Tree Improvement in Québec: A Tool for Industrial and Environmental Productivity

Research Note
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A Tool for Industrial and Environmental Productivity

by

André Rainville[1], Mireille Desponts[2], Roger Beaudoin[1], Pierre Périnet[1], Marie-Josée Mottet[1] and Martin Perron[3]

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Ministère des Ressources naturelles, de la Faune et des Parcs du Québec (MRNFP)
Direction de la recherche forestière (Forest Research Branch)
2700, rue Einstein
Sainte-Foy (Québec) G1P 3W8
CANADA

Telephone: (418) 643-7994
Fax: (418) 643-2165

andre.rainville@mrnfp.gouv.qc.ca
mireille.desponts@mrnfp.gouv.qc.ca
roger.beaudoin@mrnfp.gouv.qc.ca
pierre.perinet@mrnfp.gouv.qc.ca
marie-josee.mottet@mrnfp.gouv.qc.ca
martin.perron@mrnfp.gouv.qc.ca

www.forestrycongress.gouv.qc.ca
www.mrnfp.gouv.qc.ca

[1] Forest Engineer, M.Sc. (Forestry)
[2] Biologist, M.Sc. (Biology), Ph.D. (Plant Biology)
[3] Biologist, Ph.D. (Forestry)

Abstract

More than 30 years of tree improvement work in Québec has resulted in the establishment of a large collection of material, comprising several native and introduced species. Among them, six are currently used for reforestation—three native species: black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*P. glauca* (Moench) Voss) and jack pine (*Pinus banksiana* Lamb.), as well as a few introduced larch species (*Larix* spp.), poplars (*Populus* spp.) and Norway spruce (*Picea abies* (L.) Karst.). This large number of species contributes to meeting the diversified needs, current or anticipated, of the forest industry, and to improve the productivity of our plantations. Several hardwood species are also planted in the southern part of the province, especially on former agricultural lands.

The synergy between provincial and federal government research organizations, and the complementarity of their work, has made possible the evaluation of this material in every ecological region of Québec, in spite of the size of the territory and the diversity of forest ecosystems. In the first generation, planting improved material can bring about gains in merchantable volume of 8%–16% as compared to seeds from natural stands. Moreover, the concern to maintain broad genetic diversity among the seedlings used for reforestation is a guarantee of adaptation for Québec's diversified ecosystems and for the potential effects of climate change.

Also, planting improved material is a preferred solution to reduce the increasing pressure on natural forests, as much for the development of non-timber resources as for the creation of protected areas. In southern Québec (hardwood and mixedwood forests), where growth conditions further favour the intensive growing of high-yield species, it could play a determining role in the face of environmental (e.g., CO_2, pig manure), economic or social (local development tools) issues. In the boreal forest, even though bioclimatic conditions limit growth, planting improved material could significantly increase the overall yield of the forests, given the size of the territory and the number of seedlings planted.

Keywords: Tree improvement, forest genetics, reforestation, environment, biodiversity

Introduction

Québec's area is estimated to be 1,667,929 km^2, and stretches over more than 18°of latitude. In this immense area, climatic factors, generally more rigorous from south to north, usually determine the vegetation composition. Three distinct bioclimatic zones are found: the temperate nordic zone, composed of hardwood and mixedwood stands, the boreal zone, characterized by stands of evergreen softwoods, and the Arctic zone, dominated by shrub and herbaceous vegetation (Anonyme 2002a). Forest land covers nearly half the area of the Québec, and 85% of it is owned by the province (Anonyme 2002b). With annual deliveries of $20 billion and exports of $12 billion, the forest is one of the principal industrial sectors in Québec. It provides direct employment to more than 90,000 workers (Anonyme 2002a). The annual allowable cut in Québec's public forests is estimated at nearly 42 million m^3, and consists of 70% balsam fir (*Abies balsamea* (L.) Mill.), spruces (*Picea* spp.), jack pine and eastern larch (*Larix laricina* (Du Roi) K. Koch).

Currently, plantations account for 5% of the world's forest area. They ensure, however, an increasing part of the supply, and produce 35% of wood used in the world (Whiteman and Brown 1999; FAO 2001). As much in New Zealand (*Pinus radiata* D. Don) and Chili (*Pinus* spp. and *Eucalyptus* spp.), as in Scandinavia (*Picea abies* and *Pinus sylvestris* L., especially) and in the southern United States, vast programs aim at obtaining improved second-generation seedlings, and even third generations have been established. After only one generation, volume gains resulting from the use of seedlings from tree improvement programs vary between 5% and 15%, according to the country and the species, whereas equivalent additional gains are reported by adding intensive silviculture (*Groupe de travail sur l'amélioration génétique du MFO-Q* 1996).

