Spatially Explicit Genetic Gain Estimates in Operationally Applied Timber Supply Analyses

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EXECUTIVE SUMMARY

The use of genetically improved stock is an operational forest management strategy designed to improve stand yields, reduce economic rotations, and accelerate greenup rates. Collectively, these stand-level factors can have a positive impact on forest-level timber supply opportunities. This report provides insight into these effects by documenting the results of two timber supply analysis projects within the Nelson Forest Region. The specific study areas include the Arrow and Golden Timber Supply Areas.

While the current methodology employed in the provincial timber supply review process addresses the age-dependent nature of the genetic worth (GW) effect, there are several outstanding issues which, if explicitly addressed, could enhance the utility of the attendant timber supply analyses. These factors include:

- Variation in genetic gain associated with elevational differences;
- Allowance for future increases in orchard production;
- Reconciliation of seedling supply/demand budgets;
- Consideration of all stand-level factors impacted by GW expectations; and
- Examination of timber supply sensitivity to changes in improved seed supplies.

In both of the studies documented in this report, the approach was to develop operationally feasible methods of incorporating these effects into timber supply analyses, capturing the key elements associated with genetic gain. Through the provincial seed orchard program, genetic worth estimates have been defined in a spatially explicit manner, based on the establishment of Seed Planning Units (SPUs). SPUs are defined using combinations of administrative units, ecological boundaries, species and elevation.

The geographic resolution of the genetic worth information differed between the two studies. However, in both cases, the analyses employed the following steps:

1. Establish base case forecast without genetic gain;
2. Define genetic gain strata;
3. Subdivide base case analysis units by genetic gain strata;
4. Develop elevation-specific silviculture strategies;
5. Establish planting requirements by elevation and species;
6. Develop genetically improved managed stand yield estimates, and;
7. Develop new timber supply forecast.

The results of these analyses demonstrated the advantages associated with a more spatially-explicit accounting of the factors associated with genetic gain. This greatly reduces uncertainty around expected benefits, and therefore improves the basis for strategic program planning.

A methodology is proposed which can be implemented as part of the ongoing timber supply review process within BC. This methodology employs the following 8 steps:

1. Identify the geographic zones(seed planning units) within the TSA;
2. Define the GW estimates by species within each SPU;

3. Determine the share of total seed production within each zone;
4. Define analysis units and their attendant regeneration strategies
5. Incorporate the full genetic gain into each planted yield curve;
6. Set up reporting structure;
7. Assess the seedling demand based on the area harvested by analysis unit; and
8. Modify the managed yield expectations if a deficit in supply is identified.

The advantages in applying this spatially explicit approach lie in the increased opportunities it provides for effective strategic planning of silviculture and genetic improvement programs

The results of applying the approach may or may not result in timber supply forecasts which differ from the more general approaches employed in Timber Supply Review (TSR). The approach will however result in a reduction in uncertainly around these forecasts.

This increased spatial resolution is a natural outcome of the planning efforts underway within the Tree Improvement Branch, and as timber supply analyses become more spatially explicit in nature the logistics of incorporating this information into TSR analyses becomes more apparent.

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1. INTRODUCTION

The use of genetically improved stock has been identified as a key silviculture element for impacting timber flow and harvest levels within a given management unit. Genetic gain has been shown to not only increase timber volume yields, but also, in some cases, reduce minimum harvest age and age to green-up. This has been demonstrated is two recent studies undertaken in the Ministry of Forests (MoF) Arrow and Golden Timber Supply Areas (TSAs) within the Nelson Region. (TFIC, 2000, Golden ,2001). This technical report has been prepared to provide recommendations on how to operationally model the incorporation of genetic gain into timber supply analyses based on results obtained from the above studies. The report is designed to help enhance future timber supply analyses where current processes and standards will likely be reviewed and revised further to meet new policy requirements.

Genetic gain has been defined as "the percentage increase in certain traits (e.g., stem volume, relative wood density, or pest resistance) of trees grown from orchard seed, over those grown from wild-stand seed" (Cortex, 2000). Specifically in the case of stem volume, it is the "percent gain in merchantable (12.5+ cm) volume per hectare expected 60 years after planting (80 years for white spruce)"[1].

Methodologies described here are based on employing the MoF Table Interpolation Program for Stand Yield (TIPSY) and Forest Service Simulator (FSSIM) models. The report identifies key areas in which approach and methodologies may differ between current Timber Supply Review (TSR) practices and those used in more detailed genetic studies (Arrow & Golden). Practical applications based on results obtained from the Arrow and Golden studies will be discussed. The main focus of the report will be to provide technical recommendations to better incorporate genetic gain into future timber supply analyses (TSR3, IFPA's, TFL's) for use at the operational level.

Recommendations are largely based on results obtained from the Arrow and Golden genetic studies with some input provided from experience gained through ministry-based TSR2 analyses. This report is intended to assist seed planners and timber supply analysts in moving towards a more spatially driven genetic gain/TSR model. It is also intended to provide insight and practical options as to how modifications to existing data capture protocols and methodology could provide more streamlined solutions for the incorporation of genetic gain into timber supply.

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[1] BatchTIPSY version 3 online help.

