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Comparative evaluation of preservation and growth of spruce climatypes based on long-term provenance trials in Russia

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Abstract

The article presents the results of provenance trials carried on the Norway spruce (*Picea abies* (L.) Karst.), the Siberian spruce (*Picea obovata* Ledeb.) and hybrid forms of these two species. The trails were laid in 1977–1978 according to wide-scale All-Union program of 1972 year (Prokazin 1972) in the Arkhangelsk, Vologda, Leningrad regions and the Republic of Bashkortostan. The results of the most recent inventory of provenance trials as well as analyses of preservation and growth of spruce progenies with different geographical origin are presented.

One of the main factors affecting spruce progeny survival was north-south distance between seed collection locality and test locality. At the time of the study (2010–2012), in the Vologda and Arkhangelsk regions, spruce progeny preservation was higher in the case of mother stands distant to the north. On the contrary, in the Leningrad region and the Republic of Bashkortostan, preservation of northern climatypes' progenies was lower during the whole period of plantations' growth. With the change of seed collection locality towards west-east direction, a correlation between progeny preservation and geographical origin factors was non-existent (Vologda, Arkhangelsk regions) or weak (Leningrad region, Republic of Bashkortostan).

The most successful growth and the lowest preservation were observed under the conditions of sharp-continental climate, in provenance trials carried out in the Bashkortostan Republic. In the north of Russia, in provenance trials in the Arkhangelsk region there was observed the slowest spruce growth. On the whole, at all the objects under investigation, Norway spruce progenies and hybrid forms with Norway spruce properties showed better growth parameters when compared to those of the Siberian spruce.

Key words

Spruce, provenance trials, geographical origin, climatype, progeny

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Introduction

The study on population variability, keeping in line with the formula: genotype = phenotype + environment, aims at revealing distribution of intraspecific diversity in populations, an among otherws at investigating species geographical variation in connection with environment around (Pravdin 1975). Provenance trials are unique objects for studying geographical variability of hereditary properties of forest tree species as well as developing and improving forest-seeding zoning. Comparative evaluation of different progenies in provenance trials during an extended period of time allow for studying progenies' adaptation so as to pick out ones most resistant to changing conditions of habitats, and also those not inferior to the productivity of climatypes of local origin.

Under the aegis of the International Union of Forest Research Organizations (IUFRO) an extensive series of spruce provenance trials was established at a global level in the years 1938/1939 (in 9 countries of the world), 1942, 1964/1968 (20 sites in 13 countries), and in 1972 (Giertych 1976; Persson and Persson 1997; Shutyaev 2011; Proceedings of Conference 2012).

Consistent with the IUFRO program, in the years 1974–1978 a series of provenance experiments on the main forest-form breeds was established throughout former USSR, in line with then integrated national program and methodology (Prokazin 1972). The program envisaged a collection of seeded spruce material from 58 provenances and the use of cohesive seeded material on all the created experimental sites. Spruce provenance trials were planted at 17 points on the total area 228 ha (Shutyaev 2011). Up to date, there have endured 13 spruce provenance trials in Russia including the regions of Arkhangelsk, Vologda, Leningrad, Moscow, Lipetsk, Omsk, Nizhny Novgorod and Yekaterinburg as well as the Republic of Karelia, the Republic of Komi, the Republic of Tatarstan, the Republic of Bashkortostan and Krasnoyarsk Krai.

Application of integrated methods in establishing provenance trials has provided for capacity to execute comparative estimations of development of spruce climatype progenies, growing in different test locations. In provenance trials on different age stages, one can track effects of climatic and geographical factors on resistance of progenies. Differences and similarities between climatypes progenies can be observed based on a variety of spruce features including its preservation, growth parameters, yielding ability, phonological characteristics, wood quality and disease susceptibility.

In Russia, great experience in studies concerning spruce provenance trials has been gained (Mamaev et al. 1982; Uvarova et al. 1984; Shutyaev 1995; Tarkhanov 1998; Rodin and Prokazin 1996; Nikolaeva et al. 2010; Raevsky and Ilyinov 2002; Merzlenko and Zhivaikina 2003; Gvozdukhina 2004; Krasnobaeva et al. 2009; Ivanov 2012; Nakvasina et al. 2012).

The provenance trial net established constitutes the base for selection of the best spruce climatypes and also improvement of forest-seeded regionalization in Russia. Taking into account that the act on current forest-seeded zoning in Russia was adopted in 1982, the present research is quite on time.

Material and methods

The objects of research were 33-year-long provenance trials of spruce, located in 4 regions of Russia: Leningrad, Vologda, Arkhangelsk and in the Republic of Bashkortostan. The objects were established in the years 1977–1978. Information on geographical location of research sites, dominating species (forms) of spruce in the regions, object areas, density of planting and the number of the variants tested are presented in table 1.

There were studied seeded progenies of spruce climatypes, including Norway spruce *Picea abies* (L.) Karst., Siberian spruce *Picea obovata* Ledeb. and hybrid forms of the two species. Details on individual geographical origin of climatypes progenies are presented in table 2.

