Gowlland

Timber Supply Analysis as Risk Assessment

A "risk tranche" assessment in the Mackenzie Timber Supply Area

Oct 25, 2020

Oct 2020

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Overview

Various spatial pattern and temporal process elements of a forested landscape contribute to timber supply over time, with differing level of associated uncertainty or risk. For example, different geography regions may be differentially affected by access and transport costs, and hence economic conditions. As another example uncertainties associated with landscape-scale natural disturbance and potential effects from climate change, as well as management response (e.g. salvage), lead to uncertainty related to the degree of reliance on natural disturbance assumptions in timber supply projections. To address these uncertainties, timber supply analysis in support of the timber supply review process can be viewed as *risk assessment*. In this perspective, timber supply risk is defined as the likelihood that a given level of timber supply in one or more time periods will not be achieved in reality.

This memo presents practical methods in which we use structured sensitivity analysis to explore timber supply risk that we call the "*risk tranche*" approach. This approach applies the perspective that information on timber supply risk may be useful to better understand timber supply projections, and make decisions that anticipate and mitigate risk.

To provide a concrete illustration, we applied this method in the Mackenzie Timber Supply Area (TSA) using two different aspects of risk that are relevant in that TSA:

- Geographic access that recognizes the existence of areas with good and poor road access, and areas that rely on barge transport across the large Williston Reservoir.
- Wildfire is a significant agent of natural disturbance in Mackenzie TSA, with relatively high uncertainty regarding potential changes due to climate change, and the economics of salvage (especially if there is increased disturbance and/or changes in the age-class structure of disturbance stands over time).

The information used is draft information from the Mackenzie TSA timber supply review (TSR), and hence results were not meant to be directly compared with the TSR process. Rather, the goal is to demonstrate how this approach can be set up and applied in the context of a TSR analysis and other timber supply projects.

We use the SELES Spatial Timber Supply Model (STSM), which supports explicit modelling of natural disturbance processes in a way compatible with assessing timber supply.

1 Risk Tranche Method to Assess Timber Supply Risk

One primary goal of timber supply analysis is to identify the most likely maximum timber harvest level that can be sustainably harvested over time, based on the best available data and knowledge of the forest system, and subject to meeting the biophysical, economic and social objectives and constraints defined for a given scenario. The main scenario of focus, often called the "base case", is a representation of current management (e.g. current land-use objectives, current inventory, etc.).

There are multiple sources of uncertainty inherent to timber supply analysis, including:

- Data uncertainty: accuracy and completeness of forest inventory and other required spatial and non-spatial inputs.

- Natural process uncertainty: understanding of variable stand and landscape scale natural processes, such as tree growth, natural disturbance, and climate change.

- Operational uncertainty: variability of economic drivers of timber harvesting (including external effects such as markets, as well as aspects of decisions for which data is unavailable such as information from pre-harvest timber cruising) and access costs (including complex factors applied to develop multi-year access plans).

Much of this uncertainty cannot be significantly reduced in the foreseeable future (if ever). Hence, uncertainty should be accepted and addressed explicitly as a significant aspect of timber supply analysis.

One way that uncertainty has been addressed in timber supply analyses is via use of "sensitivity analyses", in which experiments vary one or more key parameter (e.g. increase or decrease managed stand growth by 10%). These provide useful information to understand the stability (resilience) of the base case projection. However, sensitivity analyses are typically applied as independent scenarios, each with a separate timber supply outcome.

We developed a method of structured analysis based on the financial concept of *risk tranches*. In complex financial investments, such as mortgage-backed securities, large collections of investments are stratified by risk class (from lower risk to higher risk), called tranches ("slices" in French), each of which contributes differently to expected levels of return as well as expected loss of capital (e.g. the nominal interest on "junk" bonds is higher than class A bonds, offsetting the higher levels of uncertainty of default).

We adapted this concept to timber supply assessment, in which components of a timber supply landscape system can be partitioned according to expected levels of risk due to their respective uncertainty. These components may be defined as elements of the state of the forest (e.g. existing mature volume, future managed yields) and/or elements of forest processes (e.g. potential increases in landscape scale disturbance or decreases in stand growth due to climate change).

A low risk tranche represents the portion of timber supply with high certainty of being achievable, while a high-risk tranche represents the portion of timber supply with lower certainty.

