Trends in the development of *Pinus sylvestris* breeding in the Russian Federation

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**Abstract.** The work is devoted to the study of trends in the breeding of *Pinus sylvestris* L. – the main forest-forming species in Russia. The official materials of State inventories for the last 25 years, as well as a number of scientific publications have been used. The quantitative indices of plus trees’ selection; creation of clones’ archives, provenance trials and population-ecological trials; allocation of forest genetic reserves and plus stands; organization of temporary and permanent forest-seed plots; creation of root-cutting plantations and forest-seed orchards; and progeny field tests of plus trees were studied. The analysis of the development of Scots pine breeding showed that from 1996 to 2019, the number of plus trees decreased by 22%. The area of forest seed orchards decreased by 35% over the same time period. In general, for most areas of Scots pine breeding in Russia, for one reason or another, there is a decrease in the volume of work, sometimes several times (in particular, for permanent forest-seed plots by 16.7 times). In comparison with Finland, in Russia, the intensity of plus trees’ selection is 7.7 times lower, and the existence of forest-seed orchards is 7.2 times lower.

1. **Introduction**

The modern geographic range of Scots pine (*Pinus sylvestris* L.) on the Eurasian continent extends from 70° to 37° North and from 7° West to 126° East. In addition to Russia, it grows in other countries [1]. The area of pine forests in Russia is 119,493.1 thousand hectares [2].

Scots pine is a typical forest-forming species. It creates the appearance of the forest and together with other forest plants forms characteristic forest communities – a group of pine forest types. Pine wood is strong, resistant to rot, easy to process and used mainly for lumber. They build houses out of logs; make railway sleepers, mine stands, telegraph poles. Sawdust is used to produce ‘pellets’ – small nodules that are used for heating and energy production. The bark of pine trees is pressed into briquettes, which can be used as fuel. Pine resin is a valuable raw material for the production of rosin and turpentine, which are used in the production of lacquers, paints and even medicines. Pine is well adapted to various environments: it grows on sandy and clay soils, rocks, swamps, often where other tree species cannot grow.

Improved breeding material of Scots pine must meet the following main criteria:
- high productivity;
- resistance to diseases (blistering rust, root sponge, schutte, pine pinworm, etc.) and pests (subcortical bedbug, pine sawfly, etc.);
sufficient reproducibility;
- good trunk shape and high quality wood.

In addition to the above basic criteria, some special varieties of Scots pine must have special properties, such as high resin productivity or drought resistance. Some individual criteria are often mutually exclusive. Thus, selection for productivity, as well as any selection in general, can lead to a depletion of the species gene pool and, as a result, to a decrease in immunity and resistance [3]. Taking this into account, the direction of Scots pine breeding depends on the specific purpose of plantings creating and on the region of cultivation [3-6]. In the timber-producing regions of the country, breeding is conducted for high productivity. For afforestation in the southern regions – for drought resistance, immunity to diseases and resistance to pests. In regions where concentrated logging is practiced, and the task is to quickly reforest large areas, it is necessary to focus on population-varieties. For decorative purposes, it should to select and display forms and clone-varieties with unusual morphological features (type of branching, color and shape of needles, shape of trunks, etc.).

Many breeders abroad and in different regions of Russia were engaged in the Scots pine breeding in various areas. From foreign works, we can note the capital reports of N T Mirov; the Polish works edited by S Bialoboka, A Boratynskiego and W Bugala; A Farjon [7-9], publications by Kosinski [10]; Molotkov & Patlaj [11]; R Price et. al. [12]; Klinka [13]. There are known studies on provenance trials by M. Giertych [14]; on progeny field testing by D. Lindgren [15]; on breeding in Sweden by L. Wilhelmsson & B. Andersson [16]; on forest-seed orchards by D Lindgren et al. [17].

In Russia, the breeding of Scots pine was also carried out by many researchers. The largest experimental facilities on provenance trials of Scots pine were created by M M Veresin in the Voronezh region. In the mid-50s of the last century, he created the provenance trials of Scots pine, in which seeds from 353 points of the USSR were planted on an area of 37.6 hectares [18-20]. The development of research on provenance trials based on the generalization of hundreds of the USSR and Russia scientists was continued within the framework of the state program of the State Forestry Service of the USSR approved in 1973. According to it, 827.7 ha were created in 37 localities [19]. The hybridization of Scots pine was carried out by V V Ievlev and Yu N Isakov [21]. Forest-seed orchards of this species have been created and studied by M M Veresin, Yu P Efimov, and others [18, 22-24]. The forestry enterprises of the country were engaged in the creation of industrial forest-seed orchards. The assessment of the state and development of various aspects of the forest woody plants breeding was presented by N V Laur and A P Tsarev [25-28].

