi-full-scale testing of a diesel engine and a laboratory experimental installation were developed to study the influence of unsteady engine operating conditions on its output parameters. The YaMZ-238NB engine used on tractors K-700, K-703, K-744 and the KrAZ-255L vehicle widely used in the timber industry was chosen as the object of research.

The new engine YaMZ-238NB of serial production was tested. It was run-in on a stand for 60 hours according to the modes recommended by the manufacturer, after which the engine was equipped with additional sensors for monitoring the main parameters of engine operation and all work related to the preparation of the engine for testing was completed. The power limiter was removed and the engine was additionally run for 16 hours in M_e mode = 80 kgm (800 Nm), n = 1500 rpm, N_e = 170 hp. (125 kW), for the purpose of additional running and development of test methods.

According to GOST 18509–88, before starting research on the YaMZ-238NB engine on a brake stand, the nominal and maximum values of effective power and torque, hourly and specific fuel consumption were determined according to the external speed characteristic at crankshaft speeds corresponding to these values. At the same time, measurements were made of: angular velocity of the crankshaft ω, braking torque T_b, effective torque M_e, position of the fuel pump rack h, oil pressure in the lubrication system P_o, exhaust gas temperature t_{eg}, engine indicators P_z. All of the above indicators were recorded on an oscillogram.

Experimental installation for studying unsteady engine YaMZ-238NB operating conditions consists of a load device, a frame for installing the engine under test, a software device, a system of instrumentation and recording equipment (Fig. 1).

A commercially produced test stand KI-598B (asynchronous balancing machine AKB-92-8, power 55 kW) and a load powder brake PT-250 M, power 50 kW are used as a load device. The total braking power of the load device is 160 kW (220 hp).

The engine under test is installed on a frame (front semi-frame of the K-700 tractor) and connected with a load device via a cardan shaft.

The low-frequency generator of periodic oscillations NGPK-3, which sets the law of load changes in the form of a sine wave, triangular, sawtooth or rectangular pulses in the range of 0.06–100 hertz is the software device of the installation. The frequency setting error in the range of 0.1–100 Hz is ± 3 %; amplitude stability – $\pm 0{,}1$ %.

The installation operates as follows (Fig. 2): the low-frequency generator NGPK-3 generates periodic or sinusoidal signals, which are amplified by the amplifier U and supplied to the excitation winding of the powder brake PT, the braking torque of which varies according to the law of the excitation current. Thus, the powder brake reproduces the variable component of the moment of resistance, which is summed with the constant component reproduced by the KI test stand, and arrives at the shaft of the engine under test.

The value of the constant component of the resistance moment is set by the KI brake stand by changing the value of the load resistance R in the rotor circuit of the balancing machine.

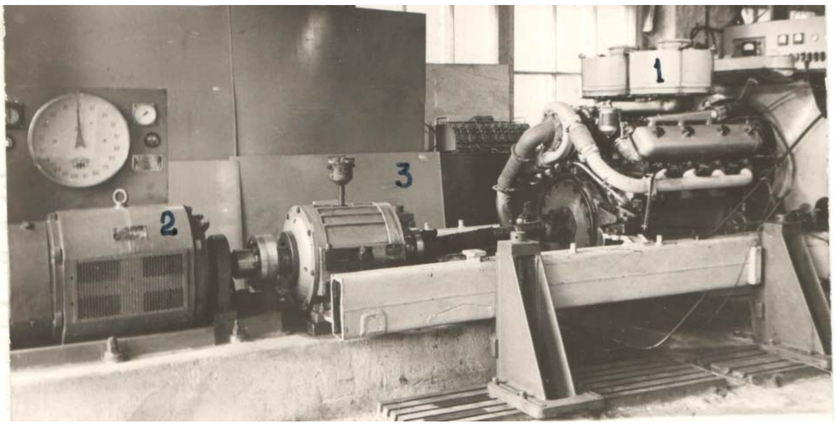

Fig. 1. General view of the experimental installation:
1 – YaMZ-238NB engine; 2 – stand KI-598B; 3 – powder brake PT-250M

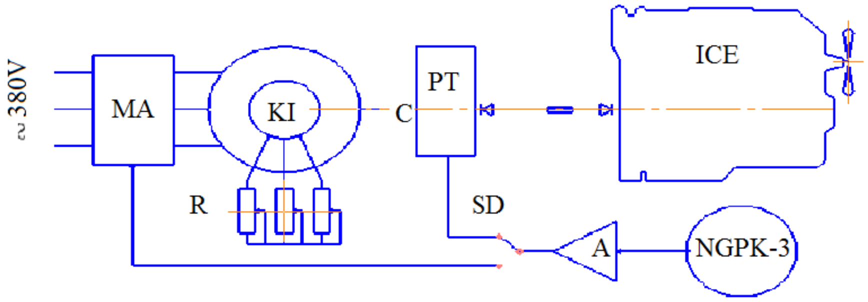

Fig. 2. Installation block diagram:
MA – magnetic amplifier; R – load resistance; KI – test stand KI-598B; PT – powder brake; SD – switching device; A – amplifier; ICE – internal combustion engine; NGPK-3 – low-frequency generator NGPK-3; C – coupling

In this mode, the installation operates at frequencies of change in the resistive torque of more than 1.5 hertz. In the frequency range less than 1.5 Hz, the KI-598B brake stand does not provide a linear dependence of the constant component of the resistance moment; therefore, in the frequency range (0.1–1.5) Hz, the variable component of the resistance moment is modeled by the KI brake, and the constant component - by the powder brake PT. In this case, the software device, using the PC switch, is disconnected from the excitation winding of the powder brake and connected to the control winding of the magnetic amplifier MA in the power supply circuit of the KI brake. The magnetic amplifier ensures a change in the current in the stator circuit of the KI brake, and therefore the braking torque according to the law specified by the software device. The constant component of the moment of resistance in this case is provided by a powder brake PT, the excitation winding of which is connected to a direct current source. Due to the design features and characteristics of the powder brake, the braking torque T_b does not change when the shaft speed fluctuates up to 200 rpm.

Researching the influence of variable loads on engine output parameters

The engine of a timber transporting machine, being an active dynamic object, reacts differently to external influences that vary over a wide range of frequencies and amplitudes. Research into the influence of the dynamic properties of the engine on the technical and economic indicators with a rapidly changing load on the crankshaft comes down to finding, first of all, the dynamic characteristics of the output parameters (angular velocity of the crankshaft ω and torque M_e) as indicators determining its reliability and resource.

From the theory of automatic control [13] it is known that the same dynamic system reacts differently to different input influences. Amplitude-frequency (AFCs) and phase-frequency (PFCs) characteristics were taken as dynamic characteristics of the engine, reflecting the engine's response to external influences. The AFCs of the engine were determined: by the engine torque – as the ratio of the engine torque to the resistance moment $M_e(f)$ / $M_r(f)$; by angular velocity – as the ratio of the angular velocity of the crankshaft to the moment of resistance $\omega(f)$ / $M_r(f)$. Amplitude values of engine torque M_e, angular velocity of the crankshaft ω, as well as the position of the fuel pump rack h, were determined from the oscillogram as their deviations from the average steady-state values.

Phase-frequency characteristics were determined from oscillograms as the phase shift between the input $/M_r(f)/$ and output $/M_e(f)$, $\omega(f)$, $h(f)/$ parameters.

