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Efficiency of Management of Bioresource Collections of Trees and Shrubs for Solving Agroforestry Problems

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ABSTRACT

One of the indicators of sustainable development of regions is the forest cover of territories, which tends to decrease in recent decades. Increasing forest cover in low-forested regions is possible through agroforestry to conserve and rationalize natural resources, including biodiversity. Implementing agroforestry programs relies on selecting tree and shrub species adapted to specific growing conditions. Theoretical and practical challenges in agroforestry are significantly addressed by the dendrological collections of the Nizhnevolzhskaya Station for Selection of Tree Species (NSSDP), a branch of the Federal Research Center for Agroecology under the Russian Academy of Sciences. Established over 90 years ago, these collections comprise trees and shrubs from diverse ecological and geographical zones. As a result of extensive research conducted over several years, a conceptual framework for enriching the dendroflora of artificial plantations was developed. The study revealed that the Rosaceae family had the highest number of taxa, with a decline from 100 taxa in 1985 to 46 in 2023. Other prominent families included *Buxaceae, Ephedraceae, Euphorbiaceae, Jingoaceae, Hippocastanaceae, Liliaceae, Polygonaceae, Scrophulaceae, Simarubaceae, Solanaceae.* It was found that the number of species in the collections decreased to 175 (77 genera), respectively, and the number of families in the structure decreased by 31%. The share of families represented by one species increased - *Tamaricaceae, Moraceae, Rhamnaceae.* Adaptive capabilities, longevity and reproductive capacity of woody plants, allows predicting changes in species composition and trends in the transformation of dendrological collections. The principles for mobilizing gene pool biodiversity are outlined to facilitate the effective management of bioresource collections of trees and shrubs. Profitability of nursery production of adapted gene pool of tree species is related to the potential volumes of sale of planting material in the course of activities on creation of agroforestry plantations within the framework of forest-climatic projects on afforestation on lands of different purposes and categories. At the Nizhnevolzhskaya station for this purpose the areas for growing poplars (by 13%), pine (by 285%), oak (by 100%) with closed and open root system were increased. The availability of own mother plantations of adapted trees and shrubs is a competitive advantage and allows us to expand the range of planting material and promptly respond to the requests of customers with different needs.

Keywords: Management, collections; Biodiversity; Trees; Shrubs; Adaptation; Introduction; Mobilization; Agroforestry

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INTRODUCTION

One of the indicators of sustainable regional development is the forest cover of territories, which in recent decades has tended to decrease. According to the forest plan of the Volgograd region (Russia) (Forest Plan, 2018), forests on forest fund lands cover an area of 680.8 thousand hectares, representing 97.7% of the total forest area. As of January 1, 2018, forests on settlement lands occupy 13.8 thousand hectares or 2.0%, a decrease of 12.8% (2,029.4 hectares) compared to the previous forest plan. This reduction is attributed to the clarification of

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areas during forest inventory, such as the exclusion of urban forests, cemeteries, and gardens, as well as damage caused by fires, diseases, and pests. Under the influence of anthropogenic factors steppe and azonal (in the floodplain of rivers) types of vegetation are subject to degradation. Increasing forest cover in the region is possible through agroforestry improvement of agricultural lands for the conservation and rational use of natural resources, including biodiversity (Le Saout et al., 2013; Lavrov et al., 2021; Tkachuk and Viter, 2022).

Forest-climatic projects as a strategy for restoration of degraded ecosystems has lower costs compared to other options for mitigation of climate change, which are dangerous for the population and cause significant economic and environmental damage. According to the "Concept for the implementation of forest-climatic projects in the Russian Federation", the assessment of land potential for project activities aimed at reducing greenhouse gas emissions and increasing carbon sequestration showed that in the Volgograd region, there are 42.2 thousand hectares of land intended for reforestation on burned and dead plantations (of which 31.6 thousand hectares can be reforested only by creating forest cultures). Implementing forest-climatic projects on reforestation on lands with a baseline close to zero increases the attractiveness of degraded areas. Land resource for project activities on afforestation on non-forest lands of Volgograd region (as of 01.01.2022) 88.4 thousand ha.

Implementation of programs to combat desertification is not possible without the involvement of an adapted assortment of trees and shrubs (Strategy, 2017; Barrett et al., 2021; Klimenko and Klimenko, 2021; Khuzhakhmetova and Melnik, 2024). Compliance with this condition is based on the selection of tree species capable of growing in a wide range of soil and climatic conditions (Zelenyak et al., 2015; Semenyutina and Tereshkin, 2016; Semenyutina et al., 2018; Semenyutina et al., 2024). Projected climate change scenarios (Bardin, 2011; Latkina and Latkin, 2018; Vacek et al., 2021; Tunyakin et al., 2022) are expected to exacerbate the growing conditions for woody plants in the region. Therefore, it is crucial to bioecologically justify the selection of woody plant species for forest amelioration in low-forested areas.

