FGC extension note 03

Benefits of Using Selected Reforestation Materials

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About the Forest Genetics Council of British Columbia

The Forest Genetics Council of BC (FGC) is a multi-stakeholder group representing the forest industry, Ministry of Forests, Canadian Forest Service, and universities. Council's mandate is to champion forest gene resource management in British Columbia, to oversee strategic and business planning for a cooperative provincial forest gene resource management program, and to advise the Chief Forester on forest gene resource management policies.

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1.0 Introduction

Many characteristics of forest trees vary from one tree to another, including seed germination, timing of growth, growth rate, size, form, wood properties, pest resistance, and capacity to withstand climatic stresses. These differences are due partly to differences in the environmental conditions in which trees grow and partly to genetic variation among trees.

To be considered "select," reforestation materials[1] must exhibit commercial traits that are deemed superior to what would be typically found in wild stands.

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This extension note discusses how select reforestation materials are developed and used in British Columbia, what types of benefits are associated with their use, and how these benefits might be enhanced in the future.

2.0 Tree Improvement in British Columbia

2.1 Selecting Breeding Stock

Tree breeders collect thousands of trees that exhibit specific desirable characteristics from wild stands of commercial tree species (Figure 1). Collections are made throughout a seed planning zone,[2] and from other zones of interest. Collecting from across a seed planning zone maintains genetic diversity in the breeding program, helping to buffer future forests from environmental extremes and attacks of insects and diseases. Range-wide collections are also made, and provide a more complete sampling of the species genetic diversity for testing.

Offspring ("progeny") of these wild parents are grown in field trials (progeny tests) to determine the extent to which specific traits are heritable, rather than the a result of environmental effects. The parents whose offspring perform best in exhibiting the desired characteristic(s) in field trials are selected to breed and produce seed carrying these traits.

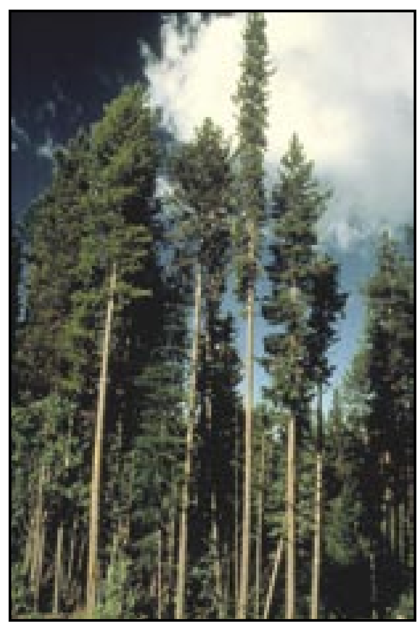


Figure 1 *Superior tree in a wild stand of lodgepole pine* (photo: J. Murphy).

1 In British Columbia, reforestation materials include seed, seedlings, and cuttings.
2 Seed planning zones are geographic areas within which trees have similar genetic adaptation and seed may be moved with low risk of maladaptation.

2.2 Tree Breeding and Seed Production

Tree breeding programs identify and select trees with desirable, naturally occurring characteristics—new genes are not introduced, and existing genes are not changed. Seedlings grown from seed produced by selected trees display high levels of desired traits compared with average trees from natural stands. Continual cycles of selection, testing, and breeding increase the extent to which each generation of select seedlings exhibits desirable traits—the genetic "gain" (Figure 2).

Trees with higher breeding values[3] are established in seed orchards[4] to produce the select seed used by forest nurseries. British Columbia has two categories of select seed: seed, which is produced from seed orchards, and seed, which is derived from natural stands of superior provenances.[5]

