Agronomy Research **19**(4), 1838–1849, 2021
https://doi.org/10.15159/AR.21.118

Dendrological collections of the Stavropol Botanical Garden: introduction and development prospects

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Received: April 15th, 2021; Accepted: July 21st, 2021; Published: August 2nd, 2021

Abstract. Botanical gardens perform active introductory work, carry out educational and academic activities, preserve the gene pool of the red book species, and serve as a source of enrichment plant resources. The leading role in solving these problems is played by dendrological collections, on the basis of which botanical research is carried out. The main part of the woody collections is located in the Stavropol Botanical Garden (SBG) arboretum. Work on the construction of the SBG arboretum began in 1959. Initially, it was planned to collect various species, natural and cultural forms of woody and shrubby plants from the temperate, and partly northern and subtropical zones. In addition, four models of forest vegetation formations of the Stavropol Krai and Karachay-Cherkessia were created on the territory of the SBG. The article presents the main stages of the introduction work on the creation of dendrological collections, the methods used. Most of the collections were formed in a short time due to the preliminary selection and mobilization of planting material. The long period of introduction made it possible to judge the advantages and disadvantages of the chosen method of genus complexes. The modern composition of the collections is analyzed, the role of the introduction process in the conservation of biodiversity is noted. The species that are promising for use in the landscaping of the region are listed. In the future, work with dendrological collections implies the attraction of new species, the introduction of information technologies, continuation of study and monitoring of plants listed in the Red Books of the Stavropol Krai, Russia and the Red List of the International Union for Conservation of Nature.

Key words: dendrological collections, arboretum, botanical garden, plant introduction, angiosperms, gymnosperms.

INTRODUCTION

In the modern world, botanical gardens play an important role. They perform active introduction work, carry out educational and academic activities, and preserve the gene pool of red book species. The dendrological collections are of particular value in the botanical gardens. Their formation takes a long period of time and requires careful long-term research. Trees and shrubs play a landscape-forming role in the park areas of the gardens (Kuzevanov & Sizykh, 2005). Arboretums of botanical gardens serve as centers for the formation of a new development level, as a source of enrichment with

new types of plant resources (Hu et al., 2020). Arboretums have accumulated a rich gene pool of woody plants *ex situ*, which can be used in forest and green construction, as well as for rare species reintroduction (Andreev, 2003).

Work on the Stavropol Botanical Garden (SBG) arboretum construction began in 1959 - the year of the foundation of the garden. Initially, it was planned to collect various species, natural and cultural forms of woody and shrubby plants from the temperate, and partly northern and subtropical zones. The employees were tasked with studying these species, identifying the most promising ones for further use in various branches of forestry and green economy. The project of the arboretum was an example of park art with the use of landscape and architectural elements. A clear layout was worked out for permanent tree and shrub plantings in the initial period of construction of the garden. Taken together, these plantings made up the entire park part of the garden and represented the final result of all its introduction work. Forest formations were also laid on the territory of the SBG for the better representation of dendrological collections.

With the growth of cities and an increase in the volume of landscape gardening in recent years, there is an increasing need for woody plants, which must have: high decorative qualities, durability, resistance to pests and diseases, as well as unfavorable environmental factors, economically useful properties. The introduction work carried out in SBG for 60 years allows expanding the modern assortment of trees and shrubs used in the landscape design of the region.

The aim of the research, based on the historical analysis of the formation of the SBG dendrological collections, is to evaluate the advantages and disadvantages of the introduction method used, and to suggest ways for further development of the collections.

MATERIALS AND METHODS

Soil and climate characteristics. The Stavropol Botanical Garden is located in the western part of the Stavropol Upland, which is a large geomorphological area and has a significant impact on the climate of the Fore-Caucasus. The Botanical Garden is located between the forestlands of the Krugly Les and the Russkaya Lesnaya Dacha at an altitude of 620–640 m above sea level. The flat terrain of the garden has a slight slope in the direction from south to north. The temperate continental climate with unstable humidification of the research area is formed under the influence of the Main Caucasian Ridge. The hydrothermal coefficient of heat and moisture supply is 0.9–1.1. The average annual precipitation is 500–600 mm. In recent decades, there has been a trend towards an uneven distribution of precipitation throughout the year. Winter is moderately mild, the coldest month is January, with an average monthly temperature of -1.9 °C. On average, the snow cover height is 10–12 cm. Often, a stable snow cover for the winter is not established at all (Badakhova et al., 2014). The duration of the frost-free period is 180–190 (up to 210) days. The number of days with thaws is 45–48. The warmest month is July, the average monthly temperature in July is +20–25 °C. There is an unfavorable dynamics of weather conditions (especially for the shoots of woody plants) - late spring frosts, drought in April, in August-September, dry winds, strong winds. The number of days with dry winds is 50–60 (Agroclimatic resources of the Stavropol Krai, 1971; Badakhova & Knutas, 2007).