The primary objective is to assess the effectiveness of managing bioresource collections of trees and shrubs to address agroforestry challenges. To achieve this goal, the following tasks have been established:

- To consolidate the experience from introduction works and current research on the gene pool of dendrological collections, focusing on the selection of economically important plants in response to climate change.
- To develop principles for mobilizing species, forms, and varieties of economically valuable tree species, including those for forest amelioration, ornamental use, fruit production, medicinal purposes, and fodder.

MATERIALS & METHODS

Objects, Location of the Study

The northern and northeastern boundaries of the territory of the Nizhnevolzhskaya station on selection of tree species (NSSDP) run along the bottom of the Kirpichny ravine. From the south and south-east the territory is bounded along the federal highway Kamyshin-Volgograd; from the west - bordered by land use of other owners and urban lands of Kamyshin (50°05′53″ N, 45°24′57″ E, 73 m above sea level), Volgograd Oblast, Russia. Soil cover is heterogeneous: alluvial soils, chestnut and dark chestnut soils, southern sandy chernozems, thick and thin sandy undeveloped on buried chestnut soil.

Monographic works (Zelenyak and Iozus, 2003; Belyaev et al., 2021; Semenyutina et al., 2024), along with databases on the gene pool of working collections of trees and shrubs, and the conceptual framework for enriching the dendroflora of artificial plantations (Fig. 1), were utilized in synthesizing research on species introduction and forecasting changes in the biodiversity of introduced resources at the Nizhnevolzhskaya Station for Selection of Tree Species (a branch of the Federal Scientific Center of Agroecology of the Russian Academy of Sciences).

Identification of species for restoration of dendrological expositions was carried out with consideration of plant age categories, condition and fruiting periodicity. These factors were determined during the inventory of collections, following the standard methodology (Semenyutina et al., 2018; Polevoy et al., 2001).

Data Collection

Studies included annual assessment of winter hardiness and drought tolerance, measurement of taxational and reproductive indices, seasonal development, and conditions. Under laboratory conditions, additional instrumental assessment was carried out to reveal tolerance of plant organisms to limiting factors (shoot freezing, detection of water deficit and water-holding capacity, fruit quality, etc.) (Polevoy et al., 2001). The sample size depended on the research objectives. Rabotnov (1992) proposed to distinguish invasive populations (consisting mainly of young individuals), normal (all cohorts are more or less evenly represented) and regressive (cohorts of senile individuals predominate) populations based on the ratio of plants of different age groups. Trees and shrubs were evaluated according to the following age states: j - juvenile plants, im - immature plants, v - virginil trees, g^1 - young generative trees, g^2 - middle-aged generative trees, g^3 - old generative trees, s - senile trees. The reliability of the obtained results was confirmed by long-term experimental studies with the use of certified equipment and statistical processing of meteorological, laboratory, field observations.

RESULTS & DISCUSSION

Dendrological expositions play an important role in solving theoretical and practical problems of agroforestry (Manasa et al., 2024; Kalmykova & Lazarev 2023). More than 90 years ago, under the leadership of N.I. Susa and A.V. Albensky, the first collections of trees from different ecological and geographical zones were created in the town of Kamyshin (Volgograd region, Russia). This was the