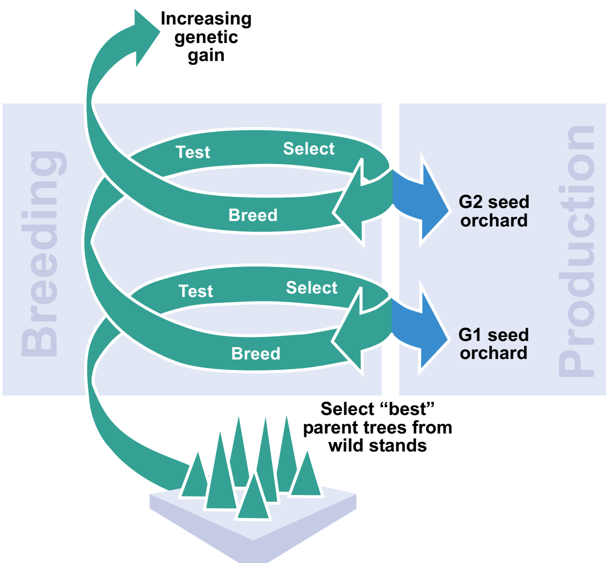


Figure 2 *Tree breeding and seed production processes* (Hadley et al. 2001).

British Columbia's tree breeding programs concentrate on selecting for growth rate and resistance to pests without loss in wood quality. The province has active tree improvement programs for 10 native species: coastal and interior Douglas-fir, western hemlock, Sitka spruce, western redcedar, yellow-cedar, interior spruce, lodgepole pine, western white pine, and western larch.

Tree improvement in British Columbia is part of a larger program of forest gene resource management, which includes gene conservation initiatives and guidelines to ensure that all planting stock—from seed orchard or natural-stand seed—is genetically diverse and adapted to the site on which it is planted.

3 Breeding value is a measure of the genetic quality of a parent tree, and indicates a level of gain for a specific trait.
4 A seed orchard typically consists of grafts from selected trees, isolated to prevent or reduce pollination from outside sources, and cultured for early and abundant production of seeds for reforestation.
5 Provenance refers to the original geographic source of seed, pollen, or propagules. It is usually defined by latitude, longitude, and elevation.

2.3 Regulating Use of Reforestation Materials

The *Forest Practices and Range Act (FRPA)* provides the legislative authority for establishing seed use regulations and standards. The objective of this legislation is to meet British Columbia's stewardship obligations for the sustainable management of the province's genetic resources.

The Chief Forester's Standards for Seed Use, established in November 2004 under the Planning, Practices and Range regulation (PPRR), includes the requirements for registering, storing, selecting and transferring seed used to reforest Crown lands. These standards come into force on April 1, 2005.

All seedlots used for Crown land reforestation must be registered and stored with the Ministry of Forests. To qualify for registration, seedlots must meet minimum standards for genetic diversity and physical quality. Select seedlots from orchards must have an effective population size (Ne)[6] of 10 or greater.

The standards recognize the benefits of tree improvement by requiring the use of seed that has a minimum genetic worth (GW)[7] of 5 percent or greater for the trait that best meets the forest management objectives of the stand. Such traits may include improved growth, or resistance to insect or disease. The registration and use of genetically modified trees is prohibited.

To ensure that reforestation materials are genetically adapted to their area of use, the standards also include transfer limits for different species and seed sources. These transfer standards consist of seed planning zones, elevation limits, and, in some cases, latitude and longitude limits which constrain the area where seedlots can be planted. These seed planning zones and transfer limits are based on information from provenance studies[8] and progeny testing.[9]

The Ministry of Forests maintains two systems to help track seed availability, and conduct seed planning activities. The Seed Planning and Registry system (SPAR) gives seed users on-line information about registered seedlots and vegetative lots,[10] including their respective GW, germination percent,[11] and transfer limits. SPAR lists all seed and vegetative materials registered for use in Crown land reforestation, and provides an on-line ordering system for field foresters placing seedling requests. SeedMap, a web-based map viewer, provides direct access to seed planning maps and associated seed information.

6 Seedlot Ne is a measure of genetic diversity.

7 GW – a measure of the genetic quality of a seedlot for a specific trait (e.g., growth), relative to natural populations from the same seed planning zone.

8 Provenance studies assess genetic differences of seed collected from different parts of the species natural range.

9 Progeny tests evaluate parent trees, based on the performance of their offspring, for traits of adaptive and commercial interest.

10 Vegetative lot – vegetative propagules of the same species and source (i.e., cuttings).

11 Germination percent – the percentage of seeds that germinate over a specified period of time, as measured in a germination test.