For example, low risk timber supply might consist of low-susceptibility stands in the existing inventory, regeneration with no projected improved future yields, stands in lower disturbance areas (e.g. areas with lower expectations of impacts from climate change). High risk timber supply might consist of stands with high-susceptibility to bark beetles or fire, assumptions about future yield improvements (e.g. anticipated genetic future gains in growth rate), stands in high disturbance areas (especially where disturbance can affect pre-merchantable stands) and stands in areas with high expected impacts from climate change.

By defining a set of risk classes in which higher risk categories embed lower risk categories, the resulting nested timber supply assessments can be expressed in terms of the contribution of each risk class to timber supply (i.e. identifying the *timber supply tranche* associated with the risk class). This provides a tool to help interpret the degree of risk associated with timber supply, and in particular how risk changes over time.

This document describes steps to apply this approach to assessing timber supply risk, and provides a practical application in Mackenzie TSA for illustration.

1.1 Step 1: Define risk classes

The first step is to define aspects of a timber supply system that have different levels of uncertainty or risk. This is dependent on the management unit, and may include one or more of the following:

- Geographic areas (e.g. high productivity, low elevation forests with good road access vs. lower productivity, high elevation forests that requires heli access or expensive road constructions)
- Forest type (e.g. cedar vs. hemlock that have different market values; old-growth vs. second growth)

- Regeneration assumptions (e.g. unmanaged natural regeneration vs. heavily managed regeneration with thinning, genetic improvements and fertilization)

- Natural disturbance (e.g. assumptions of low vs. high recovery of salvage)

- Climate change (e.g. historic wildfire levels vs. increased wildfire, climate refugia)

The approach can be applied using multiple factors, either by doing separate risk assessments for different sets of risk classes, or by combining factors into a single assessment.

At this stage, one needs to define the number of risk classes. A simple assessment may focus on just low vs. high risk, but a more detailed assessment may include a gradient of as many risk classes as desired.

1.2 Step 2: Structured sensitivity analysis

The basic method involves assessing a set of “nested” sensitivity analysis scenarios, in which risk monotonically increases as a gradient from more optimistic assumptions to more pessimistic assumptions. The first scenario to assess is the scenario with the most pessimistic assumptions (those of the lower risk class), which in general provides the lowest risk (most certain) timber supply projection.

Subsequent scenarios are then assessed, each incrementally adding the next lowest risk class. The timber supply outcome will normally be the same or higher than the previous outcome across all time periods. That is, because the included factors encompass those for a prior scenario, the resulting timber supply will generally be nested, with the subsequent scenario realizing an increased timber supply in one or more time periods (however, there can be complex interactions in which reductions in one time period can result in increases in another time period). The final scenario will include the timber supported by all risk classes.

Note that the “base case” scenario may be one of scenarios included in the risk analysis, placing it in context with higher/lower risk assumptions.

See Appendix 1 for details on how timber supply can be assessed for a given scenario using the STSM, although the general method can be applied with any timber supply tool.

1.3 Step 3: Overlay and assess results

Instead simply showing a timber supply “flow” a single line (potential volume harvested over time), the structured analysis of scenarios using risk classes allows timber supply to be shown as a surface (volume contributed from each risk class over time).

The resulting timber supply surface can then be examined for the magnitude and timing to which each risk class contributes to timber supply. Since uncertainty tends to increase over projected time, the contribution of future timber supply may come from increasingly risky classes. However, mid and long-term behaviour may have an effect on short term timber supply. Hence, higher risk timber supply classes may also contribute significantly to short term timber supply. That is because risk classes are assessed in terms of how they contribute to resulting timber supply, not to the exact stands harvested. For example, including a higher risk class may result in a significant increase in short term harvest levels. The stands harvested in the short term may be considered lower risk individually, but the timber supply assessment may allow a higher level of such stands to be harvested in the short term because of an assumption that higher risk stands will be available to support the mid and/or long-term.

2 Application in Mackenzie TSA: Risk Classes

In the Mackenzie TSA case study, we assessed two different sets of risk classes. In both cases, the lowest risk class represents the most pessimistic assumptions, and higher risk classes encompass the lower classes plus include timber supply that represents increasingly optimistic assumptions.

2.1 Geographic area risk classes

Like many TSAs in BC, Mackenzie TSA includes areas with easier as well as more challenging access. This was in part recognized in the previous TSR for Mackenzie TSA that included a partition zone in the southwest of the TSR that includes gentler terrain and a more developed road network.