In the integrated working document for Russia there was accepted methodology elaborated by Prokazin (1972) from the All-Union Forest Research Institute (VNIILM). The methods allow to perform comparative evaluations of development of homogeneous progenies, which are the components of a broad net of provenance trials. These methods are envisaged conducting various investigations during all period of the existence of objects. In the present study, preservation (%) and growth parameters of spruce progenies

Tab. 1. Information on experimental objects

Location of object				Forest-growth zone	Dominating spruce species/form	Experimental object area (ha)	Density of planting, (number of trees/ha)	Number of climatypes
region, republic	forestry unit	geographical coordinates						
		lat. (N)	long. (E)					
Arkhangelsk	Plesetskoe	62º54′	40º24′	north-taiga	hybrid forms with properties of *Picea obovata* Ledeb.	28.2	5300	27
Vologda	Cherepovetskoe	59º07′	37º57′	south-taiga	hybrid forms with properties of *Picea abies* (L.) Karst.	20.9	5300	27
Leningrad	Lyuban-skoe	59º30′	30º52′	medium-taiga	*Picea abies* (L.) Karst.	24.0	5300	35
	Gatchin-skoe	59º09′	30º02′			3.6	3500	22
Republic of Bashkortostan	Karaiedel-skoe	55º30′	56º57′	zone of mixed forest	*Picea obovata* Ledeb.	8.9	3500	26

Tab. 2. Geographical origin of spruce climatypes progenies included in provenance trials in Russia (Leningrad, Vologda, Arkhangelsk regions and the Republic of Bashkortostan)

Number of seed collection locality (as in National Registry)	Specification of spruce species/form	Province	Geographical coordinates	
			lat. (N)	long. (E)
1	2	3	4	5
5	Norway spruce (*Picea abies* (L.) Karst.)	Leningrad, Tosno	59º30′	30º52′
8		Estonia, Viliyndin	58º24′	25º38′
32A		Novgorod, Poddorsk	57º17′	31º07′
7		Pskov, Velikiye Luki	56º23′	30º30′
30		Tver, Nelidov	56º14′	32º48′
10		Latvia, Daugavpils	56º10′	26º30′
9		Lithuania, Taurag	55º17′	22º19′
11		Vitebsk, Beshenkovich	55º05′	29°28′
12		Mogilev, Cherikov (only in R. Bashkortostan)	53º50′	31°24′
32		Kaluga, Kaluzhsk	54º25′	36º16′
17		Zakarpatye, Rakhov	48º07′	24º03′
3	Hybrid forms with properties of Norway spruce (*Picea abies* (L.) Karst.)	Karelia, Prjazhin	61º40′	33º33′
4		Karelia, Pudozh	61º40′	36º40′
24		Vologda, Cherepovets	59º07′	37º57′
27		Kostroma, Galich	58º24′	42º20′
29A		Moscow, Zagorsk	56º19′	38º09′
29		Moscow, Solnechnogorsk	56º10′	36º58′

1	2	3	4	5
34	Hybrid forms with properties of Siberian spruce (*Picea obovata* Ledeb.)	Tatarstan, Sabinsk	56º00′	50º30′
35		Udmurtia, Izhevsk	56º50′	53º10′
31		Nizhny Novgorod, Sharangsk	57º11′	46º30′
28		Kirov, Slobodskoy	58º49′	50º06′
21		Arkhangelsk, Konoshsk	60º58′	40º11′
22		Arkhangelsk, Kotlas	61º15′	46º54′
25		Komi, Kortkyeros	61º41′	51º31′
21A		Arkhangelsk, Plesetsk	62º45′	40º15′
1A		Karelia, Medwezh'egorsk	62º54′	34º27′
2		Karelia, Segezha	63º40′	34º28′
23		Arkhangelsk, Cholmogor	64º14′	41º38′
20		Arkhangelsk, Pinyega	64º45′	43º14′
43	Siberian spruce (*Picea obovata* Ledeb.)	Chelyabinsk, Katav-Ivanovsk	54º45′	57º59′
36		Bashkortostan,Krasnoklyuchevsk	55º43′	55º15′
41		Yekaterinburg, Nizhny Tagil	57º54′	60º00′
42		Yekaterinburg, Tavdin	58º04′	65º18′
47		Tomsk, Byeloyarsk	58º09′	84º58′
39		Perm, Dobryansk	58º16′	56º25′
40		Yekaterinburg, Karpinsk	59º51′	60º00′
38		Perm, Krasnovishersk	60º12′	57º08′
26		Komi, Sosnogorsk	63º27′	53º55′
1		Murmansk, Monchegorsk	67º51′	32º57′

were determined. All the spruce trees growing were counted for identification of progeny preservation. For calculation of the mean diameter at the height of the breast (DBH) (exactness = 0.5 cm), the number of accounted trees was app. 150/variant (in Bashkortostan – depending on the variant – from 50 to 100). The all trees were counted in case of the lesser trees quantity in variant. For determination of the graphic height in each variant, not fewer than 25 trees were measured at 0.1 m accuracy, and these were selected respectively to diameter class.