3.0 Benefits of Using Selected Reforestation Materials

Selected reforestation materials offer a range of biological, social, and economic benefits. Biological gains include conservation of genetic diversity, resistance to disease and insect pests, and seed supply security. Social benefits relate to increasing the size and stability of the timber supply, and thereby reducing pressure on the forest land base; improving timber quality; and contributing to forest certification. Several of these benefits translate into economic gains, as more wood of higher quality becomes available for harvesting sooner. Reduced brushing costs are also realized in some areas.

Selected reforestation materials offer a range of biological, social, and economic benefits.

3.1 Conservation of Genetic Diversity

Conservation of genetic diversity is a central issue in tree improvement. Genetic diversity allows plants to adapt to changes in their environment. Seed orchards can capture the genetic diversity present in a particular breeding zone because the parents come from a broad geographic area. Seed orchards can also protect the genetic material of species that are threatened.

Provenance studies and progeny testing provide information on the genetic diversity of natural populations. This information can be utilized to efficiently catalogue the genetic resource, and to develop knowledge-based conservation plans.

The Centre for Forest Gene Conservation at the University of British Columbia has the responsibility for organizing information on the conservation needs of indigenous tree species. Using data on parks and other reserves, Centre staff estimate the level of threat to the genetic resource. In general, the large existing natural stands, combined with other gene resource management initiatives, indicate a very low risk of loss of genetic diversity.

Coniferous trees from western North America are among the most genetically diverse organisms on earth. Following the last ice age some 8,000–12,000 years ago, these species moved into new ranges and became part of the forests we find today. Since then, the rich genetic diversity of these species has been shaped by adaptation to climate and other factors.

Genetic diversity enables future forests to adapt to changing environmental conditions. It is the basis of tree improvement programs, which breed trees to increase their commercial value and to adjust planting stock to meet changing needs and conditions. Conserving the genetic legacy of existing forests is a basic requirement of forest stewardship.

A comprehensive gene resource management strategy involves coordinating tree breeding, gene archive activities, management of reserves, and the operational production of tree seed.

3.2 Pest Resistance

Pest resistance is often a goal in selective breeding. Field trials help tree breeders identify which parent trees produce offspring that are more resistant to a given insect or disease. Progeny from the resistant families can then be used in pest-prone areas and in selecting and breeding the next generation of resistant stock. Tree improvement programs in British Columbia are selectively breeding western white pine for resistance to white pine blister rust (Figure 3a) and spruce for resistance to terminal weevil (Figure 3b).

In British Columbia, tree breeders are selecting white pine for resistance to white pine blister rust and spruce for resistance to terminal weevil.

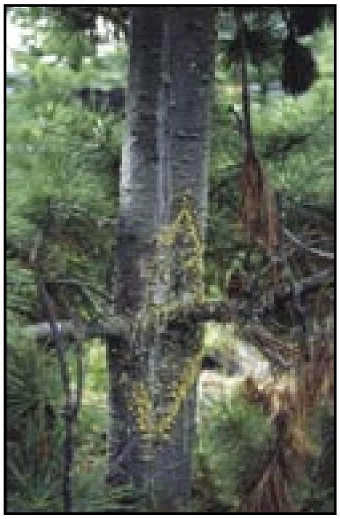


Figure 3a *White pine blister rust* (photo: R. Hunt).

Figure 3b *Weevil damage to a susceptible family* (photo: B. Jaquish).

In the early 1980s, Canadian Forest Service researchers established a British Columbia program for blister rust resistance in western white pine, modeled after a well-established program in Idaho. The seventh round of testing for resistance among the first generation progeny of the original wild parents is underway.

In 1995, the British Columbia Ministry of Forests established an orchard in the Okanagan to produce seed for regenerating rust-resistant white pine forests in the B.C. interior. These trees are now producing seed, and will form the basis for reviving the province's white pine industry.

3.3 Seed Supply Security

Assuring seed availability is especially important for species that have irregular or low seed yields due to reasons such as inadequate pollination or insect damage. Seed orchards are one means of obtaining the needed supply of seed for reforestation. A range of tree improvement methods—carefully timed drought and irrigation, and supplementing pollination—improves production within seed orchards (Figure 4).