A unique aspect of Mackenzie TSA is the relatively large area served by barge transport of logs across Williston Reservoir. Some barge transport areas consist of valleys in rugged terrain with disconnected road networks, completely accessed via the barge landing site (e.g. along Peace Arm). Other areas used barge transport due to the long distances required (e.g. north end of the reservoir), even though there are connecting roads (e.g. trucks may not have to be transported by barge, but log transport is more economic via barge). Further, some barge-transport areas also require long road transport to reach the landing.

Four risk classes were defined based on access and transport geography (Figure 1):

- Risk class 1: Areas accessible by “non-remote” roads in the southwest partition, which comprise 31% of the timber harvesting landbase (THLB).
- Risk class 2: Areas accessible by roads outside the southwest partition or from areas with “remote” road access, which comprise 14% of the THLB.
- Risk class 3: Areas that involve barge transport on Williston Reservoir and access via “non-remote” roads, which comprise 37% of the THLB.
- Risk class 4: Areas that involve barge transport and access via “remote” road access areas, which comprise 18% of the THLB.

Areas that require barging were identified using road landings on Williston Reservoir, and associated road sub-networks that were either (a) not connected to any other roads to the south end of the TSA; or (b) at the mid to northern end of the reservoir with the barge landing as the primary outlet for timber transport.

“Remote” road access was defined using estimated distance to either a road exit point on the southern boundary of the TSA or to a barge landing site. Distances more than 50km were classified as remote.

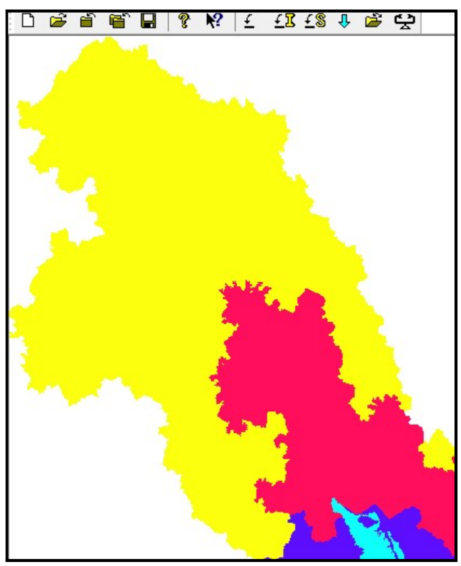

Figure 1. Geographic area risk classes in Mackenzie TSA: (1) light blue: non-remote road access areas in southwest partition that do not involve barge transport; (2) dark blue: areas outside southwest partition that do not involve barge transport; (3) red: non-remote road access areas that involve barge transport; and (4) yellow: remote road access areas that involve barge transport.

2.2 Natural disturbance risk classes

Parameters for historic/current wildfire were derived using the Provincial historic wildfire database, in which parameters were fitted to the historic fire size distribution using a log-transform:

- Rotation: 542 years
- Fire initiation: random in forested cells
- Fire patch size: log normal distribution with a mean of 4.755 and standard deviation of 2.471 for the underlying normal distribution. This resulted in a mean patch size of about 2,450 ha.
- Fire patch size: moderately complex (with shape complexity increasing with fire size, controlled by a maximum active front site of 30 grid cells).
- Salvage remaining post-fire: 80% (20% immediate loss due to fire)
- Salvage shelf life: 1 timestep (10 years).

Changes due to climate were modeled as dynamic adjustments to fire rotation. Wotton et al. (2017) estimated of expected change in key fire regime parameters for an area of boreal forest in central Alberta at 2030 and 2090 under moderate climate change (Representative Concentration Pathway, RCP 4.5) and more severe climate change (RCP 8.5) (Table 1). These factors effectively integrated changes in fire season length, individual fire behaviour and suppression potential. We multiplied these factors to estimate net fire regime effect.

Table 1. Relative change in key fire parameters (averaged over three Global Circulation Models), and multiplied net effect on fire regime, based on Wotton et al. (2017)

Factor	RCP 4.5		RCP 8.5	
	2030	2090	2030	2090
Expected number of fire growth days (spread event day probability)	1.04	1.24	1.15	1.65
Expected number of days/season with crowning potential (crown fraction burned > 0.1)	1.08	1.30	1.25	1.63
Expected number of days/season that require air tanker support (head fire intensity > 2 MW/m)	1.13	1.37	1.28	1.68
Net fire regime effect (multiplication)	1.27	2.20	1.84	4.53

While the forest in Mackenzie TSA is different from the boreal forest of central Alberta, the expected changes seemed reasonable at least for illustrative purposes. Effects between 2030 and 2090, and at the start time step, were scaled linearly. This resulted in dynamic changes in fire regime, implemented by dividing fire rotation by the dynamic change values (e.g. a 100% increase in fire regime would mean a fire rotation that was half as long). Effects after 2090 were held constant.

