FGC

extension note 01

Incorporating Genetic Gain in Timber Supply Analysis

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FOREST RENEWAL BC

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About the Forest Genetics Council of British Columbia

The Forest Genetics Council (FGC) of British Columbia is appointed by BC's chief forester to guide tree improvement activities in the province. The Council's Technical Advisory Committees (TACs) provide important avenues for technical communications among the different agencies that practise tree improvement activities in B.C., and coordinate business planning for each species in the provincial breeding programs. Council and its TACs include representatives from the forest industry, Ministry of Forests, Canadian Forest Service, universities, and Forest Renewal BC.

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1.0 Introduction

Three recent initiatives have encouraged development of methods and tools for incorporating genetic gain information in timber supply analysis. First, the Forest Genetics Council published its Business Plan (July 2000), which documents the structure and planning activities of the province's forest gene resource management program. Second, implementation of Forest Renewal's Tree Improvement Program stimulated new interest and activity in the production and use of improved reforestation materials. Third, the Ministry of Forests (MoF) Timber Supply Review (TSR) provided the means to incorporate genetic gain in timber supply analysis and determination of allowable annual cut (AAC) for each management unit[1] in the province

This extension note explains how the volume gains attributed to using select seed[2] are modelled in stand yield projections and accounted for in TSR timber supply analyses. The note briefly explains genetic gain, how it affects timber supply, and how it is modelled in timber supply analysis. The discussion draws on examples from a recent study of timber supply in the Arrow Timber Supply Area (TSA), in the Nelson Forest Region.

This note explains genetic gain, how it affects timber supply, and how it is modelled in timber supply analysis.

This extension note should interest timber supply analysts and others charged with quantifying the timber supply effects of using select seed. Decision-makers evaluating investments in forest gene resource management may also find this note useful.

2.0 What is Genetic Gain?

For reforesting Crown land, the Forest Practices Code requires foresters to use seed of the best genetic quality available. Genetic quality refers to three attributes: diversity, adaptability, and gain.

Seed orchard planning and licensing procedures and seed transfer guidelines ensure that seed produced for use on Crown land is genetically diverse and adapted to the planting site. Seed may be planted only within the seed planning zone (SPZ) of its origin. SPZ boundaries generally follow those of ecosystems as defined in the biogeoclimatic ecosystem classification (BEC) system used in B.C.

Adaptability is often related to elevation as well as geographic area, so tree breeding programs, orchard production, and seed transfer guidelines for

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[1] Timber supply areas (TSAs) and tree farm licences (TFLs).

[2] The term "select" describes seed or seedlings with some amount of genetic gain. Select seed is produced in seed orchards (Class A seed), or derived from natural stands of superior provenances (Class B+ seed).

each species are based on combinations of SPZ and elevation band. The SPZ-elevation band combinations for each species are referred to as seed planning units (SPU). For example, the *Sx BV Low* is the SPU for interior spruce in the Bulkley Valley SPZ at elevations below 1200 m. There are 76 SPUs in the province, 42 of which are included for planning purposes in the Forest Genetics Council's Business Plan.

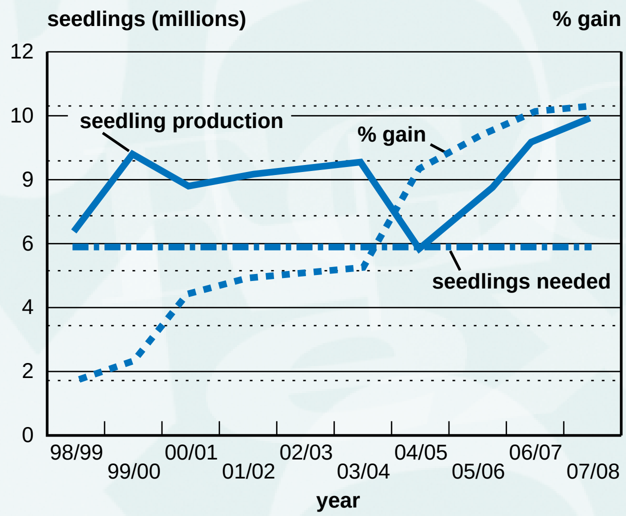

Figure 1
Projected gain, seedling production, and seedlings needed for interior spruce in the Bulkley Valley seed planning zone at elevations below 1200 m.

