Approaches to Advance Climate Change Considerations in Timber Supply Reviews:

A Discussion Paper

Prepared for Forest Analysis and Inventory Branch

&

Forest Carbon and Climate Services Branch

By

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Summary

Climate change is affecting and will almost certainly continue to affect forest ecosystems and forest operations in BC. This report reviews some of the literature on the impacts that climate change may have on forests, including wildfire regimes, insect and pathogen dynamics, and forest productivity. Climate change and associated ecosystem changes also will likely lead to maladaptation of tree species (or at least of some provenances of species), to changes in successional pathways, and to increased risk from alien invasive species. Wind damage may increase in some areas, unstable terrain will likely become more susceptible to landslides, and ice bridges and roads may not form due to increased winter temperatures, reducing logging opportunities in some areas. All of these changes could affect timber supply.

The Forest Analysis and Inventory Branch (FAIB) and the Office of the Chief Forester (OCF) face several **challenges in improving the incorporation of climate change** and its impacts into timber supply reviews (TSRs) and allowable annual cut (AAC) determinations:

- There is deep uncertainty associated with climate change, meaning that there is a lack of definitive knowledge about both future climate and how ecosystems will respond to changes, and an inability to sufficiently reduce the unknowns by gathering more information within the timeframe of AAC determination processes.
- AAC decisions have long-term implications on forests, which growth and change over many decades, meaning that most adaptive practices will not have effects for several decades.
- The most common response to uncertainty is to seek out or generate more information. However. information is not the same as decision making.
- Resource (money and time) limitations and competing demands make it challenging to add more to the already substantial analytical and decision-making load in the branch.
- Most information about the nature of climate change impacts and adaptive responses is qualitative, focusing on the kinds or directions of impacts, and kinds of potential management responses. However, AAC determination requires information that will help decide quantities, that is, at what level the AAC should be.
- Differences in scientific opinion and values mean that discussions about the nature, magnitude and timing of climate change impacts and what to do about them will inevitability be challenging; and
- There is a potential for individual overwhelm associated with attempting to integrate a new and complex dynamic into an already complex analysis framework.

Addressing these challenges will require choices about how much effort to put into assessing climate change impacts, potential changes in the nature of AAC determination to address deep uncertainties, collaborative work across disciplines, and an acknowledgement that the task may not be easy and at times will likely require skilled facilitation.

A review of current approaches for incorporating climate change into timber supply analysis and AAC determination in other provinces suggested that **BC is not behind other Canadian jurisdictions** in this work. It would be worth maintaining contact with the Quebec Chief Forester's office given the recent and ongoing analysis work in that province.

In terms of **readiness**, FAIB faces challenges of attempting to integrate climate change analysis into an already complex TSR process while meeting legislative timelines. To be effective FAIB must find creative ways to work through the deep uncertainties of climate change. While the branch has analysis tools that enable modeling of important climate change impacts, notably stand replacing disturbance and productivity change, it will be a significant challenge to parameterize the models. Existing research provides some guidance, but FAIB will need to work with content experts in wildfire, forest health, growth and yield, stand and landscape level succession, and potentially other factors (e.g., wind, geomorphology) on parameter development.

An important challenge will be increasing the ability of decision makers to navigate **uncertainty**. The most common responses to uncertainty involve highlighting gaps in knowledge and undertaking inventories, monitoring and research to improve information for future decisions. In effect, this approach does not account for uncertainties, rather it (most often implicitly) reflects a belief that the implications of uncertainty are not consequential, and that any related issues can be addressed when better information is available. The problem with this approach is that not explicitly accounting for uncertainties can reduce decision quality by failing to account for possible impacts, usually in the longer term. While sensitivity analysis is always a feature of TSRs and helps to understand the effects of uncertainties on outcomes, it does not tell one how to make the decision or what weight to place on the potential impacts associated with uncertainties. Therefore, incorporation of climate change impacts into AAC determinations may require consideration of decision tools that could provide an ability to hedge against uncertainties; for example, by accounting for risks while keeping options open by using partitions. Partitions have historically been used with hesitation and mostly in cases of severe disturbances (i.e., uplift partitions for mountain pine beetle and fire salvage). The main highlight in this context is that providing information based on best estimates or multiple scenarios, while necessary to increase understanding of key process and relationships, does not indicate how to use that information in making decisions, and does not on its own help to address uncertainty about if, when and where impacts will occur, and hence about what the appropriate AAC decision may be.