The soils of the territory of the botanical garden and the landscape arboretum in particular are represented by leached thick low-humus light-clay chernozems with a humus content in the upper part of the profile of 5.22%. The availability of mobile phosphorus in the upper horizon is increased (34 mg kg^{-1}). The exchangeable potassium content is 174 mg kg^{-1}, which characterizes the soil as low-supplied with this element. The water suspension reaction is slightly acidic in humus horizons. The humus content is 5–6%, the average thickness of the humus horizon is 63 cm, the humus reserves in the meter layer average 499 t ha^{-1} (Kuprichenkov & Kopeykin, 1988). The use of groundwater by plants is difficult, since they lie at a depth of 10 m.

The Stavropol upland is a forest-steppe. Forests and shrubs predominate on wet slopes, at altitudes of 500–600 m above sea level. The forest also grows on uplands. On the territory of the Stavropol heights there are quite large forestlands: Krugly, Tatarsky and Mamaysky, Russkaya and Tamanskaya Lesnaya Dacha. The parent rocks of the cenoses from wet to dry ecotopes are *Fagus orientalis*, *Quercus robur*, *Q. calcarea, Carpinus betulus*, *Fraxinus excelsior*, hawthorn, rose hips, blackthorn *(Prunus spinosa)*, Russian almond *(Amygdalus nana),* Pallas buckthorn *(Rhamnus pallasii)*.

The study was conducted by analyzing the data presented in the report documentation of the Stavropol Botanical Garden for the entire period of its existence.

The object of research is the dendrological collections of the SBG.

Research methods. The research was carried out by analyzing the data presented in the reporting documents of the past years, and modern data obtained using geoinformation technologies. The current state of plants in the collections was characterized using a visual assessment method (Lapin & Sidneva, 1973).

RESULTS AND DISCUSSION

Founders of the garden the chief forester of the region A.A. Klopov and D.B.Sc. V.V. Skripchinsky were at the origins of the creation of woody plants collections. M.A. Lesunova (1959–1964), L.V. Boyko (1961–1986) took an active part in the collection, replenishment and study of representatives of the tree flora. Thanks to the long-term work of A.K. Chikalina (collection of gymnosperms, 1964–2006) and M.A. Koltsova (collection of angiosperms, 1972–2015), dozens of species and intraspecific taxa were attracted, and numerous introduction studies were conducted. A.F. Koltsov (1984–2020), E.V. Bachurina (1986–1993), E.V. Pyatko (1992–2014), E.N. Obshchiya (1994–2003), T.V. Nezhentseva (curator of the gymnosperms collection since 1993) has made a contribution in the study of dendrological collections in different years (Bardakova et al., 2020).

The main part of the collections of woody plants according to the plan is concentrated in the arboretum, which is divided into two components: regular and landscape. In addition, the attraction of introduced species made it possible to create several models of forest formations on the territory of the botanical garden (Fig. 1), which also became part of the dendrological collection.

The *regular arboretum,* covering an area of 13 hectares, is the first permanent plantings, with which the construction of the botanical garden began in 1959. In 1960–61, the entire network of alleys was planted. In 1962, tree plantations were planted with border shrubs, and along with this, the replacement of sick and dead trees in the alleys was carried out. At the moment, it consists of 24 alleys, 11 of which have partially

or completely lost their decorativeness and require restoration measures (Khrapach & Gudiev, 2020).

