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Intraspecific Response of Scots pine (*Pinus sylvestris L.*) to Pathogens in a Provenance Trial in Middle Siberia

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Abstract

The results of assessing the resistance of 84 Scotch pine climatypes, growing in a provenance trial in a taiga zone in Middle Siberia, to pathogens are presented in this paper: pathogens of needle cast (*Lophodermium pinastri* Chev.), snow blight (*Phacidium infestans* Karst.), Cenangium diebak (*Cenangium ferruginosum* Fr.: Fr.) and rust (*Cronartium flaccidum* (Alb. et Schw.) Wint. and *Peridermium pini* (Pers.) Lew. et Kleb). The dynamics of the diseases caused by these pathogens are shown for a 30-year period. The authors found that Scotch pine resistance to the pathogens in the provenance trial depended both on ecological regime of the growing site and on the genetic peculiarities of the climatypes determined by their site of origin. Differences in the resistance of the same Scotch pine climatypes to the pathogens showed itself when growing them on different ecological backgrounds (on sandy soil - the bear berry pine forest type, and on dark-gray forest soil - the tall-herb pine forest type). Climatypes of "northern Lapponian" and "Siberian" pine subspecies are more tolerant to the pathogens.

Key words: Scots pine, climatypes, provenance trial, pathogens, resistance

Introduction

Long-term international provenance trials have shown that pine trees of different origin strongly differ in their susceptibility to pathogens. High resistance to needle cast (*Lophodermium pinastri* Chev.) and to snow blight (*Phacidium infestans* Karst.) is often noted in pine posterities of northern origin. Low resistance, however, is demonstrated by posterities whose place of origin is far from the test site to the south and east (Kujala, 1950; Romeder and Shenbakh, 1962; Björkmann 1964, 1972; Martinsson, 1979; Rummukainen, 1981; Pikhel'gas, 1982; Prokazin and Kurakin, 1983; Karlman, 1986; Krutov, 1989). *Cronartium flaccidum* (Alb. et Schw.) Wint. and *Peridermium pini* (Pers.) Lew. et Kleb.) are the most dangerous representatives of rust fungi which cause disease in the branches and stems in different pine species and are commonly known as bladdery rust or canker-blister rust, respectively. The analysis of genetic variability confirms that these rust fungi belong to one species (Hantula *et al*., 2002). The disease is found in middle-aged and ripening pine tree stands in Russia, Western Europe and North America (Kuprevich and Transhel' 1957; Krutov, 1972; Azbukina, 1974, 2001; Maloy, 1997; Geils *et al*., 1999; Geils, 2001; Kinloch, 2003). The area covered by this pathogen coincides with the Scotch pine (*Pinus sylvestris* L.) area. The most northern location of this pathogen in Russia is found in the Murmansk oblast (region) at the dividing line of forest zone and forest tundra (between 69º and 70° N). It can be seen everywhere in the northern and middle taiga subzones (Krutov, 1979, 1989). This pathogen has also spread to Finland (Buchwald *et al*., 1961; Červinkova, 1978). Different pine resistances to rusts have been discovered in experiments conducted in Western Europe and in Russia. According to the literature pine susceptibility to bladdery rust is inherited (Bingham *et al*., 1953; Harkins *et al*., 1998; Iroshnikov, 2001; Kinloch *et al*., 2007). The direct method of selecting special forms, individuals, populations which are not susceptible to the disease is one of the most efficient methods for rustproof pine selection. A provenance trial, which presents even-aged intraspecific diversity against a homogeneous ecological background, is very beneficial in the detectection of pathogen-proof individuals and climatypes.

Materials and Methods

The 30-year Scots pine provenance trial growing on sandy (bear berry pine forest type) and on dark-grey forest soils (rich in herbs pine forest type) in the Boguchansky leskhoz of Krasnoyarsk krai (the Priangarie region) is the subject of this study. The Priangarie region is a forested area in the Angara River Basin. Boguchansky leskhoz is located in the southern part of the Middle-Siberian plateau (58º 39′ N and 97º 30′ E). The leskhoz area is related to the Angara district of the southern taiga and subtaiga light-coniferous forests according to forest regional classifications done by the V.N.Sukachev Institute of Forest (Korotkov, 1994). The provenance trial was established in 1976 as a large-scale experiment to create a net of provenance trials of the main tree species forming Russian forests. When establishing and studying a provenance trial the method to be used was approved by the Problem

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Council in Forest Genetics, Selection and Seed Growing (Studying the existent provenance trials and establishing the new ones, 1972). The provenance trials were established using 3-year old plantings grown in a nursery from seeds which were collected from mature stands of the most typical and valuable forest types of each studied climatype. The size of the tree stand area used for seed collecting was 2-3 ha, with approximately 1000 trees. The volume of seeds collected is explained by the fact that the provenance trials were established simultaneously (1976-1977) on several sites throughout the country and in all the experiments the common climatype populations were presented.