In all scenarios, we removed the non-recovered loss factors attributed to wildfire, leaving 30,000 m3/year attributed to other natural disturbance agents (e.g. wind).

We defined five risk classes based on a gradient from a more pessimistic outlook on climate change and management response to a more optimistic outlook:

- Risk class 1: Lowest risk (most pessimistic outlook): assume “worst case” fire under RCP 8.5 climate change (increasing fires), no salvage, and no fire suppression.
- Risk class 2: Assume timber recovery from potential salvage under RCP 8.5 (accounting for emergent loss of disturbed timber that is not merchantable or that is not salvaged before passing shelf life).
- Risk class 3: Assume a less severe fire regime under RCP 4.5 climate change (with salvage).
- Risk class 4: Assume no climate change (historic fire regime and fire suppression, with salvage).
- Risk class 5: Assume no wildfires at all.

Risk class 5 was designed as an over-optimistic “book end” to help identify the magnitude of effect of fire on timber supply. Risk class 4 is similar to the TSR base case scenario, with fires modelled explicitly (rather than using non-recovered loss factors). Risk classes 3 and 2 incrementally add increasing fires under moderate and more severe climate change, respectively. Risk class 1 separates the effect of salvage, resulting in a relatively low risk scenario that assumes increased fire under RCP 8.5 climate change and no salvage.

3 Application in Mackenzie TSA: Results

3.1 Geographic area classes

The results from the geographic area risk classes indicate (Figure 2):

- About 36% of the total timber supply for the TSA over the mid to long-term is supported by areas with good road access in the southwest partition (Tranche 1);
- An additional 12% is supported by other areas non involving barge transport (Tranche 2);
- Approximately 38% is supported by areas that involve barge access, but with reasonably short road access (Tranche 3); and
- Approximately 14% is supported by areas that involve barge and as well as relatively remote road access (Tranche 4).

