Genetic Resources, Tree Improvement and Gene Conservation of Five-Needle Pines in East Asia

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Abstract—East Asia is very rich in the genetic resources of five-needle pines, including 11 species and three varieties. Of these taxa, *Pinus armandii* is the most widely distributed, ranging from Taiwan and Korea to central and western China. The natural range of *P. koraiensis* includes northwestern China, North and South Korea, Japan, inland Siberia and the Russian Far East. Because they are the most commercially important pines for wood and nut production, most genetic improvement research has been carried out with these two species. *Pinus fenzeliana* and *P. dabeshanensis* are used in plantations in some areas. However, along with the other species of five-needle pines, they are mainly of importance in studies of taxonomy and ecophytogeography. In addition to a review of genetic resources, this review paper also gives a brief overview of tree improvement and disease and insect pests of the five-needle pines in east Asia.

Key words: East Asian pines, five-needle pines, gene resources, tree improvement, tree pathogens, tree insects

Introduction

This paper attempts to give a brief review of the status of genetic resources, tree improvement and breeding programs and gene conservation of five-needle pines in east Asia, including China, Japan, the Democratic People's Republic of Korea (North Korea), Republic of Korea (South Korea), inland Siberia and the Russian Far East region.

The genus *Pinus* L. is generally divided into two subgenera, Subgenus *Strobus* (Haploxylon pines), and Subgenus *Pinus* (Diploxylon pines), commonly known as soft pines and hard pines respectively. Of the soft or five-needle pines native to east Asia, *P. armandii* Franch. and *P. koraiensis* Sieb. & Zucc. are as important for timber production as such hard pines as *P. massoniana* Lamb. and *P. yunnanensis* Franch. in China and *P. densiflora* Sieb.& Zucc. in Japan. The rest of the five-needle pines are of more limited economic importance due to their restricted gene resources. In this paper, most emphasis is placed on the research in the genetic resources, tree improvement and gene conservation of the two most important species, *P. armandii* and *P. koraiensis.* In fact, very little information other than that on taxonomy and ecology is available for other species.

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Genetic Resources

Of 24 species of *Pinus* in East Asia, 11 including three varieties of *P. armandii* are five-needle pines (Wu 1956; Mirov 1967; AASE 1978; Zheng 1983, Price and others 1998). They are listed here in conformity with the system standardized for all papers presented at this conference (Price and others 1998) and so listed in the conference program, which differs in a few cases from the taxonomic designations used in China. There is no universal agreement on the taxonomy of east Asian five-needle pines. In Chinese literature, for example, *kwangtungensis* is a separate species morphologically related to *P. wangii.* The east Asian list follows, with more detail in table 1:

P. armandii Franchet var. *armandii,* widely distributed and planted in China;

P. armandii Franch. var. *mastersiana* (Hayata) Hayata, in Taiwan of China;

P. armandii Franch. var. *amamiana* (Koidzumi) Hatusima, includes isolated populations in Japan;

P. dabeshanensis Cheng & Law, very restricted in a small area in central south China;

P. dalatensis de Ferré, central Vietnam;

P. fenzeliana Handel-Mazzetti, (including *P. kwangtungensis* Chun & Tsiang) southern China to northern Vietnam;

P. wallichiana Jackson (*P. griffithii* McClellan), Himalayan chains;

P. koraiensis Siebold & Zuccarini, China, Japan, Korea, Siberia and Russian Far East;

P. morrisonicola Hayata, central Taiwan;

P. parviflora Siebold & Zuccarini, native to Japan and exotic in China and Korea;

P. pumila (Pallas) Regel, China, Japan, Korea and Russian Far East;

P. sibirica Du Tour, northwestern China, Siberia and Russian Far East;

P. wangii Hu & Cheng, scattered and limited populations in southwestern China.

Table 1—Classification and phytogeography of five-needle pines in east Asia.

