Growth performance of introduced Canadian eastern white pine (*Pinus strobus* L.) and jack pine (*Pinus banksiana* Lamb.) in Liaoning province, China

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Introduction

The Province of Liaoning in northeast China has a long history of tree species introduction. For example, *Gingo biloba* was introduced 1,200 years ago, *Platycladus orientalis* (L.) Franco 700 years ago, walnut (*Juglans regia* L.) 350 years ago, and chestnut (*Castanea* Mill.) in 1848. More recently introduced tree species included black locust (*Robinia pseudoacacia* L.) in 1907, which has since been planted over 800,000 ha, Japanese larch (*Larix kaempferi* [Lamb.] Carr.) in 1918 and has since been planted over 200,000 ha, and Mongolian pine (*Pinus sylvestris* var. *mongolica* Litv.) in 1955 for stopping desertification in the dryer western part of the Province (Li 1990, Pan and You 1994).

At the beginning of the 20th century, eastern white pine (*Pinus strobus* L.) and jack pine (*Pinus banksiana* Lamb.) were introduced to the Xiouyuuo Tree Arboretum (southeastern Liaoning province) along with pitch pine (*Pinus rigida* L.) and ponderosa pine (*Pinus ponderosa* Laws.) from Canada and Japanese black pine (*Pinus thunbergii* Parl.) from Japan. Although the seed source origin was not recorded, eastern white pine and jack pine adapted well to the local environment with evidenced by normal flowering, fruiting, and growth over the past 80 years. The rate of growth of these two species was superior to all other local tree species of the pine family in the Arboretum, especially Korean pine (*Pinus koraiensis* L.), the common reforestation species (Yu and Sun 1999). This experience seems to be in line with the successs of many North American forest tree species introduced into other parts of the world (Rogers and Ledig 1996).
A formal tree species introduction program focusing on seventeen North American species began in the 1980s with careful seed source documentation and experimental testing at 20 sites over six climatic zones in Liaoning Province (Dong et al. 2005, Wang et al. 2006). A detailed description of this introduction program was published by Wang et al. (2006) along with some preliminary growth results. White pine was tested at eight sites using a total of 58 families from 33 seed sources. Jack pine was tested at 19 sites using a total of 200 families from 22 seed sources. Not all families or seed sources were tested at each site. Preliminary results indicated good adaptation and growth of both species.

In this paper we update the growth performance of introduced eastern white pine and jack pine from Ontario, Canada, and discuss their future as promising species for large-scale planting in northeastern China.

**General Background of Liaoning Province**

Liaoning Province is situated in the southernmost part of the northeast region of China (Lat. 38°47' - 43°26'N; Long. 118°51' - 125°46'E) with a temperate to warm-temperate climate. Liaoning borders North Korea on the north, faces the Yellow Sea and Bo Hai with the Liaotung Peninsula in between on the south, Hebei province on the southwest, and Inner Mongolia on the northwest. The total area of the province is 146,000 km² with a width of 530 km north to south and a length of 574 km east to west. The province has an annual average temperature of 5.2-10.3°C, annual precipitation of 600-1,200 mm, and 128-183 frost-free days. The forest land is primarily fertile deep brown forest soils which provide superior growing
conditions. Experimental sites were located in different environmental conditions (Table 1). Seed sources from Canada ranged from 40° to 47°N and 62° to 83°W.

**Seed Source Selection**

Range-wide provenance tests in eastern North America indicate variability among eastern white pine seed sources and sources can be selected for use in certain environments (Demeritt and Kettlewood 1975). Jack pine has wide genetic variation and large effective breeding populations with environmental factors appearing to be the dominant selection force (Rudolph and Laidly 1990). Therefore, it is critical to test and select the most suitable matching seed sources for planting sites in Liaoning province. According to past reports on species introduction, selecting suitable matching seed sources can result in increases in volume by 20 to 40% (Wang 2001).

We found large differences among eastern white pine seed sources tested, with the slower seedlots growing at a rate of 40-80% of the best (Dong et al. 2005). At the Hwaze test site 15-year-old jack pine showed growth differences between suitable and less suitable seed sources of 100% in height and 178% in DBH demonstrating the importance of formal seed source trials for species introduction. Similar results have been obtained from other studies conducted by the Liaoning Academy of Forestry. The differences among seed sources in height, DBH and crown width growth in Liaoning were closely related to the latitude of the Canadian seed source. Growth performance in Liaoning decreased with increasing latitudes of the Canadian
seed source. An analysis of 20 years of data on growth performance indicated that the Canadian seed source from approximate latitude 46°N and longitude 77-78°W had the strongest adaptability and the most rapid growth and crown development. This coincides with the reported “center of variability” of jack pine (Rudolph and Yeatman 1982). Morgenstern (1996) recommended introducing a species from the center of its range or the area of greatest variability to find the most adaptable populations. It will be interesting to see whether the superior growth performance of this seed source will continue as the plantations mature.