Comparative evaluation of progenies' preservation and growth as well as geographical variability of spruce properties in provenance trials was performed using statistical methods described by Dospekhov (1985). Based on data concerning preservation and growth parameters of the progenies tested, the growing stock for each observed variant was calculated. As a matter of record about preservation, growth parameters by diameter and height, growing stock the cluster analysis for each object was performed (Zhigunov et al. 2002).

Results

The results on preservation and growth of the progenies tested in 33-year-long provenance trials on spruce are presented in table 3 and 4, respectively.

The results on correlations between progenies' growth parameters (diameter and height), preservation and geographical origin factors are presented in table 5.

Base on collected data concerning preservation and growth of progenies, cluster analyses were performed for each object. The results obtained are presented in diagrams of similarities and differences between progenies (fig. 1, 2, 3 and 4).

Tab. 3. Spruce preservation in 33-year-long provenance trials in Russia

Province	Preservation of progenies studied objects (%)			
	Arkhangelsk	Vologda	Leningrad (Lyuban/Gatchin)	Bashkortostan
1	2	3	4	5
Norway spruce (*Picea abies* (L.) Karst.)				
Leningrad, Tosno	71	84	**59**/65	27
Estonia, Viliyndin	56	71	46/50	–
Novgorod, Poddorsk	–	–	61/–	–
Pskov, Velikiye Luki	55	84	59/–	28
Tver, Nelidov	62	63	46/57	24
Latvia, Daugavpils	53	70	**59**/63	–
Lithuania, Taurag	–	–	34/60	–
Vitebsk,Besh., Mogilev,Cher.	–	72	47/55	25
Kaluga, Kaluga	–	–	54/60	24
Zakarpatye, Rakhov	–	–	44/–	16
Average	59.4	74.0	50.9/58.6	24.0
Hybrid forms with properties of Norway spruce (*Picea abies* (L.) Karst.)				
Karelia, Prjazhin	71	81	45/**75**	–
Karelia, Pudozh	78	80	40/–	–
Vologda, Cherepovets	62	84	50/–	28
Kostroma, Galich	69	79	37/32	38
Moscow, Zagorsk	70	72	40/–	36
Moscow, Solnechnogorsk	67	62	57/57	26
Average	69.5	76.3	44.8/54.7	32.0
Hybrid forms with properties of Siberian spruce (*Picea obovata* Ledeb.)				
Tatarstan, Sabinsk	–	75	47/51	34
Udmurtiya, Izhyevsk	51	71	51/58	31
Nizhny Novgorod, Sharangsk	48	78	46/–	–
Kirov, Slobodskoy	71	78	38/58	34
Arkhangelsk, Konoshsk	–	–	43/71	28
Arkhangelsk, Kotlas	76	79	47/–	35
Komi, Kortkeros	75	77	46/55	39
Arkhangelsk, Plesetsk	78	–	43/–	–
Karelia, Medwyezh'egorsk	73	–	31/–	–
Karelia, Segezha	69	78	23/73	–
Arkhangelsk,Cholmogor	81	85	40/–	–
Arkhangelsk, Pinega	81	82	29/50	–
Average	70.3	78.1	40.3/59.4	33.5
Siberian spruce (*Picea obovata* Ledeb.)				
Chelyabinsk, Katav-Ivanovsk	–	–	–	25
Bashkir, Krasnoklyuchevsk	–	–	–	27

1	2	3	4	5
Yekaterinburg, Nizhny Tagil	61	69	40/59	33
Yekaterinburg, Tavda	–	74	39/54	30
Tomsk, Byeloyarsk	–	–	–	16
Perm, Dobryansk	63	75	41/66	29
Yekaterinburg, Karpinsk	60	82	32/50	29
Perm, Krasnovishersk	67	85	42/–	23
Komi, Sosnogorsk	68	81	40/39	–
Murmansk, Monchegorsk	70	–	14/–	–
Average	64.8	77.7	35.4/53.6	26.5