In Québec, approximately 150 million seedlings are planted annually, or an area of 75,000 hectares (ha) (0.14% of the productive forest area), mainly in the boreal forest. About 52% of the seedlings currently used for reforestation come from tree improvement programs, and this proportion should increase to 80% in 2005 (Masse 2002). The government has the responsibility of supplying the required seeds and seedlings to reforest Québec's public and private lands. The *Stratégie de protection des forêts* (Forest Protection Strategy), adopted by the Québec government in 1994, aimed at ensuring forest renewal, protecting forest resources, harmonizing the multiple uses of the environment and eliminating the use of pesticides (in effect since 2001) (Anonyme 1994). The primary aim of the Strategy was to ensure the sustainability of ecosystems and to maintain biological diversity. To reach the goal, the government identified five broad directing principles, one of which was supporting natural stand dynamics. Priority was therefore accorded to natural regeneration. Considered as a complementary silvicultural treatment, reforestation nevertheless represents a preferred means to increase the productivity of Québec's forests.

Requirements related to applying the principle of sustainable development brought about increased pressures on forests, whether for developing non-timber resources or to create protected areas (Anonyme 2000). Furthermore, the ratification of the Kyoto

Protocol could result in major impacts on the management of natural forests and on reforestation or forestation programs. Therefore, tree planting is identified as the preferred strategy to fix atmospheric carbon. Specialists evaluate that plantations could contribute to fixing between 0.8 and 2.4 t/ha/year of supplementary carbon (Brown et al. 1996).

Tree improvement programs were established in Québec starting in 1969. The acquired knowledge and available material today put Québec in a privileged position to meet the challenge of increasing forest production and conserving biodiversity. This is a sizable challenge in a context where the boreal forest covers more than 40% of the forest area of the province.

Materials and methods

The first tree improvement work on the principal forest species was undertaken at the end of the 1950s. A more sustained effort was begun starting in 1969, when the government decided to invest in establishing a structured program. At the beginning of the 1980s, a vast network of first generation seed orchards was established to produce improved seeds (Lamontagne 1992). Work was carried out by researchers with the *ministère des Ressources naturelles, de la Faune et des Parcs du Québec*[4] and of the Canadian Forest Service. Contrary to other Canadian provinces and some American states, there are no cooperatives that group together industrial partners and organizations who are interested in tree improvement.

Thirty years later, Québec has a large collection of material at its disposal (provenances, progeny, and improved varieties), including 18 native and 136 introduced species (64 hardwoods and 90 softwoods) (Anonyme 2001). In total, 3.8 million seedlings have been evaluated in 1,294 experiments distributed throughout the ecological regions. Efforts were especially made for black spruce and jack pine, two major components of Québec's boreal forest, and on white spruce. For the former two species, 81 progeny tests consisting of a million seedlings, were established to obtain an estimate of the genetic value of first-generation tree selections. The best material is conserved in 36 seed orchards, established throughout Québec's forested area. For white spruce, provenances from its entire distribution area and progeny from all over Québec have been evaluated in about 20 tests since the end of the 1950s. Seventeen first-generation clonal seed orchards were established early in the 1980s, and two second-generation orchards in 1999. The expected merchantable volume gains are 8%–16% and 15%–20%, respectively. Finally, the more recent increased interest for fast-growing forest species (poplars and larches) accelerated the establishment of sources of improved material (Périnet et al. 1998). The evaluation of more than 4,000 hybrid poplar clones, in clonal tests obtained mainly by controlled crosses, resulted in selecting about 50 of them for their frost hardiness and yield for intensive tree farming in several regions of Québec (Périnet et al. 2001; Riemenschneider et al. 2001).

[4] On April 29, 2003, the *ministère des Ressources naturelles du Québec* (MRN) became the *ministère des Ressources naturelles, de la Faune et des Parcs du Québec* (MRNFP).

Concerning high-density hardwood species, the improvement program started a little more than 10 years ago, but collections of material representing several provenances had already identified significant variations in tree quality.