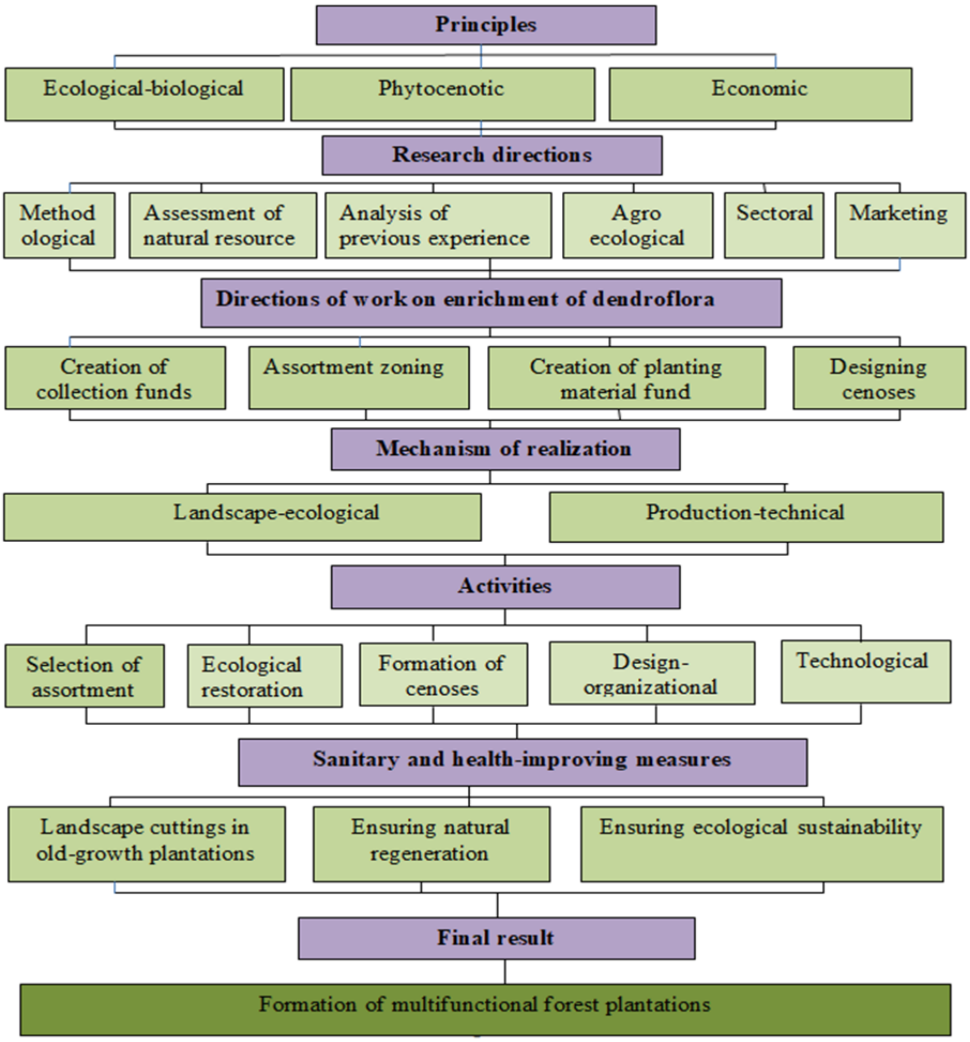

Fig. 1: Conceptual framework for enriching the dendroflora of artificial plantations.

next stage after the work on the organization of a forest nursery (1903) in the zone of dry steppes with chestnut soils. The main assortment for seed propagation was represented by *Betula pendula, Acer platanoides, Tilia cordata, Fraxinus exselsior, Ulmus species* and others.

From 1903 to 1916, experimental pine crops (75 ha) were established on the adjacent territory to the nursery. The pine massif, created on sand-buried chestnut soils and on overweighed sands, is in good to satisfactory condition, having survived a number of dry years (Fig. 2). In the arboretum, spanning 7.5 hectares, 134 species of trees and shrubs were initially tested. Eight years later, the collection had grown to over 330 species. By 1972, a dendrological base comprising 313 species (80 genera and 32 botanical families) was established, and by 1985, this expanded to 356 species (105 genera and 42 families).

The families depicted in Fig. 3 range from 2 to 26 taxa. The most represented family is *Rosaceae*, with 100 taxa in 1985 and 46 taxa in 2023. Other prominently represented families include *Buxaceae, Ephedraceae, Euphorbiaceae, Ginkgoaceae, Hippocastanaceae, Liliaceae, Polygonaceae, Scrophulariaceae, Simaroubaceae*, and *Solanaceae*. Families represented by only a single taxon are not included in Fig. 3.

It was found that the number of species in the collections decreased to 175 (77 genera), respectively, and the number of families in the structure decreased by 31%. The share of families represented by one species increased – *Tamaricaceae, Moraceae, Rhamnaceae*. However, it should be noted that taxa from these families are represented by specimens of different ontogenetic states (young and middle generative), which causes less concern for their preservation. The dendrological basis is formed mainly by species native to Europe and North America. The least number of species with habitats in Siberia, Caucasus and Crimea. The group of species from Central Asia numbers 40, from China, Japan, Korea - 52 (Fig. 4).

The dense arrangement of plants in the collection affected their scientific value and made it difficult to observe their growth, development, flowering, fruiting, and intraspecific variability in varying soil and climate conditions (Atreya et al., 2021). To eliminate the shortcomings, a systematic principle was applied in the reconstruction of the collections. Each quarter now represents trees and shrubs of a single family, with a total of 40 families included. We have also established the species composition, preserved the trees and shrubs, and determined their taxonomic indices. This new principle of plant arrangement has improved the pollination conditions for related species and has allowed for intensified research on intra- and interspecific variability, hybridization, and selection. Species of genera *Juniperus, Platycladus, Thuja, Picea, Pseudotsuga, Larix, Pinus, Abies* (families *Cupressaceae, Pinaceae*) were introduced into dendrological expositions. *Pinus: sylvestris, pallasiana,*

Fig. 2: Example of successful sand consolidation by *Pinus* cultivars (age 120 years).