The frequency characteristics of the YaMZ-238NB engine were determined on an experimental installation with a sinusoidal change in the moment of resistance in the frequency range most characteristic for engine operation under operating conditions (f = 0.05–5.0 Hz), in the regulatory region of the speed characteristic. Fig. 3 shows a sample oscillogram of changes in engine output indicators $/M_e(f)$, $\omega(f)$, $h(f)$, P_o, $t_{eg}/$ at a load M_r = 745 Nm, ω = 136 1/s, δ = 0.20, f = 0.8 Hz. Oscillogram recordings show that the engine output parameters, as well as the resistance torque, are sinusoidal in nature, but with some phase lag.

Graphs of the amplitude-frequency characteristics (fig. 4) were constructed on the basis of the experimental data obtained by decoding the oscillograms.

From the analysis of the AFC and PFC graphs of the angular velocity of the crankshaft, it follows that an increase in the frequency of changes in the input torque from 0.05 to 0.15 Hz is not accompanied by noticeable changes in the deviations of the angular velocity from steady-state oscillations. However, starting from a frequency of 0.2 Hz to 0.8 Hz, the amplitude of deviations in the angular velocity of the crankshaft increases sharply, reaching its maximum at a frequency of 0.8 Hz, which adversely affects the organization of engine operating cycles, causing an increase in dynamic loads on its parts, and therefore contributes to increased wear at these frequencies. A further increase in the frequency of changes in the input torque from 0.8 to 1.25 Hz is accompanied by a damping of the amplitude of angular velocity fluctuations from a maximum value of 11 1/s (at a frequency of 0.8 Hz) to 6.0 1/s (at a frequency of 1.25 Hz). A change in frequency from 1.25 Hz to 3.0 Hz and higher is accompanied by an exponential decay of the angular velocity amplitude to 0.4 1/s, which does not cause noticeable vibrations of the fuel pump rack, and, consequently, disturbances in the organization of the engine operating cycle.

The influence of variable loads on oil pressure in the lubrication system and angular accelerations of the engine crankshaft

The change in the angular accelerations of the crankshaft and pressure in the lubrication system depending on the frequency of changes in the moment of resistance as parameters influencing the wear rate of the main engine parts is of practical interest when the engine operates in unsteady modes in the regulatory region of the speed characteristic.

The angular acceleration of the shaft was calculated using the formula

$$\varepsilon = d\omega \,/\, d\tau \ (1/\mathrm{s}^2),$$

where $d\omega$ is the increment in the angular velocity of the crankshaft during the time $d\tau = \Delta\tau$.

At frequencies above 3 Hz, the angular accelerations of the crankshaft do not exceed 0,5 $1/\mathrm{s}^2$, i.e., the engine filters these frequencies and its operating mode can be considered steady. Low-frequency components of the amplitude of oil pressure fluctuations in the lubrication system are filtered at frequencies above 2 Hz. The study of oscillogram decoding data is presented in the graph in Fig. 5.

The graph shows that with increasing frequency, changes in the moment of resistance M_r, shaft acceleration ε and the amplitude of pressure fluctuations A_{pf} in the lubrication system increase, reaching their maximum values ($\varepsilon = 54\ 1/\mathrm{s}^2$; $A_{\mathrm{pf}} = 4 \cdot 10^4\ \mathrm{N/m}^2$) at a frequency of 0.8 Hz. Further increase in the frequency of changes in M_r leads to reducing the angular acceleration of the crankshaft and the amplitude of oil pressure fluctuations.

The influence of variable loads on the dynamic performance of the engine operating cycle

It was noted above that during the period of load changes, phase lags in the output parameters of the engine are observed, which have the most unfavorable combinations at a frequency of 0.8 Hz and negatively affect the performance of the operating cycle. Fig. 6 illustrates the nature of changes in the main engine indicators (M_e; ω; ε; h; P_z; $\Delta P/\Delta\varphi$) during the period of change in the moment of resistance at a frequency of 0.8 Hz in the regulatory region of the characteristic at $M_{\mathrm{r.\,av}} = 745$ Nm, ω = 1361 /s, $\delta_c = 0.20$. This mode of engine operation is the most typical for the operating conditions of skidders [2; 3; 7].

From Fig. 6 and 7 it is clear that all output parameters of the engine lag in phase from the moment of resistance M_r: M_e – by 1/4 T, ω – by 1/2 T, h – by 1/8T, P_z – by 3/8T, $(\Delta P/\ \Delta\varphi)_{\mathrm{av}}$ – by 3/8T. At this frequency, the amplitude of the engine torque oscillations exceeds the resistance torque by 11 %. The engine torque reaches its maximum when the load is released at a moment of 0.75T, when $M_r = M_{r.\ av}$, which leads to a significant increase in the angular velocity ω and acceleration ε.

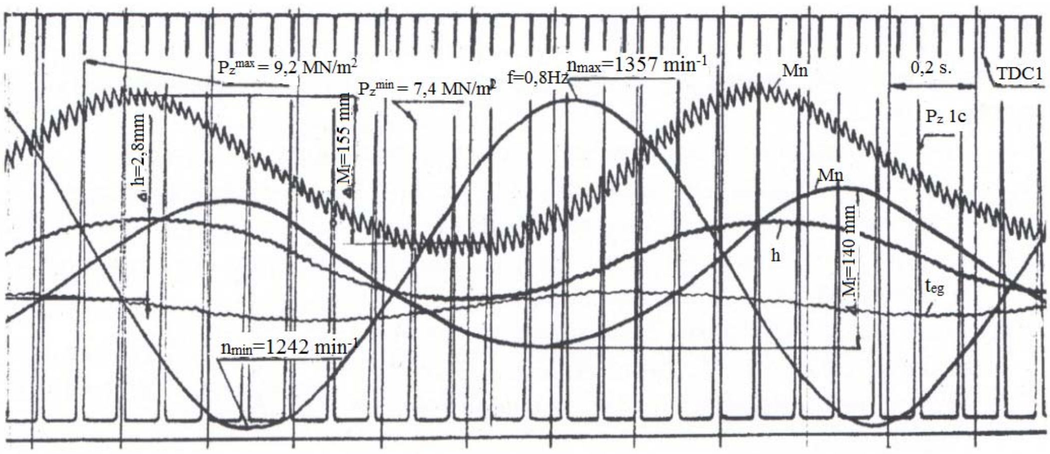

Fig. 3. Oscillogram of engine test at frequency *f* = 0.8 Hz:
M_r (M_e) – torque; TDC – mark of the top dead center of the piston of the 1-st cylinder; n – crankshaft rotation speed;
h – vibrations of the fuel pump rack; t_{eg} – temperature of exhaust gases in the outlet collector; M_l – variable load component;
P_z – gas pressure in the combustion chamber of the 1-st cylinder

