Five-Needle Pines in Russia: Introduction and Breeding

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Abstract—*Pinus sibirica* Du Tour, *P. pumila* (Pall.) Regel and *P. koraiensis* Sieb. *et* Zucc. are primarily located in Russia and occupy about 36.69, 38.30 and 2.87 million ha in the Asian part of Russia, respectively. These species, together with *P. strobus* L., *P. peuce* Gris., *P. cembra* L. and *P. monticola* Doug. ex D. Don, have been introduced in the European part of Russia. In all genetic tests *P. strobus* was found to have a high growth rate, but it was severely affected by white pine blister rust (*Cronartium ribicola* J.C. Fisch.). An intensive breeding program that would incorporate disease resistance genes from *P. peuce* is suggested to address this problem. *P. sibirica* is resistant to blister rust and has highly nutritious edible seeds and, thereby, is considered the most promising five-needle pine species for propagation in the European part of Russia. Its disease resistance and high intrapopulation variation in reproductive and growth traits provide a good basis for selecting new varieties. More than 2,500 plus trees have been selected throughout the entire *P. sibirica* area, and 6,100 ha of genetic reserves have been established. Growth traits of 12 to 32 year old plantations were studied on six common garden test sites in Siberia and on three sites in the European part of Russia. Seed sources that exhibited optimum growth were from the Altai and Sayan Mountains in southern Siberia and the southern taiga in western Siberia and are considered to contain the most valuable gene pool. Progeny from northern and sub-alpine populations had growth rates 20-40 percent lower than average, and progeny from transitional sub-zones and elevations had intermediate growth rates. There was no significant east-to-west difference in the growth rate. The similarity in growth traits corresponds well with the relatively low interpopulation differentiation demonstrated by isozyme data. The existing network of common garden tests of *P. sibirica* is insufficient for complete characterization of the gene pool and revision of existing seed zones. Certain adjustments, such as merging of some seed zones, can be suggested.

Key words: *Pinus*, *P. sibirica*, *P. koraiensis*, *P. pumila*, *P. strobus* five-needle pines, stone pines, introduction, breeding, Russia

Background

Three species of five-needle pines (*Pinus* L. subsection *Cembrae* Loudon) are naturally distributed in Russia: *Pinus sibirica* Du Tour, *P. koraiensis* Sieb. *et* Zucc. and *P. pumila* (Pall.) Regel. Each species has distinctive morphological, genetic, and, sometimes, biological traits and are adapted to specific ecological niches. *P. sibirica* naturally occurs in areas with a humid continental climate: northeastern European Russia, the Urals Mountains, Western Siberia taiga, and the northern macroslopes of mountains in southern Siberia and Transbaikalia. In these forests *P. sibirica* occupies a total area of 36.69 million ha. Forests containing *P. koraiensis* occupy a much smaller area (2.87 million ha) and occur in a monsoon climate, predominantly in the Primorskii territory and the southern part of the Chabarovskii territory. Thickets formed by *P. pumila* occupy a total area of 38.3 million ha and are located in the cold climate zones of eastern Siberia and the Far East. This species is usually found in localities characterized by a high level of snow cover.

Total stem volumes for *P. sibirica* and *P. koraiensis* are estimated as 7.4 billion m^3. Total stem volume of *P. pumila* is estimated at 1.1 billion m^3. Specific traits of these Russian five-needle pines, site descriptions, and relationships with other forest tree species have been reviewed in numerous publications (Tikhomirov 1949; Iroshnikov 1974; Pravdin and Iroshnikov 1982; Krilov and others 1983; Semechkin and others 1985; Kolesnikov 1954, 1966).

Under optimal site conditions, the high productivity of *P. sibirica* and *P. koraiensis* stands resulted in clearcutting of many large and valuable stone pine forests between the 1930s and the 1980s. Forests in the Altai, Western Sayan, and Sikhote-Alin Mountains, southern taiga in Western Siberia, and lower Amur basin were subjected to intensive exploitation. The cutting of these forests caused widespread changes in species composition, soil erosion, and declines in harvests of stone pine seeds (= nuts) and commercial fur hunting. Due to public efforts, stone pine forests were recognized for their exceptional environmental values and have been protected in Russia since 1989. Clearcutting was prohibited, and management of these forests has since been oriented to provide multiple values. Intensive reforestation efforts for these species have occurred including introduction in regions outside the respective natural ranges.