The report outlines **three general approaches that can be useful in addressing uncertainty**: enhancing information and knowledge; developing responsive decision-making processes, institutions, and regulatory frameworks; and implementing practices that help adapt to or buffer against uncertainty and change. Most discussion in AAC rationales relates to the first two categories: there is substantial discussion of information gaps and the need to fill them to improve future decisions, and a reliance on the legislative requirement to make new AAC determinations regularly to incorporate changes on the land and in information and knowledge.

The third category – related to adaptive or buffering practices – aligns with the notion of robustness. **Robust decisions would be reasonable under a broad range of plausible futures**: effectively no-regrets decisions. One commonly discussed adaptive measure that could enhance robustness is diversification; for example, requiring reforestation with diverse species as a hedge against uncertain future conditions. Under current legislation, the chief forester cannot make management decisions related to silviculture, so stand- and landscape-level diversification would have to be part of current practice to be reflected in AACs. Some may believe that reducing AACs could act as a buffer against uncertainty; however, as noted in the current guiding principles for AAC determination, it is not clear that reduced harvesting would be the best response in the context of diverse values over a broad array of futures. One existing tool could be partitions focused on areas at different levels of risk to climate change. Such partitions may provide an ability to acknowledge the potential for climate change impacts while keeping options open for use of timber supply from higher risk areas under some conditions.

Another type of robustness relates to the quality of information that supports a decision. In the context of climate change, which is characterized by deep uncertainties, a frequent lack of scientific consensus, and a context of diverse social values, it will be important for FAIB and the chief forester to work to ensure that the information on climate change and its impacts is as robust as possible. Ensuring this kind of robustness will likely require expanding involvement of content experts beyond one or two people, as is usually the case in TSRs for each factor or modeling input. Larger teams with a diversity of knowledge that work with FAIB analysts to develop parameters and approaches for timber supply modeling could help to enhance information robustness so that the incorporation of climate change impacts into analyses and determinations can withstand scrutiny from potentially skeptical interests. This type of robustness may be important if climate change impacts begin to have substantial impacts on AACs and access to timber.

Several **approaches to analysis** could be useful when incorporating climate change impacts into assessment of timber supply including: **sensitivity analysis** to explore the impacts on timber supply of different climate change scenarios and related uncertainties about ecosystem responses; **tranche analysis** that looks at the timber supply contribution of categories of forest at different levels of risk; **stochastic disturbance analysis** that could be used to demonstrate the sustainability of different harvest levels under various disturbance regimes associated different climate scenarios; **exploratory analysis** that examines the effectiveness of different management options for adapting to climate change; and **retrospective analysis** that uses actual past disturbances to evaluate the range of decisions that could be made in anticipation of major disturbances. Limited landscape- and management unit-level analysis has been undertaken in BC to explore the implications of climate change on forest management. While this type of analysis may be anticipated for Forest Landscape Planning for the future, FAIB is currently well equipped in terms of modeling tools and expertise to provide analysis support to help advance understanding of climate change impacts and to explore management options. The degree to which the scope of TSRs is expanded to provide policy-relevant analysis will be a choice for FAIB and the OCF.

The report discusses **two potential decision-making approaches to climate change**. One is focused on the outcome of **tranche analysis and the use of partitions** as a hedge against uncertainty. FAIB should work with content experts to assess types of disturbance that may be amenable to risk classification. The other is **trend-responsive decision-making**, which acknowledges that future climate will always be uncertain and hence so will climate change impacts. Given this deep uncertainty, it would be worthwhile for FAIB and the chief forester to consider the degree to which AAC determination could be responsive to trends in which experts are reasonably confident (while acknowledging uncertainty about magnitudes) as opposed to relying on point estimates, as has been the implicit approach in the past.