As a general rule, introduced species include a large number of provenances from their natural distribution areas, which allow us to simultaneously study their genetic variability and their capacity to adapt to growing conditions in Québec (Beaudoin 1995, 1996, 1996a, 1997). Geographic transfers created selection pressure on these provenances and revealed the best adapted material. A certain number of species, including Norway spruce, European larch (*Larix decidua* Mill.), Japanese larch (*L. kaempferi* (Lamb.) Carrière), hybrid larch (*Larix* X *marschlinsii* Coaz.), black poplar (*Populus nigra* L.), black cottonwood (*P. trichocarpa* Torr. and Gray) and balsam poplar (*P. maximowiczii* A. Henry), as well as poplars hybridized with native species, now contribute to increasing the diversity of reforestation species used in Québec, and to improve plantation productivity. These species are conserved principally in 19 arboretums and two populetums (Vallée and Chouinard 1976). They make up, for future use, unique collections of forest trees from the entire world, in particular from Europe, Japan and the United States. The trees best adapted to growing site conditions are an important source of genes for the tree improvement program, through the creation of local, more productive varieties having other characteristics looked for by industry. Experience acquired over more than 20 years with introduced species teaches us that it is important to evaluate them over a fairly long period in order to adequately evaluate their susceptibility to insects and diseases, as well as their growth requirements.

Still today, a large number of species (jack pine, white spruce, black spruce and Norway spruce, as well as two principal genera, *Larix* spp. and *Populus* spp.) are the objects of a sustained tree improvement program. We must highlight the great quantity and diversity of material that served as the genetic base for each species that was the subject of a tree improvement program. In fact, from the very beginning, forest geneticists undertook a representative sampling of the genetic diversity of a species, and established seed and clone banks. These banks represent insurance in case the original stands disappear, and could eventually be used to reintroduce diverse genetic elements for certain needs (different characteristics desired through improvement) and observed changes (e.g., varied ecological conditions) (Bousquet et al 1994). Molecular studies also estimated the impact of domestication on the variability and genetic structure of populations. With white spruce, for example, the analysis of seven enzymatic systems indicatesthat selecting a restricted number of individuals does not result in a significant loss of variability in relation to natural populations (Desponts et al. 1993).

Results

The sustained effort undertaken in tree improvement programs obtained interesting yields. For example, a new series of poplar hybrids, hardier and with a high yield (8 to 12 m^3/ha/year at age 20), was developed for the mixedwood and boreal forests (balsam fir bioclimatic domains) (Anonyme 2002a). In southern Québec, where the climate is more favourable (1,330 to 2,000 growing degree-days), yields can reach 20 m^3/ha/year on the best sites at age 15 years. At the same time, work done with hybrid larch resulted in a mean yield of 6 to 10 m^3/ha/year at age 35.

White spruce grown from first-generation seed orchards and planted on sites with an average fertility index gives merchantable volume gains of 8%–16% (14 to 28 m^3/ha) at age 45, compared to seeds from natural stands. However, for species best adapted to the northern boreal forest (jack pine and black spruce), more modest yields are expected. For jack pine, the average gains in merchantable volume foreseen are 7 m^3/ha at age 40. By undertaking controlled crosses between individuals from superior families and propagating the progeny by rooted cuttings afterwards (bulk propagation of the best families), gains in the order of 20% in height (30%–40% in merchantable volume) could be attained for white spruce and black spruce, compared to the mean of all the families evaluated in tests, which could represent a volume gain of 72 m^3/ha at age 45.

The synergy between the provincial and federal research organizations and L'Université Laval, as well as the complementarity of their activities, is undoubtedly an important aspect of Québec's tree improvement program for forest species. It will have permitted, in spite of the size of the territory and the diversity of the forest ecosystems, an impressive quantity of material and several species to have been evaluated in every ecological region. This cooperation also has contributed to the development of complementary aspects of practical research through more basic and exploratory studies. Thus, acquiring knowledge of the tree genome could help those working in tree improvement to carry out selections (marker-assisted selection). Yet today, in spite of the withdrawal of the federal government in 1996 from applied research programs, the provincial government, now responsible for most tree improvement programs in Québec, carries on with collaborative work between the forest genetic research organizations. Over the years, a constant concern was given to develop close links between research and activities surrounding seed and seedling production. This collaboration has made it possible to quickly make research results available, in a concrete way, by producing a very large number of improved seedlings for reforestation. It will also have helped orient research more easily in terms of expressed needs, for example, by developing models to guide the transfer of seed sources as a function of a risk calculation, or clonal techniques such as rooted cuttings and somatic embryogenesis.