Early efforts in the breeding and introduction of native and exotic *Pinus* section *Strobus* species and other economically valuable conifers in the former Soviet Union occurred in the 1920s through 1950s (Kern 1934; Georgievski 1931, 1941; Nesterov 1935; Pogrebnjak 1938; Eitingen 1938, 1946; Tikhomirov 1949; Grozdov 1952; Girgidov 1955). Specific studies evaluated the acclimatization of different species in

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different environments (Sukachev 1922; Maleev 1933; Gurski 1957). Throughout the 1960s through 1980s, several important studies evaluated the introduction of coniferous species in botanical gardens, arboreta, experimental forests, and private estates during second half of 1800s (Shin 1961; Vekhov and Vekhov 1962; Timofeev 1965; Maurin 1970; Shkutko 1970; Mashkin 1971; Nekrasov 1980; Redko and Fedorov 1982; Ignatenko 1988; Logginov 1988; Plotnikova 1988; Lapin 1971). Unfortunately, these materials were often of unknown geographic origin, which limited the value of the studies' conclusions.

In the 1960s and 1970s, broad-scale experimental studies on the introduction and breeding of prospective conifer species were undertaken by the Institute of Forestry in the Siberian Branch of the Russian Academy of Sciences, All-Union Research Association "Soyuzlesselektsia," and Moscow State Forest University. These studies were designed to: (1) review results from past plantings and the current state of introductions of section *Strobus*, subsection *Strobi* pines to Russia; and (2) evaluate introduction and breeding experiments on *P. sibirica* conducted in different regions of Russia.

Introduction of Subsection *Strobi* Species

Four of the 17 pine species classified in subsection *Strobi*, *P. flexilis* James, *P. monticola* Douglas ex D. Don, *P. peuce* Grisebach and *P. strobus* L., have been introduced, over time, into arboreta and botanical gardens in European Russia. Among these species, *P. flexilis* and *P. monticola* were found to be unfit for planting in Russia and are not widely distributed. Since the early 19th century, most introduction efforts were of *P. strobus*, initially as ornamental tree and later as a forest tree that could rapidly produce high quality wood. Between 1860 and 1890, *P. strobus* was planted in the Baranovichi forest management unit of Byelorussia (Shkutko 1970), Forest Experimental Station of Petrovsko-Razumovski Academy of Agroforestry in Moscow region (Nesterov 1935; Eitingen 1938, 1946), and in Shatilov's estate (now the Mokhovskoi forest management unit of Orlovskaia region) (Pankov and others 2000; Kapper 1954). *P. strobus* was widely planted in Byelorussia, Latvia, Lithuania, Ukraine and several regions of Russia in the late 1800s and early 1900s (Grozdov 1952; Girgidov 1955; Shin 1961; Sevalnev 1966; Fedoruk 1969, 1980; Maurin 1970; Shkutko 1970; Redko and Fedorov 1982; Usachev 1983; Sirotkin and Gvozdev 1987; Logginov 1988; Kapper 1954). Later in the 20th century, the species was evaluated in Kazakhstan (Rubanik 1974), the Far East (Samoilova 1972), Georgia, the northern Caucasus Mountains (Holjavko 1981), and Estonia (Kasesalu 2000).

Recommendations for the introduction of *P. strobus* have been adjusted in recent years, as new information on productivity and disease resistance was accumulated for different vegetation zones of the former USSR. Initially, it was recommended that the species be planted in forests, steppe-forests, and the northern part of steppe zones eastwards up to the Yenissey River. These recommendations were altered to advise planting of *P. strobus* in the following regions: northwestern Ukraine, southern Moscow region, Kurskaia, Voronezhskaia, Orlovskaia, Belgorodskaia, Lipetskaia, Tambovskaia, western Saratovskaia region, and the Republic of Moldova. It was specified that *P. strobus* should be planted only in areas where the species would be higher in growth and value than *P. sylvestris* L.