2. BACKGROUND

2.1 TSR 2 Methodology

Prior to 1999, average volume adjustments of between 2% and 8% were applied to stand yield curves in limited cases on some Tree Farm Licenses (TFLs). While these adjustments were assumed to reflect improvement at rotation, the method of application was simply to apply a constant adjustment across time. The risk associated with this approach is that gains may be underestimated prior to rotation age, and overestimated after rotation age.

To accommodate this, changes to the functionality within TIPSY were made to permit the inclusion of genetic worth (GW) estimates. This approach more appropriately accounts for the selection age / harvest age genetic correlations (Ministry of Forests, 1999). The plantation yield curves which have been adjusted in this manner are then incorporated into the attendant timber supply analyses, thereby reflecting timber supply impacts associated with the use of genetically improved seed sources.

While the current methodology employed in TSR2 addresses the age-dependent nature of the GW effect, there are several outstanding issues which, if addressed in future analyses, could enhance the utility of these analyses. These factors include:

- Variation in genetic gain associated with elevational differences;
- Allowance for future increases in orchard production;
- Reconciliation of seedling supply/demand budgets;
- Consideration of all stand-level factors impacted by GW expectations; and
- Examination of timber supply sensitivity to changes in improved seed supplies.

Two TSA studies recently completed within the Nelson Region identified opportunities to incorporate these factors.

2.2 Arrow TSA Study

A more detailed analysis of the impacts of genetic gain on timber supply was undertaken for the Arrow TSA (TFIC, 2000). This section presents a brief synopsis of this work.

The following steps describe the methodology applied in the Arrow analysis.

8. Establish base case forecast without genetic gain;
9. Define genetic gain strata;
10. Subdivide base case analysis units by genetic gain strata;
11. Develop elevation-specific silviculture strategies;
12. Establish planting requirements by elevation and species;
13. Develop genetically improved managed stand yield estimates, and;
14. Develop new timber supply forecast.

2.2.1 Establish base case forecast without genetic gain

As the TSR2 analysis results for the Arrow TSA were not available at the initiation of the genetic gain analysis project, the base case forecast established for the Arrow IFPA

(TFIC, 1999) was used as the benchmark against which to measure the forest level impacts of the seed orchard program. This analysis employed all of the inputs associated with the TSR2 analysis, and followed the typical analysis protocol, as outlined below.

1. Definition of the net timber harvesting landbase;
2. Characterization of current forest management practices;
3. Establishment of biodiversity objectives;
4. Development of stand-level growth and yield relationships;
5. Characterization of current harvesting and silvicultural practices; and
6. Modeling the dynamics of forest-level development.

The results of the IFPA base case analysis determined that a harvest of 615,000 cubic metres/year (m^3/yr) could be maintained for one decade, after which the harvest was reduced in two decadal steps to a mid-term level of 451,000 m^3/yr. A long-term level of 557,000 m^3/yr was projected in the IFPA analysis (see Figure 2.1).

2.2.2 Define genetic gain strata

Seed orchards are designed to produce seed for a specific species seed planning zone (SPZ) and elevation band. Genetic gains, seedling supply and requests are also tracked and forecast for each SPZ and elevation band.

Six elevation bands were defined for the Arrow analysis: below 1000m, 1000-1300 m, 1300-1400 m, 1400-1500 m, 1500-1700 m, and above 1700 m. Using the Geographic Information System (GIS), these elevation bands were overlaid with the Nelson SPZ[2] to spatially define the genetic gain strata needed to geo-reference the genetic gain expectations. The genetic gain strata were then incorporated into the resultant database prepared for the Arrow genetic gain analysis, thus providing a spatially explicit link to the parameters necessary for modeling genetic gains.

2.2.3 Subdivide base case analysis units by genetic gain strata

Analysis units (AUs), initially defined for the IFPA base case on the basis of inventory type group, site productivity, stand age and silvicultural regime, were further subdivided by genetic gain strata. This extra stratification of AUs provides the resolution necessary to incorporate species/elevation-specific genetic gain factors into the development of yield forecasts for future managed stands. This step also introduces added complexity to the analysis due to the large number of AUs produced by the additional level of stratification. The initial 64 AUs (32 each for natural and managed stands) defined for the Arrow base case were transformed into 408 AUs for the genetic gain analysis.

2.2.4 Develop elevation-specific silviculture strategies

After redefining the AUs as described above, the Arrow analysis initially proceeded by applying the TSR2 regeneration assumptions which define species compositions in managed stands. For TSR purposes regeneration strategies are generally based on TSA-wide expectations and do not take into account the elevational differences in species composition necessitated by silvics. With the added resolution of elevation built into this analysis, the assumptions were found to produce unrealistic results at the extreme ends of

[2] The Arrow TSA lies entirely within this single SPZ.

the elevation range. Consequently new silviculture strategies were defined for each elevation band to better reflect operational and silvicultural realities across the elevation range in the TSA. The revised species compositions were used to develop a new set of managed stand yield tables (still without genetic gain), and a revised base case harvest forecast was established.

2.2.5 Establish planting requirements by stratum

Based on the revised base case harvest forecast established using the modified analysis units and silvicultural assumptions, seedling requirements were estimated for each species and elevation band for the first two five-year periods of the analysis (i.e. years 1-5, and years 6-10). The seedling demand estimates were compared to seedling supply data for each species and elevation band, and were used to derive final genetic gain values for each species in each genetic gain stratum, based on the expected blend of "class A" and wild-stand seedlings used to fulfill the modeled planting requirements.