Genetic gain is the percentage increase in certain traits (e.g., stem volume, relative wood density, or pest resistance) of trees grown from select seed, over those grown from wild-stand seed. The genetic gain of a seedlot is expressed as its genetic worth (GW). The GW for stem volume is measured as the percentage gain in volume expected for a seedlot at or near harvest age.[3] The GW for each seedlot is recorded on the MOF Seed Planning and Registry system (SPAR).[4]

Genetic gain is projected in 10-year species plans, which contain projections of breeding programs and seed orchard production, plans for propagation and management activities, and analyses of current and proposed seed orchards. The species plans also project planting stock supply and demand, and the average genetic gain (weighted by seed orchard) for each SPU. For example, the species plan for the *Sx BV Low* SPU projects seedling production at slightly above the expected demand of 5.8 million seedlings per year, with gain projected to increase to about 12% by 2006 (Figure 1). Improvements in seed orchards result from the ongoing removal of poorer parents by roguing[5], or the addition of better parents.

[3] As stem volume is the only genetic gain trait discussed in this extension note, the terms genetic gain and GW are used interchangeably hereafter.

[4] The MoF's Seed Planning And Registry (SPAR) system provides current information on seedlots and vegetative lots and provides an on-line facility for entering seedling requests.

[5] Roguing refers to the removal of undesirable trees to increase the average level of gain in an orchard.

3.0 Timber Supply Analysis

Timber supply analysis is the method used in the TSR to forecast timber supply for each of British Columbia's 71 management units (37 TSAs and 34 TFLs). The timber supply from an area depends on how much land is available for harvesting, the tree species growing on it, its productivity, and the way the land is managed.

3.1 Information Needs

Four types of information are needed for timber supply analysis:

- Land base

  The productive forest land in a management unit is separated into two classes—the timber harvesting land base, and lands unavailable or inappropriate for timber production (e.g., areas that are inaccessible, ecologically sensitive, or designated for other uses).

- Inventory

  The forest inventory is classified to represent the existing condition of the forest and to project its growth. To facilitate the projection of timber yields, the inventory is usually aggregated into analysis units based on leading tree species, site productivity, and silvicultural regime. At least two yield tables are generated for each analysis unit—one representing naturally established or unmanaged stands and another representing managed stands.

- Yield projection

  For each analysis unit, volume per hectare is projected with models such as VDYP[6] for unmanaged stands and TIPSY[7] for managed stands. Key parameters in these models are species composition, site index, and stand density.

- Management

  Activities that enhance timber production (e.g., planting, thinning) and forest cover requirements that maintain or enhance other forest values (e.g., wildlife habitat, visual quality) are specified. Forest cover requirements are applied to the whole forest, or to parts of the land base (e.g., landscape units, community watersheds).

Four types of information are needed in timber supply analysis: land base, inventory, yield projection, and management.

[6] MOF Variable Density Yield Prediction model.

[7] MOF Table Interpolation Program for Stand Yield.

3.2 Forecasting Timber Supply

The MoF carries out timber supply analysis using a computer model (Forest Service Simulator, or FSSIM) that projects the state of the forest into the future, given specified assumptions about harvesting, management, and stand growth. In each decade of the simulation, the model harvests as much of the target volume as is available, and grows the forest, keeping track of the area in each component of the inventory and land base. The area available for harvesting in each decade is limited by management requirements such as forest cover constraints and minimum harvest ages.

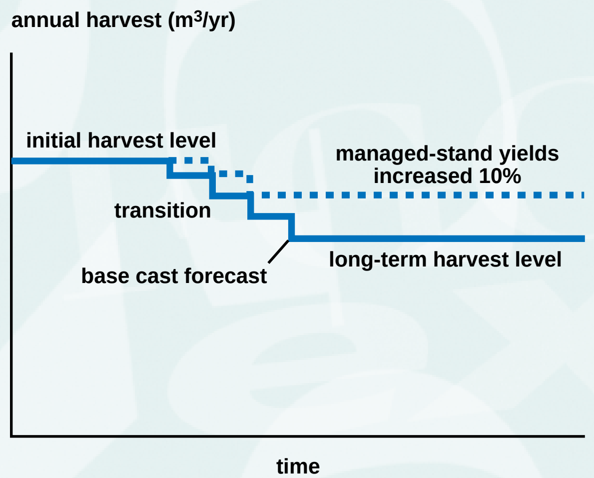

Figure 2
Typical harvest forecasts, showing the harvest level by decade for the base case (solid line) and sensitivity analysis (dashed line).