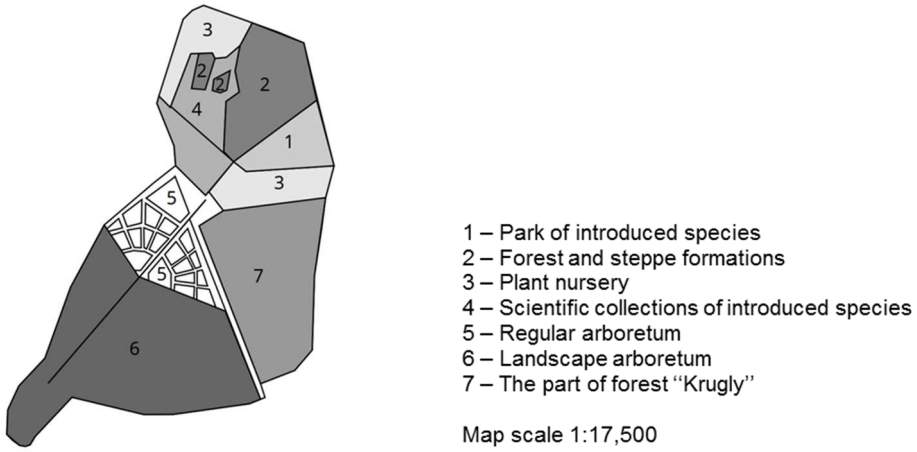

Figure 1. Schematic map of the Stavropol Botanical Garden.

In 1961, the *landscape arboretum* was laid after the preparatory work. This year, 345 plant species from 76 genera and 28 families were planted here, with a total of more than 2.5 thousand seedlings. By the end of 1962, the landscape arboretum contained 19 species from 7 genera of gymnosperms (*Picea*, *Pinus*, *Abies*, *Larix*, *Thuja*, *Juniperus, Biota)* and 556 species and forms of angiosperms. In 1964, *Taxodium distichum* was planted in a permanent place in the arboretum, in 1969 - *Pseudotsuga menziesii.* They are among the oldest specimens of the gymnosperm collection. Angiosperms were most widely represented by the families *Rosaceae* (87 species) and *Fabaceae* (43 species), as well as such genera as *Lonicera* (41 species), *Berberis* (25), *Rosa* (23), etc. (Report on the work of the Stavropol Botanical Garden, conducted in 1962).

On the territory of the botanical garden, there are expositions of forest formations representing the main tree species of vegetation of the Stavropol Krai (beech) and the Karachay-Cherkess Republic (birch, spruce, fir, pine) (Report on the work of the Stavropol Botanical Garden, conducted in 1962). Models of birch, beech, fir-spruce and pine forests were created on thin soil with a thickness of 20–30 cm on a slab of shell limestone.

Birch forest. In 1961, 1000 birch saplings were planted, harvested by Zelenchuksky forestry in the places of its natural growth. By the end of 1961, only 559 plants were preserved on an area of 0.6 hectares. In order to further expand the area of the birch grove and bring it to the design size, 1,280 pieces of natural birch seedlings of different ages were harvested by 1963 in the floodplain of the Teberda river. The model of the birch forest has been preserved to this day, but the plants do not reach the height observed in nature. The exposition is quite decorative.

The *beech forest* began to be laid in 1961 on an area of 0.3 hectares with seedlings of oriental beech (*Fagus orientalis*) grown in the Stavropol Botanical Garden nursery, and in 1962 this work was continued - seedlings from the Stavropol mechanized forestry enterprise were planted on an area of 0.73 hectares. The model corresponds to natural cenoses of the same age in their condition, self-seeding is observed by a woodsidet, decorative effect increases.

The *fir-spruce forest* was planted on an area of 0.8 hectares by three-year-old seedlings of Caucasian fir (*Abies nordmanniana*) and Oriental spruce (*Picea orientalis*) in 1961. As a result of the prevailing weather conditions, most of the plants died. In the following years, the restoration was carried out with wild fir seedlings harvested in the Teberdinsky Nature Reserve. Currently, the area of the spruce-fir forest is 0.39 hectares. When creating this model of cenosis, the method of shading was used, corresponding to the natural change of communities - conifers were planted together with taller birch seedlings, which were then cut down. The state of the model is the same as that of the birch forest exposition. Abundant self-seeding firs are formed even under the forest canopy, but their ability to replace old plants is unlikely.

The *pine forest* was planted in 1962 with two-year-old seedlings of hamated pine (*Pinus sylvestris* var. *hamata*), obtained from Kislovodsk and grown in the botanical garden nurseries. Currently, the exposition is located on an area of 0.32 hectares. The state of the model corresponds to natural cenoses, but self-seeding is almost not observed.