2.2.6 Develop genetically improved managed stand yield estimates

Managed stand yield forecasts were developed[3] using the genetic gain values and elevation-specific regeneration assumptions. The new MSYTs were in turn used to derive new minimum harvest ages (MHAs) for each AU, and new green-up ages for each forest level disturbance constraint zone. At the forest level, the genetic gains resulted in an average 4 year reduction in minimum harvest age and an average 1 year reduction in green-up age.

2.2.7 Develop new timber supply forecast

Based on the revised AUs, MSYTs, MHAs and green-up ages, a new harvest forecast was established. The three harvest forecasts developed in the Arrow genetic gain analysis are shown in Figure 2.1. The revised base case differed slightly from the IFPA base case as a consequence of the revisions to analysis unit structure and regeneration assumptions. The revised base case forecast therefore is the appropriate benchmark against which to compare the forecast incorporating genetic gains. Increases in timber supply over the revised base case forecast are apparent as early as decade 4 of the simulation, due to the impact of the reduction in green-up ages. The more significant increases in timber supply due to reduced minimum harvest ages and increased managed stand yields begin in decade 6. The relative increase in timber supply was 5.7% in decades 4 through 8, 4.5% in decade 9, 5.5% in decades 10 through 16 and 5.4% in decades 17 through 25.

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[3] MSYTs were developed using batch TIPSY version 2.1.

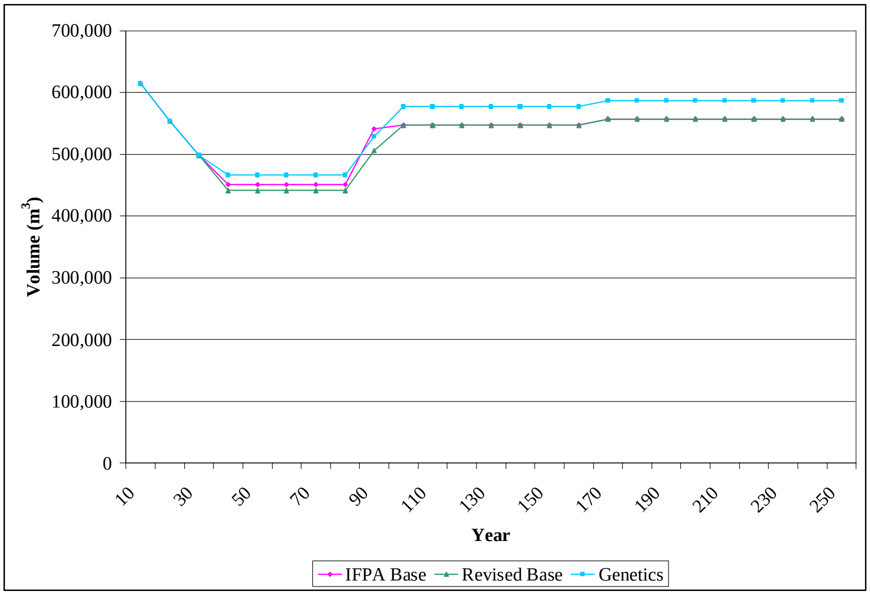

Figure 2.1 Harvest forecasts, Arrow genetics analysis

The Arrow genetics analysis also explored the targeted application of limited orchard stock to different portions of the landbase through several sensitivity scenarios. In all scenarios the methodology for introducing genetic gain estimates into the analysis was identical to the process described above.

2.3 Golden TSA

A subsequent analysis was undertaken to explore the timber supply impact of genetic gains for the Golden TSA (TFIC, 2001). The basic outline of the methodology was the same as for the Arrow analysis:

1. Establish base case forecast without genetic gain;
2. Define genetic gain strata;
3. Subdivide base case analysis units by genetic gain strata;
4. Develop elevation-specific silviculture strategies;
5. Establish planting requirements by elevation and species;
6. Develop genetically improved managed stand yield estimates, and;
7. Develop new timber supply forecast.

The fundamental difference in methodology between the two projects was the way in which genetic gain strata were defined for the Golden analysis. This is discussed in greater detail below.

2.3.1 Establish base case forecast without genetic gain

The spatial resultant database and assumptions developed by the Ministry of Forests for TSR2 were used to reconstruct the TSR2 base case as closely as possible. The reconstruction was unable to fully replicate the TSR2 base case harvest flow. Nonetheless the reconstructed TSR2 base case provided the initial benchmark against which to measure the impact of incorporating genetic gains into managed stand yield forecasts. The TSR2 reconstruction determined that an initial harvest level of 535,000 m^3/yr could be maintained for two decades, followed by a reduction over two further decades to a long-term harvest level of 433,350 m^3/yr.

2.3.2 Define genetic gain strata

Subsequent to the Arrow analysis, the Tree Improvement Branch (TIB) of the MoF introduced new geographic units called seed planning units (SPUs). SPUs subdivide the larger SPZs by elevation band and tree species and are used to develop species plans, including breeding and seed production projections, propagation and management activities, analyses of current and proposed seed orchards, timelines for genetic improvement, projected supply and demand for seedlings, and projected genetic gains.