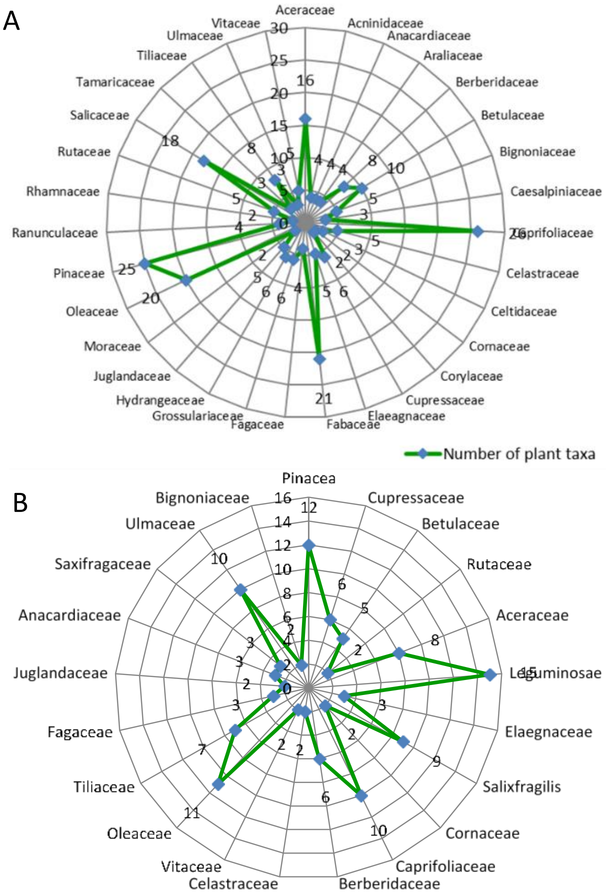

Fig. 3: Structure of NSSDP bioresources (a - 1985, b - 2023).

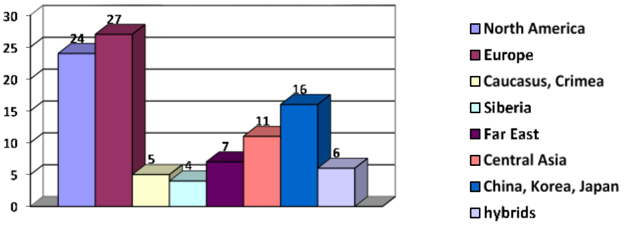

Fig. 4: Representation of bioresource collections by origin (%).

banksiana, Pseudotsuga menziesii survived up to 85 years. The trees of *Picea pungens, Pinus ponderosa, P. nigra, Thuja occidentalis, Juniperus virginiana, J. sabina, J. communis* are in good condition (Semenyutina et al., 2024). Individual specimens have survived to the present time, they are in satisfactory condition and are used as mother plants (Table 1). The long period of cultivation of woody plants allows predicting changes in the species composition and trends in the transformation of dendrological collections (Aryal et al., 2023).

Species of genera *Robinia, Acer, Ulmus, Populus, Ptelea, Lonicera, Fraxinus, Celtis*, which are distributed outside the exposition and quarter of the arboretum, were identified. According to the ratio of plants of different age groups, these species form normal populations in which all age groups are more or less evenly represented. However, this poses certain threats to the growth of rarer species in the collection (Table 2).

Given the long duration of tree and shrub cultivation, there is now a need to renovate these species into multifunctional assets (Narender et al., 2021). The measures to restore dendrological expositions of collections include: systematic removal of self-seeding of low-value species outside the quarter, seed collection from species that are represented by several specimens or have reached a critical age; development of propagation technologies (Sapronova et al., 2023a, b; Gebremedhin et al., 2020) and mobilization of planting material funds (Fig. 5).

For successful introduction of forest forming species, a series of experiments were conducted to improve the technology of containerized cultivation of seedlings and their qualitative assessment. Seeds of own collection of local reproduction were used for sowing. Selection of mother plants was based on adaptive capabilities and their promising potential for a complex of traits (drought-, salt-, frost resistance and other economically valuable properties) for rational use of material and natural resources and reduction of carbon intensity of nursery production (Rodriguez et al., 2020; Malik et al., 2021; Daugaviete et al., 2022).

In the structure of plantations a significant share of mother plants are representatives of polymorphic genus complexes from the families *Rosaceae* Juss. (6 ha), *Pinacea* Lind. (5 ha), *Leguminosae* Juss. (4 ha), *Bignoniaceae* Pers.

Table 1: Variability of parameters of taxation, reproductive indices and habitus of coniferous taxa