The report includes a brief discussion of **engagement with Indigenous communities and the general public**. And provides recommendations related to maintaining focus on the values brought forward and the effect of climate change on those values rather than on technical timber supply analysis procedures and detailed analytical results. This review did not involve consultations with Indigenous people since that would better be done directly by representatives of the provincial government.

The report concludes with the following **recommendations** that could address some of the challenges in incorporating climate change impacts into TSRs and AAC determinations:

- Undertake a process to identify specific forest dynamics to focus on when developing climate change-related timber supply model parameters.
- Build a robust, collaborative process for developing analysis parameters, including risk categorizations.
- Expand use of risk tranche analyses and link to partitions.
- Consider the possibility of employing trend responsive decision making in AAC determination.
- Undertake analysis, either as a pilot project or as part of TSRs, to address the uncertainty expressed in the current guiding principles for AAC determination related to whether changes in AACs are warranted given uncertain future climate change. Ideally, TSRs would include analysis that would address this question for each management unit, although broader exploratory analysis could assist in developing climate change policy for forestry generally and AAC determination specifically.
- Undertake analysis to explore the potential effectiveness of different forest management practices or approaches in adapting to climate change and mitigating uncertainties in timber supply. Exploratory analysis could help to advance the use of practices designed to adapt to climate change.
- Develop basic training on climate models and climate change impacts, and develop analysis guidance on incorporating uncertainty and climate change impacts into timber supply analysis.

1. Introduction and study scope

This report was prepared for the Forest Analysis and Inventory Branch (FAIB) and the Forest Carbon and Climate Services Branch (CCSB), of the British Columbia Office of the Chief Forester (OCF). The purpose of the study was to provide a discussion paper that would assist in advancing the incorporation of climate change considerations into the Timber Supply Review (TSR) process that supports allowable annual cut (AAC) determinations by the chief forester.

The study involved reviewing documentation related to BC TSRs, speaking with analysts and other experts in forest management in BC and other provinces, and reviewing scientific literature and other reports.

The focus of the report is TSRs and AAC determination. The report does not focus on considerations related to designing forest management regimes to mitigate (carbon management) or adapt to climate change (e.g., diversifying planting, assisted migration, partial harvest systems, revision of wildlife and biodiversity strategies). Nor does this report specifically address planning exercises such as Forest Landscape Planning. While acknowledging that climate change will affect all aspects of forests and the values that depend on them, the focus here is on timber supply management and decision making. Nevertheless, the perspectives developed in this report may be relevant to forest carbon management and forest planning, since like TSRs, those endeavours require assessment of how forests change over time.

Finally, the report does not outline specific research or monitoring needs to improve or generate information on climate change and its potential impacts on forests. The report does, however, propose some approaches for forest research and management experts to collaboratively develop inputs for timber supply analysis while acknowledging the challenges in doing so given the deep uncertainties associated with climate change. It also suggests analysis approaches that could help decision makers like the chief forester navigate towards decisions that meet existing forest management objectives while acknowledging those uncertainties.

2. Climate change impacts on forests

To provide context for this discussion, it is worthwhile to provide a brief outline of the kinds of climate change and associated impacts to forests that are occurring or that are expected to occur. [1] [2]

At the provincial scale, temperatures in BC have increased over the last century, particularly in winter. The northern and southern interior portions of BC are expected to continue to warm more than on the coast and in the central interior. The province experiences more precipitation than a century ago, but precipitation trends vary substantially across BC, and across seasons. Generally, more precipitation now

[1] Cariboo regional extension report. Each regional report includes a provincial summary as well as region specific discussion. The outline here focusses on the provincial level https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/regional-extension-notes/caribooen160222.pdf

[2] Natural Resources Canada: https://natural-resources.canada.ca/climate-change-adapting-impacts-and-reducing-emissions/climate-change-impacts-forests/impacts/13095

falls as rain than snow, and hence snowpacks have decreased. The trend of earlier and faster snowmelt and longer fire seasons will likely continue across the province.

Ecosystem climate envelopes[3] may shift northwards, to higher elevations, or in some cases disappear. Areas suitable for current subalpine and alpine ecosystems will likely decrease in most of BC. Grasslands, shrub-steppe and dry forested ecosystems are expected to expand.