A harvest forecast shows the projection of volume harvested in each decade of the simulation (Figure 2). The base case forecast represents the timber supply under current management practices and assumptions. Sensitivity analysis measures the change in the base case forecast caused by a change in data or assumptions. The sensitivity analysis forecast in Figure 2 shows that increasing yields for managed stands increases timber supply in the long-run, and has no short term effect. In the current TSR process sensitivity analysis is sometimes used to measure the effect of using select seed.

3.3 How Genetic Gain affects Timber Supply

Planting trees grown from select seed increases the volume available for harvesting in the distant future when the planted trees can be harvested. Using select seed can also affect timber supply indirectly through effects on factors that constrain timber supply (e.g., harvest flow requirements, green-up constraints, minimum harvest age).

Harvest flow requirements represent the management objective of avoiding large fluctuations in harvest levels. They do this by restricting the amount harvest levels are permitted to change from one decade to the next, constraining the harvest level in one decade to save volume that, if harvested, would create a scarcity in subsequent decades. Where harvest flow requirements interact with an increase in available future volume, there may be a short-term increase in timber supply, decades before the planted trees will be ready for harvesting, often referred to as the *allowable cut effect*. The dashed line in Figure 3 shows the volume available for harvesting in the absence of harvest flow constraints, with a scarcity projected in decades 7–10. The solid line in the figure shows the forecast with harvest flow constraints in effect. Some of the volume available in decades 3–6 is not harvested so that it can be made available for harvesting in the period of scarcity.

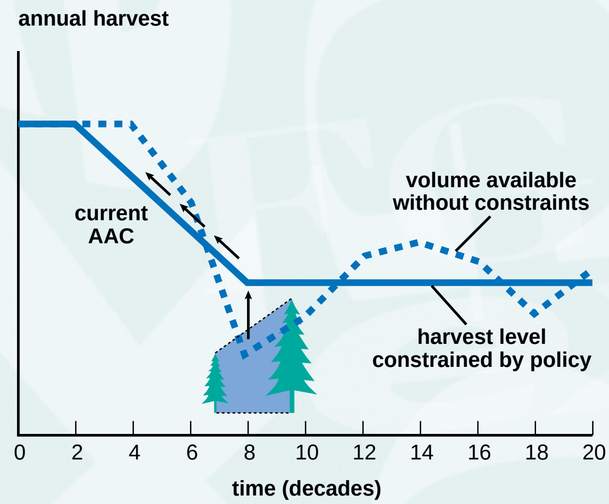

Figure 3
Any extra volume from genetic gain made available in decade 8 cascades to earlier decades because of harvest flow policy (after Williams).

By using select seed today we can make extra volume available in the future (decade 8 in Figure 3), which is the direct effect described above. The extra volume available at that future time releases hectares that were being reserved to provide volumes needed to avoid projected shortfalls in subsequent decades. The effect cascades to earlier decades. For example, extra volume available in decade 8 releases hectares being held over from decade 7. The extra volume made available in decade 7 releases hectares being held over from decade 6, and so on (Figure 3). How much extra volume becomes available and when it becomes available differs from management unit to management unit, depending on the timber supply situation.

Using select seed can also increase short-term timber supply indirectly through its effects on *green-up age* and *minimum harvest age*. Genetic gain increases height growth, meaning that gain reduces the age at which stands reach green-up height (Figure 4). In situations where green-up constraints are limiting the harvest level, reaching green-up age sooner increases the area available for harvesting. The area affected by the green-up constraint becomes available for harvesting as soon as the stands reach green-up age.

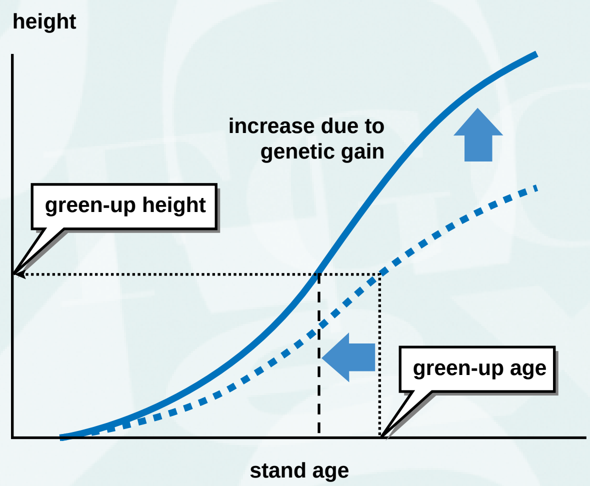

Figure 4
Genetic gain can lower the age at which green-up height is reached.