Species	Natural distribution	Characterization
Pinus armandii var. *armandii* Franch. (Armand pine, Huashan Mountain pine)	China in Shanxi, Henan, Shaanxi, Gansu, Sichuan, Hubei, Guizhou and Yunnan provinces and Tibet; elevation range 1000-3300 m.	Tree up to 35 m high and 1 m dbh. Widely planted for forestry and landscape. Flowers April- May; cones mature September-October of the following year; cone size 10-20 cm x 5-8 cm; seed 1.0-1.5 cm long,edible; 3 medial resin canals; wood density 0.43-0.48.
P. armandii var. *mastersiana* (Hayata) Hayata (Taiwan Armand pine)	Central Taiwan at 1800-2800 m elevation.	Tree up to 20 m high and 100 cm dbh; leaves 15 cm. Mature cones peduncled, ovoid, up to 10-20 cm long and 8 cm in diameter. Seeds ovoid, compressed, wingless, with a sharp edge all around, 8-12 mm long. Wood density 0.46.
P. armandii Franch. var. *amamiana* (Koidz.) Hatusima (Japanese Armand pine)	On two isolated islands, Tanegashima and Yakushima, Japan. Ecologically and genetically isolated populations, vulnerable.	Tree up to 25 m height, 1 m dbh; dark gray shoots; leaves 5-8 cm long; cones short stalked, oblong-ovoid, 5-8 cm long; seeds wingless, about 12 mm long.
P. dabeshanenesis Cheng & Law (Dabeshan Mountain white pine)	Anhui and Hubei provinces of China at elevations between 900 and 1400 m; range very restricted.	Tree over 20 m, dbh 50 cm. Wood similar to that of *P. armandii*, 2 external resin canals. Wood density 0.43.
P. dalatensis de Ferré Dalat or Vietnamese white pine	Very restricted range in evergreen subtropical forests of Vietnam at elevations of over 1500 m. Often in mixed stands, very sparsely distrubuted; species surtvival threatened.	Tree to 15-25 m, 60-100+ cm dbh, crown conical, somewhat open. Female cone has 20-30 scales, yellowish-brown maturing to dark gray. Cones mature October-December. No data on resin canals or wood density.
P. fenzeliana Hand.-Mzt. (Hainan white pine)	South China in Hainan, Guangxi, and Guizhou provinces; central Vietnam; elevation range 1000-1600 m.	Tree to 50 m in height, 2 m in dbh; leaves 10-28 cm long. Seed cones ovoid-ellipsoid, 6-9 cm long; seeds chestnut brown with a wing 2-4 mm long. No data on resin canals .Wood density 0.55-0.59.
P. koraiensis Sieb. & Zucc. (Korean pine)	Northeast China, also in Korea, Japan and Russian Far East, elevation range 150-1800 m. Dominant species in mixed stands with broadleaved trees, pure stands can be found.	Tree to to 50 m and over 1 m dbh; flowering in June; cones mature September-October in the following year, seed edible; 3 medial resin canals; wood density 0.38-0.46; major timber species in northeast forest region of China.
P. kwangtungensis Chun & Tsiang (South China white pine). In China considered a separate species; in this conference, a part of *P. fenzeliana* (Price *et al.* 1998).	China, geographically disjunct from *P. fenzeliana* proper; found in southern Hunan, northern Guangxi and Guangdong provinces, with outliers in Guizhou and Hainan provinces. Elevation range 700-1600 m. Forms pure stands or mixed stands with *Tsuga*, *Fagus, Quercus.*	Tree to 30 m high and 1.5 m dbh; flowers April-May, cones mature in October of the following year; seed 8-12 mm long. Planted trees grow fastest 10-30 years after planting, reaching 25 m in height and 45 cm dbh at about age 60; 2-3 resin canals; wood density 0.50.
P. morrisonicola Hayata (Taiwan white pine)	Central mountains in Taiwan, no pure stands; mixed with other conifers or hardwoods	Tree up to 30 m tall and 1.2 m in dbh.; 2 dorsal resin canals.
P. parviflora Sieb. & Zucc. (Japanese white pine)	Naturally distributed in Japan and introduced to China.	A tree up to 25 m tall and 1 m in dbh, 2 external resin canals. Ornamental tree, often grafted as bonsai
P. pumila (Pall.) Regel (Japanese stone pine)	Northeastern China with altitudes ranged 1 000-1 800m and extended in Russia, Japan and Korea; forms dense and low community on top of mountains and exposure sites.	Shrub or small tree 2-8 m, often multi-stemmed; 2 dorsal resin canals. Good for ground cover and ornamental
P. sibirica Du Tour (Siberian stone pine)	Northwestern Altai in Xinjiang and the Great Xingan Range in China and extended to Sibirica, ranged 66° 25'-46° 40'N in latitude and 49° 40'-127° 20'E in longitude, altitudinaly 1,600-2,350 m; dominated in the stands mixed with *Larix sibirica*	A tall tree, up to 35 m and over 1.8 m in dbh; 3 medial resin canals; flowering in May and cones mature in September-October in the following year. Wood density 0.45. Timber is as good as that of *P. koraiensis*, an important forest tree in Siberia, Russia.