There are many different ecological factors between the native growing environment and the planting sites in Liaoning such as heavy snowfall in the winter and higher relative humidity in the spring in the donor country as compared with the dry winter and low relative humidity in the spring in the recipient country. Some of these climatic differences required special cultural treatments for succulent young seedlings to over-winter safely in the recipient country. It was found the best treatment was to hold the stock for up to three years in the nursery to protect them from winter injury as compared to the normal practice of out-planting two-year-old seedlings. An important contribution to the introduction program’s success was adjustments made in nursery and planting practices allowing the new species to become established in their new environment and survive the critical early years.

Phenological Observations

To ensure future seed supply for afforestation, an introduced species has to be adapted to the new environment for normal phenological patterns. To this end, eastern white pine planted in eastern Liaoning exhibited a similar reproductive cycle to the local native species of Korean
pine and oily pine (*Pinus tabulaeformis* Carr.) with the exception that white pine’s flowering period which was 7-10 days later and seed maturity which was 40 days earlier. Generally, white pine vegetative buds swell in mid-April, needles flush-out in mid-May; flowers in late June; and cones mature in mid to late August the following year. Seeds disperse 20 days after they reach maturity. Needle-fall occurs around mid-October. Eastern white pine flowered after 16 years in Xungyue Tree Arboretum with flowering in mid- to late-May. In Chingyuan, white pine flowered in late-May and the male flowers developed one to several weeks earlier than the female flowers. The pollen cone buds were oblong, 8-10 mm long and often found on the lower crown and produce light brown pollen. The seed cone buds were 5-38 mm long born on the upper crown branch tips. Cones matured in mid-August in Xungyue and late August in Chingyuan. A single tree produced 7.5 to 10 kg of cones and it takes 30 kg of cones to yield 0.5 kg clean seeds. The weight of 1,000 seeds was 15.2 g which is comparable to the lower weight range of this species in its native habitats in Canada (Simpson and Daigle 1998).

In Liaoning, jack pine’s reproductive cycle is very similar to that of Mongolian pine. Generally the vegetative buds swelled in mid-April and flushed out in mid-May when monthly average temperatures were 10.5-10.8°C. When needle-flushing was completed in late June, seed buds appeared and pollination began 10 days later and was completed by the end of June when the monthly average temperature was 16.5-16.8°C. In Liaoning, jack pine began to bear male flowers after four years and female flowers after five years, although they were often infertile. Jack pine needle-fall occurred in mid- to late-October.
Most of the trees produced cones after six years but with few seeds. Large quantities of cones and fertile seeds were produced by most of the trees after seven years. Both male and female jack pine flowers appeared at the same time in late-May and pollination took place 10 days after. Following pollination the seed cone undergoes dormancy until the next spring when growth resumes. Jack pine cones are curved and mature in mid- to late-September. There was no seed found in the inside of the curved portion of the cones. The serotinous cones stayed on the tree until May to June of the third year when the scales opened and released the seeds. There are two types of mature jack pine cones: cones with scales that opened naturally and released seeds and cone with closed scales that remained on the tree until manually collected and processed in a kiln. Complete seed extraction from the collected serotinous cones was achieved by first scorching the cones at 300°C for 2-3 seconds and then leaving them to air drying for 15 days (Gu et al. 2003). It was found that over 75% of the jack pine cones harvested from planted trees in Kuandian in east Liaoning were of the serotinous type.

From the conservation perspective, gene flow through pollen and seed production from introduced species is a concern (Ellstrand and Elam 1993). We don’t know the pollination compatibility between the introduced and native species. The time lag in reproductive phenology between eastern white pine and local conifers, and the largely serotinous cones of jack pine as described above ought to be an effective barrier to gene flow from the two introduced species. However, long-term monitoring of such gene flow and its impact is important.
**Current Growth Performance of Eastern white pine and jack pine in Liaoning**

Introduced species are quite often tested against local species planted in the same experiment to allow comparison of the introduced species against a local benchmark to see if the introduction is providing better growth than what could be obtained from local adapted species (Morgenstern 1996). Testing was conducted using one of the following local species: Mongolian pine, oily pine, Japanese black pine, and Korean pine also known as Chinese red pine. The most common local species tested was Korean pine. In addition to a local benchmark, the length of the testing period and an indicator trait that effectively measures adaptability and productivity are equally important in species introduction testing. Testing the species for half the rotation age or longer is recommended to allow small differences in survival and adaptation to filter through (Morgenstern 1996, Morgenstern et al. 2006). In the case of jack pine and eastern white pine this would be a minimum of 30 to 40 years. Ying and Yanchuk (2006) emphasize that height growth is an effective indicator of both adaptability and productivity.