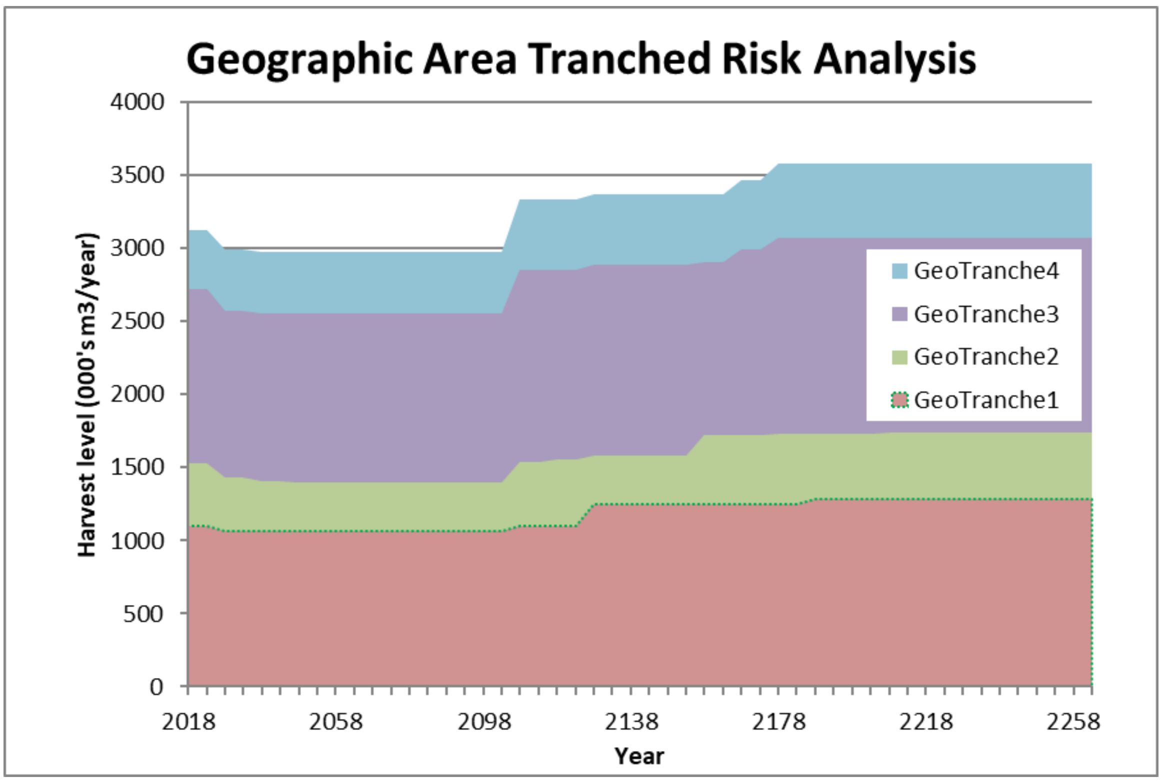

Figure 2. Timber supply for the set of risk classes based on geographic areas. Tranche 1 is supply for areas accessible by non-remote roads in the southwest partition. Tranche 2 also includes supply from other areas that do not involve barge transport. Tranche 3 also includes supply from areas that involve barge transport but via non-remote roads. Tranche 4 additionally includes supply from areas that involve barge transport and remote roads.

These tranches represent the timber supply associated with increasing access and transport costs, and hence decreasing likelihood of harvest depending on economic market conditions.

In this analysis, the timber supply for each tranche is entirely embedded within the tranche of the next higher risk class (e.g. timber supply for tranche 2 is lower than that for tranche 3 over the entire time horizon). This indicates that there is relatively low feedback between timer periods due to the inclusion/exclusion of these geographic areas.

3.1 Natural disturbance risk classes

The results from the geographic area risk classes indicate (Figure 3):

- About 51% of the long-term timber supply for the TSA (beyond 1st 100 years) term is supported in the presence of more severe RCP 8.5 climate change and no salvage (Tranche 1);
- An additional 10% of the long-term timber supply is supported by potential salvage under RCP 8.5 climate change (Tranche 2);
- An additional 18% (total 79%) of the long-term timber supply is supported in the presence of moderate RCP 4.5 climate change with salvage (Tranche 3);
- An additional 12% (total 91%) of the long-term timber supply is supported under historic fires with salvage (Tranche 4); and
- An additional 9% of the long-term timber supply is supported by assuming no wildfire at all (Tranche 5).

Short-term timber supply is dramatically affected by changing climate, with the seemingly counter-intuitive outcome that short-term harvest potential could actually increase with climate change, even if long-term timber supply declines. Showing the harvest flows from scenarios as lines helps distinguish short-term effects (Figure 4).

The more severe climate change scenarios (RCP 8.5) only stabilize after the fire regime stabilizes after about 100 years. Under moderate climate change (RCP 4.5), timber supply stabilizes after about 50 years. The increased loss from increased fire has the effect that short-term harvest can technically increase (subject to modest-size steps as harvest potential declines) without exacerbating the low point of the timber supply flow. This is in part because logging timber that has a high change of burning in the future may may have little impact on future timber supply. However, this is somewhat a technical anomaly in the sense that it this is due to how timber supply is assessed as a maximization process. The tranche approach help contextualize potential short-term “opportunity” to cut timber that may be at risk due to climate change in terms of expectations of worsening potential declines as the system adjusts to new natural disturbance regimes. In any case, the short-term differences among scenarios are relatively minor compared to the longer-term separation of the risk tranches.