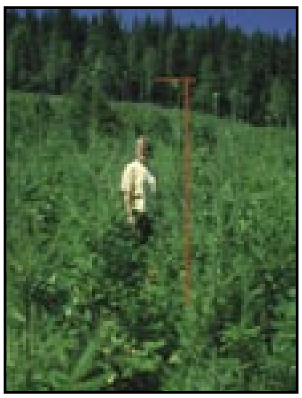
Figure 4. *(L) Controlled pollination of coastal Douglas-fir* (photo: J. Woods). *(R) Mechanized misting* (photo: W. Strong).

Western larch produces limited amounts of seed in natural stands, resulting in poor regeneration in seed-tree cutblocks. The western larch breeding and seed orchard program was started in 1987 to provide a reliable supply of high-quality seed. The orchards now supply enough seed to meet all larch planting requirements.

3.4 Increased Timber Supply

Timber supply is often increased by the use of selected reforestation materials. Trees grown from select seed achieve faster juvenile height growth and greater mean annual increment (MAI) than those grown from wild-stand seedlots. The faster growth of select planting stock affects timber supply directly by increasing future timber volume.

Offspring from parent trees selected in wild stands during the 1960s and early 1970s have been evaluated on many test sites. Trials planted to evaluate seed from the better parents show early height growth superiority relative to wild seed, averaging for example, 15% faster growth for western hemlock and 22% for interior Douglas-fir (Figure 5).



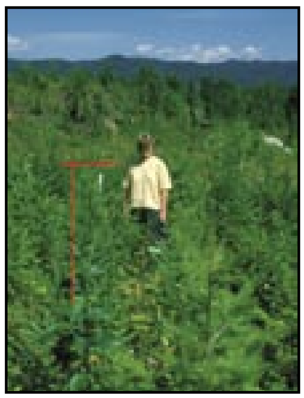


Figure 5 *This photo pair shows the results of breeding in interior Douglas-fir. The height difference between seedlings from selected parents (L) and wild parents (R) is about 1 m at age 5.* (Photos: B. Jaquish).

Some growth and yield models, such as those used by the Ministry of Forests, have been modeled to allow adjustment of projected volume yields for genetic gain using the genetic worth of a seedlot (Figure 6). This information is used in timber supply models to forecast the effects on timber supply. For further information on the method used in British Columbia for incorporating genetic gain in timber supply, see *Incorporating Genetic Gain in Timber Supply Analysis* (Tanz 2001).

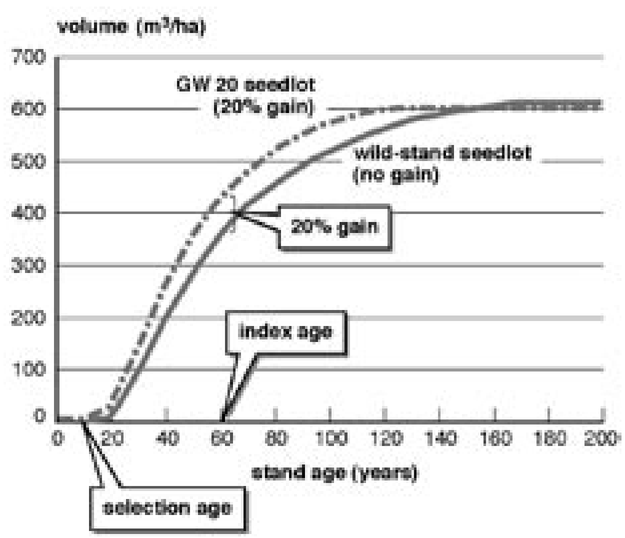


Figure 6 *Modeling genetic gain in the Ministry of Forests growth and yield model TIPSY.*

Using selected planting stock can also increase timber supply indirectly by affecting the rate at which management requirements are satisfied. For example, using selected stock that achieves faster juvenile height growth may mitigate the impacts of harvesting restrictions such as adjacency[12] constraints by reaching green-up height earlier.