SPUs provide a direct geo-referenced linkage to the parameters required for introducing expected genetic gains into the yield forecasts for managed stands. Consequently, the SPUs that intersect the Golden analysis area[4] were used as the basis for defining genetic gain strata. The SPUs for the Golden genetic gain analysis are listed in Table 2.1

Table 2.1 Seed planning units in the Golden analysis area

SPU	Description	Elevation
Fdi EK all	Douglas fir E. Kootenay SPZ	0-1500
Fdi NE high	Douglas fir Nelson SPZ	1000-1500
Fdi NE low	Douglas fir Nelson SPZ	0-1000
Fdi QLN all	Douglas fir Quesnel/Nelson SPZ overlap	0-1500
Pl EK high	Lodgepole Pine E. Kootenay SPZ	1400-2000
Pl EK low	Lodgepole Pine E. Kootenay SPZ	0-1400
Pl NE high	Lodgepole Pine Nelson SPZ	1400-2000
Pl NE low	Lodgepole Pine Nelson SPZ	0-1400
PL PG high	Lodgepole Pine Pr. George SPZ	1100-2000
PL PG low	Lodgepole Pine Pr. George SPZ	0-1100
Pl PGN high	Lodgepole Pine Pr.George/Nelson SPZ overlap	1400-2000
Pl PGN low	Lodgepole Pine Pr. George/Nelson SPZ overlap	0-1100
Pl PGN mid	Lodgepole Pine Pr. George/Nelson SPZ overlap	1100-1400
Pw KQ all	Western White Pine E. Kootenay/Quesnel SPZ	400-1400
Sx EK all	Spruce E. Kootenay SPZ	0-1700
Sx NE high	Spruce Nelson SPZ	1300-1700
Sx NE low	Spruce Nelson SPZ	0-1300
Sx NEK high	Spruce Nelson/E. Kootenay SPZ overlap	1300-1700

[4] The Golden analysis area was defined in TSR2 as the combined extent of the Golden TSA and the immediately adjacent provincial and federal parks.

Since each SPU is defined by a particular species and it's elevational ranges within a particular SPZ, SPUs can and do overlap each other. Thus the SPUs were overlaid in the GIS to create a unique genetic gain stratum for each hectare of the Golden analysis area. The resulting genetic gain strata are listed in Table 2.2 (adapted from TFIC, 2001). The elevation band occupied by each stratum was determined from the elevation ranges of the contributing SPUs.

Table 2.2 Genetic gain strata defined for the Golden analysis area

SPU Stratum	Elevation (m)	Contributing Seed Planning Units
1	all	None
2	1400-2000	Pl PGN high
3	1400-1700	Pl PGN high, Sx NE high
4	1100-2000	Pl PG high
5	1300-1700	Pl PG high, Sx NE high
6	1400-2000	Pl NE high,
7	1400-1700	Pl NE high, Sx NEK high
8	1400-1700	Pl NE high, Sx NE high
9	1400-2000	Pl EK high
10	1400-1700	Pl EK high, Sx EK all
11	400-1000	Fdi QLN low, Pl PGN low, Pw KQ all, Sx NE low
12	400-1000	Fdi QLN low, Pl NE low, Pw KQ all, Sx NE low
13	1100-1300	Fdi QLN high, Pl PGN overlap, Pw KQ all, Sx NE low
14	1300-1400	Fdi QLN high, Pl PGN overlap, Pw KQ all, Sx NE high
15	1000-1100	Fdi QLN high, Pl PGN low, Pw KQ all, Sx NE low
16	1400-1500	Fdi QLN high, Pl PGN high, Sx NE high
17	1000-1300	Fdi QLN high, Pl NE low, Pw KQ all, Sx NE low
18	1300-1400	Fdi QLN high Pl NE low, Pw KQ all, Sx NE high
19	1400-1500	Fdi QLN high, Pl NE high, Sx NE high
20	400-1100	Fdi QL all, Pl PG low, Pw KQ all, Sx NE low
21	1300-1500	Fdi QL all, Pl PG high, Sx NE high
22	1100-1300	Fdi QL all, Pl PG high, Pw KQ all, Sx NE low
23	1300-1400	Fdi QL all, Pl PG high, Pw KQ all, Sx NE high
24	400-1000	Fdi NE low, Pl NE low, Pw KQ all, Sx NE low
25	1000-1300	Fdi NE high, Pl NE low, Pw KQ all, Sx NE low
26	1300-1400	Fdi NE high, Pl NE low, Pw KQ all, Sx NE high
27	1400-1500	Fdi NE high, Pl NE high, Sx NE high
28	400-1400	Fdi EK all, Pl EK low, Pw KQ all, Sx EK all
29	1400-1500	Fdi EK all, Pl EK high, Sx EK all

2.3.3 Subdivide base case analysis units by genetic gain strata

To provide the linkage from forest inventory polygons to the genetic gain parameters, genetic gain strata were used to subdivide the analysis units defined during the reconstruction of the TSR2 base case. This additional stratification of the inventory resulted in 420 natural stand AUs, and 448 managed stand AUs (collectively referred to as genetic AUs).

2.3.4 Develop elevation-specific silviculture strategies

For the purposes of this study, MoF staff defined regeneration strategies (i.e. species compositions) for each TSR2 AU, and for three elevation bands: below 1100 m, 1100 to 1500 m, and above 1500 m. It was necessary to then apply these regeneration specifications to the genetic AUs and genetic strata elevation bands shown in Table 3.2, using the following procedure.