However, green-up constraints are applied by geographic area, so the green-up height must be translated to an age at which all stands in the area are expected to reach green-up height. Whether harvest level will be affected by the use of select seed depends on whether green-up age was limiting the harvest level, the change in green-up age caused by using select seed, and the amount of select seed used.

Minimum harvest age is the age at which a hectare is first made available for harvesting. It is usually specified as the age when a minimum volume per hectare is first reached, a minimum average diameter or stand height is reached, or a combination of all three. If using select seed reduces the age at which the minimum volume per hectare, stand height, or average diameter are reached, timber may be made available for harvesting sooner than it would be without select seed. In situations where minimum harvest age is limiting the harvest level, reducing it can increase the volume of timber available for harvesting in the short-term or long-term, depending on the specific situation.

4.0 Modelling Genetic Gain in Timber Supply Analysis

Methods for including genetic gain information in timber supply analysis are relatively new, and continue to develop as new and better information and tools become available.

One way to include genetic gain in timber supply analysis is to simply increase the volumes in each yield table by a generalized estimate of percentage gain.

Accounting for gain in timber supply analysis requires including SPZs and elevation bands in the land base and inventory.

Deriving more precise estimates of the effect of gain requires:

1. identifying SPZs and elevation bands in the timber harvesting land base
2. defining analysis units to reflect SPZs and elevation bands
3. in yield projections, accounting for the percentage gain for the SPZ and elevation band
4. adjusting green-up ages and minimum harvest ages.

The following discussion of these steps draws on methods used in a recent study of the Arrow TSA (Wang and Listar 2000). Some aspects of the Arrow study have been simplified in this presentation. See the original report for full details.

4.1 Identifying SPZs and Elevation Bands for the Timber Harvesting Land Base

In conventional timber supply analysis the land base is classified with respect to operability and management requirements (e.g., habitat, biodiversity emphasis, integrated resource management). This classification does not usually require distinguishing elevation, unless it defines the boundary between operable and inoperable areas or specific habitats.

However, since genetic gain is specified for each species by SPZ and elevation band (i.e., SPU), accounting for percentage gain requires that the land base and inventory also include the SPZ and elevation band for each species of interest. Tree Improvement Branch is currently digitizing all SPUs for this reason.

The Nelson SPZ for each orchard species covers all of the Arrow TSA, and therefore was not further differentiated in the Arrow analysis. Table 1 shows the elevation bands that were digitized to allow representation of the SPUs on which projections of genetic gain are based.

Table 1

Seed planning units in the Arrow TSA, by species. All of the Arrow TSA falls within the Nelson (NE) seed planning zone.

<table>
<tr><th></th><th colspan="5">Elevation band</th></tr>
<tr><th>Species</th><th>< 1000 m</th><th>1000–1300 m</th><th>1300–1400 m</th><th>1400–1500 m</th><th>1500–1700 m</th></tr>
<tr><td>Spruce</td><td colspan="2">Sx NE Low</td><td colspan="3">Sx NE High</td></tr>
<tr><td>Douglas-fir</td><td>Fd NE Low</td><td colspan="3">Fd NE High</td><td></td></tr>
<tr><td>Larch</td><td colspan="3">Lw NE Low</td><td></td><td></td></tr>
<tr><td>Lodgepole pine</td><td colspan="3">Pl NE Low</td><td></td><td></td></tr>
</table>

4.2 Defining Analysis Units

Analysis units normally group hectares that have the same existing species composition and site index, and will have the same management regime. Incorporating genetic gain requires that analysis units be redefined to distinguish SPZs and elevation bands.

Incorporating genetic gain requires that analysis units be defined by seed planning unit.

In the Arrow TSA study, separating analysis units by elevation band created a new analysis unit for each combination of original analysis unit and elevation band. The original TSR analysis for Arrow TSA had 32 analysis units and 64 yield tables. Including genetic gain required using 204 analysis units and creating 408 yield tables to account for existing and managed yield tables for each combination of analysis unit and elevation band.

4.3 Modifying Yield Projections to Account for Genetic Gain

For each analysis unit, a silviculture regime must be specified and yield tables projected. The yield tables must reflect planned silviculture strategies including species composition and the amount of gain expected from using select seed for each species planted in each elevation band.