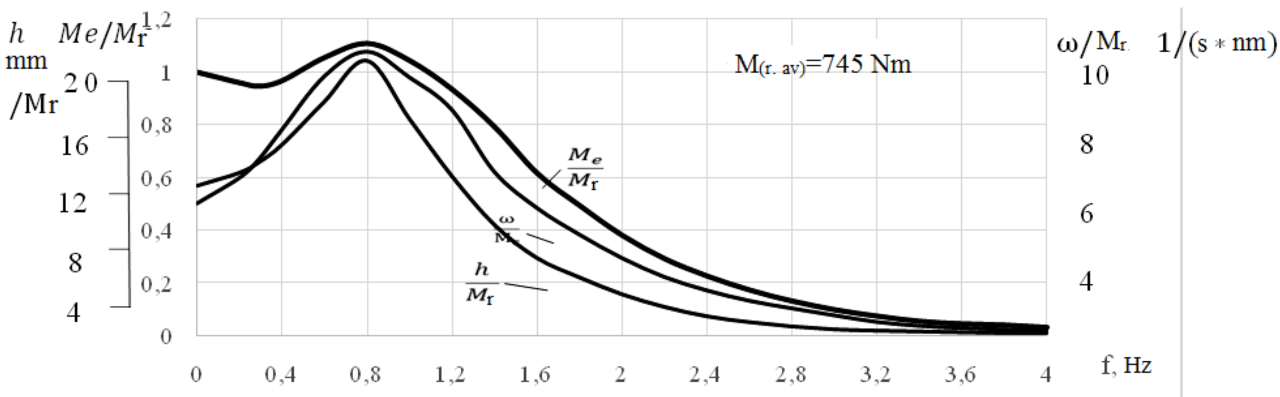

Fig. 4. Amplitude-frequency characteristics of the YaMZ-238NB engine

When the load is released in the first quarter of the period of its change (0...0.25 T), a decrease in the maximum cycle pressure P_z and the average pressure increase $(\Delta P/\Delta\varphi)_{av}$ is observed due to a decrease in engine torque M_e (maximum cyclic fuel supply for the period). In the second quarter of the load change period, the engine torque increases (g_c growth), which leads to an increase in dynamic indicators (P_z, $\Delta P/\Delta\varphi$), which reach their maximum value [P_z = 9.0 mN/m^2 (92 kg/cm^2); $(\Delta P/\Delta\varphi)_{av}$ = 29.6 MN/m^2·rad (5.28 kg/cm^2·deg)] by the middle of the last quarter of the period (0.85 T) of change in the moment of resistance M_r. Minimum values of dynamic cycle indicators [P_z = 7.4 mN/m^2 (75 kg/cm^2); $(\Delta P/\Delta\varphi)_{av}$ = 19.7 MN/m^2·rad (3.52 kg/cm^2·deg)] are reached at (0.25…0.30) T.

It should be noted that, despite the symmetrical nature of the oscillations of the fuel pump rack, its relative position in steady state, the dynamic indicators of the cycle do not maintain such symmetry (Fig. 7). The maximum value of P_z is 12.5 % greater at 0.875T, and the lowest value of P_z is 8 % less than P_z at the corresponding steady state. The average increase in pressure has an even greater deviation from the steady state: $\Delta P/\Delta\varphi)_{av}$ is 32 % more at 0.875T and 10 % less at 0.30T (Fig. 7).

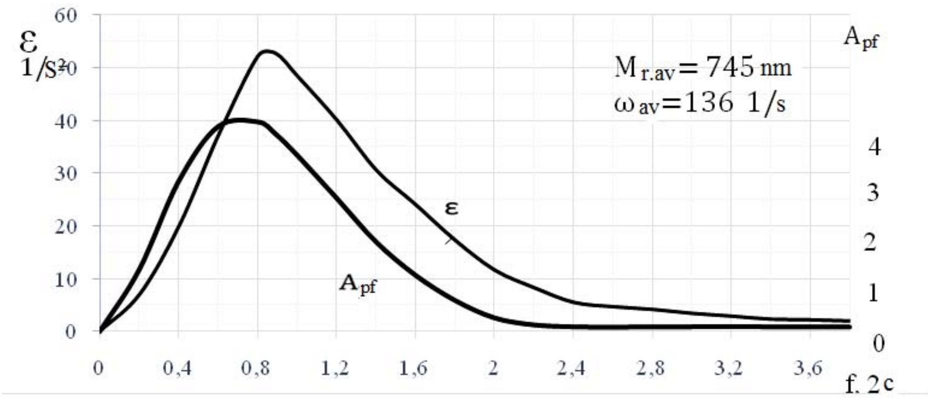

Fig. 5. Dependence of crankshaft acceleration ε and amplitude of oil pressure fluctuations A_{pf} in the lubrication system of the YaMZ-238NB engine on the frequency of change of the moment of resistance M_r

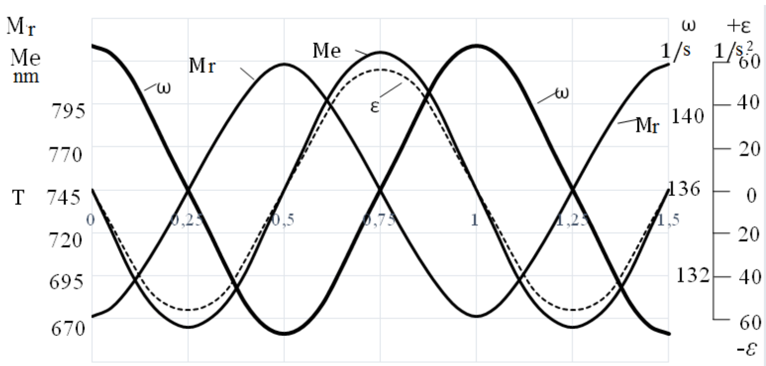

Fig. 6. Change in output indicators M_e, ω, ε of the YaMZ-238NB engine over the period of load changes at a frequency of 0.8 Hz

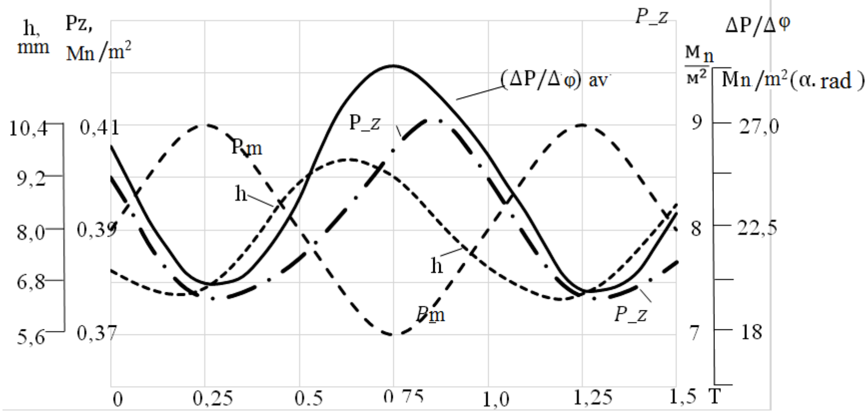

Fig. 7. Change in output and dynamic parameters h, P_z, $\Delta P/\Delta\varphi$, P_m(b) of the YaMZ-238NB engine during the period of load change at a frequency of 0.8 Hz

A significant increase in dynamic performance in the second half-cycle of change in the moment of resistance (load release) is explained by an increase in engine torque and angular acceleration of the crankshaft due to an increase in the cyclic fuel supply (at 0.875T g_c reaches its maximum). The change in engine torque M_e and the angular acceleration of the crankshaft ε are in phase. An increase in acceleration increases the ignition delay period and the duration of the third phase of fuel injection (fuel injection after seating of the injection valve, due to the expansion of the fuel located between the valve and the injector nozzle), which leads to increasing the "rigidity" of the engine operating process.