In this paper, we report the differences in height growth up to age 15 for white pine and jack pine growing in Liaoning Province and measured against the common local species planted in the same experimental blocks (Figures 1 and 2). We also compared height growth in Liaoning Province against height growth in its native habitat in North America for white (Figure 3) and jack pine (Figure 4). The purpose is to assess the potential of the two Canadian species in Liaoning, further to that of Dong et al. (2005) and Wang et al. (2006).

Eastern white pine and jack pine out-grew local species by 71% and 64% on average in total tree height by age 15 (Figures 1 and 2). These gains are less than those reported for *Casuarina*
*junghuhniana* introduced from Australia to Southern China but certainly an acceptable improvement (McKenney et al. 1993). Should the observed trends continue with time, the volume gain at harvesting age will be substantial. Higher wood volume is part of the goals of the introduction program along with environmental benefits from healthy plantations.

These above results are for all seed sources. Selection of the better seed sources for height growth and climatic adaptability could further improve the gain. Yeatman (1974) reported an early height gain of at least 12% within ten years of a jack pine breeding program. Selective narrowing of the genetic base at this time for height gain is cautioned as mortality is cumulative over time and these are only early results. Morgenstern (1996) reported an inverse relationship between height and survival across a latitudinal gradient for *Pinus armandii* in China. Trees must withstand all environmental events that occur throughout their life and short-term testing cannot replace long-term results. Should seed sources differ in survival then a balance between rapid growth and acceptable survival will have to be implemented in a breeding program.

Jack pine seems to have adapted well to western Liaoning’s dry sites, such as Jiangutai District, situated in the southern part of the Korman Desert where the annual precipitation is 400 mm as compared with the transpiration rate of 1,200 mm. Cao (2008) reported historically only 15% of the afforestation efforts on China’s arid and semiarid sites have survived, so any success has potentially national implications. On dry sites, the tolerance to dryness and rapid growth of jack pine out performed the earlier introduced *Pinus sylvestris* var. *mongolica* by 47%. In a review of work on the Korqin Sandy Lands, in the north-east of Inner Mongolia,
Jack pine was recommended on a preliminary basis after testing 13 provenances (FAO 2002). This is a very opportune result as there have been large areas of mortality in Mongolian pine that was planted earlier. It is hoped that jack pine may have a greater potential than Mongolian pine for planting on dry sites in Liaoning to help mitigate desertification.

Introduced eastern white pine and jack pine are growing similar in height with documented growth in North America (Figures 3 and 4). Height growth is quite often an expression of site quality. We had no data to evaluate differences in site but the brown soils in Liaoning appear to be more fertile than the sandy soils that white and jack pine commonly grow on in Canada.

Rudolph and Yeatman (1982) reported that genetic variation in jack pine is characteristically clinal and provenances vary in height growth with latitude and the length and temperature of the growing season. The latitudes of the Liaoning sites are slightly south of the Canadian donor sites which results in a different day length and different solar radiation (Morgenstern 1996). The growing environment in Liaoning is slightly warmer than Canadian sites with a higher average temperature and a longer growing season. Liaoning receives precipitation distributed unequally through the growing season with a minor monsoon season in the south. Transfers within North America of 2° south with any increase in degree days were defined by Matyas and Yeatman (1992) as unacceptable risk although they appear to be growing well in our study.

The plantations in Liaoning were established in open fields. Eastern white pine is seldom grown in full sun in Canada due to attacks by the deformative pest white pine weevil (Pissodes
Strobi L.) which kills the leader thus reducing height growth in younger white pine. For comparative purposes we only used data and published reports from open grown white pine. The lack of North American data for open grown white pine without weevil damage will limit future comparisons as the plantations age.

If we assume the height growth of the introduced species represents the site potential in Liaoning then the relatively poor height growth performance of the native species may be an artifact of their evolution and history. Human settlement has impacted Liaoning’s forests for generations with a decline in forested area in the dry, western part of the province that may have been initiated 1,000 years ago (FAO 2002). High-grading has also been claimed to deplete forest genetic resources and it is possible that historic forest harvesting practices negatively impacted the genetic capacity of the native conifers (Ledig 1992, Zhang et al. 2005, Salmela et al. 2010). Any selection for characteristics other than height growth may leave the native species growing below the site capacity for tree height.