It is noteworthy that Byelorussia, Latvia, Lithuania, Estonia and the northwestern regions of Russia were not designated for planting *P. strobus*. These regions have a relatively wetter climate where extensive blister rust (*Cronartium ribicola* J.C. Fisch) infection has been observed in both pure and mixed stands of *P. strobus* at different ages (Nesterov 1935; Eitingen 1946; Girgidov 1955; Maurin 1970; Shkutko 1970; Grozdova 1975; Potapova 1984; Kasesalu 2000). However, there are environments in these regions where *P. strobus* can be successfully grown. In Byelorussia, stands with different levels of tolerance to this pathogen have been noted (Shkutko 1970; Fedoruk 1980; Sirotkin and Gvozdev 1987). In the central Chernozem regions of Russia (Kurskaia, Voronezhskaia, Orlovskaia, Belgorodskaia, Lipetskaia, Tambovskaia), blister rust causes only minor damage to *P. strobus* (Shin 1961; Pismenni 1967; Kapper 1954). *P. strobus* plantings in the Ukrainian steppe zone are rarely attacked by blister rust (Logginov 1988). Pismenni (1967) concluded that the threat of *C. ribicola* to *P. strobus* plantations is largely overestimated, based on observations of 30 plantings established throughout European part of the former USSR. Despite the wide distribution of alternate hosts – black currant (*Ribes nigrum* L.) and gooseberry (*Grossularia* Mill.) – in this area, Pismenni concluded that there was a higher degree of damage associated with soil pH, relative air humidity (at 1 p.m.), mean air temperature, and number of days with cloudy weather in August in the regions of growing than with proximity of alternate hosts (table 1). Additionally, Pismenni found that stands with faster growing trees and a higher productivity class were more susceptible to the pathogen. There are some problems, however, with Pismenni's (1967) conclusions. Pismenni was not aware that diseased trees had been removed in sanitation cuttings and that there were well-known cases of extensive blister rust infections (especially on thin sandy soils) and even mortality in some of the plantations (Nesterov 1935; Grozdov 1952; Kapper 1954).

Valuable information on the intensity and dynamics of *P. strobus* mortality due to blister rust has been obtained from long-term observations (1880 to 1920) on *P. sylvestris* L. plantations established at the Forest Experimental Station in the vicinity of Moscow (Nesterov 1935, Eitingen 1946). These studies revealed extensive damage of Scots pine in several regions of Russia (Rudzski 1874, Sobichevski 1875). Long-term (130 plus years) investigations of the dynamics of Scots pine populations, in different parts of the natural range, showed populations with a high incidence of *Peridermium pini* (Pers.) Lev., and *Cronartium flaccidum* (Alb. *et* Schw.) Wint. had periodic epidemics caused by these pathogens in association with solar activity. The studies also revealed different types of interactions between the pathogen and trees, the influence of growth conditions on the metabolism of each organism, and respective levels of tree resistance and pathogen virulence. These studies suggested a similar mode of interaction between the host-pathogen pair of *P. strobus* and *C. ribicola*. Definitive conclusions, however, can not be made as *P. strobus* – *C. ribicola* interac-

Table 1—Damage of *P. strobus* stands by white pine blister rust *Cronartium ribicola* (Cr.r%) in regions differing by air humidity (W, %), mean air temperature (T, °C) and percentage of cloudy days (V,%) in August (Pismenni 1967)

Location of plantations: republic, region (forest management unit)	Age, years	Cr.r, %	W,%	T °C	V,%
Lithuania (Valkinskii, Smalininskii)	48; 45	14; 24	68	15	55
Byelorussia (Bobruiskii, Uzdenskii, Prilukskaia Dacha)	50; 56; 48	14; 12; 8	65	16	55
Ukraine, Sumskaia (Trostianetskii)	69; 52; 28	6; 4; 1	55	16.4	40
Russia, Orlovskaia (Mokhovskoi)	10; 28; 80	0; 6; 9	54	17	39
«-», Lipetskaia (LOSS, Leninskii)	28; 28	3.2; 1	54; 52	17.2	39
«-», Kurskaia (Rylskii)	16; 54; 54	0; 1; 1.5	52	17.2	39
«-», Penzenskaia (Yursovskii)	67	0,5	51	17.6	38
«-», Voronezhskaia (Vorontsovskii, Savalskii)	30; 32	0	50	18; 18.2	38
Moldova (Kalarashskii)	24	0	49	19	30

tions have been viewed for only a relatively short time in Russia, and there is a lack of comparative studies of homogenous progeny over different sites. In addition, Minkevich's (1986) observations on the lack of correlation between solar activity and *C. ribicola* outbreaks in Europe (r=0.09±0.18) over a 31-year period suggests a different interaction between *P. strobus* – *C. ribicola* than *P. sylvestris* and its pathogens.