By definition, each managed stand GAU represents a particular combination of TSR2 AU and genetic gain stratum. As a consequence of its membership in a particular stratum, each genetic AU therefore lies within a specific range of elevation. Therefore each genetic AU was assigned the species composition corresponding to its TSR2 AU and elevation band. In cases where the elevation range of the genetic AU spanned two of the elevation bands identified in. Table 2.2, the species compositions for the two bands were averaged.

As in the Arrow analysis, the revised regeneration strategies were used to develop new managed stand yield tables (without genetic gain), which were in turn used in developing a revised base case harvest forecast (see Figure 2.2).

2.3.5 Establish planting requirements by elevation and species

Based on the revised base case harvest forecast established using the genetic AUs and silvicultural assumptions, annual seedling requirements were estimated for each genetic gain stratum (averaged over the first twenty years of the planning horizon). The seedling demand estimates were compared to seedling supply data for each genetic gain stratum, and were used to derive final genetic gain values for each stratum based on the expected blend of "class A" and wild-stand seedlings used to fulfill the modeled planting requirements.

2.3.6 Develop genetically improved managed stand yield estimate

Managed stand yield forecasts were developed[5] using the blended genetic gain values and elevation-specific regeneration assumptions. The new MSYTs were in turn used to derive new minimum harvest ages (MHAs) for each AU, and new green-up ages for each forest level disturbance constraint zone.

2.3.7 Develop new timber supply forecast

A new harvest forecast was established based on the revised AUs, MSYTs, MHAs and green-up ages,. The three harvest forecasts developed in the Golden analysis are shown in

[5] MSYTs were developed using batch TIPSY version 3.0.

Figure 2.1, along with the TSR2 base case forecast. The revised base case forecast is the appropriate benchmark against which to compare the forecast incorporating genetic gains.

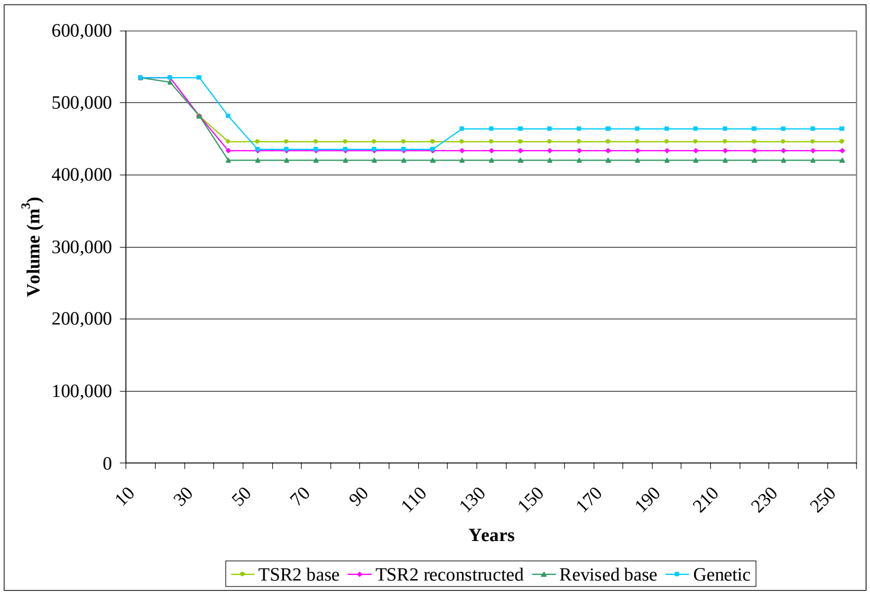

Figure 2.2 Harvest forecasts, Golden genetics analysis

As was done in the Arrow analysis, several different genetic scenarios were explored. The results of the full genetic gain scenario indicated three improvements in timber supply (when compared against the revised base case). In the short-term, the initial harvest level could be maintained for an additional decade. The medium-term harvest level was increased by approximately 4%, and the long-term by 13%.

3. RECOMMENDATIONS

3.1 Rationale for Change

Timber supply forecasting is a spatial problem. While the tendency has been to distinguish between “aspatial ”and “spatial “analyses, in reality the distinction is one of spatial scale, as all of these analyses incorporate spatially defined components. Table 3.1 provides a simple description of the current spatial scales employed in TSR analyses on TSAs. In this table, a management zone is considered to be the geographic area over which a forest cover constraint is applied. A class represents an aggregate of all forest stands with common analysis unit, age and management zone characteristics.

Table 3.1. TSR 2 spatial scales

Analysis component	Spatial Scale		
	TSA	Management Zone	Class
Inventory			**X**
Harvest schedule	**X**		
Management rules		**X**	
Regeneration rules	**X**		
Growth and yield	**X**		
Genetic gain	**X**		

In considering increasing the resolution of any of these scales, it should be understood that a more geographically specific approach may not result in a TSA-level timber supply forecast which differs significantly from that derived using the existing spatial scales. The advantage lies in a reduction in uncertainty resulting from a more explicit accounting of factors related to timber supply, such as the geographic distribution of the harvest and the way in which timber supply is constrained spatially are examples of this. While the overall forecasted timber flow may not differ significantly, the opportunities to make informed management decisions based on analysis results is enhanced.