Tab. 4. Spruce growth in 33-year-long provenance trials in Russia

Province	Growth parameters: diameter and height							
	Arkhangelsk		Vologda		Leningrad (Lyub.)		Bashkortostan	
	DBH	H_{graph}	*DBH*	H_{graph}	*DBH*	H_{graph}	*DBH*	H_{graph}
1	2	3	4	5	6	7	8	9
Norway spruce (*Picea abies* (L.) Karst.)								
Leningrad, Tosno	8.5±0.3	10.7	10.3±0.2	11.5	12.4±0.3	14.1	17.8±0.7	18.1
Estonia, Viliyndin	7.6±0.3	9.6	9.5±0.2	10.2	14.9±0.4	14.5	–	
Novgorod, Poddors	–		–		11.6±0.3	12.6	–	
Pskov, Veliki. Luki	8.7±0.3	10.0	10.2±0.3	11.0	14.0±0.3	14.1	17.3±0.6	17.3
Tver, Nelidov	7.3±0.3	8.8	9.5±0.2	10.8	12.8±0.3	13.6	17.7±0.9	16.8
Latvia, Daugavpils	7.7±0.3	10.3	9.5±0.3	10.5	12.8±0.3	12.8	–	
Lithuania, Taurag	–		–		13.0±0.4	13.3	–	
Vitebsk, Mogilev	–		9.0±0.2	10.0	13.3±0.3	13.7	18.4±0.4	16.9
Kaluga, Kaluga	–		–		13.8±0.4	14.4	17.4±0.4	16.9
Zakarpatye,Rakhov	–		–		11.9±0.3	12.5	17.3	17.3
Average	7.96	9.88	9.67	10.67	13.24	13.56	17.65	17.22
Hybrid forms with properties of Norway spruce (*Picea abies* (L.) Karst.)								
Karelia, Prjazhin	8.9±0.3	9.8	8.8±0.2	9.6	11.5±0.4	13.0	–	
Karelia, Pudozh	7.6±0.3	9.4	9.1±0.2	9.8	14.1±0.4	13.9	–	
Vologda, Cherepov	9.5±0.3	10.1	10.0±0.3	10.7	12.3±0.3	13.7	18.2	18.8
Kostroma, Galich	7.0±0.2	8.6	9.5±0.2	11.4	13.1±0.4	12.8	18.9±0.8	17.3
Moscow, Zagorsk	6.3±0.3	6.7	8.5±0.2	9.0	14.4±0.4	14.3	17.3	17.2
Moscow, Solnechno	8.7±0.3	10.6	8.8±0.2	9.8	13.6±0.4	13.8	18.0	17.7
Average	8.00	9.20	9.12	10.05	13.17	13.58	18.10	17.75
Hybrid forms with properties of Siberian spruce (*Picea obovata* Ledeb.)								
Tatarstan, Sabinsk	–		8.2±0.2	9.1	9.8±0.2	11.0	18.1±0.6	17.3
Udmurtiya, Izhyevs	6.2±0.2	7.7	8.6±0.2	9.7	10.0±0.3	10.3	16.6±0.4	16.9
N.Novgorod, Shar.	6.1±0.3	7.0	9.2±0.2	9.8	9.3±0.3	9.8	–	
Kirov, Slobodskoy	7.0±0.2	8.3	9.8±0.2	10.2	10.1±0.4	11.1	17.2±0.5	16.7
Arkhangelsk, Kon.	–		–		10.0±0.2	11.6	17.7	16.4

1	2	3	4	5	6	7	8	9
Arkhangelsk, Kotl.	8.1±0.3	9.9	8.6±0.2	9.5	10.1±0.3	11.5	17.3±0.8	16.3
Komi, Kortkeros	8.3±0.3	9.5	8.8±0.2	9.7	8.5±0.2	9.0	17.3	16.7
Arkhangelsk, Pleset.	8.5±0.3	10.2	–		9.6±0.3	10.4	–	
Karelia, Medwyez.	7,4±0.2	7,8	–		11.2±0.3	11.5	–	
Karelia, Segezha	7.1±0.2	7.1	8.9±0.2	9.5	10.7±0.3	11.0	–	
Arkhangelsk, Chol.	7.3±0.2	7.8	8.0±0.2	8.5	10.0±0.3	10.2	–	
Arkhangelsk, Pineg.	7.5±0.2	8.0	7.8±0.2	8.3	10.0±0.3	10.1	–	
Average	7.35	8.33	8.66	9.37	9.95	10.63	17.37	16.72
Siberian spruce (*Picea obovata* Ledeb.)								
Chelyabinsk, K.-Iv.	–		–		–		16.5±0.6	15.2
Bashkir, Kr.-klyuc.	–		–		–		17.4±0.4	16.2
Yekaterinburg, N.Ta	7.1±0.3	7.7	8.9±0.2	10.1	10.4±0.3	10.6	16.5±0.5	15.8
Yekaterinburg, Tav.	–		8.3±0.2	8.4	10.1±0.3	10.0	17.9±0.7	17.3
Tomsk, Byeloyarsk	–		–		–		16.2±0.6	15.2
Perm, Dobryansk	7.2±0.3	8.4	9.5±0.3	10.3	10.2±0.3	10.9	16.3±0.4	15.8
Yekaterinburg, Karp	7.7±0.3	7.7	8.5±0.2	9.1	12.1±0.4	11.9	17.6	17.1
Perm, Krasnovisher	8.2±0.3	9.2	8.7±0.3	9.3	9.6±0.3	9.6	15.8±0.7	15.9
Komi, Sosnogorsk	8.3±0.3	9.9	8.6±0.2	9.6	7.1±0.2	7.5	–	
Murmansk, Monch	5.3±0.3	5.3	–		8.2±0.2	8.2	–	
Average	7.30	8.03	8.75	9.47	9.67	9.81	16.86	16.19