Thus, the most successful models were formed of beech and pine forests, they are easier to save from overgrowth by local species - ash and hornbeam. The created models of forest communities are always popular with tourists, have decorative, educational and scientific significance, thus performing important functions of botanical gardens.

The introduction work carried out in the SBG during the formation of collections consists of 4 stages. The first stage is preliminary selection, which is based on the most common method of climatic analogs (Mayr, 1909). The second stage is the mobilization of species diversity and the formation of collections directly, in which the method of (phylogenetic) generic complexes is used (Rusanov, 1950). The third stage is the analysis of plant adaptation (methods of visual observation - phenology, growth dynamics, methods of reproduction). The fourth stage is summing up the results of the implementation, which consists in assessing the prospects and possibilities of using the studied plants in ornamental gardening, forestry and in environmental protection measures. The implementation process is long and continuous.

Analysis of the geographical origin of woody plants, carried out at the first stage, showed that in the temperate zone of the North Caucasus, the main sources of collection fund replenishment are dendroflora of the East Asia (from the northern and mountainous regions of China, Korea, Japan, the forest-steppe of the Russian Far East), North America, European-Siberian flora, and to a lesser extent - the flora of the Mediterranean (Takhtajyan, 1978).

At the second stage, the main source for the mobilization of the species diversity of the local flora were expeditions. The plant material collected in this way was used for planting in nurseries and permanent plantings. In addition, the number of species, varieties and cultivars in the collections has increased significantly due to established relations with botanical organizations of the former USSR. Thanks to the creation of the Council of Botanical Gardens in the early 60s and the seed exchange system (delectus) there was an active replenishment with new introducers. Botanical gardens and arboretums of Moscow, Kiev, Alma-Ata, Vladikavkaz, Minsk, Sochi, St. Petersburg and other cities became the sources of planting material. A special place in the dendrological collections of the botanical garden is occupied by plants grown from seeds obtained from foreign botanical gardens in Germany, Poland, Japan, Canada, Hungary, etc. (Kozhevnikov et al., 2000).

In the first years of laying dendrological collections, the main work was focused on the collection, cultivation of planting material and care of plantings. The received species were initially tested in botanical garden nurseries, the formation of which was carried out in parallel with active introduction work with taxa from different climatic zones. The creation of shady areas made it possible to start mass reproduction of coniferous and deciduous species. Plantings in the arboretum were almost annually replenished with new species and forms.

According to the systematic principle of the Rusanov method, genera of the same family are located in a single array. Within the exposition of each genus, species, varieties, forms and hybrids are presented, from which genus diversity is composed.

In modern conditions, the importance of phenological studies and especially long continuous series of observations is increasing (Zheng et al., 2002; Firsov et al., 2010). In the SBG in different years and up to the present time, phenological data are collected according to the method developed in the Main Botanical Garden (Moscow) (Alexandrova et al., 1975). The results obtained make it possible to judge the degree of compliance of introduced species with new growing conditions. In the course of research work, winter hardiness, drought resistance, methods of reproduction, characteristics of decorative and economic features of introduced species are studied, which will further allow assessing the results of introduction.

About 90 species of trees and shrubs from different angiosperm families were recommended for reproduction for economic purposes as the first preliminary result of the introduction in 1967: *Berberis thunbergii*, *Betula populifolia*, *Castanea sativa*, *Cercis siliquastrum*, *Corylus avellana*, *Forsythia ovata*, *Quercus rubra*, *Spartium junceum*, *Viburnum lantana*, etc. (Report on the topic No. 15, 1967). In 1970, the prospects of representatives of the *Rosaceae* family consisting of 28 genera and 280 species were evaluated. As a result, 211 species of the most promising plants were identified, which accounted for 77% of the representatives of the family. Numerous species and forms of the genera *Crataegus*, *Sorbus*, *Malus*, *Photinia*, *Physocarpus*, *Rosa*, etc. are among the economically valuable ones for the Stavropol Krai. In the period from 1970 to 1973, attention was paid to representatives of the local flora - 35 species from 41 genera and 18 families were planted in the arboretum. More than 1,000 species and forms of woody and shrubby plants were tested by the end of the 70s (Report on the work of the Stavropol Botanical Garden, conducted in 1976).