The place of origin of the 84 Scots pine climatic ecotypes (hereafter climatypes) tested in this provenance trial were from 50º 10´ to 69° 40´ N and from 26º 28´ to 138° 00´ E. The Scots pine climatypes tested represent four subspecies (geographical population is correct races) of Scots pine (Pravdin, 1964): northern or Lapponian pine (*P. sylvestris* subsp. *lapponica* Fries); Scots forest pine (*P. sylvestris* subsp. *sylvestris* L.); Siberian pine (*P. sylvestris* subsp. *sibirica* Ledeb.); Kulunda or steppe pine (*P. sylvestris* subsp. *kulundensis* Sukaczew). The natural range of the northern Lapponian pine is north of 62º N. The Scots forest pine grows in the European part of Russia, Western Europe, to south of 62º N, except in Crimea and the Caucasus. The Siberian pine grows in Asia between 52º and 62º N. The Kulunda or steppe pine grows in the isolated steppe pine forests of the Asiatic part of Russia, south of 52º N.

The results of the studies of the growth dynamics and stem productivity of the provenance trial were published earlier (Kuzmina, 1999; Kuzmina *et al*., 2004). Inventory characteristics of pine posterities of different geographical origin differ between each other within each experimental site and largely differ between sites. So, the mean height of 30-year-old climatypes growing on sandy soil varies from 2.9 to 6.6 m, and the ones on the dark-grey forest soil - from 8.1 to 12.8 (Photo 1). Mean diameter at breast height varies on sandy soil from 2.9 to 8 cm, and on the dark-grey forest soil - from 8.1 to 18.7 cm (Kuzmina, 2005; Kuzmina and Kuzmin, 2005a).

Pine posterities suffered from several diseases in the 30-year life of the pine. Identification of diseases was done by the phytopathologists G.N. Lebkova and I.S. Kossinskaya from the V.N.Sukachev Institute of Forest. A special procedure of recording disease development was established, especially for the period of each disease. Assessment of the vital status of trees was made visually by determining the damage level of needles, shoots, stems of all the trees. The aim of this research is to assess the resistance of Scots pine to pathogens in the provenance trial for the objective selection of perspective climatypes as well as to provide recommendations for growing them in the region.

Results

1. Needle cast

The first disease observed in pine trees of different geographical origin was caused by needle cast (*Lophodermium pinastri* Chev.) in the 2-year-old forest nursery. At first the yellowing of seedlings, then needle drying and their complete defoliation were observed. Shedding intensity in geographical seedings varied from 1 to 38%, in the control (Boguchany climatype) it was 4%. Defoliation increased the second year of the disease and reached 20% in the control and an average of 42% in the posterities whose place of origin was rather far from the test area to the west and southwest. Pine trees, mainly, from the western and central regions of Russia (Moscow, Vladimir, Tambov oblasts), the Urals and Volga regions (Saratov and Sverdlovsk oblasts, Tatarstan, Udmurtia, Bashkorstan) were among this group of posterities. The highest seedling mortality (up to 85%) was observed in western and southern pine posterities (Gomel', Rovny, Kiev and Sumy oblasts). Seedling defoliation of pine posterities from the central and southern Siberian taiga (Krasnoyarsk krai, Tumen and Irkutsk oblasts, Yakutiya) was within 17-30%. For posterities from European north (Lapponian pine) seedling elimination was within 9-35% (Figure 1).

2. Snow blight

The second most damaging disease was snow blight (*Phacidium infestans*) and it was observed in the 8-year-old pine trees, especially on the site with sandy soil. Seedlings growing on sandy soil grew slower than those on the dark-grey forest soil. Variations in mean height in 8-year-old pine posterities of different origin on sandy soil were 28-70 cm, the ones on dark-grey forest soil were 49-95 cm. The type of injury from snow blight was different depending on the level of damage. Severely damaged trees had dried up terminal buds and shed more than 50% of their needles in the crown. In intermediately damaged trees the needle shedding varied from 20 to 40%. And slightly damaged trees had needle loss of not more than 20%.