Tab. 5. Correlation between growth parameters, preservation and factors of geographical origin of spruce progenies

Location of objects	Growth parameter	Correlation coefficient of progenies' growth parameters		
		preservation	geographical factors	
			latitude (N)	longitude (E)
Arkhangelsk region	diameter *DBH*	+0.173	–0.077	–0.117
	height H_{graph}	+0.040	–0.283±0.180	–0.215±0.187
Vologda region	diameter *DBH*	+0.019	–0.435±0.158	–0.440±0.158
	height H_{graph}	–0.090	–0.404±0.163	–0.447±0.156
Leningrad region	diameter *DBH*	+0.327±0.153	–0.521±0.134	–0.577±0.114
	height H_{graph}	+0.440±0.138	–0.552±0.119	–0.636±0.102
Republic of Bashkortostan	diameter *DBH*	+0.175	–0.119	–0.587±0.131
	height H_{graph}	+0.158	–0.076	–0.694±0.104

Discussion

High resistance and polymorphism of the Norway spruce (*Picea abies* (L.) Karst.) and the Siberian spruce (*Picea obovata* Ledeb.) allow for their adaptation to very different climatic and geographical conditions. Taking into account specific observations on spruce trees on the objects in the Arkhangelsk, Vologda regions and the Bashkortostan Republic, hybrid forms' progenies with *P. obovata* properties showed the best preservation; in the Lyubanskoe Forest District whereas in the Leningrad region, better preservation was observed in *P. abies* progenies (tab. 3).

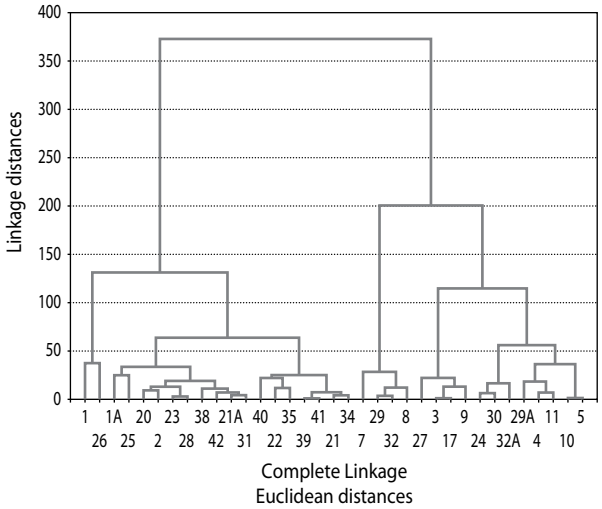

Fig. 1. Diagram of similarities and differences between progenies in provenance trials in the Leningrad region

1, 26, 1A, … – number of seed collection locality (as in National Registry)

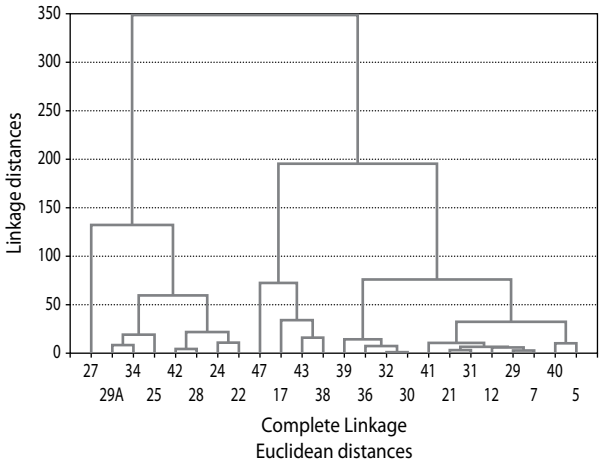

Fig. 2. Diagram of similarities and differences between progenies in provenance trials in the Bashkortostan Republic

27, 29A, 34, … – number of seed collection locality (as in National Registry)

For the time being, the best preservation was indicated in provenance trials in the Vologda region, where preservation percentage varied from min 62–63% (Moscow-Solnechnogorsk, Tver progenies) to max 80–85% (local Vologda, Perm-Krasnovishersk, Yekaterinburg-Karpinsk, Komi-Sosnogorsk, Leningrad, Pskov, Karelo-Prjazhin and also all Arkhangelsk progenies).