At a later time in Russia, scientific work on Scots pine breeding was continued in different regions of the country. We have noted the studies in Karelia [29-31], in Siberia [6], in the Leningrad region [32], in the Voronezh region [33-35], and in the Nizhny Novgorod region [36]. A number of works on Scots pine breeding have also been published abroad. For Russian practice, work in this direction is particularly interesting in neighboring Finland and Sweden – countries with similar climatic environments [37-40].

The objective of the work is to determine the state and trends in the development of Pinus sylvestris breeding in the Russian Federation and to determine a possible scenario for its further development.

2. Methods and Materials

When analyzing the state and dynamics of the development of the so-called Unified Genetic And Breeding Complex (UGBC) in our country, we used official data from State inventories in the last 25 years: ‘The Forest Fund of Russia’, 1995 [41]; ‘The Forest Register...’, 2014 [42]; ‘Objects of the forest seed-production...’, 2018 [43]; ‘The state of the Russian Forest Genetic Resources...’, 2020 [2]; data from the Institute ‘Soyuz Reclamation Forestry’ and the Federal Center ‘RosForestProtection’ [26], as well as from scientific domestic publications. In addition to Russian sources, some data on the development of forest genetic resources in Finland were also used for comparative studies [37].
The quantitative indices of plus trees’ selection (PT, pieces); creation of clones’ archives (CA, ha), provenance trials (PT, ha) and population-ecological trials (PET, ha); allocation of forest genetic reserves (FGR, ha) and plus stands (PS, ha); organization of temporary and permanent forest-seed plots (TFSP and PRSP, ha); creation of root-cutting plantations and forest-seed orchards (RCP and FSO, ha); and progeny field tests of plus trees (PFT, ha).

Materials on the development or degradation of forest genetic resources of Scots pine in Russia were analyzed by years. In some cases, when there was no data in the sources for the year of analysis, interpolation was used between the nearest official data.

The above-mentioned official domestic and foreign publications were used for the calculations. When analyzing the development trends, the Excel platform was used.

3. Results and Discussion

The dynamics of changes in the quantitative indices of the main breeding objects in the Russian Federation in recent years is presented in table 1. All the represented objects of the UGBC are important for sustainable reforestation without reducing the quality of the resulting new stands.

Table 1. Dynamics in the quantitative indices of the main Scots pine breeding objects in the Russian Federation.

| Objects of the UGBC | Years of registration | Notes |
|---------------------|-----------------------|-------|
| PT, pieces          | 1996, 2007, 2013, 2019| 1996 – interpolation |
| CA, ha              | no data, no data, no data | 1996, 2007, 2013 – interpolation |
| FGR, thousand of ha | 9.0, 103, 99.3, 69.2 | 1996-2013 – interpolation |
| PS, thousand of ha  | 9.9, 9.5, 9.0, 8.8 | 1996, 2013 – interpolation |
| PT, ha              | no data, 511, 382.1, 412.8 | 2007, 2013 – interpolation |
| PET, ha             | no data, no data, 19.7, 22.1 | 2013 – interpolation |
| TFSP, thousand of ha| 35.0, 11.0, 8.4, 2.1 | 2007, 2013 – interpolation |
| RCP, ha             | no data, 88.6, 83.2, 103.8 | 2007, 2013 – interpolation |
| FSO, ha             | 4 100, 3 500, 3 152.8, 2 655.8 | 2013 – interpolation |
| PFT, ha             | 661.7, 485, 388.7, 387.4 | 1996 – data from 2006, 2013 – interpolation |

From the data in table 1, it can be seen that in most areas of pine breeding, for one reason or another, there is a decline. Thus, the number of PT decreased by 21.8%; the area of the FGR from 2007 to 2019 – by 32.8%; the area of the PS from 1996 to 2019 – by 11.1%; the PT from 2007 to 2019 – by 19.2%.

The area of TFSP decreased from 1996 to 2019 by 16.7 times; FSO from 1996 to 2019 – by 35.2%; and PFT from 1996 to 2019 – by 41.5%. The only exception was the creation of RCP and PET. The area of the RCP from 2007 to 2019 increased by 17.1% (to 103.8 hectares), and the area of the PET increased by 12.2% in 6 years from 2013 to 2019. But the absolute value of PTC itself is just a microscopic amount of the total area of pine forests in Russia – 0.00000018%.