The snow blight dynamics show that the degree and share of damaged trees in the provenance trial depended on their geographical origin. The 50-100% damage covered climatypes mainly from the central pine growing regions (Moscow, Vladimir, Gor'ky, Kostroma, Bryansk, Tambov, Voronezh, Pensa and Ryazan' oblasts), but also from the western ones (Latvia, Rovny, Pskov, Gomel' oblasts), southern regions Sumy, Kiev oblasts) as well as Kazakhstan (Semipalatinsk oblast) and several Siberian southern and forest steppe regions (Omsk, Novosibirsk oblasts, the Altai krai and south of Krasnoyarsk krai). A majority of the trees of these climatypes were severely damaged as seen in the loss of a terminal bud and more than 60% of the needles in the crown (Table 1).

Siberian climatypes and three climatypes from the European north turned out to be resistant to snow blight. More than 80% of the healthy trees were from the Krasnoyarsk krai, Yakutia, Irkutsk and Chita oblasts as well as Murmansk oblast and the Komi Republic.

Snow blight largely affected the health and growth of the trees. Low incremental growth in severely damaged climatypes was observed in the years following the disease. Pine climatypes of subspecies Scots forest pine from the European part of Russia and Kulunda pine from the band and steppe pine forests of Kazakhstan and southern Siberia were part of this group.

3. Cenangium dieback

Needle damage from Cenangium dieback was observed in 23-25-year-old (1997-1999) trees growing on sandy soil. *Cenangium abietis* is the pathogenic organism that causes this fungal disease. Visual damage was yellowing and reddening of the needles of young age group were the following: the mean tree height varied from 2.7 to 6.5; tree diameter was from 2.2 to 7.9 cm. Assessment of the state of vegetative crown parts revealed various degrees of resistance to this pathogen. Damaged trees were classified into three groups. The first group covered trees with slight needle damage in the crown which was expressed by needle yellowing and reddening up to 30%. The second group was characterized by intermediate damage, 50% or greater needle reddening was observed in the crown. The third group of severely damaged trees showed 90% or greater needle loss. Growth of the leading and sucker

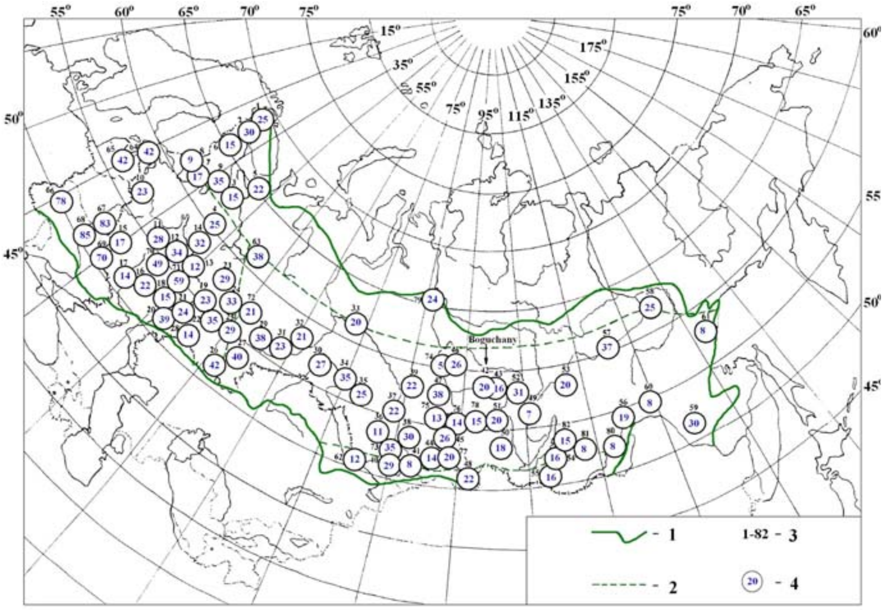

Fig. 1. Seedling elimination in 2-year-old pine posterities of different origin caused by needle cast (1 - Scots pine area border, 2 - Scots pine subspecies border, 3 - number of climatype (climatype names are in the table 1), 4% of trees died).