In the 70s, the staff of the garden set up an experiment on growing a salt-resistant form of scots pine (*Pinus sylvestris*) for testing on saline soils of the Sengileevskaya depression. As a result, the survival rate of seedlings was 80% (Report on the work of the Stavropol Botanical Garden, conducted in 1974). Experimental studies on determination of the optimal conditions for gymnosperms (shading, watering, mulching) have become relevant. As a result, recommendations were formulated on agricultural techniques for growing seedlings of Oriental spruce (*Picea orientalis*) and Caucasian fir (*Abies nordmanniana*), taken from under the forest canopy. A long-term series of experiments on vegetative propagation by stem cuttings of ornamental forms, species and cultivars of the Cypress family (*Cupressaceae*) deserves attention. A special feature of the experiment was a detailed study of the factors that affect the rhizogenesis process (various substrates, temperature, humidity, rooting time, growth stimulators) (Nezhentseva & Kozhevnikov, 2018). Long-term researches of the garden staff were aimed at identifying the dynamics features of growth and development, the introduction

possibilities of species, natural forms and cultivars of gymnosperms. The results obtained allow to select adapted plant genotypes for use in forestry, which is consistent with modern methods of rational nature management (Jansons et al., 2020).

In the period from 1981 to 1985, the generic complexes of the *Oleaceae* family were studied: *Fraxinus*, *Syringa*, *Ligustrum*, *Forsythia*. Based on the integrated assessment of the prospects for the introduction of plants of the genus *Fraxinus*, recommendations were developed for the use of various types of ash in landscaping, depending on the soil and climatic conditions in the regions of the Stavropol Krai (Koltsova et al., 1980). Subsequent years were devoted to the study of ecological and biological features, accelerated methods of reproduction of such genera and species as *Sorbus*, *Salix*, *Crataegus*, *Chaenomeles*, *Pentaphylloides daurica* and *P. fruticosa*, *Exochorda racemosa*, *Aronia*, *Cornus mas* (varieties), *Asimina triloba*, etc. (Koltsova et al., 2009; Pyatko, 2010; Koltsova et al., 2014). Since 1994, the SBG has been working on the introduction of tree and shrub exotics. A significant part of these plants have a natural range in the warm-temperate and subtropical climate zone. Therefore, special attention was paid to their winter hardiness. The prospect group of some representatives of the families *Hamamelidaceae*, *Magnoliaceae*, and *Styracaceae* was determined (Khrapach et al., 2009).

In 2015, a large-scale inventory of the arboretum's ancestral complexes using information technologies was launched. The creation of a detailed map using modern software using the layout scheme of the arboretum of previous years (Fig. 2), the creation of a map of the area using satellite navigation, and the work with the electronic database of the complete list of arboretum species served as a prerequisite for further research in this direction (Petin & Nezhentseva, 2011; Kotenko, 2016).