The low resistance of *P. strobus* plantations to *C. ribicola* in different regions of the former USSR stimulated selection of individuals resistant to the pathogen and the introduction of *P. peuce* Grisebach, as a species highly tolerant to blister rust (Eitingen 1946; Grozdov 1952; Maurin 1970; Shkutko 1970). However, the limited availability of seeds of this Balkan species has prevented widespread field testing.

Tables 2 and 3 present growth data of different subsection *Strobi* species in plantations throughout the country. Plantations older than 20 to 30 years are reviewed; that is, those that have reached the "critical age when fitness of exotics at particular conditions is finally elucidating" (Maleev 1933, p. 108).

Toward the end of the 20th century, the total area occupied by *P. strobus* plantations reached 259 ha (Beloborodov and others 1992). Some stands were 60 to 120 years old, highly

Table 2—Growth indices of some five-needle pine species in the points of their introduction in Russia.

Region	Age year	Height, m	Diameter, cm	Source
		Pinus peuce		
Moscow. LOD MSHA	53	19	28	Eitingen, 1946
Moscow. Ivanteevka	33	9.8	13	Grozdova, 1975
Lipetsk. LOSS	31	11	15	Kuzmin, 1969
Orjol. Mokhovoe	70-80	22-24	40-46	Vekhov, Vekhov, 1962
Orjol. Shestakovo	75-80	26	50	Mashkin, 1971
		P. flexilis		
Lipetsk. LOSS	44[a]	14.2	31	Vekhov, Vekhov, 1962; Kuzmin, 1969
		P. monticola		
Lipetsk. LOSS	40[a]	11.4	26.8	Kuzmin, 1969
		P. koraiensis		
Altai. G.-Altaisk	32	6-10	11-15	Luchnik, 1970
Lipetsk. LOSS	40	9.4	20.2	Kuzmin, 1969
Mari. Ioshkar Ola	30	7-8	10-12	Alimbek, 1991
Moskow. Ivanteevka	35-38	6-8	6-9.5	Yablokov, Dokuchaeva, 1976
		P. cembra		
Lipetsk. LOSS	30	5.4	8	Vekhov, Vekhov, 1962
Moscow. Chlebnikovo	80	16.6	25.5	Ignatenko, 1988
Smolensk. Dugino	35	11	6	Grozdov, 1952
		P. pumila		
Altai. G.-Altajsk	30	3-4	2-6	Luchnik, 1970
Lipetsk. LOSS	36	3.3	-[b]	Kuzmin, 1969

[a]Very sensitive to fungal disease *Cronartium ribicola*
[b]Not measured

Table 3—Growth indices of *Pinus strobus* artificial stands on the territory of the former USSR.

Republic region	Age, year	Height m	Diameter cm	Number of trees per ha	Growing stock, m-3/ha	Source
The Ukraine						
Ivano-Frankovsk	70	30.5	37.6	700	960	Usachev, 1983
Trans-Carpathians	68	38.5	35.3	633	915	" - "
Right-bank forest steppe	60	27	28	-[a]	570	Logginov, 1988
Byelorussia						
Brest	54	25	42.2	429	650	Usachev, 1983
Minsk, Uzdenski	66[b]	25.5	32.5	550	386	Shkutko, 1970
Latvia						
Shkedovskoe	70[b]	23.9	39.7	-	348	Maurin, 1970
Skriverskaya	70[b]	24	36.8	-	360	" - "
Lithuania	60	25	40	-	-	Jankauskas, 1969
Estonia						
Agali arboretum	33[b]	16.6	22	900	282	Kasesalu, 2000
Kazakhstan						
Alma-Ata	23[b]	5	7	-	-	Rubanik, 1974
Russia						
Bryansk	84	22.3	23.1	940	468	Smirnova, 1997
Kaliningrad, Nagornoe	67	29.8	37.2	699	1199	Redko, Fedorov, 1982
Kaliningrad, Novo-Bobruyskoe	93	29.3	41.8	294	630	" - "
Kursk, Rilsky	55	22	18	-	250	Sevalnev, 1966
Leningrad, Viborgsky	45[b]	14.9	26	-	-	Girgidov, 1955
Lipetsk, LOSS	41	15.6	37	-	-	Kuzmin, 1969
Moskow, LOD MSHA	47[b]	16.5	20	-	-	Eitingen, 1946
" - "	45[b]	14	14	-	-	Timofeev, 1965
Moskow, Ivanteevka	40[b]	15.5	19.2	-	-	Grozdova, 1975
Orjol, Mokhovoe	125	31.4	35.2	103	383	Pankov et al., 2000
Penza	67	18.4	28	750	425	Usachev, 1983
Voronezh	40	18	28	-	-	Dorofeeva, Sinitsin, 1996