In conventional timber supply analysis, species composition of regenerated hectares is usually defined based on typical TSA-wide practices. In analyses where elevation bands are explicitly represented, species composition for regenerated stands must be appropriate for the elevation bands. The extra resolution (elevation bands) used in the Arrow TSA study also allowed forest district staff to examine the seedling requirements implied by the harvest forecast. After a preliminary projection of the harvest forecast, district staff adjusted the species composition for regenerating stands to ensure that the seed and seedling requirements were reasonable and reflected current silviculture practices in each elevation band.

In TIPSY...the specified amount of gain is applied at the index age (expected harvest age).

With the analysis units defined based on elevation band, genetic gain can be specified in TIPSY, the yield model used to prepare managed-stand yield tables (Table 2).

Table 2
Genetic gain (%) by elevation band, for Arrow TSA

<table>
<tr><th></th><th colspan="5">Elevation band</th></tr>
<tr><th>Species</th><th>< 1000 m</th><th>1000–1300 m</th><th>1300–1400 m</th><th>1400–1500 m</th><th>1500–1700 m</th></tr>
<tr><td>Spruce</td><td colspan="2">12%</td><td colspan="3">18%</td></tr>
<tr><td>Douglas-fir</td><td>26%</td><td colspan="3">22%</td><td></td></tr>
<tr><td>Larch</td><td colspan="3">7%</td><td></td><td></td></tr>
<tr><td>Lodgepole pine</td><td colspan="3">10%</td><td></td><td></td></tr>
</table>

In TIPSY, genetic gain causes an increase in top height, which accelerates stand development. TIPSY retrieves supporting information (e.g., volume, diameter) from its internal yield tables, which are based on height. By design, gain is highest close to the *selection age* (the measurement age of progeny tests), and declines thereafter, such that the specified amount of gain is applied at the *index age* (the expected harvest age). This conservatism reflects the risk inherent in estimating gain when trees selected (tested) are younger than the expected harvest age, as is currently the case. As information from older tests becomes available, estimates of yield increase in TIPSY will be changed accordingly (B.C. Ministry of Forests 2000).

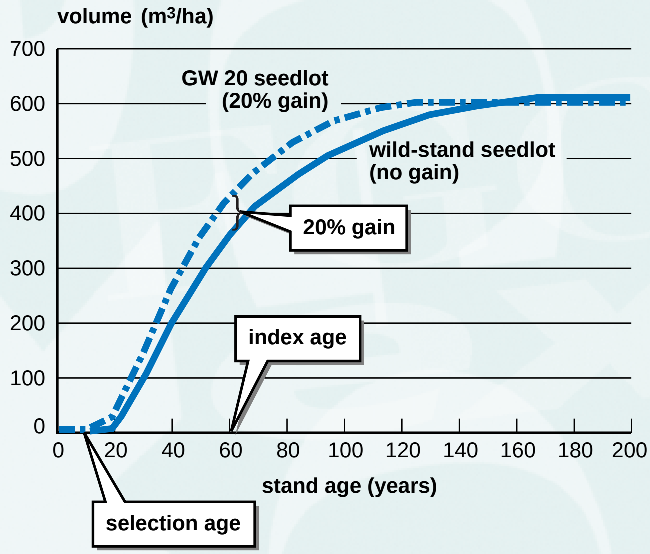

Figure 5
Modeling genetic gain in TIPSY.

Table 3 shows the selection ages and index ages used in TIPSY. Figure 5 shows projected yields with no gain and with 20% gain for lodgepole pine. The percentage gain is highest at the selection age. The specified 20% gain is reached at age 60, the index age for interior lodgepole pine.

Table 3
Selection ages and index ages used to model genetic gain in TIPSY, by species.

Species	Selection age	Index age
Coastal Douglas-fir	12	60
Western hemlock	15	60
Western redcedar	10	60
Sitka spruce	8	60
Interior lodgepole pine	10	60
White spruce	15	80
Interior Douglas-fir	10	60

Including gain in the yield projections implies that a reliable supply of seed with known percentage gain is available. The MoF Tree Improvement Branch should confirm this availability before gain figures are used in timber supply analysis. Percentage gain (GW) for any individual seedlot can be obtained from the SPAR database.

4.4 Adjusting Management Information

Genetic gain affects projections of several stand attributes. In timber supply analysis the most important of these are height, volume, and diameter. These changes affect two key data items in addition to volume tables:

- minimum harvest age, which is usually based on volume and diameter, and
- green-up age, which is a function of height.

New values should be calculated for each of these parameters for each new analysis unit.