From the above analysis of the influence of variable loads on engine performance, it follows that in unsteady engine operating modes there is a significant increase in the dynamic performance of the operating cycle (P_z – by 12.5 %; $\Delta P/\Delta\varphi)_{av}$ – by 32 %), compared with comparable steady-state modes. An increase in the dynamic indicators of the cycle ("rigidity" of the working process) leads to an increase in the specific dynamic loads on the interfaces, and, consequently, to an increase in the wear rate of the main engine parts when operating in unsteady conditions.

CONCLUSIONS

1. The proposed methodology for studying automotive engines in unsteady operating modes makes it possible to evaluate their dynamic properties, to study the influence of these modes on the performance of the operating cycle of internal combustion engines, in conditions that are as close as possible to to operational ones.

2. An experimental laboratory installation which makes it possible to create constants with different load levels on the shaft of the tested engine, as well as sinusoidal, pulsed and stochastic variables with a range of 60 dB has been developed and created.

The proposed methodology and the developed installation can be used to carry out accelerated wear tests of automotive engines according to a given program, without resorting to full-scale operational tests.

3. It has been experimentally established that for the YaMZ-238NB engine there is a frequency range of changes in the moment of resistance on the crankshaft (f = 0.7...0.9 Hz), in which the maximum deviation of the main parameters from their average values in comparable steady-state modes is possible.

On the basis of the analysis of the amplitude-frequency characteristics of the fuel pump rack, it was established that in this frequency range (f = 0.7...0.9 Hz) of changes in M_r, there is a coincidence of the frequencies of forced oscillations with the natural frequency of the sensitive organ of the regulator, which drives the "engine–governor" system into a resonant state.

4. Experimental studies have established that the output parameters of the engine, with a sinusoidal change in the moment of resistance in the regulatory region of the characteristics, also change according to the sinusoidal law of the same frequency, but with some phase lag. All parameters reach the maximum deviation in amplitude from the average steady-state values at the frequency of the variable component equal to 0.81 Hz. Under these conditions, there is a phase delay in the angular velocity by 1/2 T, the engine torque by 1/4 T, and the fuel pump rack by 1/8 T.

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ИССЛЕДОВАНИЕ ТЕПЛОВОЙ ЭФФЕКТИВНОСТИ ОГРАЖДАЮЩИХ КОНСТРУКЦИЙ ИЗ ДРЕВЕСНО-ЦЕМЕНТНЫХ КОМПОЗИТОВ

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Задача сокращения энергопотребления и затрат на эксплуатацию зданий и сооружений является предпосылкой для разработки энергосберегающих технологий и материалов. Повышение энергоэффективности достигается при уменьшении потерь тепла через ограждающие конструкции. Технология производства древесно-цементных композиционных материалов имеет большое значение с инженерной точки зрения, а также как технология утилизации древесных отходов, имеющая экологическую привлекательность. В ходе исследований определялись удельные потери тепла через ограждающую конструкцию и термическое сопротивление ограждающей конструкции из древесно-цементного композита в виде опилкобетона и арболита, а также влияние на показатели тепловой эффективности наличия в массиве стены изолированных воздушных полостей и включений из экструзионного пенополистирола. Исследование проводилось с применением программного пакета Elcut. Полученные величины удельных потерь теплоты расчетной конструкции составляют от 19,5 до 51 Вт/(м^2 ·°С), величина сопротивления теплопередаче ограждающей конструкции 1,07 до 2,9 (м^2 ·°С)/Вт показатели зависят от условий эксплуатации и варианта исполнения (цельное тело конструкции, воздушные полости либо вставки из экструзионного пенополистирола). Полученные результаты могут быть использованы при проектировании и эксплуатации строительных конструкций.

Ключевые слова: *древесно-цементная композиция, арболит, опилкобетон, удельные потери теплоты, сопротивление теплопередаче, эксперимент, тепловая эффективность.*

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RESEARCH OF THERMAL EFFICIENCY OF ENVELOPE STRUCTURES FROM WOOD-CEMENT COMPOSITES

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The task of reducing energy consumption and operating costs of buildings and structures is a prerequisite for the development of energy-saving technologies and materials. Increased energy efficiency is achieved by reducing heat loss through envelope structures. The technology for the production of wood-cement composite materials is of great importance from an engineering point of view, as well as a technology for the disposal of wood waste, which has environmental attractiveness. In the course of the research, the specific heat losses through the envelope structure and the thermal resistance of the envelope structure made of wood-cement composite in the form of sawdust concrete and arbolite were determined, as well as the influence on the thermal efficiency of the presence of isolated air cavities and inclusions from extruded polystyrene foam in the wall massif. The study was carried out using the Elcut software package. The obtained values of the specific heat losses of the design structure are from 19.5 to 51 W / (m^2 · ° C), the value of the heat transfer resistance of the envelope structure is 1.07 to 2.9 (m^2 · ° C) / W, the indicators depend on the operating conditions and version (one-piece body of the structure, air cavities or inserts from extruded polystyrene foam). The results obtained can be used in the design and operation of building structures.

Keywords: *wood-cement composition, wood concrete, sawdust concrete, specific heat loss, resistance to heat transfer, experiment, thermal efficiency.*

INTRODUCTION

Industrial and civil construction consumes significant amounts of building structural and thermal insulation materials. The growing cost of energy carriers acutely raises the issue of reducing energy consumption for heating of residential and industrial buildings. Rational energy consumption is achieved through the use of modern materials and implementation of highly efficient structural solutions at the stage of design, construction and subsequent operation of buildings and structures [1; 2]. In the conditions of sharply continental climate of Eastern Siberia with extremely low temperatures in winter, the walls of buildings and structures should ensure heat preservation in the building, and in summer time – to insulate rooms from penetration of high temperatures. Providing high thermal insulation values of external walls increases the temperature of their inner surface. This improves the sanitary condition of the object, improves the microclimate. When the indoor temperature is +20 °C, the temperature of the wall surface should be at least +19 °C, and in the corners of the exterior walls – 14–15 °C, so even if the air humidity increases, no condensation will form on the walls. In addition to increasing the comfort of the object and improving its microclimate, there is a real economic efficiency from reducing the cost of electricity and heat required for heating construction objects [3].

The aim of the research is to determine the thermal resistance of the envelope structure made of wood-cement composite (WCC)

To achieve the goal the following tasks should be solved:

– to analyze the methods of determining the thermal resistance of the envelope from wood-cement composite (WCC);

– to determine by methods of simulation modeling the thermal resistance of the envelope of WCC;

– to study the influence of air cavities in the body of the building envelope on the thermal resistance indicators

MATERIALS AND METHODS RESEARCH

The reduced resistance to heat transfer of the external building envelope is the main heat-protective characteristic of the external envelope, the calculation of which is based on the area-averaged density of the heat flux passing through the envelope in the design conditions of operation.

Considering the performance indicators of thermal insulation of walls made of different materials should be based on the requirements of certain regulatory documents. Determination of thermal conductivity of materials is carried out in accordance with GOST 7076–99 [4]. The essence of the method is to create a stationary heat flux passing through a flat sample of a certain thickness and directed perpendicular to the front (largest) edges of the sample, measuring the density of this heat flux and the temperature of the opposite face edges.