Planting trees that have been selected or bred for superior growth can increase timber supply:

- directly, *by increasing the volume of timber available in the future*
- indirectly, *by affecting the rate at which management requirements are satisfied.*

Figure 7 illustrates the direct and indirect timber supply effects of genetic gain from tree improvement in studies of the Arrow and Golden Timber Supply Areas (TSAs) (Timberline 2001, Wang and Listar 2000).

In the Arrow TSA, explicitly incorporating genetic gain in timber supply analysis resulted in a 5% increase in timber supply. This benefit, noted as early as decade 4, is due to increases in managed stand volumes and reductions in minimum harvest, age and to the time needed to reach green-up height. The use of select seed in the "genetic gain" harvest forecast decreases the mid-term decline in timber supply and increases the long-term timber supply compared with the "no genetic gain" harvest forecast.

In the Golden TSA, projected increases in timber supply in the "genetic gain" forecast were noted by decades 3 (11%) and 4 (15%), with an average long-term increase of 10%.

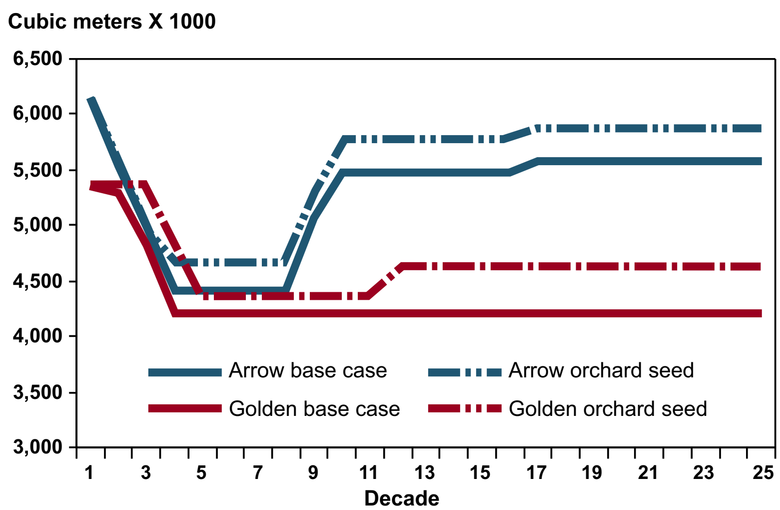


Figure 7 *Effect of genetic gain on timber supply in the Arrow and Golden Timber Supply Areas (TSAs).*

12 *Adjacency* refers to requirements that trees on harvested cutblocks reach a specified minimum height before adjacent cutblocks can be harvested.

3.5 Reduced Pressures on Land Base

The use of select seed allows timber supply needs to be met from a smaller land base by making certain stands available for harvest earlier, and producing more timber volume per area. In this way, it allows timber supply to be maintained or increased, and reduces harvest pressure on lands with high value for non-timber resources (e.g., wildlife habitat, recreation).

3.6 Improved Wood Quality

Tree selection and breeding can also be used to increase wood quality, or the suitability of wood for a particular end use. Tree improvement programs can select for wood properties such as, percentage latewood width, relative density, strength and stiffness, microfibril angle, fibre length, and cellulose, lignin, or extractives content. British Columbia's tree improvement programs are currently studying fibre characteristics that improve pulp qualities in hemlock and wood durability in western redcedar. Relative wood density is assessed for most species, and incorporated in selection criteria for advanced breeding populations and seed orchards.

3.7 Support to Forest Certification

The worldwide move to set principles and standards for sustainable forest management will increasingly affect forest practices, including the use of select seed. While principles and standards vary, most certification systems require implementing conservation strategies for commercial and endangered forest species, using high quality seed and seedlings from indigenous species that are locally adapted, and prohibiting the use of genetically modified trees.

Attention to gene conservation, cataloguing genetic resources prohibition on the use of genetically modified organisms (GMOs), and the use of only well adapted seed from native species increases the ability of British Columbia's forest lands to become certified under internationally recognized certification systems.