[a]Not measured
[b]Very sensitive to fungal disease *Cronartium ribicola*

productive, free from blister rust, and produced large seed yields with high quality (Kapper 1954; Maurin 1970). In order to conserve gene pools and create a permanent seed base of *P. strobus* in the USSR, a gene reserve (1.6 ha), plus stands (5 ha), 180 plus trees, 17 ha of permanent seed orchards, and 2.5 ha of clonal plantations were established in the early 1990s (Beloborodov and others 1992). In addition experiments on hybridization of this species with *P. wallichiana* A.B. Jackson and *P. ayacahuite* Ehrenberg *ex* Schlechtendahl, were initiated in the Ukraine, and 11 candidates for varieties were selected (Patlaj and others 1994). Currently, a spontaneous hybrid between *P. wallichiana* and *P. strobus* is under observation at the Sochi Arboretum, Institute of Mountain Forestry and Ecology in the northern Caucasus Mountains. The hybrid tree measured 23 m in height and 42 cm in diameter at the age of 39 years (Soltani 2001).

Genetic plantings and orchards of *P. strobus* have been established at different locations. Since the 1980s, the Research Institute of Forest Genetics and Breeding in Voronezh has been evaluating seed and clonal progenies of plus and phenotypically superior *P. strobus* trees selected in old plantations in three forests from the Kaliningrad region, Borskoie forests of Voronezh Natural State Reserve, Glushkovskoie forests of Lipetskaia region, and Mokhovskoie forests of Orlovskaia region (Beloborodov and others 1993, 1994). Testing of 29 families was initiated in 1984 in a 1.2 ha area within the Homutovskoie forest, and 96 families were established in 3.8 ha planting at Mezen Pedagogical College in Orlovskaia region in 1986 and 1987. An additional 33 families are being evaluated in a 1.2 ha planting that was established in 1989 in the Davydovskoie forest (Voronezh area). An archive (0.7 ha) of 41 clones was established in the Gremyachenskoie forest within the Voronezhskaia region, and a clonal seed orchard consisting of 25 plus trees (1.4 ha) has been established in Zagon forest (Smolenskaia region).

The 10 year-old results of these progeny testing experiments have shown superior growth of eight families from the Mokhovskoie and Glushkovskoye forests, while progenies from Kaliningradskaia region and Voronezh State Reserve show significant variability in growth rate. Only 25 percent of the tested families have shown resistance to white pine blister rust (Beloborodov and others 1993, 1994). Further studies of these plantations and clonal archives indicate that the stands become more susceptible to blister rust with advancing age. At age 16, only 7.7 percent of families and 36 percent of clones were free from blister rust. In some families, all trees are infected, and up to 67 percent of the ramets were susceptible in the clonal plantings (Shirnina and Beloborodov 1999).

A blister rust resistance study on subsection *Strobi* species was conducted by Bsaibes (2000) in northwest Russia (St. Petersburg and Leningradskaia region) and in Central-Chernozem regions. This study confirmed the high resistance of *P. peuce* to *C. ribicola* and the extremely high susceptibility of *P. monticola* and *P. strobus* to the pathogen. To ensure resistance of *P.* strobus, Arefiev and Bsaibes (2000) recommended combining selection of resistant provenances and progenies with site selection and silvicultural practices to form plantations with a genetic composition and environmental conditions not favorable for the pathogen. To some extent, these plantations represent a synthesis of earlier recommendations (Maleev 1933; Nesterov 1935) but do not assume blister rust resistance through interspecific hybridization, which was shown to be effective in the case of *P. strobus* and *P. peuce* in Romania (Blada 1994, 2000a,b), or inoculation with pathogen spores at early stages of pine ontogenesis that became a common practice in North America (McDonald and Hoff 2001).

Strategies for establishment of future *P. strobus* plantations will benefit from knowledge of the modes and mechanisms for coadaptation of *P. strobus* and *C. ribicola* (Millar and Kinloch 1991). Understanding host-blister rust interactions in spatially and temporarily heterogeneous environments will provide a significant contribution to the theory and practice of species introduction, as well as to forecasting and development of preventive measures for decreasing the negative effects of pathogen epidemics.