Determination of heat transfer resistance of envelope structures is performed according to GOST R 54853–2011 [5]. The standard normalizes the method of determining the heat transfer resistance on the basis of creating conditions of stationary heat exchange in the envelope and measuring the temperatures of indoor and outdoor air, the temperature of the surfaces of the envelope, as well as the density of the heat flux passing through it.

These methods have certain inconveniences and limitations, such as the need for an expensive heat chamber, the duration of the observation process, the need to install and mount the structure, block or masonry to be tested, the difficulty of obtaining a steady-state heat flux in real conditions, influence of local inhomogeneities, limited number of measuring sensors.

To determine the thermal efficiency indicators in the research process, the Elcut software product was used, the principle of which is based on the finite element method.

The object of the study was to determine the thermal efficiency of the envelope structure of two variants of wood-cement composites. The first variant was sawdust concrete, the second – arbolite, made on the basis of wood chips – crushed wood. Calculation of the reduced resistance to heat transfer is based on the representation of a fragment of the thermal envelope as a set of independent elements, each of which affects the heat losses through the fragment. Specific heat losses due to each element are based on a comparison of the heat flow through the node containing the element and through the same node without the element under study.

The normative document [6] describes a method of determining the reduced heat transfer resistance of the building envelope based on the calculation of temperature fields using computer programs.

Calculation of specific heat losses through the elements of the envelope contains the following parts:

– element scheme;

– temperature field;

– outdoor and indoor air temperatures assumed in the calculation of the temperature field;

– minimum temperature of the internal surface of the structure and heat flow through the node.

The heat transfer coefficient of the homogeneous *i*-th part of the fragment of the building envelope (specific heat loss through the *i*-th flat element), *Ui*, is determined by the formula

$$U_i = \frac{1}{R_i^{\text{усл}}}, \quad \text{Вт} / \left(\text{м}^2 \cdot C^0\right), \tag{1}$$

where $R_i^{\text{усл}}$ is the conditional resistance to heat transfer of the *i*-th element, (m^2·°C) / W. It is determined by the formula

$$R_i^{\text{усл}} = \frac{1}{\alpha_{si}} + \sum R_s + \frac{1}{\alpha_{se}}, \ \left(\text{м}^2 \cdot C^0\right) / \text{Вт}, \tag{2}$$

where *Rs* is the thermal resistance of the homogeneous part of the fragment, (m^2·°C) / W; α_{si} is the heat transfer coefficient of the inner surface of the envelope, W / (m^2·°C); α_{se} is the heat transfer coefficient of the outer surface of the envelope, W/(m^2·°C),

$$R_s = \frac{\delta_s}{\lambda_s}, \tag{3}$$

where λ_s is the heat conductivity coefficient of the material, W/(m^2·°C); δ_s is the thickness of the material layer, m.

Then it is necessary to check the fulfillment of the condition

$$R_s \geq R_{\text{норм}}, \tag{4}$$

where $R_{\text{норм}}$ is the standardized value of the reduced heat transfer resistance of the envelope, (m^2 ·°C) / W.

To determine the thermal protection indicators, a thermal calculation was performed according to the requirements of SP 50.13330.2012. The value of the reduced resistance to heat transfer was estimated. The envelope structure made of WCC was modeled in the Elcut system. Then the structure was divided into a finite element mesh and the steady-state heat flow through the envelope was calculated.

The program determined the heat flow through a certain cross-section using thermal fields [7]. Mathematical modeling of the envelope and its thermal regime was based on certain boundary conditions, which were:

– Indoor air temperature with walls made of WCC according to GOST 30494-2011, $t_{int} = 20$ °C [8].

– Outdoor air temperature according to SP 50.13330.2012, $t_{ext} = –35$ °C [6].

– Heat transfer coefficient of the wall surface (internal) according to SP 50.13330.2012, $\alpha_{si} = 8.7$ W/(m^2·°C) [6].

– Heat transfer coefficient of the wall surface (external) according to SP 50.13330.2012, $\alpha_{se} = 23$ W/(m^2·°C) [6].

The object of modeling was a fragment of the envelope structure, the dimensions of which are shown in Fig. 1. The heat flow was directed normal to the surface and crossed a 40 cm thick layer of material.

In the first variant it is a full-body construction. Wood-cement composite in two variants (sawdust concrete and arbolite) was taken as a design material. Indicators of density, thermal conductivity of materials determined in the course of previous works are presented in Table 1. Operating conditions of envelope structures for the Krasnoyarsk region can be taken as A or B depending on the humidity regime of the rooms and moisture zones of the construction area.

The thermal resistance of the insulated air layer with dimensions of 10×30 cm can be assumed to be R = 0.16 m^2 ºC/W. The calculated coefficient of thermal conductivity is 0.26 W/(m ºC) [9]. In the second variant, insulated air cavities of a certain size are made in the body of the structure. In the third variant these cavities are filled with an effective heat insulator (extrusion polystyrene foam), R = 0,033 m^2 ºC/W [10]. The thermal conductivity values of wood-cement composites have been determined previously [11].

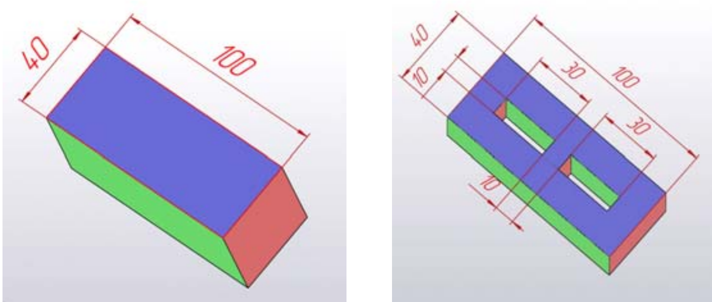

Fig. 1. Geometric dimensions of the wood-cement composite envelope structure

Table 1
Thermal conductivity coefficient

Material	Density kg/m^3	Thermal conductivity coefficient W/(m ºC)		
		In dry condition	Operating conditions	
			A	B
WCC sawdust concrete	880	0,25	0,41	0,63
WCC arbolite	670	0,18	0,33	0,53
Extrusion polystyrene foam	40	–	0,033	–

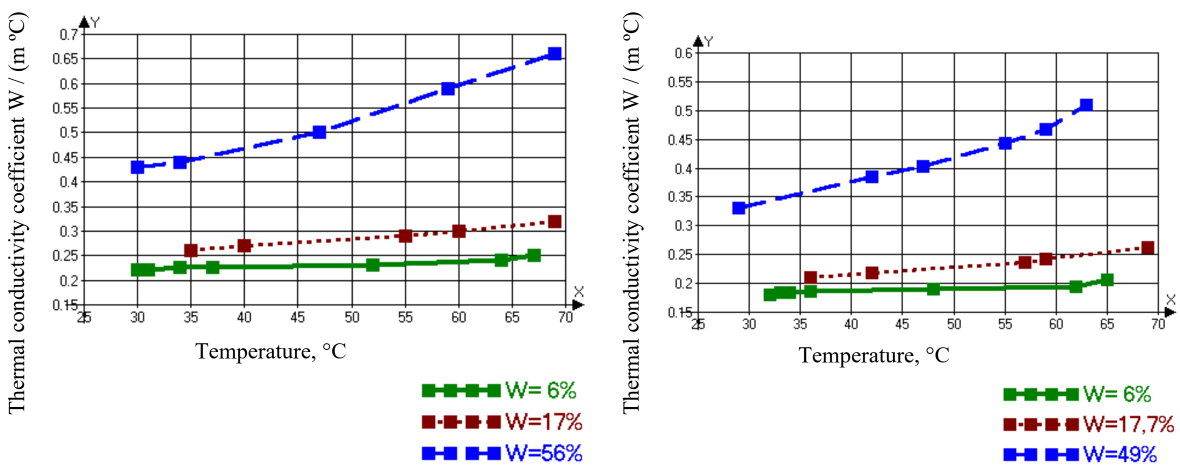

Fig. 2. Value of thermal conductivity coefficient of WCC (sawdust concrete on the left, arbolite on the right)