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Table 1—(Con.)

Species	Natural distribution	Characterization
P. wallichiana Jacks. (Himalayan white pine)	Southern Tibet and northwestern Yunnan in China, Bhutan, Burma, Nepal, India, Pakistan and Afghanistan. at 1600-3300 m elevation.	Tree to 50+ m with straight trunk and short, down-curved branches. Branches longer in solitary trees, creating a dome-like crown. Leaves 15-20 cm, usually pendant but in some trees spreading. Cones 20-30 cm, bluish-green when young, maturing to light brown.
P. wangii Hu & Cheng (Yunnan white pine)	Restricted area in southeastern Yunnan Province in China altitude 1100-2 000 m. Occurs in or mixed stands with oaks on limestone slopes. Endangered status.	Tree to 20 m high and 60 cm dbh; 3 medial resin canals.

From an ecological standpoint, five-needle pines are, in contrast to hard pines, mostly adapted to cold or temperate and moist environments. There exists a latitudinal gradient and a trend of species replacement from north to south within their natural occurrences in East Asia (Wu 1956; Wu 1980; Kuan 1982; Zhao, G. 1991; Ma 1992). In the north, *P. sibirica*, *P. pumila* and *P. koraiensis* occur at relatively lower elevations; southward in the temperate and subtropical zones, they are replaced by *P. armandii;* still farther south, *P. fenzeliana* and *P. dalatensis* occur discontinuously at higher elevations in subtropical and tropical areas. *P. dabeshanensis* and *P. wangii* occur as relicts on difficult sites for tree growth and survival in central south and southwestern China respectively as restricted populations or scattered individuals.

From a geographical standpoint, all the five-needle pines in east Asia are discontinuously distributed. *P. sibirica* (Zhao, G. 1991) and *P. armandii* (Ma 1989,1992) are typical examples. *P. armandii* is extensively distributed on the mainland of China from temperate to subtropical regions, with its two varieties, *P. armandii* var. *mastersiana* extending to Taiwan Island and *P. armandii* var. *amamiana* appearing in Japan (Nakashima and Kanazashi 2000). The populations of *P. fenzeliana* and its form recognized in China as *P. kwangtungensis* Chun & Tsiang are also geographically isolated from each other. The ecological and geographic patterns have introduced great genetic variability into these five-needle pines, making some of them very difficult to classify taxonomically. For instance, *P. koraiensis* and *P. sibirica* were confused with each other in taxonomic status for long time (Zhao 1991).

Tree Breeding and Improvement

Tree improvement in East Asian countries is mainly focused on commercially important species. Five-needle pine research activities are mostly undertaken with *P. koraiensis* and *P. armandii,* although *P. fenzeliana* and *P. dabeshanensis* have been used locally in planting programs.

Pinus koraiensis

Pinus koraiensis is by far the most important species in conifer tree improvement programs in northeast China, North Korea and South Korea. Kim and others (1994a) estimated that more than 250,000 ha of plantations had been established with this species in South Korea by 1994. In North Korea 305,000 ha were established with this species for wood and nut production. For nut production, 250 clones were selected. It is estimated that the plantation area of Korean pine in North Korea is increasing at a rate of about 30,000 ha per year.

In China, tree improvement and breeding research programs were launched in the early 1980s with emphasis on provenance trials, plus tree selection and gene conservation. A provenance trial was established in 1986 with 12 seedlots collected from natural stands throughout the range and one seedlot from a plantation. Tenth-year results showed that there were significant differences in growth rates between provenances, and that the seedlots collected from areas around Changbaishan Mountain performed best (Zhang and Wang 2000).

Wang and others (2000a) reported tenth-year results of progeny tests established on three sites using open-pollinated seeds of 557 parents from natural stands. Significant differences were found in growth performance between individual families and between provenance zones, and there were also large genotype x environment (GxE) interactions. Based on the progeny testing, a genetically improved seed orchard was established by grafting (Wang and others 2000b). Observations indicated that the average interval between every two good seed crops was five years. Strobilus abortion rate reached 46.5 percent in the seed orchard, but cone yield could be increased by 20 percent through crown pruning and controlled pollination (Wang and others 1992).

Although seed orchard clones varied in fertility level, leading to an increased level of relatedness in the offspring, genetic diversity in seed orchard progenies was nevertheless only slightly depressed compared with that of the reference populations from which the plus trees were selected (Kang and Lindgren 1998).