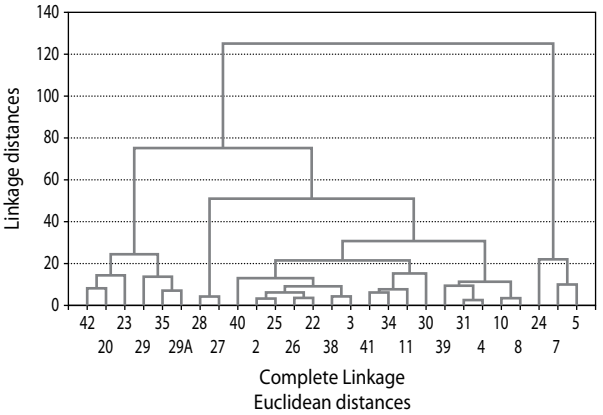

Fig. 3. Diagram of similarities and differences between progenies in provenance trials in the Vologda region

42, 20, 23, … – number of seed collection locality (as in National Registry)

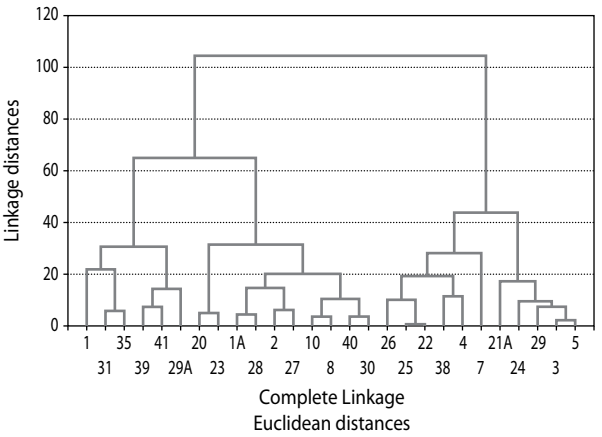

Fig. 4. Diagram of similarities and differences between progenies in provenance trials in theArkhangelsk region

1, 31, 35, … – number of seed collection locality (as in National Registry)

Progenies' preservation in the Arkhangelsk region was from 48% (N. Novgorod) and 51–53% (Udmurtia and Latvia progenies) to 73% (and Karelo-Medwezh′egorsk) and 75–81% (all Arkhangelsk progenies and also Komi-Kortkyeros, Karelo-Pudozh progenies).

The most essential differences in preservation were recorded in provenance trials in the Leningrad region: on the object in the Lyubanskoe Forest District – from min 15% (Murmansk-Monchegorsk) and 23% (Karelo-Myedwezh'egorsk progeny) to max 54–59% (local Leningrad, Novgorod, Pskov, Latvia, Kaluga, Moscow-

Solnechnogorsk progenies). On the object in the Gatchinskoe forest District, preservation was from 32% (Kostroma) and 39% (Komi-Sosnogorsk) to 66–74% (also local Leningrad progeny, Perm-Dobryansk, Karelian Prjazhin and Segezh progenies).

The lowest preservation was found in the provenance trial in Bashkortostan: from min 16% (Zakarpatye and Tomsk), 23–24% (Perm-Krasnovishersk, Kaluga, Tver progenies) to max 34–39% (Komi-Kortkeros, Tatarstan, Arkhangelsk-Kotlas, Kirov, Kostroma, Moscow-Zagorsk progenies); local Bashkir progeny had 26.2% preservation. One has to bear in mind that in 2007 snowbreak and glaze had negative effects on spruce stability, especially on that of the Norway spruce.

The analysis of correlation between progenies preservation percentage and geographical factors showed, that in the Vologda and Arkhangelsk regions, preservation of progenies was significantly higher in the case of mother stands distant to the north (r = +0.620–0.686), whereas in the case of moving seeds in the direction west-east – the correlation was very weak.

In the Leningrad region, during the whole period of plantations' growth, the correlation between preservation and factors of geographical origin was always reverse. The farther seed provenance was situated to the north or the east, the lower preservation was observed. In 33-year- old plantations, the reliable correlation was determined in the case of moving seeds in the north-south direction (r = –0.553) and the weak and doubtful correlation was found in the case of moving seeds in the west-east direction (r = –0.183).

In Bashkortostan, in spite of negative weather factors in 2007, progenies' preservation was increased with moving seed collection to the north (r = +0.49), and decreased (r = –0.254) when seed collection was moved to the east.

In the Arkhangelsk region the provenance trials showed very slow growth rate. The severe climate, short summer and accordingly – the short growing period are key factors, which can explain slow spruce growth; maximum averages are not more than DBH = 9.5 cm (Vologda-Cherepovets progeny) and $H_{graph.}$ = 10.6–10.7 m (Leningrad and Moscow-Solnechnogorsk progenies) (tab. 4).

In the Vologda region the maximum average did not exceed DBH = 10.2–10.3 cm (Leningrad and Pskov progenies) and $H_{graph.}$ = 11.4–11.5 m (Leningrad and Kostroma progenies).

Opposite, in south-eastern Russia (Bashkortostan), where provenance trial preservation was the lowest, the growth rate was well above when compared with other objects. Appropriate soil conditions and long vegetation noted at the trial site were responded by successful spruce growth. On average, most of progenies in Bashkir plantations were 2 times higher and thicker than those in the Arkhangelsk region. In the latter, the lowest variability of growth parameters was determined. The highest growth values found in the best progenies were less then 20% above those for the worst ones. Averages of growth parameters were within the following range: from DBH = 15.8 cm (Perm-Krasnovishersk) and $H_{graph.}$ = 15.8 m (Yekaterinburg-Nizhny Tagil and Dobryansk progenies) to DBH = 18.9 cm (Kostroma) and $H_{graph.}$ = 18.8 m (Vologda progeny).