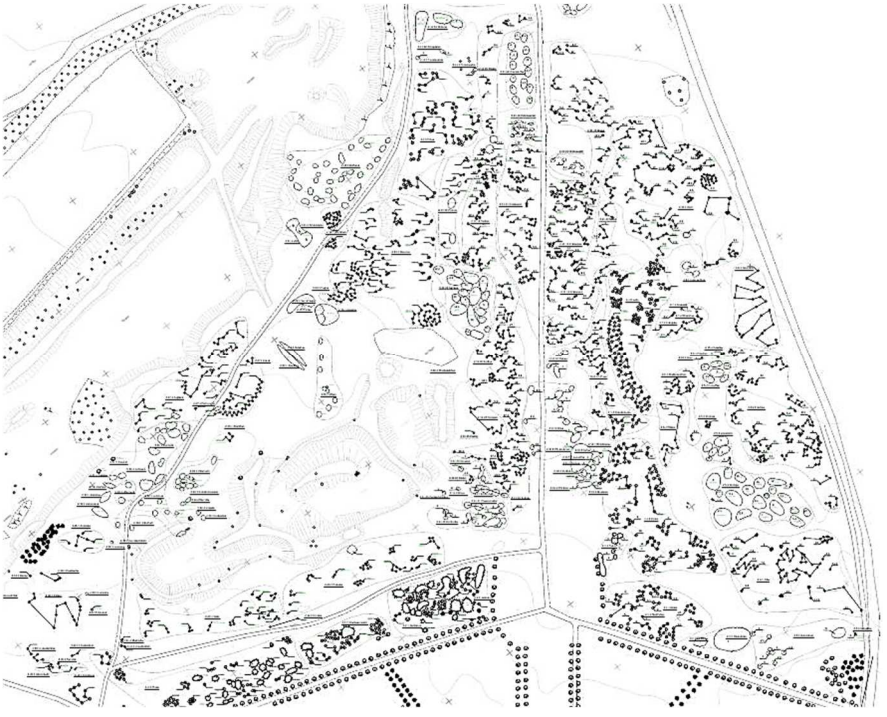

Figure 2. Schematic map of the SBG arboretum (fragment).

Inventory of species composition for such an object as a landscape arboretum is a labor-intensive, long-term task and will be continued in the coming years. Currently, the arboretum collection contains about 580 species of cultivars and forms of Angiosperms *(Magnoliophyta)* and 164 - Gymnosperms *(Pinophyta)* plants (Nezhentseva & Shchegrinets, 2018; Bardakova et al., 2020). The generic complexes of the family *Rosaceae* are still the most widely represented in the arboretum collection: *Crataegus*, *Sorbus*, *Malus*, from other families – *Betula*, *Fraxinus*, *Acer.* The largest families of Gymnosperms are *Pinaceae* and *Cupressaceae* (Figs 3 and 4). Despite the fact that most of the plants in these complexes are more than 50 years old, a significant part of them are in good or satisfactory condition, but many of them require a lot of work to update and repair, for some of them it is necessary to verify the taxonomic affiliation.

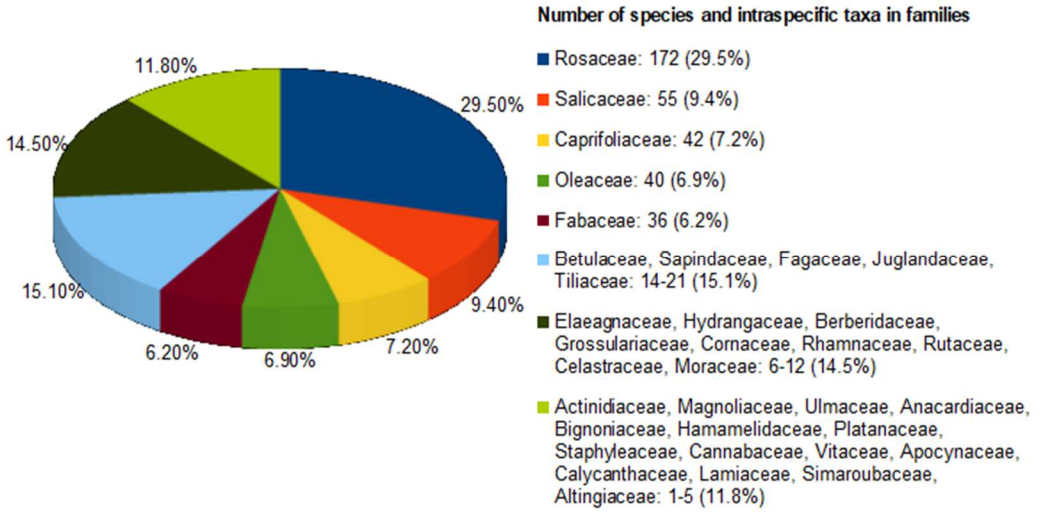

Figure 3. Current state of the angiosperms collection of the arboretum.

In the period 2006–2020, more than 100 promising species and forms from different families of angiosperms and gymnosperms were recommended from the SBG dendrological collection for use in landscape design (Koltsova et al., 2006; Nezhentseva & Kozhevnikov, 2018). During the entire period, part of the research work was to monitor the growth and development of plants transferred to the landscaping of the city of Stavropol and more than 40 settlements of the region. Many introduced species and varieties have received a good biological and economic assessment. As an assessment scale, we used a method for assessing the prospects for the introduction of woody plants based on visual observation data (Lapin & Sidneva, 1973). The main criteria characterizing the state of introduced species were: the degree of annual ripening of shoots, winter hardiness, preservation of habitus, shoot-forming ability, regularity of shoot growth, ability for generative development, methods of reproduction. Currently, the most popular species in the landscaping of the region are such species as *Thuja occidentalis* 'Fastigiata', *Juniperus chinensis* 'Pfitzeriana', *Pinus pallasiana, P. mugo, Taxus baccata, Betula pendula, Tilia cordata, Cercis canadensis, Paulownia tomentosa, Catalpa bignonioides, Aesculus hippocastanum, Castanea sativa, Corylus colurna.*