4.0 Investment Analysis

Financial analyses are useful for estimating the benefits and costs of tree improvement programs and comparing alternative options for breeding and seed orchard programs.

4.1 Analyzing the Benefits and Costs of Tree Improvement[13]

Tree improvement activities are generally characterized by a long period between expenditures and receipt of direct benefits. Comparing projects with different schedules of costs and revenues requires discounting values to a common year, using approaches such as internal rate of return (IRR), net present value (NPV), and cost / benefit ratios.

Tree improvement activities are generally characterized by a long period between expenditures and receipt of benefits. To compare projects, the values of benefits are discounted to a common year.

Comparing the benefits and costs of tree improvement is challenging. The private sector usually uses methods such as NPV or IRR. Evaluating public sector investments is more complicated, as both financial and social benefits must be considered.

Cost-effectiveness analysis is another approach that is useful for evaluating costs and benefits, and for comparing public-sector tree improvement projects. This approach discounts to the present the volume attributable to tree improvement rather than the value of the additional wood produced, and estimates the additional cost-per-cubic-metre of wood attributable to tree improvement activities (Lester 1994). Cost-effectiveness analysis has been used to estimate costs for tree breeding and seed production, and the added cost-per-tree for selected planting stock, including vegetatively propagated trees (Lester and Yanchuk 2002). It has been successfully used to evaluate and choose among options for breeding programs.

4.2 Economic Benefits of Tree Improvement

Tree improvement can be pursued at many levels of intensity, from simple selection of seed trees in shelterwood systems, to the use of clonally propagated hybrids in short-rotation intensive culture. It can also be applied to a multitude of traits. Given the many levels of intensity of tree improvement and the multitude of traits under selection, there is a correspondingly wide array of potential benefits.

Economic benefits

Economic benefits may include more wood, higher value wood, or earlier harvest of selected plantations. Many of the costs associated with investments in tree planting are incurred early in the crop cycle. These include site preparation, tree planting and early stand tending. Because of the rotation length of most forest plantations, the front-loaded costs must be carried until

13 This section draws on *Dollars and Sense in Tree Improvement* (Lester 2002).

harvest and the returns on investment are only then realized. A reduction in the rotation can have a large impact on the profitability of plantation forestry. Tree improvement provides the most efficient way of reducing rotation length (Figure 6).

Tree improvement is a fundamental component of intensive silviculture, and can provide indirect compensatory benefits such as reduced harvest need on areas with high non-timber values.

More wood, better wood, earlier harvest

Increased wood production is the most common goal of tree improvement programs. Mature tree improvement programs around the world commonly report height gains of 4 to 5% with harvest volume gains of 8 to 20% or more in the first generation of selection (see Table 1 for examples). Gains of a similar order of magnitude are expected in the second and third generations of selection, and have already been realized in radiata pine in New Zealand and loblolly pine in southeastern USA. In British Columbia, tree improvement work has resulted in a range of gains in rotation-age volume per hectare estimates. The highest levels achieved are for interior spruce and interior Douglas-fir, with gains of over 20% in the first generation of testing and selection. Coastal Douglas-fir gains estimates of 17% are being confirmed by realized-gain trials (Stoehr, 2003 – MoF unpublished data).

Selection for increased stem volume concurrently selects for fast juvenile height growth. Faster earlier height growth can result in an earlier release from liability for reforestation. Rapid green-up may also permit earlier harvesting of adjacent stands sooner in certain situations. Relief from adjacency constraints is a significant consideration in timber harvesting and supply planning.

Wood quality may be improved through tree breeding. This can apply to internal wood quality as determined by wood density, fibre characteristics or wood chemistry, or external wood quality as determined by stem straightness, taper, stem form, and branching characteristics. In the south-east United States, manipulation of tree form is considered to be one of the easiest and quickest ways to improve wood, because it can be done both genetically and silviculturally (Zobel and Talbert 1984). Unimproved loblolly pine has a reputation for being a crooked tree with a high percentage of undesirable reaction wood. With one generation of selection, the amount of sweep was reduced by 27%, and log value increased (Lambeth 2000).