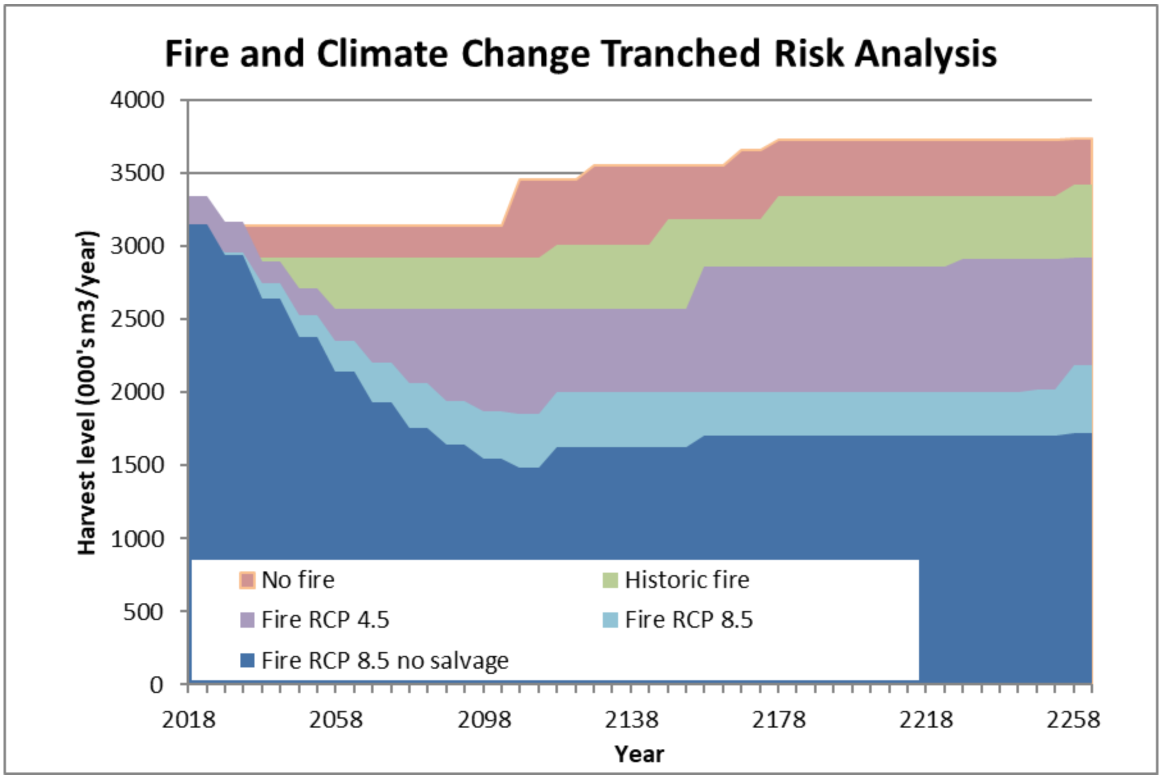

Figure 3. Timber supply for the set of risk classes based on wildfire, climate change and salvage. Tranche 1 is the most pessimistic assumption regarding climate change and no salvage (RCP 8.5; dark blue). Tranche 2 additionally includes timber supply from salvage (light blue). Tranche 3 assumes less pessimistic climate change (RCP 4.5; purple). Tranche 4 assumes no climate change (green). Tranche 5 assumes no wildfire at all (orange).

A key message from this analysis is that even modest climate change (RCP 4.5) has the potential for significant disruption to timber supply based on more optimistic assumptions (e.g. projecting historic fire). While the parameters derived for this analysis could certainly be refined and improved, it seems reasonable to expect increased fires to a combination of increased fire season length, increased change of fires crowning and increased fire intensity (decreased suppression potential). Combined, this suggests that there can be an expectation of a protracted time period of adjustment, and increased timber production from salvage (which may interact with the economic aspects of the geographic risk analysis).

That said, the analysis also indicates that there is a window of a couple of decades over which the timber supply in the fire risk scenarios are similar. This represents a planning opportunity to refine understanding of how climate change may affect this landscape, and improve anticipation of appropriate strategic forest management response.