Species, age, origin	Average height (min-max), m/ average diameter (min-max), cm	Crown projection, cm		Crown shape	Color needles	Shape Of Cones	Score flowering /fruiting *
		North-South	West-East				
Pseudotsuga menziesii;	10.7 (8.5-12.9)	659.1***	389.6	Conical	Green	Oval-	1. 3- 4
40-50 years, North America	19.9 (12.0-34.0)	380-824	238-500			Ovate	
	8.0 (7.8-8.5)	641.5	279.5	Conical	Blue-Gray	Oval-	2. 4
	21.0 (16.3-25.5)	601-682	262-297			Ovate	
Picea pungens	6.8 (4.0-8.9)	491.2	452.1	Conical	Blue-Gray	Elongated Ovoid	1-3
40-50 years. North America	26.9 (8.0-34.0)	265-710	164-585				
	7.9 (6.2-8.5)	616.0	411.3	Conical	Green	Elongated Ovoid	1-3
	29.7 (24.0-39.0)	492-718	305-500				
Picea abies **	7.0	311.5	233.0	Conical	Green	Elongated Ovoid	2
40-50 years. Russia. Europe	14.0						
Picea glauca **	5.0	307.0	228.4	Conical	Green	Elongated Ovoid	3
40-50 years. Europe	10.0						
Picea engelmannii **	5.5	234.1	290.0	Conical	Green	Elongated Ovoid	3
40-50 years. North America	11.0						
Larix sibirica	10.2 (10.0-10.5)	517.8	335.0	Pyramidal	Light	Egg-	0
40-50 years. Western Siberia	22.0 (15.0-18.0)	386-704	227-512		Green	Shaped	
*Platycladus orientalis***	5.5	300.0	211.0	Openwork	Green	Spherical With	3
40-50 years. China	12.0			Pyramidal		Growths	
Juniperus virginiana	6.84 (6.4-7.0)	564.2	571.0	Ovoidal	Green	Cone-	5
40-50 years. North America	32.0 (23-46)	462-685	500-622			Berries	
Pinus sylvestris	11.8 (11.0-12.0)	533.0	673.8	Round	Green	Conical	1
100 years. Europe	37.5 (32.0-42.0)	404-618	510-1100	and Wide			

*Flowering/fruiting scale: 0 - plant does not flower/fruit, 1 - plant has only single flowers/fruit, 2 - weak flowering/fruiting, 3 - satisfactory, 4 - good, 5 - complete; ** species is represented by a single specimen; *** – the numerator shows the average value of the indicator, the denominator shows the minimum and maximum values of the indicator.

Table 2: Register of families in dendrological plantations of the Nizhnevolzhskaya tree species selection station, taxa and their ontogenetic state

№	Family	Ontogenetic state							Number taxa, pcs.
		sm	j	im	v	g1	g2	g3	
1.	Pinacea	3	6	5	4	4	9	-	12
2.	Cupressaceae	2	5	6	5	6	6	-	6
3.	Tamaricaceae	-	1	1	1	1	1	-	1
4.	Rosaceae	5	13	14	14	14	46	5	46
5.	Betulaceae	2	2	2	2	2	5	1	5
6.	Rutaceae	-	1	1	1	1	1	1	2
7.	Aceraceae	4	2	2	2	2	8	1	8
8.	Leguminosae	1	1	2	2	1	15	-	15
9.	Simarubaceae	-	-	-	-	1	-	-	1
10.	Moraceae	-	1	1	1	1	1	-	1
11.	Elaegnaceae	-	-	1	1	2	3	-	3
12.	Salixfragilis	-	3	3	3	3	9	-	9
13.	Cornaceae	-	-	1	1	-	1	-	2
14.	Rhamnaceae	-	-	-	-	-	1	-	1
15.	Caprifoliaceae	2	2	2	2	2	10	-	10
16.	Poligonaceae	-	-	-	-	-	1	-	1
17.	Berberidaceae	2	2	2	2	2	6	-	6
18.	Celastraceae	1	-	-	-	-	2	-	2
19.	Vitaceae	1	1	1	1	1	2		2
20.	Oleaceae	3	3	3	3	3	11	-	11
21.	Tiliaceae	1	1	1	1	3	5	-	7
22.	Fagaceae	1	2	2	2	2	3		3
23.	Juglandaceae	-	-	1	-	-	2	-	2
24.	Anacardiaceae	2	2	2	2	2	3	-	3
25.	Saxifragaceae	2	2	2	2	2	3	-	3
26.	Ulmaceae	1	-	-	4	4	6	-	10
27.	Bignoniaceae	1	1	1	2	2	1	-	2
28.	Hippocastanaceae	1	1	1	1	1	1	-	1
29.	Euphorbiaceae	-	-	-	-	1	-	-	1
	Total:								175

(3 ha), *Ulmaceae* Milb. (2 ha), *Aceraceae* Lindl. (1.3 ha), *Caprifoliaceae* Vent. (1.2 ha). The station has large-scale planting material of species that have already entered the fruiting phase. Therefore, these plots are also used for additional seed collection. As a result of studying the biodiversity of tree species, regularities and mechanisms of adaptation of plant organisms have been revealed taking into account a set of criteria that determine the efficiency of management of bioresource collections of trees and shrubs for solving agroforestry problems (Rolo et al., 2020).