Selection for fast growth results in larger trees at a given age. The benefit can be realized in a number of ways. The rotation may be unchanged, but the increased volume will produce higher revenues, without concurrent increases in other costs such as site access. Alternatively, the rapid growth can be exploited through a reduction in the length of rotation. Increased options for harvest scheduling and market response may also add value.

The benefits of a shortened rotation may be modeled through a calculation of alternative values of discounted harvest volume. However, changes in product value are more difficult to quantify (e.g., reductions in piece size or average wood density).

Combining benefits

Most tree improvement programs yield multiple benefits. The values of the individual benefits need to be combined in order to assess the appropriate level of investment. Volume figures alone do not explain all the value increases, since volume gains are usually accompanied by shortened rotation length and earlier greenup. A further benefit may be realized through reduced losses to pests and increased forest management options. In some situations, tree improvement programs allow the use of species that may otherwise not be readily available (e.g., yellow-cedar and western larch, where obtaining adequate viable seed from natural stands is problematic).

In conclusion, tree improvement can be used to provide a variety of economic and ecological benefits. Economic analyses of well established tree improvement programs generally show positive returns on investment. Table 1 summarizes benefits for a number of tree improvement programs worldwide.

Table 1 *Examples of published gains from tree improvement programs worldwide.*

Location	Species	Benefit	Trait	Reference
Southeast USA	Loblolly pine (*Pinus taeda*)	8–12%	Harvest volume	Weir 1996, quoting Talbert *et al.* 1985
		4–8%	Quality	
		12–20%	Total (volume + quality) 1st gen. gains	
		28–60%	Harvest volume 2nd and 3rd generation	Weir 1996, quoting Todd *et al.* 1995; Frampton and Huber 1995
		3.9%	Site index	Lambeth 2000
		27%	Reduction in sweep	
New Zealand	Radiata pine (*Pinus radiata*)	4.5–5.3%	Height	Carson *et al.* 1999
		6–11%	Diameter	
		12–30%	Basal area	
		15–34%	Stem volume	
Australia	Hybrid pine (*Pinus elliottii x P. caribaea v. hondurensis*)	5%	Height increment	Rockwood 2000
		10%	Volume	
		5%	Wood quality	
Great Britain	Sitka spruce (*Picea sitchensis*)	5%	Top height	Lee 1990
		15%	Harvest volume	
		7%	Stem form	

4.3 Strategic Planning for Public Sector Benefits

In 1997, the Forest Genetics Council adopted an objective and business-like approach to decision-making in the provincial tree improvement program. The Tree Improvement Investment Priority (TIIP) model was developed to support the ranking of seed planning units (SPUs)[14] for investment (Table 2), and to identify likely returns to the province from various levels of investment.

The TIIP model evaluates the contribution (NPV) of each SPU to the provincial economy. It includes only direct economic benefits to the province derived from increased harvest due to tree improvement activities. The model does not consider other sources of value such as higher quality wood, reduced brushing costs due to faster seedling growth, and genetic conservation.

Table 2 *Criteria used to evaluate and rank seed planning units (SPUs) for investment.*

Ranking criteria	Description
Net present value (NPV)	Incremental NPV from Tree Improvement Investment Priority (TIIP) model.
Technical feasibility for breeding	Biological feasibility and probability of success of a breeding program based on other programs, etc.
Delivery feasibility	Feasibility of success for operational delivery of gains (i.e., orchard or cutting program success).
TSR value to management units	Value of timber supply gains in the management units based on existing timber supply analyses, adjacency limits, etc.
Uncertainty and risk	Uncertainty of the long-term demand for select material (i.e., long-term seedling demand).
Opportunities	Specific opportunities for higher gains (e.g., clonal testing and delivery through cuttings, SE,[a] use of exotics).
Seed transfer information needs	Need for seed transfer or other genecology[b] information within the SPU.

a Somatic embryogenesis (SE) – The production of embryos from non-reproductive (somatic) tissue

b Genecology – The study of the geographic patterns of genetic diversity

14 Seed planning units (SPU) – the unique combinations of tree species, seed planning zone (SPZ), and elevation band, which form the basis for tree breeding and seed production planning in the province.