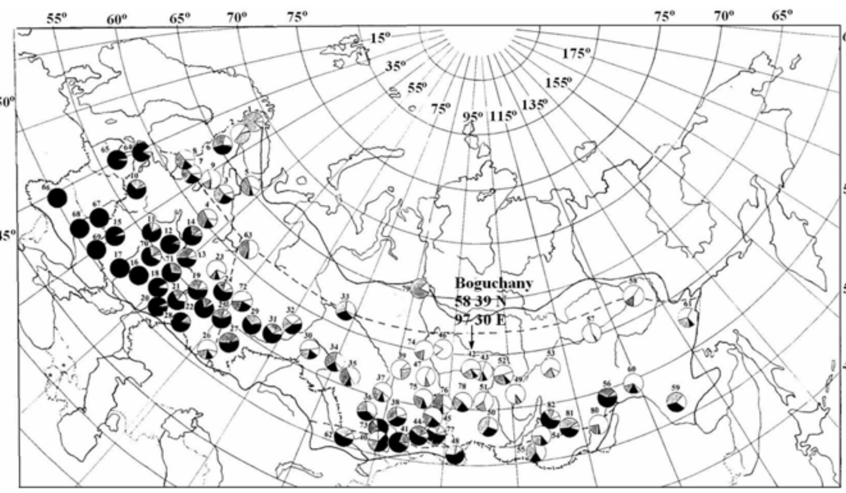

Fig. 2. Resistance of Scots pine trees of different origins to Cenangium dieback in the provenance trial of Boguchany leskhoz of Krasnoyarsk krai (black part - severely damaged trees; grey part - immediately damaged trees; white part - healthy and slightly damaged trees). Climatype names are in Table 1.

shoots of the upper whorls was absent in trees of this group in the following two years after the disease. A small portion of severely damaged trees maintained their vitality due to two or three lower whorls with healthy green needles. The percentage of trees with different degrees of damage for all the trees of the climatypes in the trial is shown on the map (Figure 2).

The differentiation of Scots pine trees revealed climatypes with different resistance to the pathogen and can be seen by the degree of needle damage. Climatypes from the European north (Karelia, Murmansk and Arkhangelsk oblasts) and Siberia (Krasnoyarsk krai, Irkutsk and Chita oblasts, Sakha Republic) had better resistance. From 50-90% of the trees in these climatypes were healthy or had little needle damage.

Pine posterities from the Baltic countries, central regions of Russia, several Urals and Volga regions as well as from southern regions of Siberia were related to the less resistant climatypes (occurrence of damaged trees varied from 50 to 80% of trees) with severe to intermediate needle damage. The lowest resistance is a characteristic of pine posterities from Penza, Voronezh, Sumy, Orenburg, Vladimir oblasts. A mass character, with a severe and intermediate needle damage (80-100% of trees), was observed in this group of climatypes (Photo 2).

Thus, the highest resistance to Cenangium dieback was found in Scots pine posterities, subspecies: northern Lapponian and Siberian of southern taiga subzone. The low resistance to the pathogen is characteristic of pine posterities, subspecies Kulunda pine, Scots forest pine. and Siberian pine from the steppe regions of the Siberian south. Since the 84 Scots pine climatypes studied were grown under similar climatic and ecological conditions it may be concluded that the observed pine differentiation in its resistance to the pathogens is determined by genetic peculiarities which are evolutionally remembered in posterities from their places of origin.

4. Rusts

In the last 10 years the damage that was observed was caused by rusts - mostly by canker-blister rust (*Cronartium flaccidum*) on the dark-grey forest soil. The cankers on tree stems are the result of this infection. Canker localization is more often observed between 0.5-1.0 m from the ground (Photo 3), but seldom between 1.5-2.0 m.

