Adaptive ability comprehensive assessment of introducers in Koltsovsky Square (Voronezh)

Olga Ryazantseva[1*], *Alexey* Tseplyev[1], and *Valentina* Popova[1]

[1]Voronezh State University Forestry and Technologies named after G F Morozov, 394087 Voronezh, Russian Federation

Abstract. The article presents the results of research in assessing the results of the introduction of some species of introduced plants planted on the territory of Koltsovsky Square in Voronezh. The objects of research were woody plants grown in nurseries in Belgium and Germany, and in adulthood (8-12 years old) and transplanted into the conditions of a more severe climate of the Voronezh region. During the study, a comparative analysis of the natural and climatic conditions of the city of Voronezh and the location of the nurseries from which the objects of research were brought, the distribution of objects by groups of prospects was carried out and frost resistance zones. As part of a comprehensive assessment of the introduction results, calculations of the percentage of the average periodic increase of the studied objects, correlation and regression analysis were carried out in order to establish the relationship between the average periodic increase and other indicators. A cluster analysis was also carried out, which makes it possible to divide the studied population into groups of similar objects simultaneously according to several criteria. The data obtained were processed by the method of mathematical statistics using computer software MS Excel 2013 and Statistica 12.

1 Introduction

Currently, the social, ecological and cultural functions of the forest are among the priorities for Russia and the world as a whole. All of them are considered in connection with the improvement and enhancement of biological diversity, including urban green spaces [5].

The quality and quantity of urban green spaces is one of the fundamental factors in the formation of a comfortable urban environment. A modern city is a complex, open, dynamic artificial–natural system, the peculiarity of which is that it becomes a tangible factor of influence on both natural systems and humans [4].

Recently, there has been an active process of urbanization on the planet, as a result of which the ecological state of the environment is deteriorating. Green spaces play a significant role in neutralizing and reducing the negative effects of industrial areas of cities on people and the natural environment. They act as the main means of improving the microclimate and sanitary and hygienic conditions in places of mass residence of people, and are also one of

* Corresponding author: dnb-87@mail.ru

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

the most effective and economical means of improving the comfort and quality of the living environment [8].

The restoration of urban ecosystems to a level that guarantees the stability of the environment is possible due to the expanded introduction of introduced species into that systems.

Generalization of the experience of growing introduced and extrazonal species in urban green spaces is an original and generally recognized methodological approach to substantiating the improvement of biodiversity, assuming, first of all, the preservation and support of established plant structures. This is one of the ways to promote new economically valuable, ornamental and food plants.

An objective assessment of the prospects of introducers is possible only on the basis of comprehensive studies of their growth and development in the new conditions of their place of growth. A fully naturalized plant is practically indistinguishable from native species, and sometimes its artificial introduction into the ecosystem can be established only on the basis of historical data [1]. Various works by V.F. Abaimov et al. are devoted to the issue of introduction, as well as to the study of the degree of resistance of ornamental woody plants of introducers to new growing conditions. ((2007), Y.N. Karpunova (2004), P.I. Lapina, G.Z. Abbasova (2012), I.S. Akimov (1997), I.S. Belyuchenko (2014), G.S. Varaksina (2009), E.V. Zolotareva et al. (2012), K.S. Kocharyan (2008) and many others [8].

The main share of urban green spaces includes age categories – more than 30 years old, which indicates the "aging" of the green fund of cities and requires compensatory replacement. In this regard, it is the planting of large-sized plants that can be a good option for such a replacement.

The purpose of the work was to assess the results of the introduction of some species of woody plants planted in the Koltsovsky Park of Voronezh in 2018, which were previously grown in nurseries in Belgium and Germany and transplanted into the conditions of a more severe climate of the Voronezh Region in adulthood (8-12 years old).

At the same time, it should be noted that the study of the results of the introduction of woody plants that were transplanted into a harsher climate in adulthood has not been conducted before. In this regard, we can talk about the scientific novelty of this area of research.