The highest interpopulational variation (between progenies) in terms of growth parameters was observed for the provenance trials in the Leningrad region (Lyubanskoe FD), where average growth parameters for the best and the worst progenies differed 2-fold and more. For example, there were found average values for DBH = 7.1 cm and $H_{graph.}$ = 7.5 m (Komi-Sosnogorsk progeny) as well as DBH = 13.8–14.9 cm and $H_{graph.}$ = 13.9–14.5 m (Estonia, Kaluga, Moscow, Pskov, Karelia-Pudozh progenies). In the Leningrad region was noted the highest individual variation for the diameter (from 29 to 47%).

A characteristic feature in all the objects tested was observed: the worst growing progenies were Siberian spruce trees and hybrid forms with Siberian spruce properties, whereas the best growing trees were Norway spruce properties and hybrid forms with Norway spruce properties.

In the provenance trials of Bashkortostan Republic as well as those in the Vologda and Arkhangelsk regions there were observed weak or doubtful correlations between preservation and growth parameters of spruce (max r = +0.175), whereas in the provenance trial in the Leningrad region this correlation was direct and moderate (r = +0.327 and r = +0.440) (tab. 5).

Growth of climatypes' progenies in different locations of their testing showed different degrees of impact of geographical factors. However, at all the objects there were showed that the more distant to the north and the

east was the place of seed collection, the worse growth of progeny was observed in the plantations. There was also noted that the growth of spruce in height, as compared to the growth by diameter (DBH) had more essential dependence on geographical origin seeds.

At the northern object – in Arkhangelsk region trial, the influence of geographical origin factors on the spruce growth was almost absent or weak (from $r = -0.077$ and to $r = -0.283$). However, there was a tendency found, that with moving seed collection locality to the north and the east progenies' growth was getting worse, and especially in the case of tree height. The reliable and moderately stable correlation was observed in the provenance trial in the Vologda region (from $r = -0.404$ to $r = -0.447$). The significant and strong correlation was found in the provenance trial in the Leningrad region (from $r = -0.521$ and to $r = -0.636$). The more substantial correlation was observed in the trail in Bashkortostan, where the more distant to the east was the province of seed collection, the lower was diameter and height growth intensity, $r = -0.587$ and $r = -0.694$, respectively. However, of seed moving towards the direction south-north indicated very weak influence on spruce growth. It should be noted, that in the conditions of Bashkir, the long growing season promotes successful growth of both the Norway spruce and the Siberian spruce.

It was established that in the Arkhangelsk region the growing stock of local Plesetsk progeny was the best (130 m^3/ha). Similar parameters (124–126 m^3/ha) were shown by Leningrad, Prjazhin and Vologda progenies. Among the worst, there were marked the progenies of Murmansk and Nizhny Novgorod origin (28–31 m^3/ha).

In the Vologda region, the best growing stock (215–225 m^3/ha) was found in the progenies of Leningrad and Pskov origin, whereas that of local Vologda progeny was lesser (203 m^3/ha). Among the worst at the object, there were marked extreme North Pinyega and extreme East Tavda progenies (100 m^3/ha).

In the Leningrad region, the growing stock of local progeny was lesser than that of Moscow-Solnechnogorsk, Pskov, Estonia and Kaluga progenies (298 m^3/ha against 350–385 m^3/ha). Among the worst progenies, there were distinguished Murmansk (15 m^3/ha) and Komi-Sosnogorsk progenies (40 m^3/ha).

In the Bashkortostan Republic, if to exclude snowbreak and glaze effects in 2007, i.e. when not considering low preservation at the object, in some progenies the highest growing stock could be observed: Tatarstan and Komi progenies – 405–415 m^3/ha, Kostroma – 485 m^3/ha. At the same time, local Bashkir progeny had growing stock 280 m^3/ha. Among the worst at the object, there were extreme east Tomsk (140 m^3/ha) and extreme south Zakarpatye progenies (180 m^3/ha).

The diagrams, presented in fig. 1, 2, 3 and 4 show similarities and differences between progenies tested with regard to a set of characteristics (preservation, growth, growing stock). Each diagram shows division of progenies into 2 overall clusters.

On the diagrams for the trails in the Leningrad and Vologda regions, one overall cluster embraced only *Picea obovata* progenies and hybrid forms with properties of *P. obovata*, whereas the other one embraced– *Picea abies* progenies and hybrid forms with properties of *P. abies*. The diagrams concerning the provenance trials in the Bashkortostan and Arkhangelsk regions showed that Norway spruce and Siberian spruce progenies were together in one cluster.

More significant differences between the progenies tested are demonstrated in the diagrams for Leningrad region trials, whereas the least significant and not substantial differences between progenies were observed for the trials in the Archangelsk region.