The Forest Genetics Council's Tree Improvement Investment Priority (TIIP) model and annual Business Plan help to quantify some of the benefits to the province from using selected reforestation materials.

The Forest Genetics Council's planning tools, such as TIIP and its annual Business Plan, have enabled it to provide credible estimates of the value to the province of investments in forest gene resource management. These valuations of the program have been very important in both configuring the program and setting priorities.

Figure 8 shows estimates of timber supply increments from tree improvement activities:

- with a conservative 1% gain from relief of adjacency constraints in management units where adjacency constraints are a limiting factor
- without adjacency constraint benefits.

It illustrates the manner in which forest-level timber supply analysis integrates the direct and indirect effects, and the interaction between physical (volume) and policy (adjacency) effects. Business planning models provide essential information for this work.

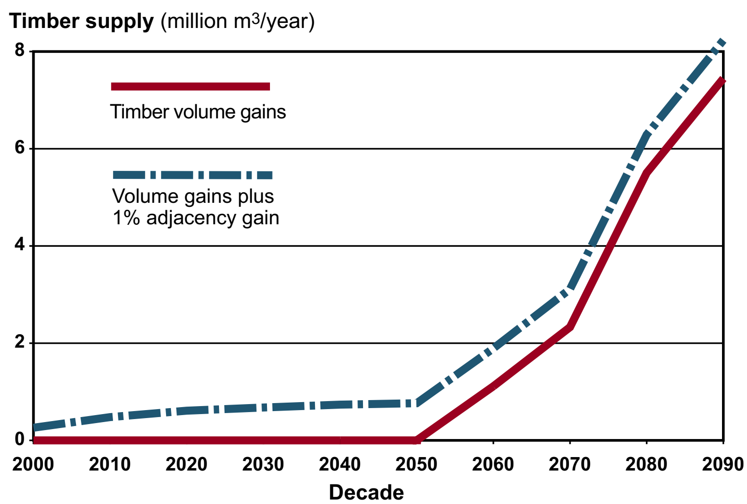


Figure 8 *Estimated timber supply gain from all provincial tree improvement investments, with and without a 1% adjacency gain in management units limited by adjacency constraints*

5.0 Conclusion

A range of biological, social, and economic benefits can be achieved from using selected reforestation materials.

Tree improvement is continuously increasing genetic worth and producing more and better select seed for operational use. The Forest Genetics Council's goals include increasing the use of select seed to 75% by 2013 (51% in 2004) and enhancing the genetic gain of reforestation materials to 20% by 2020 (10.5% in 2004). Seed orchards deliver a reliable and, in some cases, pest-resistant supply of seed derived from the province's best-performing native trees.

Using trees grown from select seed is one of the most effective ways to enhance forest productivity and value, especially when combined with silvicultural treatments to protect and enhance the investment. Meeting timber supply objectives from a reduced land base, and meeting stewardship objectives through comprehensive gene resource management are added advantages. In addition, the modification of seed transfer limits and seed deployment strategies are a key means for response to climate change—another focus of FGC stakeholders.

Several initiatives are likely to increase the genetic worth of selected reforestation materials, and the future benefits of using them:

- The genetic quality and quantity of orchard seed will continue to increase as new information allows parents with lower levels of gain to be removed (rogued) from orchards, and trees with higher genetic worth to be added.
- Tree breeders are focusing on ways to increase pest resistance and select trees with higher economic values.
- Orchard expansions through SelectSeed Company Ltd., a corporation created to help achieve Forest Genetics Council objectives, will continue to mature and provide increasing amounts of select seed.
- Researchers are pursuing ways to protect trees, cones, and seeds from damaging insects and disease.
- The Centre for Forest Gene Conservation at the University of British Columbia will continue to work on gene conservation, conservation strategies, and research on genetic diversity in native tree species. Response to climate change through the modification of seed transfer limits is also part of the focus. Through long-term stewardship, British Columbia's existing genetic diversity can be maintained and enhanced.

Using selected reforestation materials is one of the most effective ways to enhance forest productivity and value, especially when combined with silvicultural treatments to protect the investment.

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