2 Methods and materials

The objects of research were made by the representatives of 20 species of woody plants introduced plants, among which *Quercus coccinea, Quercus laurifolia, Quercus macrocarpa, Quercus palustris, Quercus pétraea, Quercus imbricaria, Acer platanoides 'Globosum', Aesculus x arnoldiana 'Autumn Splendor', Aesculus hippocastanum 'Homestead', Bétula nígra, Bétula pendula 'Laciniata', Celtis occidentalis, Malus baccata 'Street Parade', Malus x purpurea 'Royaltii', Malus x purpurea 'Neville Copeman', Malus x purpurea 'Red Sentinel', Sorbus intermedia 'Brouwers', Tilia x europaea 'Pallida', Prunus padus 'Watereri', Gymnocládus dióicus.*

Voronezh is located in the European part of Russia on the border of the Central Russian Upland and the Oka-Don plain between 51° 29’ and 51° 54’ north latitude and 39° 01’ and 39° 40’ east longitude. The climate of the city can be characterized as temperate continental with an average annual temperature of +4.6 to +5.6 °C.

The average temperature in January is at the level of 10-15 degrees, the average temperature in July is 20-25 degrees. It can be said that the annual temperature course is characterized by evenness, without sharp amplitudes and fluctuations. Recurrent cold weather is possible in spring. The annual rainfall is below 430-450 mm. Winter and autumn highs are highlighted.

At the same time, it is noted that the climate of the Voronezh region is becoming increasingly arid. The duration of the frost-free period in Voronezh is 220-227 days, the growing season is about 185 days [9].

In the course of the study, a comparative analysis of the natural and climatic conditions of the city of Voronezh and the location of the nurseries from which the objects of the study were brought was carried out. According to the results of this analysis, it was noted that the climate of the area in which the nursery is located is much milder than the study area. The minimum temperature in Belgium in accordance with the USDA-frost resistance zone does not fall below -12.2 °C, while in the Voronezh region it can fall below -30 °C. The annual precipitation reaches 816 mm, in the Voronezh region this indicator is almost 2 times lower. The duration of the frost-free period in Belgium and Germany is about 260 days, the growing season lasts more than 210 days, which is on average 15% more than in the territory of Voronezh [2].

It should be noted that despite of the significant difference in the climatic conditions of these areas, the survival rate of the studied plants was 100%.

During the field work, measurements of trunk diameters and subsequent comparative analysis of increases in trunk diameter were carried out. It should be noted that the study of height gain is not possible, because the studied objects are subjected to periodic pruning and crown molding.

Measurements were carried out during planting in 2018, repeated measurements were carried out in 2024. In the studied specimens, the trunk diameter was measured at a height of 1.3 m from the root neck.

In the course of the study, the percentage of the average periodic increase in the studied objects was estimated, and regression analysis was carried out in order to establish the relationship between the average periodic increase and other indicators. A cluster analysis was also carried out, which makes it possible to divide the studied population into groups of similar objects simultaneously according to several criteria.

When summarizing the results of the introduction, it is important to determine the degree of adaptability of plants to new natural and climatic conditions, to identify how much they retain useful properties and signs for economic use.

For the analysis, the researchers propose to determine the success of the introduction by schools focused on the assessment of various indicators, which allows taking into account the variety of options for the passage of the introduction process.

We selected the integral assessment of Lapin P.I., which combines several indicators characterizing the condition of plants at the site of introduction and is determined only by regular visual observations.

The assessment is based on the definition of specific estimates of indicators: the degree of annual ripening of shoots, winter hardiness, preservation of habit, shoot-forming ability, regularity of growth of shoots in height, the ability of plants to generative development, available methods of reproduction in culture.

Based on the integral assessment, the total viability score for each year of observations and the average score for the observation period are calculated. The highest final or integral viability score is estimated at or equal to 100 points and consists of the highest scores in all indicators, namely: the degree of annual ripening of shoots – 20 points, winter hardiness – 25, preservation of habit – 10, shoot–forming ability – 5, regularity of growth of shoots in height - 5, generative development – 25, methods reproduction – 10 points. If one of the viability indicators does not receive the highest score, then the total score will be less than 100.