Furthermore, the large number of species which are still the object of tree improvement represent an advantage, because they allow us to choose the best-adapted material to each site and to favour a better diversification of products for industry. From an ecological point of view, resistance and stability of ecosystems against biotic and abiotic disturbance agents is associated with species richness (Larsen 1995). The same goes for the large number of families and clones included in our tests and production orchards. Though it is generally acknowledged that a number as limited as 50 trees allows for the long-term control of the effects of inbreeding and the risks of loss of alleles (Namkoong et al 1988), we have chosen to maintain a very large genetic diversity by retaining a much larger number of individuals. Thus, our white spruce improvement populations are represented by 240 individuals, while second-generation seed orchards contain 125 individuals. This choice may limit plantation yields, yet render them more apt to adapt to climatic changes and its consequences, whether they are of an environmental, entomological or pathological nature (Perry and Maghembe 1989). The potential impacts on the environment associated with planting improved material in the natural forest are thus also minimized. The selection of individuals having new characteristics or sharing our genetic resources with other countries will also be promoted.

Conclusion

Québec is now able to increase its forest production by reforesting with improved material, thanks to the development of better-performing varieties, and acquiring scientific knowledge and expertise in many disciplines applicable at an operational scale. The diversity of improved material now available also allows us to maximize returns on fertile sites, mainly in the southern part of the province, or to profit from the immense areas available in the boreal forest. In the hardwood forest and in the southern part of the mixedwood forest, planting improved material could be an economic and social development tool, in that it could lead to the elaboration of systems to produce timber on demand (specialized products). In the agricultural land, it could be integrated with traditional agriculture (agroforestry) or create a favourable environment to develop products other than wood (chemicals, pharmacological and natural products—for example, yew (*Taxus* spp.) and sea buckthorn (*Hippophae* spp.). In an intensive production system, planting improved material could help resolve environmental problems, such as hog manure excess used as fertilizer, or increasing levels of greenhouse gases. For this, hybrid poplars are already widely used in North America in phytoremediation projects to decontaminate agricultural or industrial environments (Isebrands and Karnosky 2001). The planting and intensive tending of improved material could also bring about a reduction in the harvest of timber in southern forests, and thereby favour other uses for the forest (hunting, fishing, , recreation, etc.).

In the boreal forest, in spite of more unfavourable growing conditions, the extra volume obtained by reforestation using improved material is not negligible given the size of the territory. Managing high-yield plantations, combined with intensive silviculture and the use of genetically improved material, remains a sure way to increase forest production. As illustrated in **Figure 1**, the production of one million cubic metres of wood requires four to six times more area of natural forest, according to the species, as the area needed to plant with improved varieties on productive sites. The yield obtained would significantly reduce the pressures on natural forests and thereby increase protected areas.

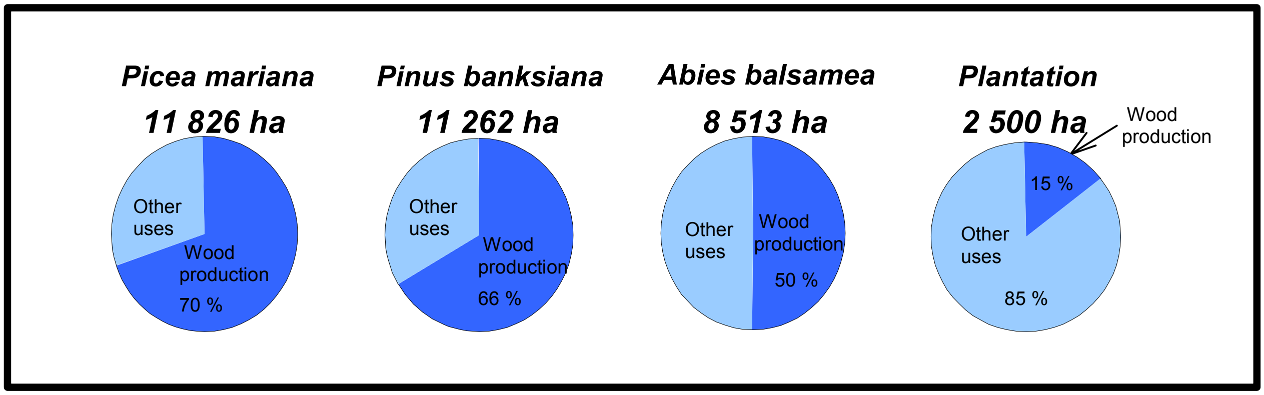

Figure 1. Areas required to produce 1,000,000 m^3 in 50 years from natural stands of average productivity and from plantations having a mean yield of 8 m^3/ha/year. These areas are expressed arbitrarily in terms of a fictitious territory of 17,000 ha. With plantations, a large part of the territory could be allocated to other uses, compared to natural forests, according to the species being considered.

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