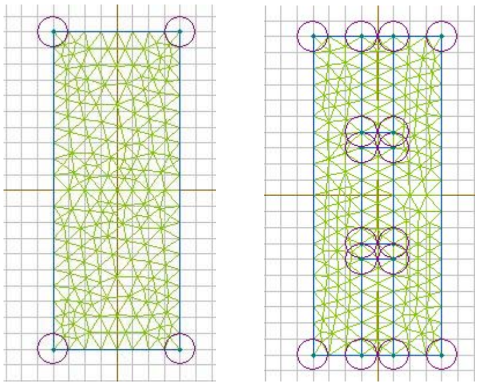

Fig. 3. Base reference points and nodes, finite element mesh partitioning of the design body in the Elcut program

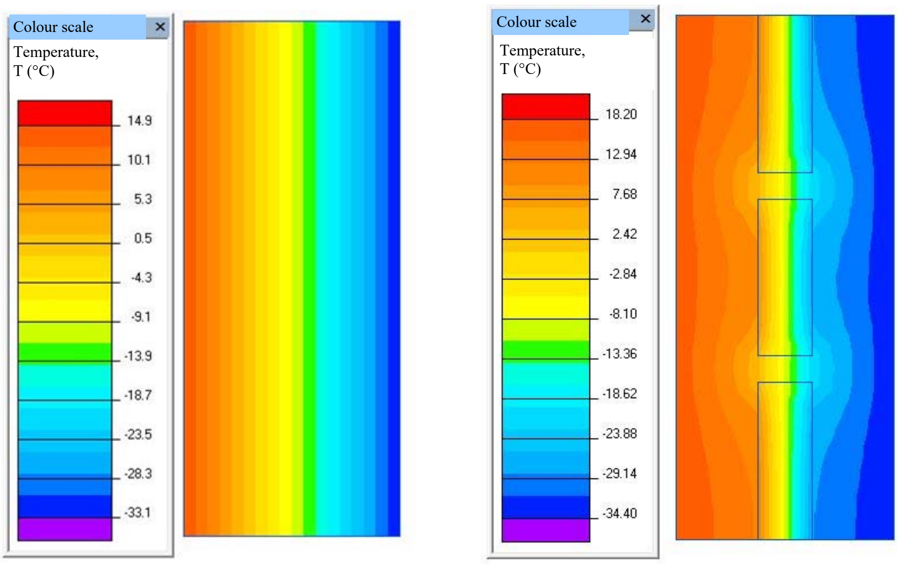

Fig. 4. Thermal fields and temperatures of the design body in the Elcut program (solid WCC body on the left, filled cavities with extrusion polystyrene foam on the right)

RESULTS AND DISCUSSION

Table 2 shows the calculations of specific heat losses and the obtained values of heat transfer resistance for different operating modes of the structure.

The obtained values of specific heat losses of the design structure are from 19.5 to 51 W / (m^2 · °C), the value of heat transfer resistance of the envelope structure is 1.07 to 2.9 (m^2 · °C) / W, the values depend on the operating conditions and the version of execution (solid body of the structure, air cavities or inserts from XPS foam).

The normative value of heat transfer resistance of the envelope for the climatic conditions of Krasnoyarsk according to the requirements [6] is R = 3.6 (m^2 · °C) / W. Thus, it turns out that even the wall of wood-cement composite in the form of arbolite with a density of 670 kg/m^3 400 mm thick with inserts of extruded polystyrene foam, which has in the most favorable conditions (dry state) R = 2.9 (m^2 · °C) / W, does not meet the requirements of the normative document. That is, to meet the existing regulatory requirements requires a multi-layer construction with high-performance insulation. The real experience of individual builders shows a somewhat different picture. Usually, the thickness of the building envelope is assumed to be equal to double the cross-section of the most common masonry block with the size of 0.4×0.2×0.2 m. In the best case we have a massive wall with a thickness of 40 cm. The experience of living and the value of heating costs of houses with walls made of wood-cement composite, even in the absence of thermo-efficient inserts or insulated air cavities in the wall construction, shows that such a construction has the right to exist and heating costs do not exceed critical values [12; 13].

High thermal efficiency indicators (with an energy saving coefficient value of 3 or more) inevitably require comprehensive justification because of the need to use expensive effective thermal insulation of sufficient thickness. In this case, it is important to fulfill the condition according to which the service life of effective insulation materials will exceed their payback period. Consequently, there are prerequisites to consider the normative values of thermal efficiency coefficients somewhat overestimated, which is in good agreement with the research data [14].

CONCLUSION

1. Methods of determining the thermal resistance of the envelope structure from wood-cement composite, provided by the requirements of GOST 7076–99, GOST R 54853–2011 are very labor-intensive and have significant drawbacks.

2. Modern methods of simulation modeling and finite element method allows us to analytically determine the

thermal resistance values of the envelope structure made of wood-cement composite. The obtained values of specific heat losses of the design structure are: (for average operating conditions) 36.3 W / (m^2 · °C) for WCC arbolite, 44.37 W / (m^2 · °C) for WCC sawdust concrete, the value of resistance to heat transfer of the envelope structure for WCC arbolite is 1.52 (m^2 · °C) / W, for WCC sawdust concrete it is 1.25 (m^2 · °C) / W.

3. When placing in the body of the building envelope insulated air cavities indicators of thermal resistance of the building envelope increases: (for average operating conditions) 34.1 W / (m^2 · ° C) for WCC arbolite, 38.8 W / (m^2 · °C) for WCC sawdust concrete, the value of heat transfer resistance of the building envelope for WCC arbolite is 1.61 (m^2 · °C) / W, for WCC sawdust concrete it is 1.41 (m^2 · °C) / W. Under the condition of replacing the volume of these cavities with high-performance thermal insulator in the form of extrusion polystyrene foam thermal resistance indicators increase significantly to the levels of 19.5 W / (m^2 · °C) for WCC arbolite, 20.35 W / (m^2 · °C) for WCC sawdust concrete, the value of heat transfer resistance of the building envelope in this case for WCC arbolite is 2.82 (m^2 · °C)/W, 2.7 (m^2 · °C) / W for WCC sawdust concrete.

The increase in the thermal efficiency of the structure with the introduction of XPS foam inserts into its array is: for arbolite 167 %, for sawdust concrete 192 %. Wall structures made of sawdust concrete, which has a higher density than arbolite, it is advisable to equip with inserts made of highly efficient thermal insulation material – extrusion polystyrene foam.