Introduction of Stone Pines, Subsection *Cembrae* Loudon

Stone pines with all uncertainty about their phylogeny and taxonomy have always been attractive objects for botanists and foresters. Concern about protection of *P. sibirica* stands against fire and unwarranted clear-cutting is reflected in early publications, such as before the 19th century, which also discussed their diversity and biological, and aesthetical resources (Pallas 1786; Dmitriev 1818). In the 19th century, data on testing of stone pines in botanical gardens, arboreta, and various experiment stations (Lisinskoie forest near St. Petersburg and the Petrovsko-Pazumoskaia Forest Station in Moscow) stimulated a broader introduction of Siberian stone pine in parks and orchards in European Russia. These plantings were studied to evaluate species variability and ecology (Gomilevski 1909). At the same time, there was a shift from seed collections in natural stands in remote taiga regions to seed production and collection in seed orchards formed from progenies of highly productive trees of foothill (low mountain) populations in optimal growth conditions (Barishentsev 1917).

Numerous publications and documents have been focused on broad-scale popularization of seed production in seed orchards (Georgievski 1932; Vekhov and Vekhov 1962; Yablokov 1962; Nekrasov and Tvelenev 1970; Shkutko 1970; Potapova and Potapova 1984; Ignatenko 1988; Usmanov and Korolkova 1997; Drozdov and Drozdov 2002; Titov 1999; Iroshnikov and Titov 2000). A number of methods have been developed for seed and vegetative reproduction of stone pines.

The limited number and area occupied by old plantations of *P. sibirica* in European Russia, as well as the unexplained mortality of 55 to 68 year-old stands in Lisino and Petrovsko-Razumovskaya Experiment Station has hindered planting of the species outside of its native range. Establishment of *P. sibirica* plantings also would be hindered by competitive ability in sites outside of the native range. Comparison of growth between 22 and 32 year-old stone pines with local forest tree species in common garden tests in the Leningradskaia region (forest-steppe site), Moscow region (subtaiga site), and Yaroslavskaia region (foothill site) has shown inferior growth of *P. sibirica* by 20 to 40 percent (Iroshnikov 2000).

The results discussed above as well as data from subsequent studies (summarized in tables 4 and 5) show that there is substantial interspecific variation in *P. sibirica.* The tests show that the best growing seed sources are from low and middle mountain belts in the south Siberia mountain ridges and the sub-taiga and southern taiga zones in western Siberia. Progenies from northern and subalpine regions had growth rates 20 to 30 percent lower. Meridian (west-east) differences in origin within corresponding zonal and altitudinal complexes of stone pine forests had little effect on growth of progenies.

Common garden and test plantations of *P. sibirica* have been established in different vegetation zones, as well as a study of variation in natural populations of *P. sibirica* (Iroshnikov 1974). These tests confirmed the high variability of the species and also revealed unique morphological tree forms and variation in reproductive processes. Significant variation was detected in needle size, shape, and position on shoots, duration of juvenile phase, long-term dynamics of macrostrobili formation, macrostrobili maturation dates, and in premature ripening of cones within the first year after "flowering" with formation of 40 to 60 percent of unsound seeds.

Investigations on natural populations of *P. sibirica* have been limited to Altai and Sayan Mountains and do not allow conclusions about the distribution of blister rust across the species range. Lebkova (1964, 1967) found a high frequency of *Cronartium* species, including *C. ribicola* in a 10 to 15 year-old stone pine understory in the subalpine and middle mountain zone in the western Sayan Mountains and the northeastern Altai Mountains. Tovkach (1968) also reported severe damage to the *P. sibirica* understory by *C. ribicola* (up to 36 percent of trees) in the eastern Sayan Mountains (Nizhneudinskii forest management unit of Irkutskaia region). Ulcerous cankers putatively caused by *Biatoridinia pinastri* Colov. *et* Stzedr. were also detected in the *P. sibirica* understory in the Shestakovskii and Kyrenskii forest management units of the Irkutskaia region (Osipova 1968).

The only *P. sibirica* common garden study damaged by *C. ribicola* was in the Dmitrovskii forest management unit in the the Moscow region (table 5). Aeciospores were detected in 1993 and 2001 on seedlings of 17 of the 24 families. Approximately 2 to 11 percent of the trees were infected. After 40 years of observation, *C. ribicola* damage was rarely detected in Siberian plantations or the seed orchards and tests planted at the Yemelyanovskii, Ermakovskii and Uzhurskii forest management units of the Krasnoyarskii territory.