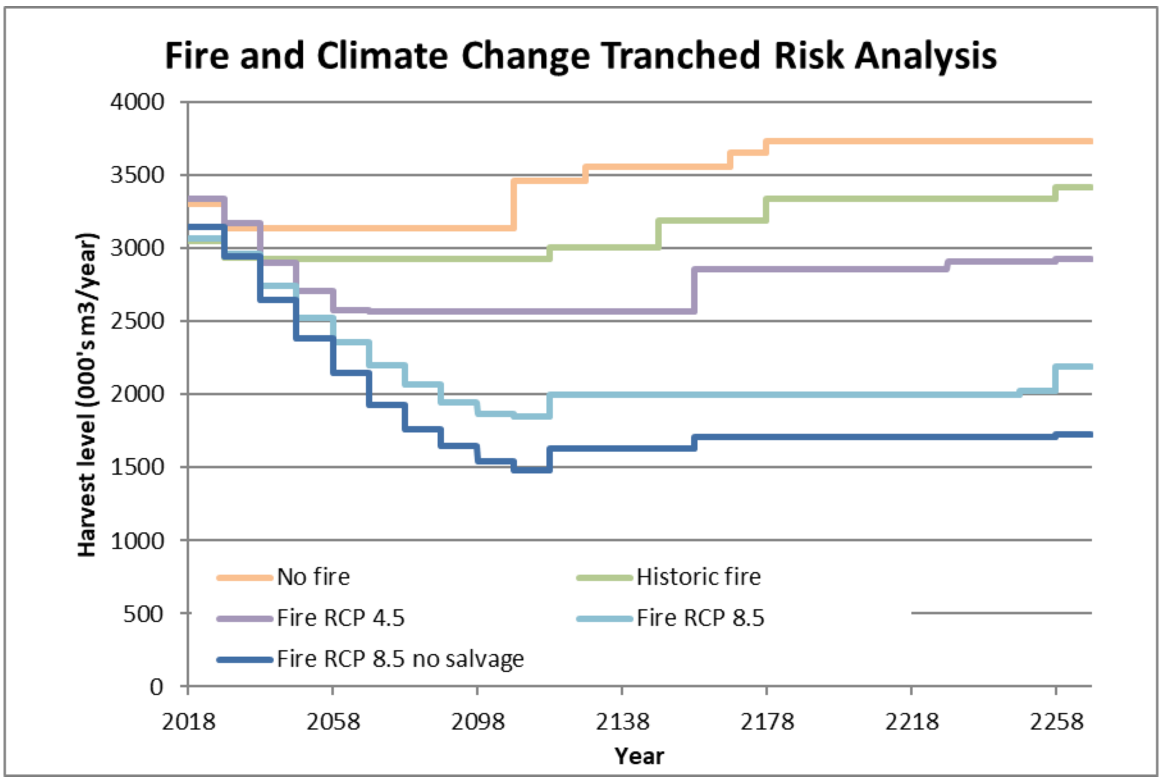

Figure 4. Timber supply from the wildfire / climate change risk classes as in Figure 3, but shown as lines rather than areas. Tranche 1 is the most pessimistic assumption regarding climate change and no salvage (RCP 8.5; dark blue). Tranche 2 additionally includes timber supply from salvage (light blue). Tranche 3 assumes less pessimistic climate change (RCP 4.5; purple). Tranche 4 assumes no climate change (green). Tranche 5 assumes no wildfire at all (orange).

Appendix 1: Assessing timber supply using STSM

A *scenario* in the context of timber supply analysis is defined as the set of inputs parameter setting (spatial and non-spatial). These may include policy scenarios (e.g. different land-use zones), or to assess the sensitivity of outcomes for uncertain inputs (e.g. different assumptions regarding volume growth and yield).

Timber supply analysis is performed using the STSM using a semi-automated sequence of steps for a given scenario. In this context, *timber supply analysis* refers to the goal of identifying the maximum sustainable harvest flow supported for a given scenario. The goal of maximization requires some consideration. One may aim to maximize long-term, short-term, time to maintain a current harvest level, etc. Also, given the uncertainty in the system, one must be careful that maximizing the modeled use scenario has a high chance of being feasible and sustainable in practice. This is one rationale for a simulation-based approach to timber supply analysis, with interaction and consideration by a human analyst.

To perform timber supply analysis, we need to state clear objectives and constraints for timber supply: Sustainable timber supply has two key aspects:

(i) Feasible harvest target: The annual harvest target must be achievable in all periods. If the target cannot be met in one or more periods over a long time horizon (e.g. 400 years), this indicates a harvest level that is too high according to forest cover and access constraints and other considerations.

(ii) Stable long-term growing stock: Stable growing stock over the long run is a key indicator of sustainable timber supply. If this is declining, harvests are higher than can be supported, while if it is increasing, there are some harvest opportunities. To assess this, we define “long-term” as 3-4 centuries. That is, between years 200-400 growing stock must be effectively non-declining. We allow a slight decline (e.g. 1% per century) to allow some flexibility.

The above give us a test to assess if a given harvest target is sustainable. From a given start point, if a harvest target is sustainable, we may look for further harvest opportunities by increasing harvest in one or more time periods. If not, we need to reduce the target in one or more periods. This provides a general approach to seek a maximum sustainable harvest target. However, there are many such targets, and the most desirable depends on other goals. Hence, we define some key constraints and objectives on the attributes of the maximum sustainable harvest target (based on guidelines from Forest Analysis and Inventory Branch):

(i) The harvest target must be maintained at or above the level of the maximum long-term harvest level (LTHL). This condition may not always be desirable, in particular for management units that have significant historic harvesting where a drop in some periods below the maximum LTHL may be necessary to achieve management objectives. In most units, however, this effectively captures the criteria that short and medium term management should not compromise future generations.

(ii) The maximum short-term harvest level, up to the current AAC, should be attempted and maintained as long as possible. This condition is designed to minimize short-term impacts, in particular if the current AAC must be reduced to meet objectives for a given scenario. When assessing units that do not have an AAC, selection of a starting target harvest is a subjective choice that should be made based on technical information and social choice (e.g. via a technical working group).