After scoring points on 7 indicators, a six-step scale of prospects for introduction is used: Index or group 1. A group of plants is quite promising (91-100 points). Group 2 – promising plants (76-90 points). Group 3 – less promising plants (61-75 points). Group 4 – unpromising

plants (41-60 points). Group 5 – unpromising plants (21-40 points), group 6 – plants unsuitable for introduction (5-20 points).

This technique allows us to give an integral assessment of the viability of introduced plants, expressed by numerical indicators [6, 7].

Frost resistance zones (USDA zones) are territorial zones delimited according to the principle of the average annual minimum temperature. The division into zones helps to determine whether a certain plant can survive in winter conditions at a given temperature.

The data obtained were processed by the method of mathematical statistics using computer software MS Excel 2013 and Statistica 12.

3 Results and discussion

The growth of a tree should be understood as a natural increase in its size, which is determined, among other things, by the diameter of the trunk. The increase in trunk diameter is most often determined based on measurements at chest height. The linear value of the current increase in diameter can be expressed as a percentage relative to the arithmetic mean diameter for the period under study.

The increase, expressed in absolute terms, is called absolute, and in fractions or percentages – relative. In practice, both are used, the first – to determine the amount of growing wood, the second – for a comparative assessment of the energy of tree growth. For our study, we used a relative indicator [11].

To estimate the percentage of the average periodic increase ($P_T^{av.p.}$) we have chosen the Pressler formula:

$$P_T^{av.p.} = \frac{200}{n}\frac{T-T_n}{T+T_n} \qquad (1)$$

where T – the current tax rate, Tn – the tax rate n years ago; $T - Tn$ – the current periodic increase, n – the period for which the current increase is taken into account [11].

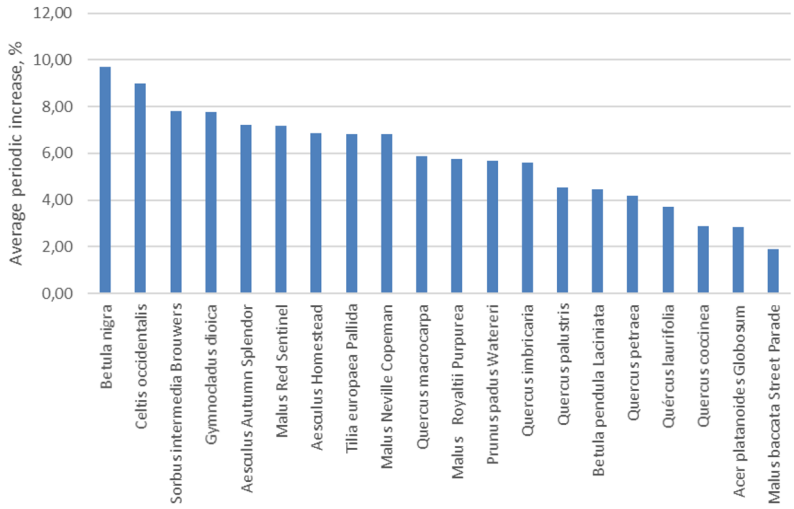

Fig. 1. The average periodic increase in the analyzed types of introductions

As can be seen from Fig. 1, the average value of the percentage of growth for the studied objects varies from 1.9% to 9.7%. The best growth rates were noted in Black birch (*Betula*

nigra), Western Frame (*Celtis occidentalis*), Swedish mountain ash (*Sorbus intermedia Brouwers*) and Gymnocladus dioecious (*Gymnocladus dioicus*). The smallest increase is shown by the Holly maple "Globosum" (*Acer platanoides Globosum*), Malus "Street Parade" (*Malus baccata Street Parade*), the Sharlakh oak (*Quercus coccinea*).

For our sample, we calculated the coefficient of variation using the formula:

$$CV = (\sigma/k) \times 100 \quad (2)$$

where σ — the standard deviation of a random variable, k — the expected (average) value of a random variable [12].

It can be said that the population is heterogeneous, the growth rates in diameter have a significant coefficient of variation (35%), which is due to a significant difference in the amount of growth, different rock composition and environmental factors. At the same time, the coefficient of variation according to the data of the initial diameter when planting plants in 2018 and the data of diameter measurements in 2024 are at the level of 13% and 15%, respectively.