At the current moment, based on the results obtained one can tell that, in Leningrad region trials, the most conformity with the local progeny can be tracked for the Norway spruce of Latvia origin, whereas in the Bashkir trials – with the Norway spruce of Tver and Kaluga origins and the Siberian spruce of Perm-Dobryansk origin. In Vologda region trials the local progeny shows the greatest similarity to nearly related Pskov and Leningrad Norway spruce progenies, and in the trials in the Arkhangelsk region, the greatest similarity to the local Plesetsk progeny is shown by hybrid forms of Norway spruce of Vologda, Moscow-Solnechnogorsk, Karelia-Prjazha origins and Norway spruce of Leningrad origin.

Taking into account the results of the present study, the best climatypes can be selected:

– for the Leningrad region – climatypes of the Norway spruce of Pskov (leader), Estonia, Kaluga, Leningrad origins and hybrid forms of Moscow-Solnechnogorsk origin; taking into account the object in Gatchinskoe FD, also – the Norway spruce of Karelia-Prjazhin origin;

- for the Republic of Bashkortostan – climatypes of hybrid forms of Kostroma (leader), Komi-Kortkyeros, Tatarstan, Moscow-Zagorsk, Vologda, Arkhangelsk-Kotlas, Kirov origin and the Siberian spruce of Yekaterinburg-Tavda origin;
- for the Vologda region – climatypes of Norway spruce of Leningrad (leader) and Pskov origins and hybrid form of local Vologda-Cherepovets origin;
- for the Arkhangelsk region – climatypes of hybrid forms of local Arkhangelsk-Plesetsk origin (leader) and Kotlas, and also Vologda, Karelia-Prjazhin, Moscow-Solnechnogorsk, Komi-Kortkyeros origin and the Norway spruce of Leningrad origin.

Particular attention should be paid to the progenies with sufficiently high potential of natural reforestation (Nikolaeva and Zhigunov 2012). Specific point seen here is that in the provenance trials of the Leningrad, Arkhangelsk and Vologda regions indicated abundance of flowering and seed production in *P. abies* progenies and its hybrid forms, which were nothing like in *P. obovata*.

Conclusions

The features of preservation and progenies growth has depended both from genetic signs of each tree and geographical origin of progenies and from new cultivation environment.

This way, the influence of geographical origin of spruce seed to the preservation and growth of progenies in 33-year old provenance trails on the four objects in Russia was revealed. In the trails of the Vologda, Arkhangelsk regions as well, as those carried out in Bashkortostan, preservation of progenies was well above others when mother stands were distant to the north. However, in the Leningrad region conservation of progenies was lower in such situation, during the whole period of plantations' growth. Changing of seed collection locality towards west-east direction did not influence progenies' preservation (trials of the Vologda and Arkhangelsk regions) or else – preservation weakly decreased with moving seed collection locality to the east (trails in the Leningrad region and Bashkortostan).

The highest preservation (depending on variant – from 62% to 85%) was found in Vologda trials. The lowest preservation (depending on variant – from 23% to 39%), and also the tallest and thickest trees were observed in the trials of Bashkortostan, i.e. in the conditions of sharp-continental climate. The thinnest trees, either *P. abies* or *P. obovata* were observed in the trials of the Arkhangelsk region, where the lowest productivity, in spite of the good preservation of cultures, has been installed also.

At the provenance trials of Arkhangelsk (Plesetsk) and Vologda (Cherepovets) regions, with dominating spruce hybrid forms, weak tree growth was compensated with high resistance to adverse environment factors.

The results of the present study allowed for distinguishing the best progenies and leaders. On the objects in the Leningrad, Vologda, Arkhangelsk regions, among the best Leningrad, Pskov, Karyelia-Prjazhin and Moscow-Solnechnogorsk progenies were selecting; on the objects in the Vologda, Arkhangelsk regions and Bashkortostan Republic – Vologda progeny also. All these progenies are belong to *P. abies* or to hybrid forms with properties *P. abies*. At the conditions of Arkhangelsk region and Bashkortostan, where are dominating *P. obovata* and hybrid forms with properties of *P. obovata*, amongst of best were distinguishing Arkhangelsk-Kotlas and Komi-Kortkyeros progenies; in the Bashkortostan trail the leader is hybrid form with properties *P. abies* of Kostroma origin.

In north-west Russia, within of the Leningrad, Vologda, Novgorod, Pskov regions, approximately southerner from 60°30′N and westerner from 34°E for the cultivation of spruce the preference should to given to seeds of *P. abies* species and hybrid forms with properties of *P.abies*. In the Bashkortostan Republic, there is promising seeded material from the zone of introgressive hybridization of this species.

At the research objects, the common features of progenies development are noted:

- preservation, is mostly higher in progenies of local climatypes and those originating from neighboring areas;
- progenies of the Norway spruce and its hybrid forms indicate more successful growth in comparison to those of the Siberian spruce and its hybrid forms;
- progenies with origin from southern and western regions of Russia grow better than those from northern and eastern parts of the country; moving seeds of spruce from the north to the south is less promis-

ing, than that from the south to north; the northerner region of the cultivation, the less the possibilities of seeds dislocation.

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