(iii) The maximum decline between subsequent 10-year planning periods is 10% of the starting harvest level. This condition is designed to minimize the social and economic impacts of declining timber supply within any given decade.

These conditions can be used as guidance to find an appropriate maximum harvest flow for a given scenario. The general steps are:

(i) Determine the maximum even-flow harvest level: Using a binary search algorithm, iteratively assess different levels of constant volume harvest until the maximum level is found (Figure 5, step 1). This can be contrasted with the maximum theoretical long-range sustainable yield that can be calculated by summing up the cumulative mean annual increments for each cell according to its analysis unit). The maximum even-flow level will usually be less than the theoretical maximum long-term harvest level due to stand age structure, timing of harvest, forest cover constraints, etc.

(ii) Increase the short-term harvest level: Using another binary search algorithm, iteratively assess different levels of short-term increases ("shifts" of short-term) until the maximum level is found (Figure 5, step 2). For example, in a TSA, the current AAC may be attempted for 8 decades (before declining to the long-term level). If this is unsustainable, it may be reduced to 4 decades, otherwise it may be attempted for 12 decades. Careful design of the harvest pattern to shift is based on the results of the first step plus the guidelines described.

(iii) Refine the long-term harvest level: sometimes, increasing the short and mid-term harvest levels results in an increased capacity of the long-term harvest level (e.g. Figure 5, step 3). This may occur, for example, if the area harvested in the short-term is closer to the LRSY, and so the age-structure is transformed earlier to support a higher long-term level. The point at which harvest can increase requires examination of harvest indicators (e.g. after bottlenecks of harvest availability and after growing stock starts to increase significantly). In some cases, this may increase the entire long-term level, while in others it may result in a long-term level that is higher than the mid-term. It is important to note, however, that the lower mid-term level in this latter condition is not a consequence of higher harvest in the short-term, but is due to interactions between stand age structure and regeneration.

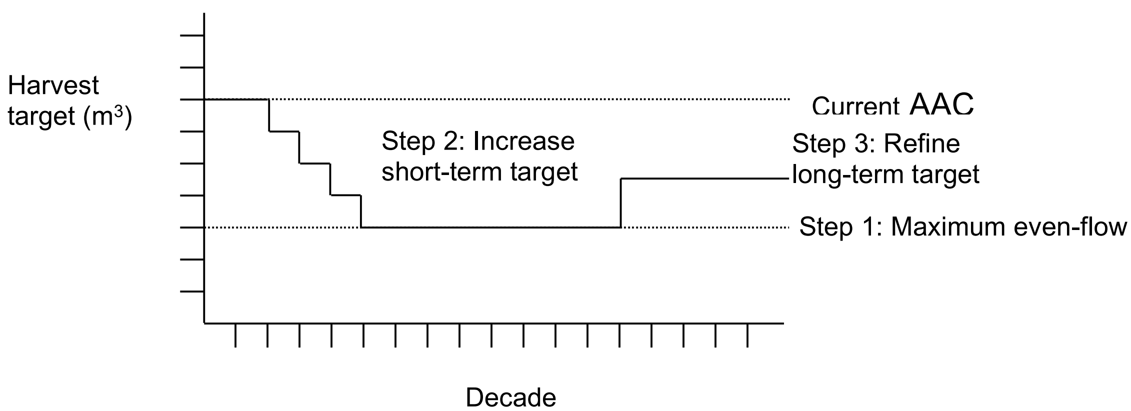

Figure 5. Diagram outlining the steps used to assess sustainable timber supply with STSM in each scenario of this analysis. Step 1 is to estimate the maximum even-flow harvest level (constant harvest level; lower dashed line). Step 2 is to increase the short-term level consistent with the even-flow level (steps from current AAC line down to level identified in step 1). In the diagram, the current AAC can be maintained for two decades before declining in 10% steps to the harvest level identified in step 1. Step 3 is to refine the long-term harvest level based on the results of the previous two steps. In this example, after 130 years, the long-term harvest level can increase by about 15%.

The approach outlined is most useful for situations where the initial harvest level is above the long-term level due to differences in volume between old-growth forests and second growth forests. This is a common situation in central and northern coastal B.C, and northern B.C. Adaptations are straightforward for cases where the short-term is lower than the long-term level (e.g. in certain units on Haida Gwaii).

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