At the next stage of evaluating the results of the introduction, we analyzed the distribution of the studied objects into groups of prospects according to the Lapin P.I. method described above, and identified their possible dependence on the percentage of increase. Fig. 2 shows the distribution of the studied objects by groups of prospects, published in our works earlier.

According to the results of the analysis, 25% of the studied species are classified as “Quite promising”, 35% - as “Promising”, 40% - “Less promising” [10].

When evaluating the obtained parameters, a correlation analysis was performed in order to identify the presence of a relationship between the percentage of the average periodic increase in diameter and the group of prospects determined by the Lapin P.I. method. The obtained correlation coefficient was $r < 0.1$, which indicates the absence of a linear relationship between the signs.

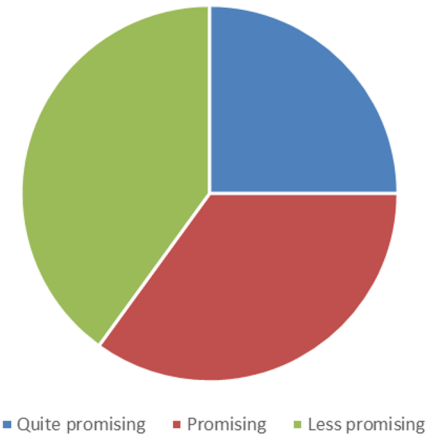

Fig. 2. Distribution of the studied objects by perspective groups

According to the results of the distribution of the studied objects by frost resistance zones, 55% of the analyzed introducents belong to Zone 4, 25% belong to Zone 5 and 20% belong to Zone 3 (Fig. 3).

It should also be noted that the territory of Voronezh belongs to Zone 4 with an average minimum temperature of 34.4-28.9 °C, and the territory of the nurseries where the introduced

plants were grown belongs to Zones 7-8, i.e. the average minimum temperature is 12.5-6.7 °C.

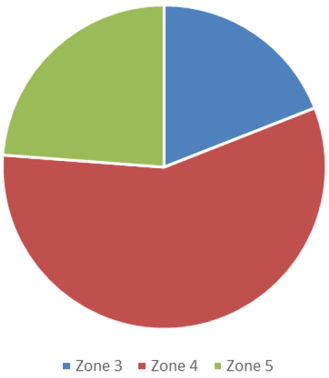

Fig. 3. Distribution of the studied objects by winter hardiness zones

The most interesting, in our opinion, is the condition of woody introducents belonging to Zone 5 (*Aesculus Autumn Splendor, Aesculus Homestead, Quercus laurifolia, Quercus palustris, Quercus coccinea*). According to Lapin P.I.'s methodology, these species are classified into Promising and Less promising Groups. The less promising ones do not bear fruit and do not bloom, the promising ones bloom, but do not bear fruit, i.e., we can say that they are all hardy, retain their habit well, but reproduction is possible with the help of artificial vegetative reproduction.

When evaluating the obtained parameters using correlation and regression analysis in order to determine the presence, size and direction of the relationship between the percentage of average periodic increase in diameter and the frost resistance Zone, a correlation coefficient was obtained, which was -0.26, which indicates the presence of a weak feedback between the signs (Fig. 4).

The next stage in the analysis of the increase in diameter of the studied species of introduced species was a cluster analysis, the purpose of which was to distribute the results obtained into groups. Cluster analysis allows you to divide the studied population into groups of similar objects simultaneously on several grounds. At the same time, the distance between these objects in the multidimensional space of the studied features is used as a measure of the separation of objects into groups [3].