A clear difference in resistance of Scotch pine posterities of different climatypes to bladdery rust was observed in the experiment. Trees of different growth and development were damaged by this pathogen. A maximum of 10% of the pine trees were damaged by this pathogen in the provenance trial, the minimum one was 0.21% (Figure 3). The number of injured trees in the control climatype (Boguchany leskhoz, Krasnoyarsk krai) did not exceed 1.0%. Pine posterities from steppe and forest steppe sites of Volga, the southern Urals region, Kazakhstan and south of Siberia (Buzuluksky leskhoz from Orenburg oblast, Dyurtyulinsky leskhoz from Bashkorstan, Kurgansky leskhoz from Kurgan oblast, Dolonsky leskhoz from Kazakhstan, Kyakhtinsky leskhoz from Buryatia, Rakitovsky from Altai, Minusinsky from Krasnoyarsk krai) are climatypes with the largest share of damaged trees (4-10%). A lesser percentage of damaged of trees (1-3%) were found in climatypes from the southern taiga subzone (Tambov, Kostroma, Zelenodolsky, Melekessky, Votkinsky, Avzyansky, Kyshtovsky). In some Siberian climatypes located close to the trial area (Prospikhinsky, Yeniseisky, Achinsky, Katangsky) between 2-4% of the trees were damaged by this pathogen.

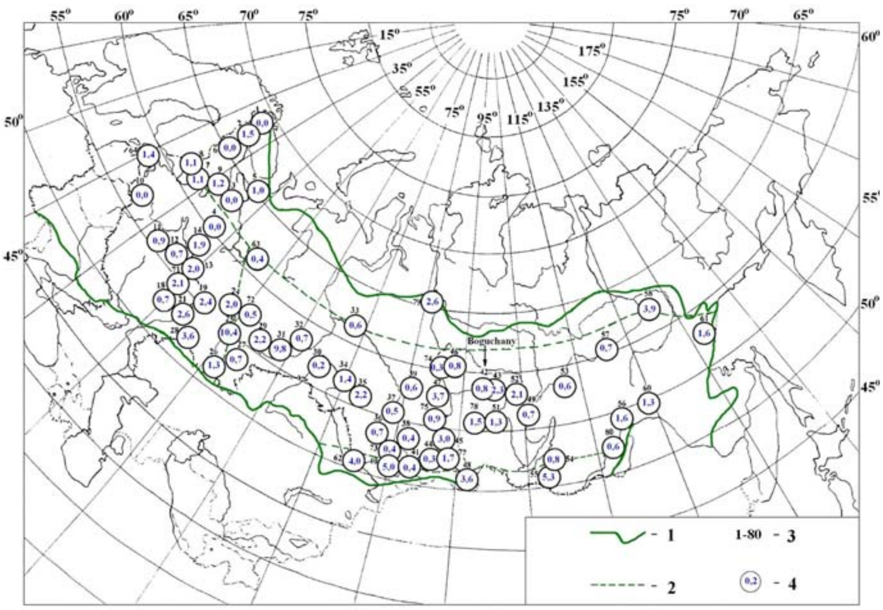

Fig. 3. Tree share (%) with canker caused by rust in the 30-year provenance trial (1 - Scots pine area border, 2 - Scots pine subspecies border, 3 - number of climatype, 4 - share (%) of trees with canker).

Photo 1. The 30-year provenance trials of Scots pine (Yeniseisky climatype) in the Boguchany leskhoz of Krasnoyarsk krai: left - on the dark-grey forest soil, right - on sandy soil.

Photo 2. Disease caused by *Cenangium abietis* in 23-year-old Scots pine provenance trial on sandy soil. Left and in the center - the climatypes (Voronezh and Kostroma) which present the subspecies - Scots forest pine, right - the control (Boguchany) presenting the subspecies - Siberian pine (by Pravdin, 1964).

Photo 3. Canker in the lower stem caused by rust fungi in trees of the Minusinsk climatype from the forest-steppe zone of Krasnoyarsk krai south. Provenance trial plot on the dark-grey forest soil, 25 years old.

Table 1. Damage of Scots pine by snow blight in the provenance trial on the plot with sandy soil.