In the case of genetic gain issues, further advantages lie in a more explicit accounting of factors surrounding the seed orchard program (TFIC, 2000). These factors include:

- Variation in genetic gain associated with elevational differences;
- Allowance for future increases in orchard production;
- Reconciliation of seedling supply/demand budgets; and
- Consideration of all stand-level factors impacted by genetic gain expectations.

As an example of spatial variation, in the Golden TSA genetic gain estimates for Douglas-fir range from 9 to 26 %, and for spruce from 12 to 25%. The genetic gain expected on a specific area is determined by its geographic position within the TSA. Explicit spatial definition of these factors therefore greatly reduces uncertainty around expected benefits, and therefore improves the basis for strategic program planning.

Considerable investments have been made through the Forest Genetics Council and the MoF to geo-reference seedling supplies and their attendant genetic gain values. To capitalize on this information, it is essential to link these supplies to the seedling demand associated with a specific landbase (TSA/TFL). This in turn requires that the spatial scales of both supply and demand be harmonized. Demand is driven by the interaction between the harvest schedule and the regeneration strategy. As it relates to seedling demand, the latter can be simply defined as the species mix used to regenerate a specific harvested area.

For example:

Harvested area: 100 ha

Regeneration strategy: Douglas-fir 50%, Spruce 30%, Pine 20%

Planting density: 1000 stems/ha

	Douglas-fir	**Spruce**	**Pine**
Species %	50%	30%	20%
Stems/ha	500	300	200
Seedling Demand	50000	30000	20000

The spatial distribution of the demand for seedlings is driven by the spatial distribution of the harvest schedule, which is in turn largely driven by the zonal constraints defined by different non-timber objectives. These constraints change over the time horizon of the timber supply forecast, and therefore have the effect of altering the spatial distribution of the harvest and the attendant demand for seedlings.

3.2 Proposed Methodology

To capitalize on this planning opportunity in future timber supply analyses, and based on experience gained through the studies described in the previous sections, the following methodology is proposed, including the identification of any critical implementation issues.

3.2.1 Spatial data preparation

Step 1. Identify the geographic zones(seed planning units) within the TSA

Two sets of SPZs are currently in use in the interior:

1. Natural stand SPZs (of which there are 24 zones covering all species) based on a combination of administrative (district) and ecological (BEC) boundaries and
2. Orchard (Class A) SPZs (which are species-specific - Fdi, Lw, Pli, Pw and Sx) based for the most part on BEC, with some alignment with lines of latitude and longitude.

Coastal SPZs (1 set covering both major and minor species) are based on BEC boundaries, including the boundary between the coastal/interior SPZs.

Note: The interior natural stand SPZs can not easily be georeferenced, therefore, a proposed provincial SPZ model that incorporates natural stand SPZs within the orchard species model (i.e. major versus minor species maps) is planned for implementation in Fall 2003. This proposed model will likely include revisions (i.e. lines of latitude) to the coastal SPZ's to better incorporate species ranges within the SPZ boundaries.

SPUs are based on species, seed planning zone and elevation. For some coastal species, lines of latitude (as an interim step to the proposed changes above) were added to the coastal SPUs to denote the northern limit of the species' range.

As demonstrated in the two Nelson studies, SPZs or SPUs can be used to geo-reference the genetic gain information, either by incorporating elevation band polygons with the SPZs to define elevation-specific resultant polygons (Arrow study), or by employing the SPUs directly (Golden study). In either case, the resultant polygons must be assigned genetic gain parameters and regeneration strategies which are explicit to those polygons

The experience in the Arrow and Golden projects has shown that the methodology followed in the Arrow TSA genetic gain analysis produced a more tractable and flexible data model for analysis, in that regeneration assumptions were linked directly to the TRIM elevation bands, which were also used to define genetic gain within the zone. With the SPUs used in the Golden TSA analysis, it was necessary to infer elevation solely based on the ranges specified for each SPU, a situation complicated by partially overlapping SPUs (TFIC, 2001). Although the resolution of the elevation data in the Arrow study was more refined, SPUs are likely to remain the basic planning unit of the forest genetics program, and therefore the methodology developed should employ these units. The delineation of these bands would be specific to each TSA, dependant upon the characteristics of the SPUs.

Figure 3.1 depicts the relationship between elevation and seed planning units in the Golden TSA. There are nine elevation bands (defined by the blue horizontal lines) required to uniquely define the elevation breaks associated with the seed planning units. Clearly, the finest elevation bands are associated with the mid-elevations (1000-1400 metres).

New Biogeoclimatic (BEC) linework is currently being prepared, and will probably be employed in TSR3 to define old seral constraint zones. To minimize spurious data associated with combining this information with SPU boundaries, it is important that the latter be updated where necessary to conform to the new BEC linework.