The introduction of *P. cembra* and *P. sibirica* occurred in the 19th century in botanical gardens in the Ukraine, Latvia,

Table 4—Growth indices of 37-year-old descendants of Siberian pine of various origins in Krasnoyarsk forest-steppe (Emelyanovsky Forest of Krasnoyarskii Territoty). (Iroshnikov A.I.).

Origin of seeds			Height		Diameter
Region	Forest management unit	Altitude above sea level, m, zone	cm	% of control	cm
E. Kazakhstan	Leninogorsky	1200-1500	731±37	83	8.3±0.9
Altai	G.-Altajsky	1200-1500	712±55	81	8.7±0.8
Kemerovo	Kuzedeevsky	300-700	930±27	106	11.8±0.8
	Myskovsky	1000-1300	856±40	98	9.9±0.9
	Tisuljsky	700-1000	897±17	102	10.6±0.4
	Mariinsky	subtaiga	876±24	100	10.0±0.6
	Yurginsky	subtaiga	875±19	100	10.3±0.6
Khakasia	Tashtypsky	900-1000	931±14	106	10.9±0.4
	Birikchuljsky	1000-1300	885±17	101	11.9±0.6
	Balyksinsky	900-1000	877±38	100	9.4±0.6
	Khakassky	900-1000	900±14	103	11.4±0.4
	Oktyabrsky	1100-1300	822±26	94	12.6±1.1
	Sonsky	1100-1400	891±23	102	12.6±1.2
Krasnoyarsk	Ermakovsky	400-500	877±57	100	13.1±1.3
	" - "	1500-1600	594±53	68	7.8±1.3
Irkutsk	Cheremkhovsky	1200-1300	893±24	102	10.8±0.7
	Ikejsky	900-1000	932±33	106	13.7±0.8
	Slyudyansky	600-900	930±29	106	11.8±0.8
	Oljkhonsky	1000-1300	768±22	88	10.3±0.6
Buryatia	Zakamensky	1100-1300	800±19	91	12.5±0.6
	Dzhidinsky	1300-1400	809±21	92	13.4±0.9
Chita	Kr.-Chikojsky	900-1100	807±40	92	11.4±1.1
	Khiloksky	900-1100	888±20	101	10.9±0.4

Table 5—Indices of growth and damage with *Cronartium ribicola* of Siberian and Korean pine geographic cultures in Dimitrovsky Forest in Moscow Region (Iroshnikov and Tvelenev 2002).

Origin of seeds				Height[a]			
Region	Forest management unit	Latitude/longitude °N	°E	cm	% of control	Diameter,[b] mm	Stem rust[b], %
Siberian pine							
Komi	Troitsko-Pechersky	63	57	522±16	71	99±4	8.9
Sverdlovsk	Novo-Lyalinsky	59	60	533±18	68	110±5	0.0
	N.-Tagiljsky	58	60	572±17	73	125±4	0.0
Tomsk	Tymsky	60	80	651±18	84	123±5	2.4
	Chainsky	58	83	671±18	86	118±4	0.0
	Shegarsky	57	84	644±22	83	119±7	3.2
	Zyryansky	57	86	705±18	90	141±5	2.4
Tver	Kalininsky	57	36	605±16	78	118±5	11.1
		Elevation above Sea Level, m					
Altai	Baygolsky	1300-1800		655±17	84	124±7	2.3
	Kyga	430		779±24	100	146±6	0.0
	" - "	1250		730±20	94	150±6	2.1
	" - "	1500		635±16	82	129±5	2.4
Krasnoyarsk	Shushensky	550		745±26	96	146±8	0.0
	" - "	800		816±18	105	170±4	2.4
	" - "	1300		621±16	80	113±5	0.0
Irkutsk	Slyudyansky	1000		722±13	93	160±3	2.0
Buryatia	Dzhidinsky	1000		612±19	79	115±5	0.0
	Bichursky	1000		678±16	87	146±4	5.1
Korean pine		°N	°E				
Khabarovsk	Bikinsky	47	134	804±23	103	159±8	0.0

[a]At 32-year age (2001)
[b]At 30-year age (1999)

Lithuania, and Central-Chernozem regions of Russia (table 2). Due to lack of information about geographic origin, combined data on the state of these stands has been often presented in literature (Maurin 1970; Shkutko 1970; Fedoruk 1980). Plantations established in Khlebnikovskii Park near Moscow in 19th century (described by Ignatenko as *P. sibirica*), evidently originated from seeds obtained from the Balkans, as the planting also contains several *Abies alba* Mill. trees and three cone-bearing *Pinus peuce* individuals. Single trees were observed to be infected by *C. ribicola*, although natural stands of *P. cembra* in eastern Carpathia have been reported to be highly resistant to pathogens up to age 400 to 500 years (Smagljuk 1969).