Table 2
Calculation results

Type of wood-cement composite	Density kg/m^3	Specific heat losses Q, W / (m^2 · °C)			Calculated value of the heat transfer resistance of the envelope structure R, (m^2 ·°C) / W		
		In dry condition	Operating conditions		In dry condition	Operating conditions	
			A	B		A	Б
Sawdust concrete	880	42,1	44,37	51,3	1,31	1,25	1,07
Sawdust concrete with air cavities		36,4	38,8	43,25	1,52	1,41	1,27
Sawdust concrete with XPS foam inserts		20,21	20,35	22,4	2,72	2,7	2,45
Arbolite	670	34,23	36,3	38,8	1,61	1,52	1,41
Arbolite with air cavities		31,12	34,1	39,6	1,77	1,61	1,37
Arbolite with XPS foam inserts		18,67	19,5	20,1	2,9	2,82	2,73

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ИССЛЕДОВАНИЕ ВОЗДЕЙСТВИЯ СНЕГОВОЙ НАГРУЗКИ НА КАРКАС ТЕПЛИЦЫ ДЛЯ ВЫРАЩИВАНИЯ СЕЯНЦЕВ С ЗКС В SOLIDWORKS*

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Развитие компьютерных технологий оказывает значительное влияние на все сферы деятельности человека, упрощая его жизнь. При этом совершенствуется не только аппаратная составляющая, но и программное обеспечение, в том числе и системы автоматизированного проектирования, способные облегчить труд инженера не только по разработке проектной документации, но и по выполнению трудоемких прочностных расчетов любой сложности. Программа SolidWorks предназначена для решения подобных задач. Кроме того, использование специализированных инструментов структурного анализа SolidWorks Simulation, SolidWorks Motion и других позволит значительно разгрузить умственный труд инженера, исключив монотонные арифметические вычисления.

Объектом исследования данной научной работы является каркас теплицы для выращивания сеянцев с закрытой корневой системой. Предмет исследования – напряжения, возникающие в конструкции теплицы под воздействием снеговой нагрузки и собственной силы тяжести. Цель работы – обоснование параметров конструкции каркаса теплицы для выращивания сеянцев с закрытой корневой системой (ЗКС) на основе анализа нагрузок и напряжений, возникающих в ее элементах под действием веса элементов конструкции и снеговых воздействий для обеспечения необходимой и достаточной прочности методом твердотельного моделирования.

В процессе работы проводилось исследование модели каркаса теплицы для выращивания сеянцев с ЗКС с целью оптимизации конструкции. В результате исследования определены: максимальные напряжения, возникающие на каркасе теплицы под действием снеговой нагрузки; наиболее нагруженные места конструкции. Даны рекомендации по оптимизации конструкции.

Ключевые слова: *лесовосстановление, теплица, твердотельное моделирование, анализ нагрузок.*

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STUDY OF THE IMPACT OF SNOW LOAD ON THE GREENHOUSE FRAME FOR GROWING SEEDLINGS WITH CRS IN SOLIDWORKS*

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The development of computer technology has a significant impact on all spheres of human activity, making his life easier. At the same time, not only the hardware component is being improved, but also the software, including computer-aided design systems that can facilitate the engineer's work not only in developing design documentation, but also in performing time-consuming strength calculations of any complexity. SolidWorks is designed to solve such problems. In addition, the use of specialized structural analysis tools SolidWorks Simulation, SolidWorks Motion and others will significantly lighten the engineer's mental work by eliminating monotonous arithmetic calculations.

The object of study of this scientific work is the frame of a greenhouse for growing seedlings with a closed root system. The subject of the study is the stresses arising in the structure of the greenhouse under the influence of snow load and gravity. The purpose of the study is to substantiate the design parameters of the greenhouse frame for growing seedlings with the closed system based on the analysis of loads and stresses arising in its elements under the influence of the weight of structural elements and snow impacts to ensure the necessary and sufficient strength by the method of solid modeling.

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In the process of work, a study of the model of the greenhouse frame for growing seedlings with the closed root system is carried out in order to optimize the design. As a result of the study, the following are determined: maximum stresses arising on the greenhouse framework under the influence of snow load; the most loaded places of the structure. Recommendations for design optimization are given.

Keywords: *reforestation, greenhouse, solid-state modeling, load analysis.*

INTRODUCTION

The basics of state policy in the field of use, protection and reproduction of forests in the Russian Federation for the period up to 2030 and the Forest Code of the Russian Federation provide for the further development of forest reproduction. The law specifies that reforestation is carried out to restore cut down, dead, damaged forests and should ensure the restoration of forest plantations, the conservation of the forests biological diversity and useful functions of the forests. Methods of forest restoration are defined by part 1 of Article 62 of the Forest Code: natural, artificial and combined. Artificial reforestation is carried out by planting seedlings or sowing seeds of forest plants. Planting of seedlings and saplings is carried out with an open and closed root system (CRS) [1].

Studies on growing pine with a closed root system have shown that despite the lag in growth at the first stages compared with the open root system, crops with a closed root system already in the fourth year of cultivation give a gap in height growth compared with the open root system. This factor shows that crops with the CRS grow in height faster and in the coming years will surpass crops with the open root system in diameter [2].

Repeated buildings collapses, including greenhouses, due to the snow loads have led to the fact that the task of regulating snow loads on the coatings has become very actual. This problem is difficult and extensive, and its solution, for a number of reasons, turns out to be insufficient and still far from being completed. The snow formation on the coating depends on the geometric characteristics of the greenhouse and its position relative to the wind direction. Snow loads on the coatings of heated and unheated greenhouses differ by 3–4 times [3]. Proceed from this, optimization of the greenhouse frame design based on analysis of the impact of snow load using high-precision intelligent computer-aided design systems is an actrual topic.

MATERIALS AND METHODS STUDIES

Before analyzing the loads and stresses that arise in the structural elements of a greenhouse under the influence of internal and external forces using solid-state modeling tools, it is necessary to calculate the snow load, which, in turn, depends on the territorial location of the greenhouse (see the table).

The standard value of the snow load on the horizontal projection of the coating should be determined by the formula [4]

$$S_0 = c_e c_t \mu S_g , \quad (1)$$

where c_e is a coefficient that takes into account the removal of snow from building coatings under the influence of wind or other factors; c_t – a thermal coefficient; μ – a coefficient of transition from the weight of the snow cover of the ground to the snow load on the coating; S_g is the standard value of the weight of snow cover per 1 m^2 of horizontal surface of the earth, kPa.

Algorithm for performing analysis in SolidWorks [5]:

1) creating a new static study;
2) determining the material of the greenhouse structural elements using material editing tools;
3) imposing external connections that limit the movement of the greenhouse model in space;
4) imposing external loads and gravity on the greenhouse frame according to the above calculations for snow and wind loads;
5) creating a model mesh;
6) launching study analysis;
7) assessment of the strength of the greenhouse frame structure based on the results obtained.

RESULTS AND THEIR DISCUSSION

Based on the initial data, a three-dimensional model of the greenhouse to study and justify the design parameters was developed (Fig. 1).

To analyze the resulting greenhouse frame model in a computer-aided design system, we create a new static study and set the characteristics of steel St3 [6].

We apply external links on the greenhouse model that limit the movement of the greenhouse model in space. It is planned to install reinforced concrete piles as the foundation of the greenhouse; we fix the plane of each pile at the level of the supporting surface.