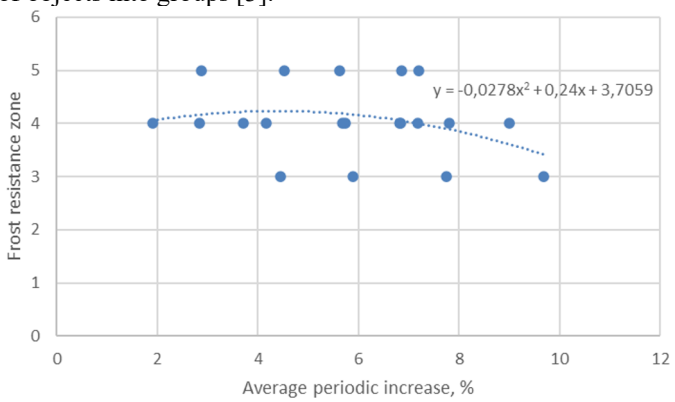

Fig. 4. The tightness of the relationship between the percentage of the average periodic increase in diameter and the frost resistance Zone

As a result of the cluster analysis of the studied objects carried out using the Statistica program, we obtained a dendrogram (Fig. 5), which is based on determining the Euclidean distance between objects.

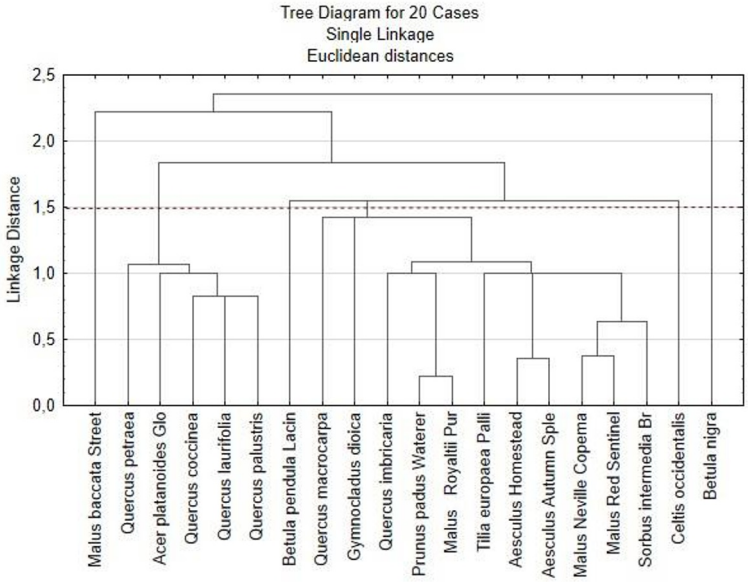

Fig. 5. Dendrogram for 20 cases

Based on the results of the analysis, we identified 5 clusters in the studied population:

- cluster No. 1 is the most extensive, including representatives of the Rosaceae family of the genera Malus and Sorbus. The closest relationship was shown by Prunus padus ′Watereri′ and Malus x purpurea ′Royaltii′, as well as Malus x purpurea ′Neville Copeman′, Malus x purpurea ′Red Sentinel′, Sorbus intermedia ′Brouwers′. Similar indicators were demonstrated by representatives of the genus Aesculus (Horse chestnut, family Sapindaceae) - Aesculus x arnoldiana ′Autumn Splendor′, Aesculus hippocastanum ′Homestead′. The second cluster includes representatives of the genus Oak (Quercus), family beech family (Fagaceae): Quercus palustris, Quercus laurifolia, Quercus coccinea, Quercus patraea and Acer platanoides 'Globosum', which are similar to them in terms of growth and adaptation characteristics. The third cluster, occupying an intermediate position, included Gimnocladus diocica, Bétula pendula 'Laciniata', Celtis occidentalis. The fourth and fifth clusters, the most distant from each other and all other representatives of the dendroflora, included Bétula nígra and Malus baccata 'Street Parade'.

The selection of Bétula nígra, Malus baccata 'Street Parade', Celtis occidentalis is probably due to their opposite contrasting growth percentage values.

A close relationship can be traced between several species of oak. Thus, we can conclude that there is some connection between representatives of the same family.

4 Conclusion

Based on the conducted research, the following conclusions can be drawn.

According to the results of the comparative analysis of the natural and climatic conditions of the city of Voronezh and the location of nurseries, significant differences were revealed, which, however, did not affect the survival rate of plants, which amounted to 100%.