Variation in effective number of clones in the seed orchards of *P. koraiensis* was examined. The mean number of clones averaged about 70 in each orchard, but the average effective number (N_c) was 43 (Kang and others 2001).

Pinus armandii

P. armandii is the most widely and discontinuously distributed of the five-needle pines in China, occurring in 12 provinces ranging in latitude from 23°30' to 36°30' N, in longitude from 85° 30' to 113° 00' E and in altitude from 1,000 to 3,500 m, which suggests that a large amount of geographically-related genetic variation may exist within the species.

Range-wide provenance trials of *P. armandii* were established on 9 experimental sites in 1980. The trials were coordinated by the Research Institute of Forestry of the Chinese Academy of Forestry, using seed collected from 30 provenances. Because the seedlings of southern seedlots were all killed by frost at northern experimental sites, successive trials were established on 12 sites in the following year using all northern seedlots. The provenance trial results indicated that not only did GxE interactions exist but also that the differences in morphological characteristics and growth rates among provenances were so significant that two provenance zones, southern and northern, could be clearly distinguished (Ma and others 1992a,b; Cooperative 1992). Moreover, Ma (1992) was of the opinion that these two population groups should be considered for recognition as two varieties, namely, *P. armandii* var. *armandii* and *P. armandii* var. *yunnanensis*. Ma noted that many plantations of *P. armandii* have failed, especially in central China in the 1960s and 1970s, due to the wrong provenances being used in afforestation programs. He cautioned that great attention must be paid in plantation forestry to provenance selection, and *P. armandii* should not be grown for commercial purposes north of 40°N and beyond its natural altitudinal limits in central subtropical China.

To establish clonal seed orchards by grafting, 850 superior trees were selected in the southern provenance zone, covering Yunnan, Sichuan and Guizhou provinces. Research in reproductive biology showed that *P. armandii* starts flowering at 5-7 years of age, but over 70 percent of female strobili abort (Wu 1992; Zhang and others 1992). Generally, seed yields of *P. armandii* are very low, averaging 15kg/ha for the 133 ha of seed orchards in the whole of China. In addition to much rain and wind during flowering in May, genetic variation in reproductive ability between clones has been recorded (Liao and others 1998).

Genetic Diversity and Gene Conservation

Genetic diversity has been studied in recent years using analysis of isoenzyme gene markers. Kim and Lee (1995) found that the overall mean proportion of polymorphic loci was 66.7 percent in *P. koraiensis* compared with 86.2 percent in *P. densiflora* , the most widely distributed native pine in South Korea. They also found that although many populations of *P. koraiensis* were small in size, distributed at high elevations and composed of closely related individuals, gene flow between these isolated populations still remained high in this species. To study genetic variation, eight populations of *P. koraiensis* were sampled within its range in South Korea. Research results suggested that seven of the eight populations should be included in gene conservation programs (Kim and others 1994b; Kim and Lee 1998).

Politov and others (1999) reported genetic evidence of natural hybridization and possible gene exchange in Siberia between *P. sibirica* and *P. pumila*.

In northeastern China, where the natural forest resources were over-exploited in the last several decades, the establishment of natural reserves with total area of 56,000 has protected the remaining forest of P. koraiensis ha. In addition, 88 natural stands totaling over 40,000 ha have been identified and conserved *in situ* as gene resources for sustainable forest management (Li 1997). However, due to the increasing number of plantations of *P. koraiensis* being established, necessitating the proper seed sources, more than 30 ha of seed stands in the natural forest were documented for seed supply on several locations, with about 1,000 individuals selected for *ex situ* gene conservation (Niu and others 1992).

In South Korea, three outstanding stands of *P. koraiensis* and one of *P. pumila*, with areas of 55 ha and 2 ha respectively, have been identified and reserved for *in situ* gene conservation. In the last 30 years, 91 ha of Korean pine seed orchards have been established, the seed orchards also serving as *ex situ* gene conservation (Lee 1997).

Diseases and Insect Pests

A survey of the literature indicates that little breeding for resistance to diseases and insect pests has been done on any species of five-needle pine in east Asia. However, major pathogen and insect pests attacking *P. koraiensis* and *P. armandii* have been investigated.

Histopathological research has shown that the stem rust disease of *P. koraiensis* is caused by *Cronartium ribicola* J.C. Fischer in Raben. (Xue and others 1995). Occurrence of *C. ribicola* attack on *P. koraiensis* depends on the coexistence of *Pedicularis* sp. (lousewort), the alternate host of the pathogen (Jia and others 2000).