Initial data for conducting research work

№	Parameter	Meaning
1	Territorial location of the greenhouse	Krasnoyarsk region
2	Snow area	V
3	Dimensions of the area for the greenhouse, m	30×17,3
4	The shape of the end and row structures of the greenhouse	arched
5	Number of end structures	2
6	Number of row structures	14
7	Step between arches, m	2
8	Maximum distance between the axes of the upper and lower belts of the arch, mm	465
9	Steel grade of greenhouse structural elements	St3

Having previously determined the snow load and the equivalent forces corresponding to this load, we apply them to the greenhouse frame together with the force of gravity (Fig. 2). The equivalent forces of the asymmetric snow load are 442.5 kN and 737.5 kN [4; 7].

Creation of a model grid. To automatically adapt the element size to the local curvature of the geometry and to create a smooth grid array, we will use a grid density set based on mixed curvature, with the grid density set to the maximum, which ensures maximum calculation accuracy.

Analysis of the study: based on the calculation results, a load diagram was obtained in the form of a ribbon with a color indication, where red is the maximum voltage, blue is the minimum (Fig. 3).

The maximum stresses arising on the greenhouse frame under snow load are 1038 MPa, which is 4.15 times higher than the permissible stresses (250 MPa). The spot of maximum stresses concentration is located at the bend of the inner belt on the side of the seventh arch (Fig. 4). This is due to the fact that the arches, located closer to the center of the greenhouse structure, experience the greatest stresses, since they do not have additional supports inside the structure.

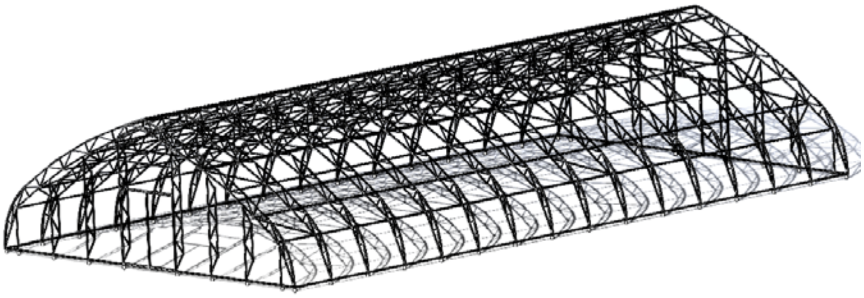

Fig. 1. Three-dimensional model of a greenhouse

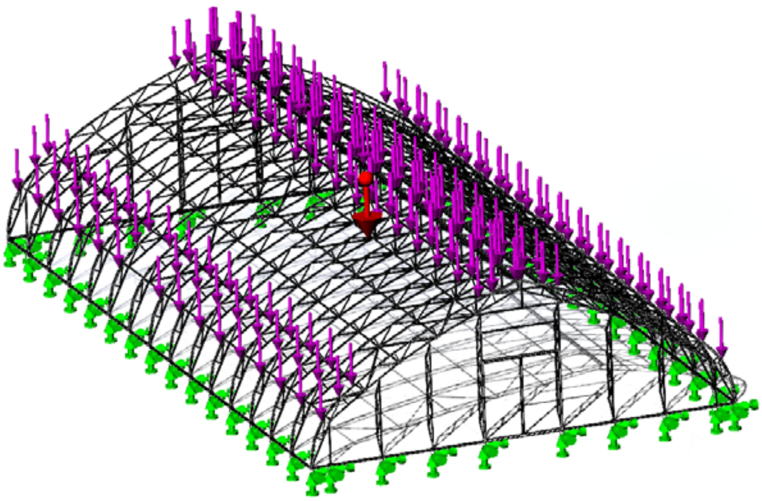

Fig. 2. Application of equivalent snow load forces to the greenhouse frame

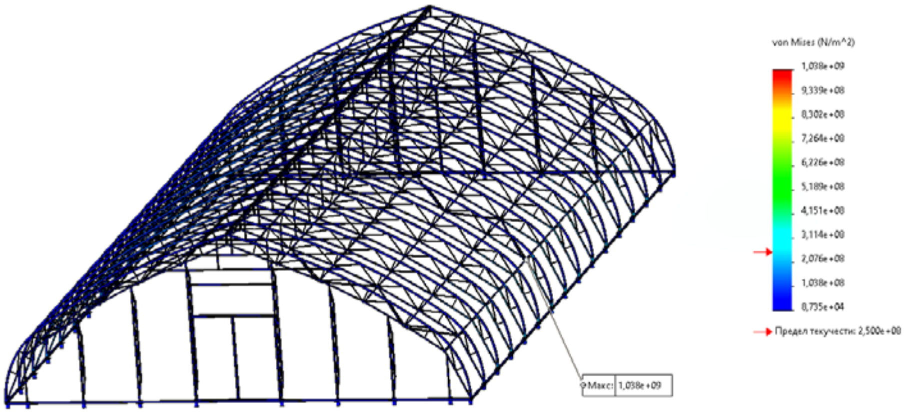

Fig. 3. Stress diagram on the greenhouse frame from snow load

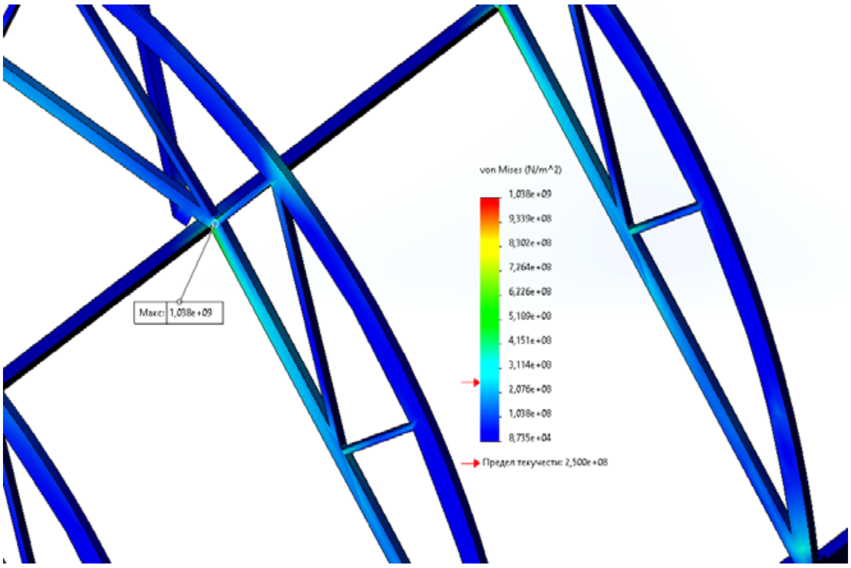

Fig. 4. Spot of maximum stress concentration from snow load

The data obtained make it possible to conclude that it is necessary to increase the distance between the inner and outer belts of the arch by 1.5-2 times, which will increase the load capacity of the loaded nodes.

CONCLUSION

Based on the results of the stress analysis of the construction of the greenhouse frame for growing seedlings with a closed root system under the influence of a snow load, the following conclusions are made:

– the maximum stresses arising on the greenhouse frame under the influence of a snow load exceed the permissible stresses by 4.15 times;

– the most loaded place is the node on the inner belt of the arch, where the small and large radii of the belts of ordinary greenhouse structures meet;

– to significantly increase the strength of the greenhouse frame structure, it is necessary to increase the distance between the inner and outerbelts of the arch by 1.5–2 times;

– it is recommended to replace the steel of the greenhouse frame structure with steel of a higher strength class S345 [8].

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АВТОРСКАЯ ССЫЛКА

AUTHOR'S LINK