The pace of climate change will likely exceed the ability for trees species to migrate to more suitable locations, and in many areas, tree species may become maladapted to new climate regimes and experience more stress, with effects on growth and increased vulnerability to fire, insects, disease, and invasive plants.

More fire and drought are likely in southern and coastal BC, and mortality due to insect pests and diseases is also likely to be greater.

Hydrological regimes have changed and will likely continue to change with increased summer evaporation leading to lower streamflow. More intense storms will likely lead to more frequent flooding and landslides. Declines in snowpack and earlier melt will likely lead to earlier and shorter spring flows.

Operationally, higher winter temperatures may shorten winter logging seasons by limiting the use of winter ice bridges and roads.

Climate change is expected to affect tree growth, mortality, disturbance patterns and the distribution of tree species. Impacts could often be interconnected. For example, mortality of some trees by insects can increase the risk of stands to fire, and drought can stress trees increasing their susceptibility to insect and disease attack (Woods et al, 2011).

Seasonal changes such as earlier springs and longer summers will likely result in changes to tree behaviour, such as the timing of dormancy, leafing out, flowering and seeding.

Forest productivity may increase in some regions and decrease in others in response to changes in temperature, precipitation, season lengths, forest insect and disease dynamics, and drought stress. There could be shorter-term increases in productivity due to higher temperature and longer growing seasons, however, at least in some areas, evaporative stress could counteract those effects and ultimately reduce growth relative to historic levels (D'Orangeville et al. 2018).

The FPInnovations Climate Vulnerability Forest Management Tool[4] focuses on potential impacts on forest operations of changes in: dry conditions (average annual maximum daily temperature), extreme flooding (20-year daily precipitation), sustained rainfall (annual 5-day max precipitation), snow accumulation (precipitation as snow), freeze-thaw cycles (days on which maximum daily air temperature is >0 °C and the minimum is ≤0 °C), and spring thaw (freezing degree days – winter).

To summarize this tool identifies impacts on:

- length of shutdowns related to fire and rain

[3] A climate envelope describes the relationship between species occurrences and climate variables like temperature and precipitation. It defines a species' climate niche (https://www.usgs.gov/centers/wetland-and-aquatic-research-center/science/climate-envelope-modeling-evaluating)

[4] https://storymaps.arcgis.com/stories/be140461a0874d9cb9c3e0aebe69d4cf

- delay of slash burning
- challenges in meeting management objectives, in particular soil disturbance
- risks to equipment
- costs associated with road maintenance, infrastructure and equipment repair, and operating in difficult weather
- safety and health
- usability of winter roads and hence access to winter logging areas

This FPInnovations resource is directed more at the needs of forest harvesting operations than at strategic harvest level decisions. However, winter access could be a climate change-related risk category, which will be discussed in a later section on the potential role of partitions in increasing AAC robustness.

In summary, the implications for forests that could lead to changes in timber supply include:

- changes to climatic envelopes (which can change the geographic range in which a species is well-adapted) leading to maladaptation and vulnerability of many tree species to pests and drought
- more abiotic (fire, drought, wind) and biotic (insects, disease) disturbances leading to stand-replacing events or tree-level decline or death
- potentially higher productivity in some areas due to higher temperatures and more CO_2 but balanced with higher activity of some forest diseases and evaporative stress
- Forest operations could be affected by landbase loss to landslides and flooding; and reduction of winter logging opportunities

Incorporating climate change into timber supply analysis and AAC determination requires development of analysis parameters to model impacts. For instance, how could climate change affect fire frequency, extent, and intensity? Ideally, these impacts would be quantified, otherwise development of modeling parameters and factoring the impacts into the quantitative AAC decision would be challenging. These challenges and some potential approaches are discussed in a later section on parameter development.

This report focuses on disturbance and productivity, since these are the forest-related impacts most frequently discussed in the literature and in vulnerability assessments (e.g., Morgan and Daust 2013)

Figure 1below provides a high-level overview of the linkages of climate change to timber supply, and therefore of the challenges involved in incorporating climate change into TSR and AAC determinations.