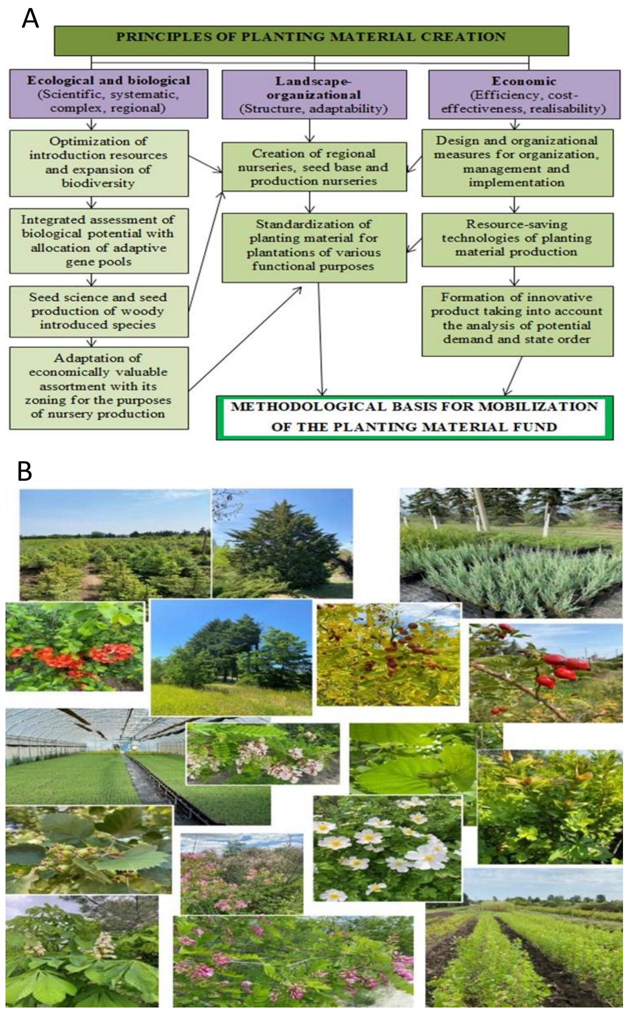

Fig. 5: Science-based principles for mobilizing tree species (a) and their collections

Conclusion

Methodological approaches to restoring bioresource collections of introduced tree species and their rational use in arid regions are grounded in the analysis and synthesis of long-term experimental data on dendrological resources. These efforts contribute to the development of cluster areas within the Federal Scientific Center for Agroecology of the Russian Academy of Sciences. During the century 356 taxa of trees, shrubs, lianas (105 genera, 42 families) were tested. The most represented family *Rosaceae* (in 1985 - 100 taxa, in 2023 - 46) and families (*Buxaceae, Ephedraceae, Euphorbiaceae, Jingoaceae, Hippocastanaceae, Liliaceae, Polygonaceae, Scrophulaceae, Simarubaceae, Solanaceae*). It was found that the number of species in collections decreased to 175 (77 genera), respectively, and the number of families in the structure decreased by 31%. The share of families represented by one species increased - *Tamaricaceae, Moraceae, Rhamnaceae*. Taxa from these families are represented by specimens of different ontogenetic states (young and middle generative), which causes less concern for their conservation.

Assessment of age structure and adaptive potential allowed to select priority species for mobilization taking into account long-term data on seed and vegetative propagation. Funds of coniferous taxa were created at the production nursery in the ratio: virginial - 50 %, generative - 50 %. Seed collections are represented by species of *Pinacea* Lind (5 ha), *Cupressaceae* F.W. Neger. (0.5 ha), *Tamaricaceae* (0.02), *Rosaceae* Juss. (6 ha), *Betulaceae* C. A. Aqardt. (0.05 ha), *Rutaceae* Juss. (0.01 ha), *Aceraceae* Lindl. (1.3 ha), *Leguminosae* Juss. (4 ha), *Salixfragilis* L. (0.5 ha), *Caprifoliaceae* Vent. (1.2 ha), *Berberidaceae* F. (0.8 ha), *Celastraceae* Lindl.(0.02 ha), *Oleaceae* Lindl. (0.07 ha), *Tiliaceae* Juss. (0.7 ha), *Fagaceae* A. Br. (0.05 ha), *Anacardiaceae* Lindl. (0.03 ha), *Saxifragaceae* DC. (0.9 ha), *Ulmaceae* Milb. (2 ha), *Bignoniaceae* Pers. (3 ha), *Hippocastanaceae* Tet G. (0.6 ha). The nursery has created gene pools of coniferous taxa in the ratio: virginile - 50 %, generative - 50 %.

At present, the station's structure includes an arboretum (10 ha, cadastre number 34:36:000014:178), a nursery (11 ha, cadastre number 34:36:000014:177), and artificial plantings (100 ha, cadastre number 34:36:000014:178), created in different years to evaluate the results of scientific research on introduction, selection, and nursery production.

The presence of the above-mentioned structural elements allows the management of collections through the implementation of the developed principles of mobilization of species, forms and varieties of economically valuable (forest ameliorative, ornamental, fruit, medicinal, fodder) tree species, and is also consistent with the conceptual basis of enrichment of dendro-flora of artificial plantations.

Creation of forest cover (planting: seedlings, seedlings, cuttings; sowing, restoration of woody vegetation) leads to an increase in carbon absorption and reduction of greenhouse gas emissions from the production activities of the Nizhnevolzhskaya tree species breeding station. Targeted use of planting material in large-scale national and regional projects is determined by its quality and cost. In this connection, the technologies of growing tree species have been improved to ensure fast growth, phytomass accumulation and high survival rate. Availability of our own mother plantations of adapted trees and shrubs is a competitive advantage and allows us to expand the assortment of planting material and promptly respond to the requests of customers with different needs.