Implementation Issue: *SPU data custodians within the TIB and MoF are currently developing spatial data update methodology to revise SPZ/SPU boundaries to be harmonized with the release of new BEC changes (Leslie McAuley, personal communication).*

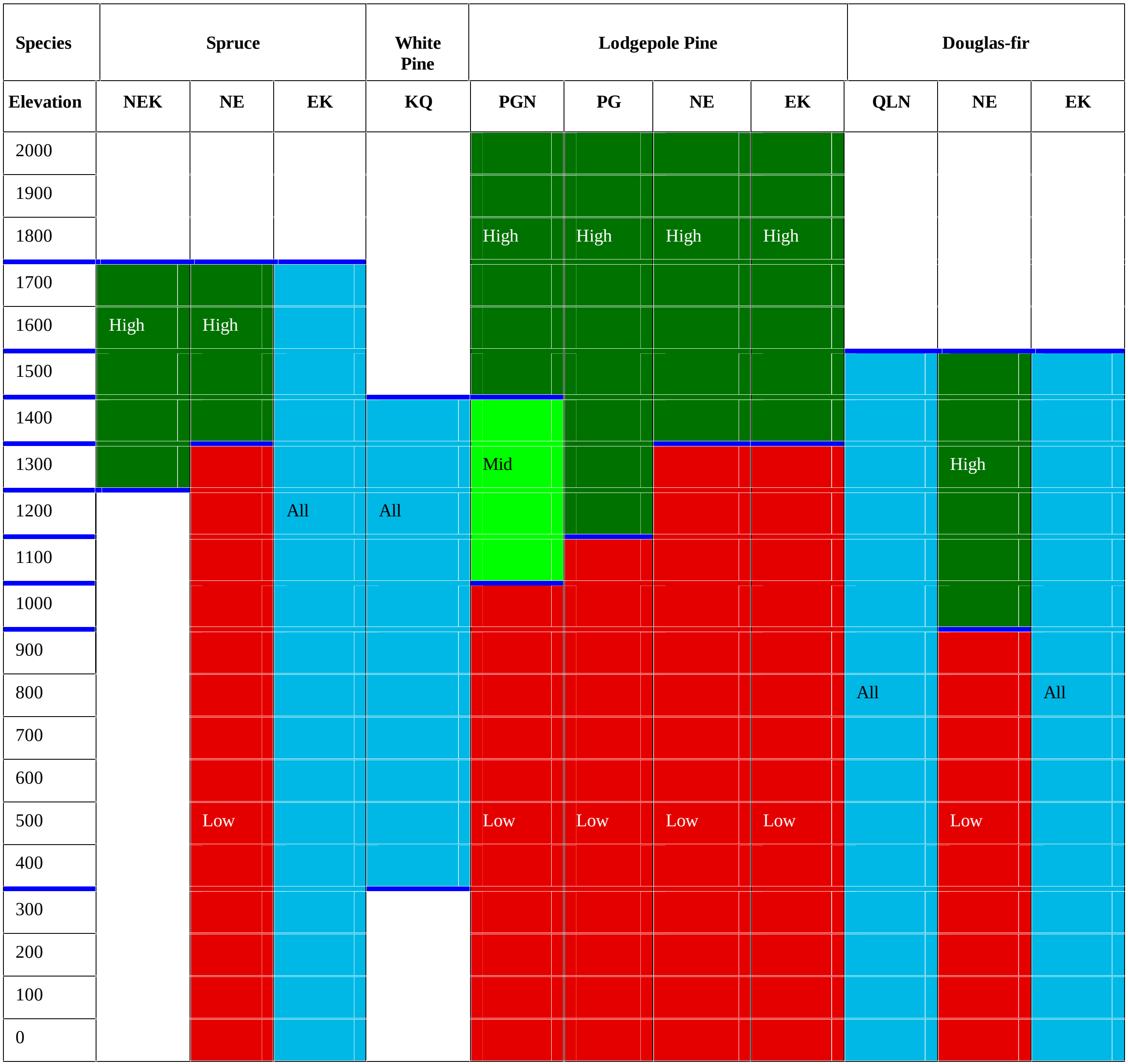

Figure 3.1. Relationship between elevation and seed planning units

Step 2. Define the GW estimates by species within each SPU

GW estimates are readily available from the Tree Improvement Branch. Genetic gain estimates are reviewed annually and updated to reflect new information, where required, by the Forest Genetics Council technical species subcommittees. There is usually a temporal scale associated with this information, in that GW estimates increase over time as orchard development progresses. Depending upon the duration of this 'ramp-up' period, there may be implications associated with the timing of benefits in a timber supply context. As discussed in the analysis steps, the significance of this ramp-up needs to be considered

Step 3. Determine the share of total seed production within each zone available to the TSA

This information can be obtained from the Tree Improvement Branch (TIB). Currently for planning purposes, the supply of seed from a SPU is assumed to be proportionally shared by users based on historical requests. Operationally however, seed is distributed on a first-come, first-served basis. (Leslie McAuley, personal communication) Therefore, there is some uncertainty with respect to future TFL/TSA seed supplies, in cases where the supply is less than demand.

Implementation Issue: *The TIB should investigate approaches to strengthen forecasts of seed distribution. It should be noted that, with the exception of lodgepole pine, improved seed supply is expected to meet demand within 10 years.*

3.2.2 FSSIM data model construction

Step 4. Define analysis units and their attendant regeneration strategies

Traditionally, analysis units have been defined based on existing inventory characteristics (species mix and current site index range), with "average" regeneration strategies assigned to these groupings. However, it is also reasonable to stratify or classify analysis units based on managed stand characteristics, with more of the averaging applied to existing inventory characteristics.

Under this approach, three themes are necessary to define analysis units:

- regeneration strategies defined by elevation band;
- GW assignments defined by SPU; and
- baseline productivity normally defined by site index range.