A dieback fungus isolated from *P. koraiensis* was identified as *Cenangium abietis* (Pers.) Duby (*Cenangium ferruginosum* Fr.). When it was inoculated on five-year-old seedlings of *P. koraiensis*, 80 percent of the seedlings were infected with the same symptoms and signs as those of naturally infected trees (Lee and others 1998)

P. armandii in the Qinling Range and Dabashan Mountains have been attacked since 1956 by D*endroctonus armandii* Tsai & Li and also by 20 other species of beetles, causing mortality in many trees over 30 years old in the natural forest (Tang and Chen 1999). *Ophiostoma* sp. and L*eptographium* sp., which are fungi symbiotic with the insects, attack the host prior to the beetle invasion.

Chen and others (1999) studied the ecology of the insect pests in natural stands of *P. armandii* at middle elevations (1,600-2,000 m) in the Qinling Range. In this study, 19 species of beetles were listed as follows:

Dendroctonus armandii Tsai & Li
Xyloterus lineatum Olivier
Hylurgopus longipilis Reitter
Polygraphus sinensis Eggers
Pityogenes sp.
Ips acuminatus Gyllenhal
Ips sexdentatus Borner
Tomicus piniperda Linnaeus
Cryphalus lipingensis Tsai & Li
Cryphalus chinlingensis Tsai & Li
Cryphalus pseudochinlingensis Tsai & Li

Hylastes paralellus Chapuis
Hylastes techangenesis Tsai & Huang
Hylurgopus major Eggers
Polygraphus rudis Eggers
Polygraphus verrucifrons Tsai & Yin
Dryocoetes luteus Blandford
Dryocoetes uniseriatus Eggers
Dryocoetes autographus Ratzeburg

Of these listed species, the first 11 coexist, since they possess different spatial and temporal niches in the stand, enabling an equilibrium between living space and nutrient availability among these insects.

Cone damage in seed orchards of *P. koraiensis* caused by *Dioryctria mendacella* Staudinger and *Rhyacionia pinicolana* Doubleday was reported by Liao and others (1998).

Another type of injury to *P. koraiensis* is terminal shoot attack leading to forking of the main stem (Zhao and others 1999). *Pissodes nitidus* Roelofs and *Diorictria splendidella* H.S. are the main agents responsible for the damage.

Blister rust usually occurs in association with *Pineus armandicola* Zhang on *P. armandii,* necessitating control of both the pathogen and the insect (Li and others 2000). Other diseases found by Liao *et al* .(1998) in a study of seed orchards include *Pestalotia funereal* Desm*., Hypoderma desmazieri* Duby*, Coleosporium solidaginies* (Schw.) Thum*., Capnodium* sp. and *Lophodermium pinastri* (Schrad. *ex* Fr.)

Conclusions

P. koraiensis and *P. armandii* are important forest species for wood and nut production. Traditional breeding programs for advanced generations should be maintained and strengthened by using molecular genetic markers, especially for *P. armandii,* which has such a wide geographic range. No resistance breeding research is yet under way for any species of five-needle pine in east Asia.

Currently genetic structure and genetic diversity in these five-needle pine species in China is not well understood. Therefore priority in research programs should be given to studies of genetic variation, a critical prerequisite for long-term breeding and gene conservation of the two most important species. There is a trend, however, to use more Japanese larch, [*Larix kaempferi* (Lamb.) Carr.], to establish plantations in China, since Japanese larch grows much faster in early years than *P. armandii* growing under similar ecological conditions.

Biochemical and molecular genetic markers have proven to be a powerful tool in biosystematic and biogeographic studies of forest trees (Adams 1992; Strauss and others 1992). Molecular biology can also help with understanding of the scattered patterns of occurrence of the less-known five-needle pines, providing information on evolutionary history and intraspecific variation, fields of investigation not yet undertaken in China. Without this information, conservation strategy cannot be established on a sound scientific basis.

In China, the remaining genetic resources of *P. koraiensis* are mostly protected in nature reserves, whereas the outstanding seed stands of *P. armandii* identified in earlier provenance trials have not yet been integrated into forest management activities. Gene conservation is a crucial component of sustainable forest management (Eriksson and others 1993; Palmberg-Lerch 1999). Therefore, a strategy for gene conservation and utilization of five-needle pines should be developed and integrated into a regional action plan for the conservation of the forest genetic resources in east Asia, as recommended by the FAO and other concerned organizations (Palmberg-Lerch 2000; Sigaud and others 2000).

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