The profitability of nursery production for an adapted gene pool of tree species is linked to the potential sales volume of planting material during the establishment of agroforestry plantations. These efforts are part of forest-climatic projects focused on afforestation of agricultural lands, as well as lands designated for industry, transportation, and other categories. According to preliminary estimates, only in 2021 for the purposes of reforestation in the Volgograd region it was necessary about 5.8 million seedlings, including 2.5 million of coniferous species. At the Nizhnevolzhskaya station the areas for growing poplar (by 13%), pine (by 285%), oak (by 100%) with closed and open root system were increased for this purpose.

Planting material of forest forming species meets the requirements and applicability criteria for implementation of climate projects (in the field of reforestation, afforestation and forest management) of the main international programs on greenhouse gases in the Agriculture, Forestry and Other Land Use (AFOLU) sector within the framework of international standards - Verified Carbon Standard: Afforestation, Reforestation and Revegetation (ARR), Reduced Emissions from Deforestation and Degradation (REDD), Agriculture Land Management (ALM); Gold Standard - Afforestation, reforestation; Agriculture and similar “green projects”.

Authors Contributions

Conceptualization, A.Kh. and A.B.; Data curation, Methodology, Investigation, Supervision, Validation, A.Kh. and D.S.; Funding acquisition, Visualization, A.B. and A.Kh.; Writing – original draft, A.Kh. and D.S.; Writing – review & editing, A.Kh. and A.B. All authors have read and approved the final version for publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

Aryal, K., Maraseni, T., & Apan, A. (2023). Transforming agroforestry in contested landscapes: a win-win solution to trade-offs in ecosystem services in Nepal. *Science of the Total Environment*, *857*, 159301. https://doi.org/10.1016/j.scitotenv.2022.159301

Atreya, K., Subedi, B. P., Ghimire, P. L., Khanal, S. C., Charmakar, S., & Adhikari, R. (2021). Agroforestry for mountain development:

Prospects, challenges and ways forward in Nepal. *Archives of Agriculture and Environmental Science*, *6*(1), 87-99.

Bardin, M. Y. (2011). Scenario forecasts of air temperature change for the regions of the Russian Federation until 2030 using empirical stochastic climate models. *Meteorology and Hydrology*, 4, 5-20.

Barrett, K. J., Cannon, J. B., Schuetter, A. M., & Cheng, A. S. (2021). Effects of collaborative monitoring and adaptive management on restoration outcomes in dry conifer forests. *Forest Ecology and Management*, *488*, 119018. https://doi.org/10.1016/j.foreco.2021. 119018

Belyaev, A.I., Huzhahmetova, A. S., & Semenyutina, A.V. (2021). Historical formation and prognostic estimates of den-droflora enrichment with generic complex taxa in protective afforestation and landscaping. *Voprosy Istorii*, 7-1, 179-188.

Daugaviete, M., Makovskis, K., Lazdins, A., & Lazdina, D. (2022). Suitability of Fast-Growing Tree Species (Salix spp., Populus spp., Alnus spp.) for the Establishment of Economic Agroforestry Zones for Biomass Energy in the Baltic Sea Region. *Sustainability*, *14*(24), 16564.

Forest Plan of Volgograd Oblast. Volgograd, 2018. 211.

Gebremedhin, A. T., Gedo, A. H., Edo, G. Y., & Haile, S. T. (2020). Evaluation of multi-functional fodder tree and shrub species in mid-altitudes of South Omo Zone, Southern Ethiopia. *Journal of Horticulture and Forestry*, *12*(1), 27-34.

Khuzhakhmetova, A. & Melnik, K. (2024). Assessment of ecological and biological characteristics of *Gleditsia triacanthos* L. for agroforestry of degraded areas. *International Journal of Agriculture and Biosciences,* 13(2), 112-117. https://doi.org/10.47278/journal.ijab/2024.094

Klimenko, O.E., & Klimenko, N.I. (2021). Changes in the Properties of Crimean Haplic Chernozems under the Impact of Forest Plantations. *Eurasian Soil Science,* 54, 5, 750-762. https://doi.org/10.1134/S1064229321050124

Kalmykova, E., & Lazarev, S. (2023). Increasing the Biodiversity of the Dendroflora of Sparsely Wooded Regions by Adapted Representatives of the Genus Robinia L. *Agriculture*, *13*(3), 695.

Latkina, T.V., & Latkin, V.N. (2018). The state of forest protection strips in the Volgograd region. *The Successes of Modern Natural Science,* 9, 93-100.