The average value of the percentage of growth for the studied objects varies from 1.9% to 9.7%. It can be said that the population is heterogeneous, the growth rates in diameter have a significant coefficient of variation (35%), which is due to a significant difference in the amount of growth, different rock composition and environmental factors. At the same time, the coefficient of variation according to the data of the initial diameter when planting plants in 2018 and the data of diameter measurements in 2024 are at the level of 13% and 15%, respectively.

Among the studied objects, the most successfully growing trees can be distinguished, which differ in the largest increase in diameter. At this stage of development, the best growth rates were noted in Black birch (*Betula nigra*), Western Frame (*Celtis occidentalis*), Swedish Mountain ash (*Sorbus intermedia 'Brouwers'*) and Gymnocladus dioecious (*Gymnocladus dioicus*). These plants, in our opinion, can be attributed to fast-growing introducers.

The relatively slow-growing trees in our research include the Holly maple "Globosum" (*Acer platanoides 'Globosum'*), Malus "Street Parade" (*Malus baccata 'Street Parade'*), Sharlach oak (*Quercus coccinea*), which showed the lowest percentage of growth.

At the same time, the assessment according to the Lapin P.I. method, characterizing the state of plants at the site of introduction, shows that 25% of the studied species are classified as “Quite promising”, 35% - as “Promising”, 40% - “Less promising”. I.e., they all show good indicators of the degree of passage of the introduction process.

The correlation analysis performed in order to identify the presence of a relationship between the percentage of the average periodic increase in diameter and the group of prospects determined by the Lapin P.I. method indicates the absence of a linear relationship between the signs.

The conducted correlation and regression analysis in order to determine the presence, size and direction of the relationship between the percentage of the average periodic increase in diameter and the frost resistance Zone indicates the presence of a weak feedback between the signs.

In order to determine the most promising species for landscaping in the conditions of Voronezh, it is necessary to conduct further research on the growth and development of introduced species.

References

1. M.M. Andronova, Stepwise introduction of woody plants in the north of the Russian plain: dis. ...Doctor of Agricultural Sciences 06.03.01Arkhangelsk, (2019) 430 p.
2. Average length of the growing season in Europe for the period https://www.researchgate.net/figure/Average-length-of-the-growing-season-in-Europe-for-the-period-1961-1998_fig3_237201658
3. A.S. Bondarenko, A.V. Zhigunov, Statistical processing of forestry research materials. (St. Petersburg: Polytechnic University Press, 2016)
4. I.L. Bukharina, A.N. Zhuravleva, O.G. Bolyshova, Urban plantations: ecological aspect: monograph. (Izhevsk, Publishing house "Udmurt University", 2012)
5. Convention on Biological Diversity. https://www.un.org/ru/documents/decl_conv/conventions/biodiv.shtml
6. P. I. Lapin, K. K. Kalutsky, O. N. Kalutskaya, Introduction of forest species (M., "Forest industry", 1979)
7. P. I. Lapin, S. V. Sidneva, Assessment of the prospects for the introduction of woody plants based on visual observations (The experience of the introduction of woody plants, M., 1973)

8. L.I. Masalova, Introduction and prospects of use of North American woody plants in green construction: on the example of the Orel region: dissertation ...(Candidate of Agricultural Sciences : 06.01.08, Michurinsk, 2022)
9. Weather and climate of the Voronezh region and Voronezh https://www.meteonova.ru/klimat/36/Voronezhskaya%20Oblast/
10. O. S. Ryazantseva, A. N. Tseplyaev, Evaluation of the results of the introduction of woody plants planted in the Koltsovsky Park of Voronezh and in the village of Ramon in the Voronezh region. Modern geographical research: theory, practice, innovation: materials of the international scientific and practical conference, Samarkand, May 12-13, 2023. Samarkand: Samarkand State University, 2, pp. 231-236 (2023)
11. I. S. Salnikova, G. V. Anchugova, Z. Ya. Nagimov, Forest taxation : a textbook for course work /. – Yekaterinburg. (Ural State Forestry Engineering. Univ., 2017)
12. A.N. Smolyanov, A.V. Mironenko, Mathematical methods in forestry: texts of lectures, Ministry of Education and Science of the Russian Federation, FGBOU VPO "VGLTA" - Voronezh, 2013 140 p.