4.5 *Assessing the Effects of Genetic Gain*

The effect of genetic gain on timber supply can be measured by comparing forecasts for scenarios with and without genetic gain. If "current management" is taken to exclude the use of select seed, then the TSR base case represents the "without genetic gain" scenario. However, comparing scenarios requires that they be based on the same basic data to avoid confounding effects.

If the land base and inventory have been restructured to include SPZs and elevation bands, a new base case without genetic gain must be projected so that subsequent scenarios reflect the effects of genetic gain and not the effects of restructuring the data. The forecast for the new base case scenario should be based on the new analysis units, but with no genetic gain incorporated in yield tables, green-up age, or minimum harvest age.

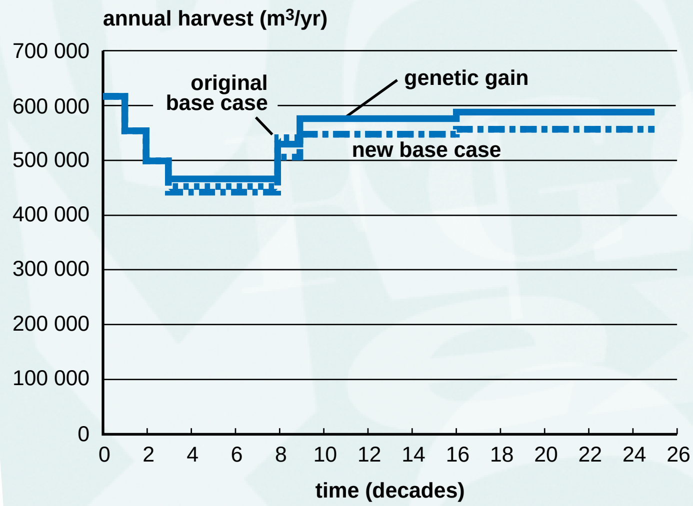

Figure 6
Timber harvest scenarios for Arrow TSA (after Wang and Listar).

Once the new base case has been established, genetic gain can be incorporated by adjusting yield tables, green-up ages, and minimum harvest ages. The genetic gain scenario forecast can then be prepared. The difference in harvest level between the new base case scenario and the genetic gain scenario quantifies the effect of genetic gain on timber supply.

In the Arrow TSA study, the new base case harvest level was slightly lower than that in the original base case in decades 4–9, but was otherwise identical. The difference was due mainly to the redefinition of analysis units and modified regeneration assumptions (Figure 6). The harvest level for the genetic gain scenario was about 5% higher than that of the new base case scenario from decade 4 to the end of the planning horizon.

5.0 Conclusions

Recognizing SPUs is a key step in accounting for gain in timber supply analysis.

The Arrow TSA study showed a clear timber supply effect (of about 5%) attributable to using select seed, with increases in potential harvest level occurring as early as decade 4 even though the hectares on which the extra volume is growing will not actually be harvested until much later. This effect occurs because of increases in volume, and changes in green-up height and minimum harvest age.

The Arrow TSA study demonstrated a more detailed approach for representing tree improvement effects than has been previously used with the MOF timber supply model, FSSIM. Recognizing SPUs (SPZs and elevation bands for each species) in the land base and inventory information is a key step in accounting for gain in timber supply analysis and strategic silviculture plans.

While more general approaches for incorporating genetic gain (e.g., increasing volume in yield tables by a given percentage) may produce results similar to those found in the Arrow TSA study, explicitly incorporating gain in the timber supply model greatly reduces uncertainty around expected benefits—an important narrowing of the "confidence interval" around the timber supply forecast.

We are clearly still learning how to incorporate genetic gain in timber supply analysis. The Arrow TSA study provided valuable insights, and helped focus attention on improvements needed in data and modelling tools. As a result, important changes have recently been made to TIPSY, allowing genetic gain to be specified as a parameter for each species. Also, SPAR has been modified to display genetic gain (GW) for each seedlot.

Tree Improvement Branch is currently developing a new Web-based mapping system, *SeedMap*, that will give Internet browser access to seed planning maps and associated spatial and attribute data summary reports.[8] Map queries will enable clients to access information on spatial data as well as summary species plan, seed use, genetic gain, and inventory data. Ensuring direct access to genetic gain information and relevant SPU maps will provide the tools needed to incorporate genetic gain into timber supply analysis well into the future.

[8] A pilot release of SeedMap is planned for April 2001.

6.0 References

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