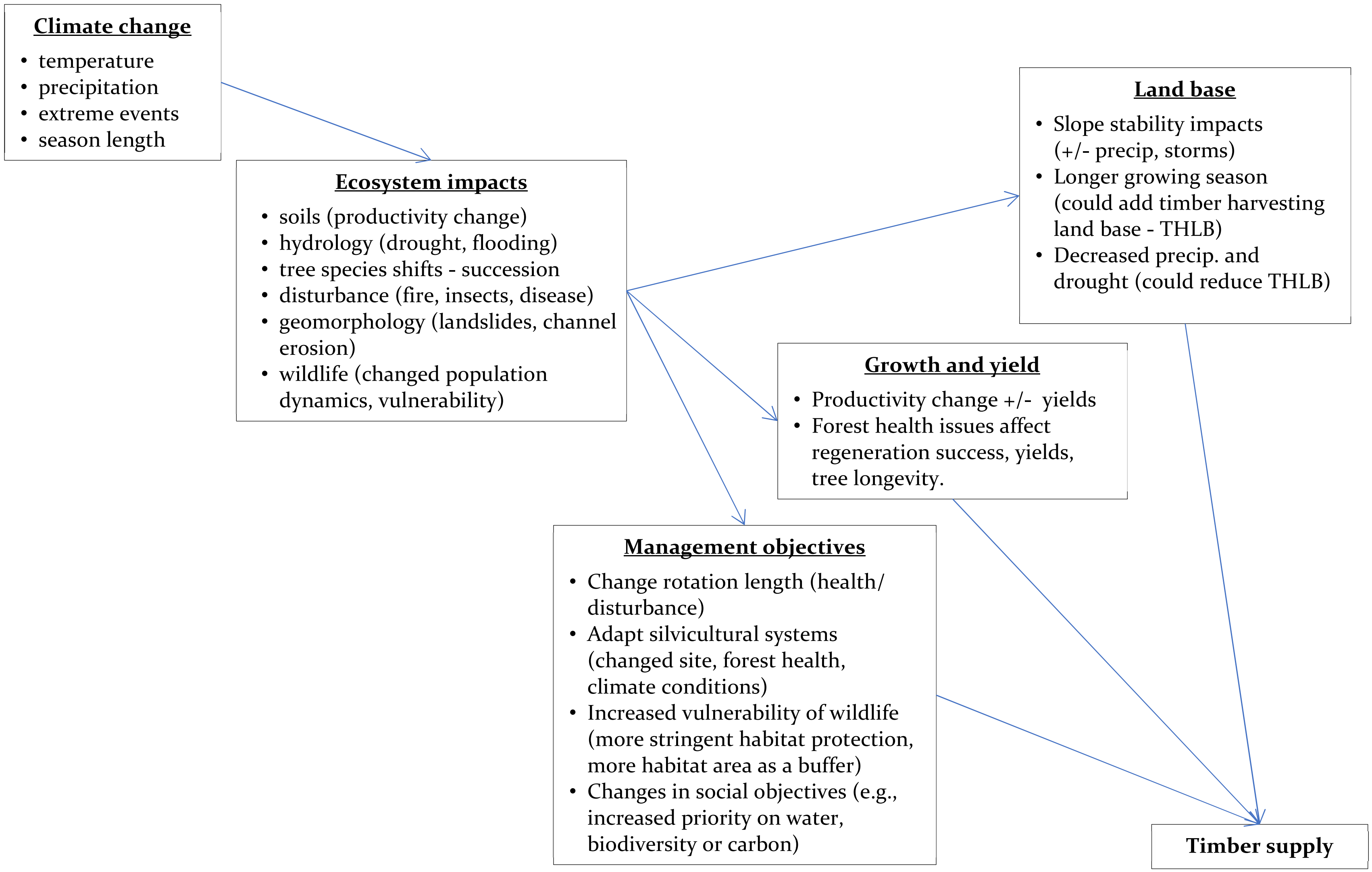


Figure 1 Conceptual map of linkage between climate change and timber supply.