Progenies of two *P. cembra* clones originating from the Carpathians were planted in the forest-steppe zone in Krasnoyarsk territory. Testing of 40-year-old clones grafted in 1963 onto *P. sylvestris* stocks showed the same growth characteristics as even-aged *P. sibirica* grafts originating from the western Sayan Mountains and bore few cones (10 to 50 per tree). Grafts of two other Carpathian clones (20 to 28 years-old) planted in the Dmitrovskii forest management unit (Moscow region) are characterized by exclusively high level of micro- and macrostrobili formation, up to 300 to 500 per each tree with a well-developed crown.

P. koraiensis was introduced in Russia after *P. sibirica* and *P. cembra*. In many regions of European Russia, Korean pine grows quickly during the first few decades (table 2) and has early formation of female cones (macrostrobili). For instance, in the Dmitrovskii forest management unit, 32 year-old plantations originating from seeds (brought from the Khabarovskii territory) grew as fast as the best *P. sibirica* stands (table 5). However, some trees were infected by *C. ribicola*. Azbukina (1974, 1984) describes white pine blister rust outbreaks across the whole Korean pine range. Additional studies are required to evaluate the different perspectives of broad-scale introduction of this species in Russia.

Dwarf Siberian Pine

P. pumila is relatively rare in botanical gardens and arboreta. Tikhomirov (1949) concludes that cultivation is possible, as there has been successful cultivation in the subalpine zone of in the Urals and at other locations. However, the species has been somewhat ignored due to a comparatively low economic value. Semechkin and Semechkina (1964) concluded that *P. pumila* is sensitive to mechanical squeezing when planted in loamy and loose soils, and sown seeds are often destroyed by rodents and nutcrackers (*Nucifraga caryocatactes* L.). In our (A. I. Iroshnikov) experiments in the western Sayan foothills, *P. pumila* did not survive longer than 15 years. Low survival of this species was also observed in Khakasia (Likhovid 1994) and in the Lipetsk region (Vekhov and Vekhov 1962). Additionally, grafts of *P. pumila* to *P. sylvestris* and to *P. sibirica* at the Dmitrovskii forest management unit did not survive past 20 to 25 years.

Susceptibility to blister rust is another factor that should be considered when planting *P. pumila.* Azbukina (1974, 1984) observed intense blister rust damage of *P. pumila* in the Far East. A subsequent study (Azbukina and others 1999) demonstrated that *Cronartium kamtschaticum* Joerst., which had been described as a pathogen of *P. pumila*, is really *C. ribicola*.

In conclusion, it appears that successful introduction of *P. pumila*, as well as other stone pines, is largely dependent of number and origin of individuals. Genetic differentiation within the range of pines of subsection Cembrae is reviewed in this volume (Politov and Krutovskii, this proceedings).

Conclusions

Effectiveness of using exotic woody plants for increasing forest biodiversity, productivity, quality and sustainability to biotic and abiotic factors depends on genotype, adaptive potential, and competitiveness. Approximately 200 years of studies in Russia suggest that the success of an introduced species can be evaluated only through long-term testing of progenies representing a broad spectrum of provenances and tested in different ecological conditions. Information from such studies increases when more genotypes are involved.

Pinus sibirica progeny tests established in diverse ecological conditions, inside and outside the species' natural range, have revealed intra- and interpopulation diversity, high breeding potential, and have helped to specify a geographic zone that is optimal for *P. sibirica* growth with maximal genetic variation. Long-term experiments with *P. sibirica* and *P. strobus* have allowed for development of current forest seed zone recommendations for *P. sibirica* (in 1982) and help direct the planting program for introduction of *P. strobus.*

To increase successful introduction of exotic five-needle pine species requires the development of international collaboration, coordination of corresponding studies within Russia, wider publication of results in peer-reviewed journals and monographs, maintenance of available and establishment of new experimental objects, and *in situ* and *ex situ* conservation of genetic resources.

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