**Future Prospect for Eastern White Pine and Jack Pine in Liaoning**

Gene conservation of introduced exotic tree species is an integral component of tree species introduction. Maintaining a diversified genetic base for long-term tree improvement and genetic breeding purposes is an important strategy. With the early evidence of adaptability and excellent growth performance of jack and white pine, it is expected that there will be future demand for large quantities of seeds in large-scale planting programs in Liaoning Province. To meet such seed requirements, we established seed production stands or modified seed source and family test trial stands for seed production. These will be managed not only by
maintaining their original population genetic diversity but also by expanding their genetic base with more families.

In Liaoning, productive reforestation species are relatively limited although there are abundant forest resources. The trend has been towards single species monocultures. This approach can potentially lead to serious threats from insects and diseases. Eastern white pine, judging from its impressive growth, can become a common plantation species in northeastern China. Naturally, the immediate concern is the threat of white pine blister rust (*Cronartium ribicola*) and white pine weevil; although the former is native to China, no sign of its infection was detected, and neither the latter as well. It is vital that diagnostic signs should be closely monitored and protective measures exercised should an infestation be encountered. According to the provincial forest resource survey, over 80% of the conifers are larches and over 80% of the hardwoods are oaks in the east; Mongolian pine and oily pine are the primary species in the west; and black locust (*Robinia pseudoacacia* L.) with small areas of Japanese black pine in the south. Because of the dominant mono-cultured forests, local pests such as *Dendrolimus tabulaeformis*, have destroyed thousands of hectares of plantations in the eastern and western part of the province, while the Japanese black pine forests have suffered a severe attack by *Matisucoccus maisumurae* that they are on the verge of a total wipe-out.

Recent discovery of *Massicus raddei* in the east has provoked a great concern of the forestry officials. Recently, the previously successfully planted Mongolian pine established for wind-breaking and sand-fixing in western Liaoning has suffered large areas of mortality. Under these circumstances, efforts searching for exotic tree species have become an imperative
alternative strategy. It is timely that the early promising results of the jack pine introduction from Canada will likely fulfill that objective as it has performed satisfactory in this role. It is estimated that jack pine will be suitable for planting widely in 3,500,000 ha across the province; a vast expansion from the 15,000 ha of jack pine reported previously for all of China (Rogers and Ledig 1996). If the early performance proves to be true, jack pine will become an important afforestation species in Liaoning.

Conclusion

Liaoning is fortunate to be geographically located in temperate humid and warm-temperate semi-humid climate conditions at the junction of the Chiangbai Range, Northern China and Inner Mongolia regions, where ecological conditions are conducive for tree adaptability and growth. These climatic conditions make it ecologically feasible for successful introductions from temperate North America. Promising experimental results from the introduction of these tree species to Liaoning can be applicable to the northeast, northern as well as northwest China.

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Research Institute for data from the former Maple Research Centre, and Michelle D’Eon of Deep River, Ont. for editorial comments.

References


Figure 1: Height of introduced eastern white pine (China Pw) and species native to Northeast China (China Native Sp.).

$y = 0.232x$, $R^2 = 0.8825$

$y = 0.3961x$, $R^2 = 0.8359$
Figure 2: Height of introduced jack pine (China Pj) and species native to Northeast China (China Native Sp.).

\[ y = 0.2884x \quad R^2 = 0.4326 \]

\[ y = 0.4723x \quad R^2 = 0.5259 \]
Figure 3: Height growth of introduced eastern white pine (China Pw) and eastern white pine growing in North America (N. America Pw).

\[ y = 0.4095x \quad R^2 = 0.861 \]
\[ y = 0.3961x \quad R^2 = 0.8359 \]

Data sources:
Garrett et al. 1973
Boucher et al. 1998
Fu et al. 2007
Major et al. 2009
Pitt et al. 2009
Petawawa Research Forest, Unpublished data, Project P-128.
Figure 4: Height growth of introduced jack pine (China Pj) and jack pine growing in North America (N. America Pj).

Data Sources: Klein 1990.
Weng et al. 2008.
Petawawa Research Forest, Unpublished data, Experiments 432-2, 469-2, 392-2-1, and Project P-134.
Table 1. Key experimental sites of planted Canadian eastern white pine and jack pine in Liaoning Province.

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<th>Location</th>
<th>Lat.</th>
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<th>Average annual precipitation (mm)</th>
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