3. Challenges

Several substantial challenges must be considered when developing approaches for incorporating climate change into timber supply analysis and AAC determinations. These challenges are provided here to provide some context within which to consider and evaluate currently used and potential approaches.

<u>Deep uncertainty</u>

Deep uncertainty results when there is lack of agreement or clarity on agreement on (i) the key external driving forces of the system of interest, (ii) the system's boundaries, key components and functional relationships, (iii) the relative importance of the various values or outcomes the system provides, and/or (iv) the potential for unpredictable, surprising, events. Essentially, it stems from a lack of definitive knowledge about the composition and functioning of a system, which cannot be sufficiently reduced by gathering more information (Marchau et al., 2019).

In forest management. as in Euro-American society generally, there is a reluctance to engage with uncertainty beyond providing information about it and highlighting needs for better information. In situations where associated costs are low, forms of insurance such as diversification and keeping options open by retaining a buffer may be employed. This insurance approach is often discussed but less frequently used in forestry, largely due to its cost.

The most common responses to uncertainty in applied sciences like forestry are to attempt to eliminate it through better inventories, monitoring and research, and when that is not possible to provide descriptive information such as confidence intervals and sensitivity analyses. Sensitivity analyses and requests for better information to improve future decisions are central elements to TSR analyses. However, explicit discussion of risk – in particular, the differential risks faced by competing values – and factoring risk assessment into decisions is less common. This is not surprising. Risk-informed decision making in the face of multiple objectives is difficult and may seem more applicable to land use planning than AAC determination. The guiding principles outlined for AAC determinations in rationales explicitly indicate that AACs account for existing land use and management decisions that account for value decisions. However, AAC decisions still must account for the long-term, intergenerational implications of forest management and harvest level decisions. A future section provides more discussion about responses and approaches to uncertainty. The main point is that progress on determining how to make good decisions under uncertainty is challenging and fundamentally involves value decisions related to different values and time periods.

<u>Making decisions with long-term implications in a slow-dynamic system</u>

This is connected to the discussion of uncertainty. The main concern is that common tools to address uncertainty – monitoring and frequent decision making – may not always discover problems on time to take proactive measures and avoid negative outcomes in the long term.

<u>Providing Information is not the same as decision making</u>

This was discussed under uncertainty above but warrants highlighting. Generating information, such as analysis runs with different future wildfire regimes or stand development trajectories to correspond to climate change scenarios, does not provide guidance on what to do with the information. It *is* possible to generate information to assist decision makers navigate through challenges involved in weighing divergent values, however, this requires explicit discussion of what those values are. In AAC determination, the most relevant values likely relate to time preference, or intergenerational equity (that is, whose timber supply matters more?).

Resource (money and time) limitations and competing demands
FAIB and the OCF in general must meet legislative timelines, achieve service plan goals, meet minister mandates, and participate constructively in Reconciliation, among other tasks, all within a limited budget. Addressing the complexities associated with assessing the impacts of climate change and making decisions that account for them add to the challenges of this complex set of goals, tasks, and resource limits.

"Kinds of things to do" *versus* "How much to do."
Much of the guidance in scientific and professional literature related to the impacts of climate change and potential management responses is qualitative or categorical: there will likely be more frequent abiotic and biotic disturbance, less snowpack, more frequent extreme weather, more evaporative stress and so on. In some cases, it may be possible to place stand types or areas into risk categories with respect to drought, insects, fire and other dynamics. However, it is a challenge to determine how to move from such qualitative or categorical information to quantitative AAC determinations. By contrast, a silviculture regime could more easily be designed based on more categorical knowledge; for example, given uncertainty, more diverse stands could be established. Obviously, there are quantitative aspects, such as the number of seedlings of different species to order, but those quantities are not statutory decisions. However, in most cases trend and categorical information may be the best information available on climate change impacts. Factoring climate change into AAC determinations requires that this challenge be addressed.