Lavrov, V., Grabovska, T., and Shupova, T. (2021). Forest shelter belts in organic agricultural landscape: structure of biodiversity and their ecological role. *Folia Forestalia Polonica*, 63(1), 48-64. https://doi.org/10.2478/ffp-2021-0005

Le Saout, S., Hoffmann, M., Shi, Y., Hughes, A., Bernard, C., Brooks, T. M., & Rodrigues, A. S. (2013). Protected areas and effective biodiversity conservation. *Science*, *342*(6160), 803-805. https://doi.org/10.1126/science.1239268

Malik, A. R., Namgyal, D., Butola, J. S., Bhat, G. M., Sofi, P. A., Islam, A. U., & Mugloo, J. A. (2021). Integrated Approach of Sustainable Agroforestry Development in Cold Arid Region of Indian Himalaya. In *Diversity and Dynamics in Forest Ecosystems* (pp. 195-213). Apple Academic Press.

Manasa, P. A., Hegde, R., Salimath, S. K., & Maheswarappa, V. (2024). Intercropping performance and its influence on soil nutrient status in bamboo-based agroforestry practice. *Agroforestry Systems*, 1-14.

Narender, K., Arya, S., & Nanda, K. (2021). Potential of Melia dubia agroforestry system in soil improvement and environmental sustainability. *Environment Conservation Journal*, *22*(1&2), 65-72.

Polevoy, V.V., Chirkova, T.V., & Lutova, L.A. (2001). Practicum on growth and stability of plants. St. Petersburg: St. Petersburg University Press, 212.

Rabotnov, T.A. (1992). Phytocenology: Textbook for universities. Moscow: Izd-vo MSU, 352.

Rodriguez, H. G., Maiti, R., & Kumari, C. A. (2020). *Experimental Ecophysiology and Biochemistry of Trees and Shrubs*. CRC Press.

Rolo, V., Hartel, T., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., & Moreno, G. (2020). Challenges and innovations for improving the sustainability of European agroforestry systems of high nature and cultural value: stakeholder perspectives. *Sustainability Science*, *15*, 1301-1315.

Sapronova, D.V., Belyaev, A.I., Khuzhakhmetova, A.S., & Sapronov, V.V. (2023a). Technological aspects of growing *Juglans nigra* (L.) with closed root system for agroforestry in arid regions. *Research on Crops*, 24(4), 784-788. https://doi.org/10.31830/2348-7542.2023.ROC-1023

Sapronova, D.V., Belyaev, A.I., Semenyutina, A.V., Sapronov, V.V., & Khuzhakhmetova, A.S. (2023b). Improved technologies for growing seedlings of forest-forming species in the Volgograd region. *Siberian Journal of Life Sciences and Agriculture,* 15(5), 228-245. https://doi.org/10.12731/2658-6649-2023-15-5-935

Semenyutina, A.V., & Tereshkin, A.V. (2016). Protective forest plantations: analysis of species composition and scientific basis for increasing the biodiversity of dendroflora. *Uspekhi Sovremennoi Naukhnostvennosti*, 4, 99-104.

Semenyutina, A.V., Huzhahmetova, A.S., Sapronova, D.V., Dolgikh, A.A., & Sapronov, V.V. (2024). Scientific basis methods of monitoring the state and dynamics of dendroflora of forest-reclamation complexes in order to prevent degradation and desertification of territories. Volgograd, Russia: FNC agroecology RAS, 196.

Semenyutina, A.V., Svintsov, I.P., Huzhahmetova, A.S., & Semenyutina, V.A. (2018). Regulations of safe and sustainable use of biodiversity of woody plants in protective afforestation. *Journal of Agriculture and Environment,* 3(7), 3. https://doi.org/10.23649/jae.2018.3.7.3

Strategy, 2017. Strategy for the development of protective afforestation in the Volgograd region for the period up to 2025. FSC Agroecology RAS, 2017, 39.

Tkachuk, O., & Viter, N. (2022). Biological aspects of functioning of field protective forest belts in conditions of climate change. *Balanced Nature using*, https://doi.org/10.33730/2310-4678.1.2022.255218

Tunyakin, V., Rybalkina, N., & Shenshin, L. (2022). Forest formation process in extremely narrow forest shelter belt. *Forestry Engineering*, 12(2), 56-67 https://doi.org/10.34220/issn.2222-7962/2022.2/5

Vacek, Z., Cukor, J., Vacek, S., Linda, R., Prokůpková, A., Podrázský, V., Gallo, J., Vacek, O., Šimůnek, V., Drábek, O., Hájek, V., & Spasić M. (2021). Production potential, biodiversity and soil properties of forest reclamations: Opportunities or risk of introduced coniferous tree species under climate change? *European Journal of Forest Research,* 140(5), 1243-1266. https://doi.org/10.1007/s10342-021-01392-x

Zelenyak, A.K., & Iozus, A.P. (2003). Nizhnevolzhskaya station on selection of tree species - 100 years. *Forestry,* 4, 15-16.

Zelenyak, A.K., Iozus, A.P., & Morozova, E.V. (2015). Results of adaptation of economically valuable coniferous introducers in arid conditions of the Lower Volga region. *Fundamental Research*, 7-1, 20-23