The intersection of these three themes provides the combinations used to develop TIPSY yield curves. Existing yield curves (usually developed using the VDYP model), would then be developed based on the average existing yield characteristics for each of these strata. If it appears that this results in an unacceptable level of averaging, the strata could be further subdivided based on existing inventory parameters, such as inventory type group. Regardless, a significant increase in the number of analysis units is inevitable under this approach. It is strongly recommended that an effort be undertaken by the Tree Improvement and Forest Practices Branches, to facilitate this step. Genetic improvement and regeneration strategies are logically linked strategic planning processes, and their coordination is logical.

Coordination at this step is critical to streamlining the methodology. A joint effort to link genetic gain and regeneration inputs in a spatial environment is the key to making this practical in a TSR context.

Step 5. Incorporate the full genetic gain into each planted yield curve

This is easily accomplished using current TIPSY functionality, and assuming no supply deficit. This step must include increases in yield, changes to minimum harvest ages, and calibration of greenup ages.

Increases in yield are captured through the genetic gain functionality incorporated into the current version of TIPSY. However, anomalies can be created at older ages using this functionality. Specifically, TIPSY predicted decreased volume at increased genetic gain at older ages for several large analysis units (Golden). This apparent anomaly arises from the need to extrapolate TIPSY yield curves beyond the current data ranges in order to predict volumes at older ages (300 years) for timber supply analysis purposes. (Ken Mitchell, Albert Nussbaum, personal communication).

Implementation Issue: *Development of Future versions of TIPSY will address this issue. (Albert Nussbaum, personal communication).*

Given the potentially large number of analysis units generated in this process, minimum harvest age determination should use quantitatively based rules, rather than relying on professional judgment. Criteria such as minimum volume, piece-size and relationship to MAI culmination are examples of quantitative criteria that are currently employed.

Greenup requirements within FSSIM are currently specified using age-based forest cover constraints, while operationally these are height-based constraints. A conversion is therefore required based on the average age required to achieve the target greenup height within a given management zone. As these management zones typically span a range of SPUs, this approach dilutes the genetic gain effects on greenup requirements. It is recommended that FSSIM functionality be expanded to permit the specification of height-based constraints. This functionality was pursued in earlier versions, but is not implemented in the current version.

Implementation Issue: *Height-based greenup constraint functionality will be implemented in the next version of FSSIM (Dave Waddell, personal communication).*

As discussed in the previous step, there may be a ramp-up of GW values, which should be considered in developing yield curves. This can be accommodated in FSSIM utilizing the Transfer functionality to alter regeneration responses over time. While this is possible, it can be computationally cumbersome where there are a large number of analysis units. As a rule of thumb, where the duration of the ramp-up period to full expected genetic gains is on the order of one or two simulation time steps, this complexity could be ignored, and the full genetic gain applied from the start of the simulation.

Step 6. Set up reporting structure

The timber supply analysis data model should be set up to report on area harvested by analysis unit. This is essential to predict seedling demand by SPU.

3.2.3 Analysis of results

Step 7. Assess the seedling demand by species and SPU based on the area harvested by analysis unit.

Step 8. Modify the managed yield expectations if a deficit in supply is identified. This is most appropriately accomplished by proportioning regeneration responses into two yield responses (with and without GW) using the percent regeneration functionality within FSSIM. Varying these proportions in successive FSSIM runs provides a measure of the benefits to be accrued from future increases in production.

4. SUMMARY

The Arrow and Golden projects afforded opportunities to demonstrate the feasibility of incorporating tree improvement genetic gain information into forest level timber supply analyses in a spatially explicit manner.

The advantages in applying this spatially explicit approach lie in the increased opportunities it provides for effective strategic planning of silviculture and genetic improvement programs. As discussed earlier, these opportunities include:

- Accounting for variation in genetic gain associated with elevational differences;
- Allowance for future increases in orchard production;
- Reconciliation of seedling supply/demand budgets;
- Harmonizing of regeneration strategies and tree improvement programs; and
- Consideration of all stand-level factors impacted by genetic gain expectations.

The results of applying the approach may or may not result in timber supply forecasts which differ from the more general approaches employed in TSR. However, the approach will result in a reduction in uncertainly around these forecasts.

This increased spatial resolution is a natural outcome of the planning efforts underway within the Tree Improvement Branch, and, as timber supply analyses become more spatially explicit in nature, the logistics of incorporating this information into TSR analyses becomes more apparent.

There is however, an attendant increase in the complexity of the data preparation, at both the GIS spatial data preparation and analysis unit/managed yield curve preparation stages. It is particularly important to harmonize the development of regeneration strategies with the elevation and species parameters associated with the seed planning units. Inevitably, the result will be an increase in the number of analysis units necessary to capture the combinations of species mixes and genetic worth likely to be encountered. While this requires additional data preparation, the experience in the Arrow and Golden projects indicated that it is a tractable problem, and one which can be accommodated using the existing forest level analysis tool (FSSIM). Again however, this experience underlined the need for careful design of the GIS and FSSIM data models.

The eight-step process outlined in the previous section reflects the experience gained in these two studies. Based on the potential improvements to strategic planning initiatives, It is recommended that the approach be considered in future strategic forest level analyses undertaken at the TSA/TFL level.

5. REFERENCES

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