Differences in opinion and the inevitability of difficult conversations.
Given the complexities and uncertainties associated with generating information and analysis approaches for incorporating climate change into forest management decisions, different perspectives and conflicts are almost inevitable. Conflict has already occurred within the ministry with respect to what appear to be climate change-related impacts of diseases on stand development. If such differences of expert opinion cannot be resolved easily through information sharing, participants may become entrenched in defending the validity of their expertise and positions. In such situations, the focus on problem solving decreases. Once conflicts reach this stage, they are not amenable to resolution solely by participants who have stakes in the outcome. A common approach to conflict in organizations and society in general is to attempt to discount conflicting views, rather than focusing on the need to maintain space for different views to strengthen problem solving. A later section speaks at a high level to need to engage appropriate expertise if conflict appear to be hindering collaboration on developing information and approaches to climate change.

Individual overwhelm
A survey of the knowledge and confidence of FAIB staff on climate change, impacts on forests and timber supply and the available information and tools was not undertaken as part of this project. However, given the complexity of the topic, some may experience overwhelm and uncertainty about where to begin. This topic is not addressed in detail in this report. A general suggestion is to consider ensuring that a body of relevant information is curated and made readily available. This could include information on climate models, climate change and associated emissions scenarios, shared socioeconomic pathways, choosing climate models and scenarios, timber supply model functionalities

available, regional extension notes, and existing TSR examples to use as guidance for developing management unit specific approaches.

4. Current approaches in BC Timber Supply Reviews

This section provides a summary of the guiding principles for AAC determination that apply to climate change, and approaches for providing information and undertaking analysis to inform determinations.

Guiding principles for AAC determinations

The chief forester's guiding principles for AAC determination acknowledge that measures to adapt to climate change will be required in forest management, but also that "… the potential rate, amount, and specific characteristics of climate change in different parts of the province are uncertain" and that "[a]s research provides more definitive information on climate change" the findings will be considered in AAC determinations. These components of the principles focus on reducing uncertainty through research and monitoring and, implicitly, the use of sensitivity analysis to highlight specific topics on which research may be beneficial to inform determinations. The principles outline that adaptation and mitigation practices that are implemented will be considered in the determination. The principles also note that dialogue is needed on the appropriate response to the risks associated with climate change – for example, whether reducing AACs to reduce risks or potential increasing or focusing AACs to avoid losses to climate change-induced disturbance is the better response, and under what circumstances. Finally, the principles note the role of regular determinations in allowing for incorporation of updates in knowledge and forest conditions, as well as change to forest practices.

The guiding principles, therefore, do not outline a framework for explicit, quantitative analysis of climate change as part of timber supply analysis.

Information on climate trends and projections

Information on climate trends and projections is now available for Timber Supply Areas (TSAs) and Tree Farm Licenses (TFLs). These climate summaries were developed under the guidance of Vanessa Foord, Climatologist for the Omineca, Northeast and Northwest. They provide historical trends for the mid-20th century to early 21st century, and climate projections are based on ClimateBC[5] data for various Shared Socioeconomic Pathway (SSEP) emissions scenarios and time periods. Projections are available for changes in average and seasonal precipitation, temperature, temperature extremes, precipitation as snow, moisture deficit, growing-degree days, and frost-free days. Forest management-related interpretations are often provided by request from ministry climatologists.

Regional extension notes are at times also used as information sources[6]. The extension notes are now outdated with respect to climate models and projections. They still provide relevant general information on trends likely to be experienced but would be more useful if they were updated for Coupled Model Intercomparison Project Phase 6 (CMIP6) climate models and the new IPCC 6th Assessment Report (AR6) socioeconomic pathways, for which a synthesis report is due in March 2023.

[5] https://climatebc.ca/ ClimateBC can be downloaded and is a source of climate data including BEC projections.
[6] https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/natural-resources-climate-change/natural-resources-climate-change-adaptation

Timber supply modeling tools

The Spatial Timber Supply Model (STSM) built with the SELES modeling language (Fall and Fall 2001) has functionalities to enable changes to yield estimates and explicit modeling of stand-replacing disturbance that were developed for FAIB between 2016 and 2019 (Fall 2016, 2019a, 2019b). For both processes, functionality allows for progressive changes over time to approximate the likely unfolding of climate change impacts, as well as explicit modeling of salvage assumptions for disturbance.