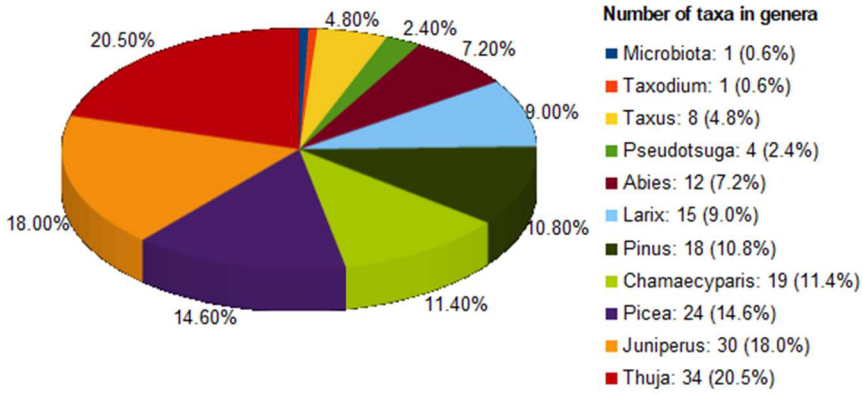

Figure 4. Current state of the gymnosperms collection of the arboretum.

Another important area of work with dendrological collections in SBG is the *ex situ* conservation of plant biodiversity. This has acquired particular relevance after the adoption of the International Strategy for the Conservation of the Gene Pool of Rare and Endangered Plant Species (Andreev, 2003; Wyse Jackson, 2009). The SBG dendrological collection currently includes 68 angiosperm taxa and 15 gymnosperms with different rarity status. Of these, 28 species are included in the Red Data Book of Russia, 49 species are included in the Red Data Books of the regions of Russia and neighboring countries, and 6 species are included in the IUCN Red List (Bardakova et al., 2020). Monitoring of the state of rare and endangered species in the SBG collections and in nature is carried out annually, and the methods of their reproduction are studied. As a result of this work, promising species recommended for landscaping were identified: *Picea omorica, Pinus pallasiana, Taxus baccata, Betula raddeana, Acer laetum.*

CONCLUSIONS

In SBG, as a result of planned introduction work carried out since 1961, representative collections of woody plants have been created that have scientific and practical significance. Currently, the landscape arboretum contains all the variety of species of trees and shrubs introduced in the botanical garden. Most of the taxa have entered the generative phase of development and are producing viable seeds, which indicates their acclimatization at the point of introduction. The collected seed material makes it possible to expand research on seed reproduction of these species.

As a result of the integrated assessment, it was found that the most appropriate is the further introduction of fast-growing and rather durable species and cultivars of poplars, related to white poplar (*Populus alba*) and aspen (*P. tremula*), drought-resistant species of maple, birch, mountain ash from the *Lobatae* section, from slow-growing ones - species of oak, cultivars of magnolia kobus. In the long term, it is possible to introduce plants that do not tolerate local soil conditions (species of rhododendrons, except for *Rhododendron lutea*, which successfully grew in the birch forest model, and the highly ornamental Xanthoceras *(Xanthoceras sorbifolia*)).

Analysis of the history of the formation of woody collections of SBG outlined the main stages of introduction research. Most of the collection was formed in a short time due to the preliminary selection and mobilization of planting material. A long period of research has made it possible to judge the advantages and disadvantages of the chosen method of generic complexes. Positive aspects: the visibility of the species diversity within each complex, the possibility of comparative studies in similar ecological conditions. The negative side: the limited spatial distribution of species of the same genus leads to closely related crosses, which affects the purity of the species.

In the future, work with dendrological collections implies the attraction of new species, the continuation of information technologies introduction. The increased needs of the population for a variety of highly ornamental plants create prerequisites for the development of new directions in the study of dendrological collections. It is planned to reconstruct the lost decorative elements and create new expositions. It is planned to continue studying and monitoring plants listed in the Red Books of the Stavropol Krai, Russia and the Red List of the International Union for Conservation of Nature.

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