Subspecies	Region	Climatype №	Climatype Origin (leskhoz, oblast, krai, republic)	Total number of trees	Tree share (%) with different degree of needle damage: severe (> 50%)	intermediate (from 20 to 50 %)	slight (up to 20 %)	Share of undamaged trees, %
lapponica	European north	1	Pechengsky, Murmanskaya	219	0	0	25	75
		2	Kandalakshsky, Murmanskaya	218	1	10	7	82
		3	Plesetsky, Arkhangelskaya	555	12	26	8	54
		5	Pinezhsky, Arkhangelskaya	413	1	6	50	43
		6	Chupinsky, Karelia	595	9	17	57	17
		7	Pryazhinsky, Karelia	647	41	37	18	4
		8	Sortoval'sky, Karelia	436	21	18	27	34
		9	Pudozhsky, Karelia	125	24	29	22	25
	Siberian north	79	Turukhansky, Krasnoyarsky	83	0	0	20	80
sylvestris	Eastern Europe	64	El'vassky, Estonia	471	26	15	15	44
		65	Yaunelgavsky, Latvia	393	52	10	20	18
		67	Leninsky, Belarus	8	17	0	47	36
		66	Dubrovitsky, Ukraine	110	33	29	17	21
	European part of Russia	4	Totemsky, Vologodskaya	641	18	27	20	35
		10	Velikoluksky, Pskovskaya	33	50	20	23	7
		11	Kurovsky, Moskovskaya	86	55	21	12	12
		12	Kovrovsky, Vladimirskaya	115	50	17	17	16
		13	Gorodetsky, Nizhnegorodskaya	900	48	18	14	20
		14	Kostromskoy, Kostromskaya	1248	50	17	23	10
		15	Gavan'sky, Bryanskaya	17	100	0	0	0
		16	Chelnavsky, Tambovskaya	60	75	5	20	0
		17	Voronezhsky, Voronezhskaya	46	60	5	19	16
		18	Nikol'sky, Pensenskaya	1199	60	17	17	6
		19	Zelenodol'sky, Tatarstan	1564	34	22	24	20
		20	Vol'sky, Saratovskaya	27	50	8	36	6
		21	Melekessky, Uliyanovskaya	164	77	12	6	5
		22	Kamsky, Tatarstan	480	51	18	23	8
		23	Slobodskoy, Kirovskaya	548	38	24	33	5
		24	Votkinsky, Udmurtia	1060	25	23	18	34
		69	Svessky, Sumskaya	90	52	7	41	0
		70	Solotchinsky, Ryazanskaya	136	14	31	17	38
		71	Sursky, Ul'yanovskaya	660	25	9	40	26
	Ural	25	Dyurtyulinsky, Bashkorstan	286	64	15	19	2
		26	Avzyansky, Bashkortostan	290	14	34	19	33
		28	Buzuluksky, Orenburgskaya	150	82	5	12	1
sibirica	European part of Russia	63	Kortkerossky, Komi	437	2	4	6	88
	Ural	27	Beloretsky, Bashkorstan	171	18	47	29	6
		29	Revdinsky, Sverdlovskaya	680	40	26	32	2
		72	Okhansky, Permskaya	516	5	20	65	10

	Siberia	30	Tavdinsky, Sverdlovskaya	1172	10	40	22	28
		31	Kurgansky, Kurganskaya	506	24	26	12	38
		32	Zavodoukovsky, Tyumenskaya	955	14	31	30	25
		33	Surgutsky, Tyumenskaya	814	–	1	36	63
		34	Tarsky, Omskaya	619	28	45	14	13
		35	Kyshtovsky, Novosibirskaya	1260	10	20	40	30
		36	Suzunsky, Novosibirskaya	942	19	33	25	23
		37	Bolotninsky, Novosibirskaya	952	10	38	31	21
		38	Gurievsky, Kemerovskaya	965	16	28	35	21
		39	Kolpashevsky, Tomskaya	500	3	23	56	18
		42	Boguchansky, Krasnoyarsky	3775	2	11	22	65
		43	Prospikhinsky, Krasnoyarsky	1089	1	17	22	60
		44	Abazinsky, Krasnoyarsky	579	11	27	21	41
		45	Minusinsky, Krasnoyarsky	1876	18	26	25	31
		46	Severo-Yeniseisky, Krasnoyarsky	635	7	2	0	91
		47	Yeniseisky, Krasnoyarsky	153	1	1	13	85
		49	Ust'- Kutsky, Irkutskaya	606	3	11	–	86
		50	Ziminsky, Irkutskaya	869	6	20	28	46
		51	Vikhorevsky, Irkutskaya	398	4	5	37	54
		52	Katangsky, Irkutskaya	588	1	2	26	71
		53	Mamsky, Irkutskaya	271	4	9	64	23
		57	Olyokminsky, Yakutiya	360	0	0	9	91
		58	Yakutsky, Yakutiya	511	0	1	9	90
		60	Urushinsky, Amurskaya	1098	24	38	24	14
		73	Borovlyansky, Altai	500	54	17	19	10
		74	Nizhne-Yeniseisky, Krasnoyarsky	354	0	1	12	87
		75	Achinsky, Krasnoyarsky	300	3	19	47	31
		76	Daursky, Krasnoyarsky	390	4	6	4	86
		77	Yermakovsky, Krasnoyarsky	389	4	6	18	72
		78	Kansky, Krasnoyarsky	493	5	12	31	52
	Zabaikalie	54	Zaudinsky, Buryatia	1054	2	7	49	42
		56	Mogochinsky, Chitinskaya	731	0	2	16	82
		80	Nerchinsky, Chitinskaya	260	0	0	9	91
		81	Chitinsky, Chitinskaya	559	0	0	2	98
		82	Barguzinsky, Buryatia	392	2	8	0	90
	Far East	59	Svobodnensky, Amurskaya	1091	0	2	18	80
		61	Ayansky, Khabarovsky	1210	0	1	5	94
kulundensis	Siberia	40	Rakitovsky, Altai	944	52	13	24	11
		41	Chemal'sky, Altai	831	49	24	3	9
		48	Balgazynsky, Tyva	934	7	9	19	65
	Zabaikalie	55	Kyakhtinsky, Buryatia	1181	1	4	28	67
	Kazakhstan	62	Dolonsky, Semipalatinskaya	269	62	19	0	19