For example, let’s take a closer look at the dynamics of the development of two areas of the UGBC: the selection of PT and the creation of FSO.

Plus trees occupy one of the most important places in breeding. Firstly, because they can be the owners of valuable genotypes, and secondly, they often cut down the best areas of the forest, so that soon there will be nothing to select either plus trees or plus stands. The trend of plus trees selection and survival is shown in figure 1. And examples of plus stands and plus tree are shown in figures 2 and 3.
Figure 1. The trend of selection and survival of Scots pine plus trees in the Russian Federation over the last quarter of a century.

As can be seen from table 1 and figure 1, the number of plus trees in the country over the last quarter of a century has not increased, but on the contrary has decreased by 4 167 pieces, or by 22%.

Another important indicator that characterizes the degree of concern of forest owners about the reproduction of forests with improved seed material is the indicator of the number of FSO creation. The trend of creating a first-order FSO is shown in figure 4.

From the data in table 1 and figure 4, it can be seen that the area of FSO-I has been steadily decreasing. Over the last quarter of a century, this decrease was 1 444 hectares, or 54.4%. There is no question that it is necessary to move to the creation of more progressive FSO-II, because the area of the PFT of Scots pine, with all its insignificant size for our country, is also continuously decreasing and according to the latest data amounted to only 387 hectares, or 35.2% of the data for 1996.

4. Discussion
Analysis of the development of the main directions of forest tree breeding in Russian Federation has shown that in the last quarter of a century, their steady decline has been observed. But what is the reason for this phenomenon? Is global warming to blame for this? In this regard, it is interesting to compare the development of Scots pine breeding in our country with one of our neighboring country with similar climatic conditions – Finland. This comparison was carried out for two important sections of breeding: the selection of plus trees and the creation of forest seed orchards (figures 5 and 6). At the same time, data from Finland for 2012 [37] and Russia for 2019 [2] were compared.
Figure 2. A plus stand of *Pinus sylvestris* L. in the Petrozavodsk Central Forestry of the Krelian Republic. Photo courtesy by N V Laur.

Figure 3. A separate plus tree of *Pinus sylvestris* L. in the Petrozavodsk Central Forestry of the Krelian Republic. Photo courtesy by N V Laur.

Figure 4. The number of Scots pine FSO-I in the Russian Federation in the last quarter of the century.
Figure 5. Development of Scots pine breeding in Russia and Finland: Selection of one plus tree per area of pine forests, in ha.

Figure 6. Development of Scots pine breeding in Russia and Finland: Creation of 1 ha of FSO per area of pine forests, in ha.

As can be seen from the data in figure 5, the number of plus trees of Scots pine per area of this species in Russia is 7.7 times lower than in Finland. And figure 6 shows that one hectare of FSO of Scots pine per the area of pine forests less by almost the same amount (by 7.2 times).

Thus, we can conclude that the sharp lag in the development of forest breeding in our country in general and of Scots pine in particular, does not depend on meteorological conditions and not on global warming. The analysis shows that this is most likely due to the lack of desire among forest owners to preserve biological diversity and maintain sustainable forestry in our country.

5. Conclusion
The analysis of the development of Scots pine breeding in Russia showed the following.

From 1996 to 2019, the number of plus trees decreased by 22%.
The area of forest seed orchards decreased by 35% over the same period of time.

In comparison with Finland, in Russia, the intensity of the plus trees’ selection is 7.7 times lower, and the creation of FSO is 7.2 times lower.

In general, in most areas of pine breeding in Russia, for one reason or another, there is a decline, sometimes several times (in particular, PFSP).

All this, unfortunately, indicates a completely insufficient attention to the development of the Scots pine breeding in our country.

In this regard, for the breeding of this species, it is necessary to involve scientific, project teams and representatives of forestry industry to develop an appropriate program for the breeding of Scots pine. And Federal State Institutions responsible for the sustainable development of forestry should comply with the provisions of this program during forest exploitation.

Acknowledgements

The authors thank their colleagues for their help in finding information on the genetic resources of Scots pine in foreign sources: Jim Richardson and Gwylim Blackburn (Canada); Julia Kuzovkina and Ronald Zalesny (USA); and N I Ryzhkova (Karelia, Russia).

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