Discussion

In assessing the resistance of 84 Scots pine climatypes to fungal diseases it was discovered that genetic heterogeneity of the species is influenced by ecological-climatic factors of the places of origin. Differences in resistance to pathogens appear in the same Scots pine climatypes grown in the provenance trials at different ecological locations. Pine trees growing on poor dry soils (bear berry pine forest type, sandy soil) are subject to needle cast, snow blight and Cenangium dieback. However, on the more humid and rich soils (dark-grey forest soil, rich in herbs pine forest type) the rusts are found.

It is known that phacidiosis (*Phacidium infestans*) occurs in natural pine forests beginning from the northern timberline. In the northern taiga subzone there are favorable conditions for the development and spread of pathogens (Krutov, 1989). Their negative impact strengthens towards the higher latitudes as the soil-climatic regime worsens, the winter period becomes much longer and snow cover becomes more stable. High resistance of northern Scots pine climatypes (subspecies northern Lapponian and Siberian from southern taiga subzone) to fungal diseases was observed in the provenance trial in the Priangarie region. Therefore we can assume that resistance to the pathogens of these diseases was formed and developed over time in pine posterities of northern populations. Resistance to the pathogens has not formed in pine climatypes from the western, central and southern regions, the place of origin, subspecies Kulunda pine and Scots forest pine. Therefore in the test area (under Priangarie region conditions) they are more vulnerable to pathogens. The disturbance of linear growth was observed in pine climatypes not tolerant to snow blight. It was connected to more than 50% needle loss, with drying up of a terminal bud of the central shoot and sucker shoots and with the replacement of a central shoot due to a living shoot of a lower whorl. The plant develops a bushy form in this situation. This type of a stem form is observed in the bear berry pine forest type (sandy soil) in climatypes from steppe and forest steppe regions.

The literature on the relationship of bladdery rust to forest site conditions is fragmentary and contradictory. According to Pyldmaya (1967) a mass fungus outbreak in young pine tree stands is seen only under unfavorable growing regimes, mainly, in lichen pine forest. According to other authors (Shevchenko, 1978) – the loss from this pathogen is found in pine stands with a better (richer) growing regime. This disease was seen in this experiment only in the more humid and richer forest types (rich in herbs pine forest type, dark-grey forest soil). As the trees aged the number of damaged trees, mainly from southern regions, increased.

The results of the provenance trial confirm the mosaic character of pathogen foci in the Scots pine area. Iroshnikov (2001) has obtained similar results in his experiments in the central (Krasnoyarsk forest steppe) and southern (Uzhur forest steppe and West Sayan foothills) regions of Siberia. Resistance of Scots pine to pathogens in the provenance trial depended simultaneously on ecological conditions of the growing site and genetic peculiarities of climatypes.

Pine tree resistance to fungal diseases influences the survival of the plants. This characteristic is one of the most important on which to base the suitability of using this or that climatype in a forestry project in a specific region. Therefore, in selecting climatypes, from the perspective of stem productivity, it is necessary to take into account their resistance to pathogens in order to solve problems concerning transporting seeds from other regions, especially from the south to the Priangarie area.

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