The functionality for stand-replacing disturbances has been used to model wildfire. The model uses spatial historic fire perimeters to define fire rotation period (i.e., the time it would take to burn an area equivalent to the total forest area of a management unit); the average annual area burned; and parameters related to fire patch size distribution (statistical shape of size distribution, mean and standard deviation). Other variables needing definition are the immediate loss of volume due to fire; the "shelf life" of remaining burned timber (time during which damaged timber is assumed to still be merchantable); the preference for fire initiation (i.e., random or linked to BC Wildfire Provincial Strategic Threat Analysis dataset); fire spread preference (e.g. based on threat data); complexity of patch shape; and whether or not fires can skip over cells in the forest data. The preference for salvage can be set in the timber supply model, with the volume left unsalvaged emerging from the modeling process as opposed to being predetermined as has been standard practice in TSRs historically.

In addition, the concept of risk “tranches” (French for slices) was explored (Fall 2019c). Risk tranches can be used to describe the contribution to a timber supply projection of components of the forest that are subject to different levels or types of hazards (e.g., drought, fire, insects, disease, etc.).

Developing parameters for climate change impacts on disturbance and productivity presents a substantial challenge, as will be discussed in a later section, however, FAIB has model functionality to allow exploration of climate change impacts on timber supply.

Substantial work was done for the recent Mackenzie TSA TSR using these model functionalities, particularly for fire, transport methods and distance (Appendix 3 of BC MOF 2022), and drought. While the climate change-related functionalities do not appear to have been used extensively in TSRs to date, the work for the Mackenzie TSR will provide a good template for others. At the time of writing, there are plans to do similar work for the Bulkley and Morice TSRs. In addition, for those NW BC units, work is underway, including development of model functionality for linking regenerated yield curves to projected BEC[7] and BEC-linked managed stand yield tables from databases maintained in FAIB.

The following three sections provide more detail on approaches and general findings from modeling for the Mackenzie TSA TSR.

Wildfire modeling – emergent non-recovered losses

Historically in TSRs, the non-salvaged volumes of killed timber were averaged, and removed from timber supply forecasts as non-recoverable losses (NRLs), effectively being treated as a timber harvest. Figure 2 demonstrates how explicit modeling of fire and salvage (as described in the previous section) changes the pattern of affected volume relative to the average NRL approach. The average of the explicitly

[7] ClimateBC https://climatebc.ca/

modeled NRLs (mean NRL) shown in Figure 2, which averages about 200,000 m^3/year was approximately 25% larger than the average calculated for the previous TSR (160,000 m^3/year).

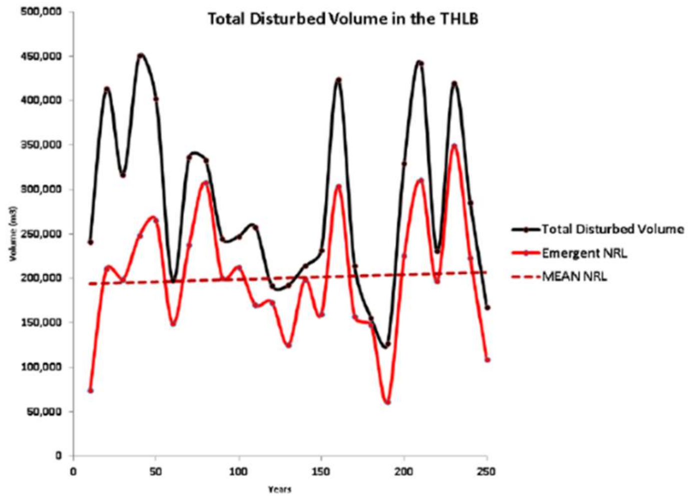


Figure 2 Chart of volume affected by wildfire and emergent NRLs for analysis for the 2022 Mackenzie timber supply review.

Figure 3, below, compares timber supply projections for scenarios based on the historic fire regime (red line in left chart) to a projection based on a climate change induced increase in wildfire frequency (flat red line in right chart). For this analysis, fire frequency was gradually increased over 100 years until it was double the current average frequency (i.e., the fire rotation was half of the current average).

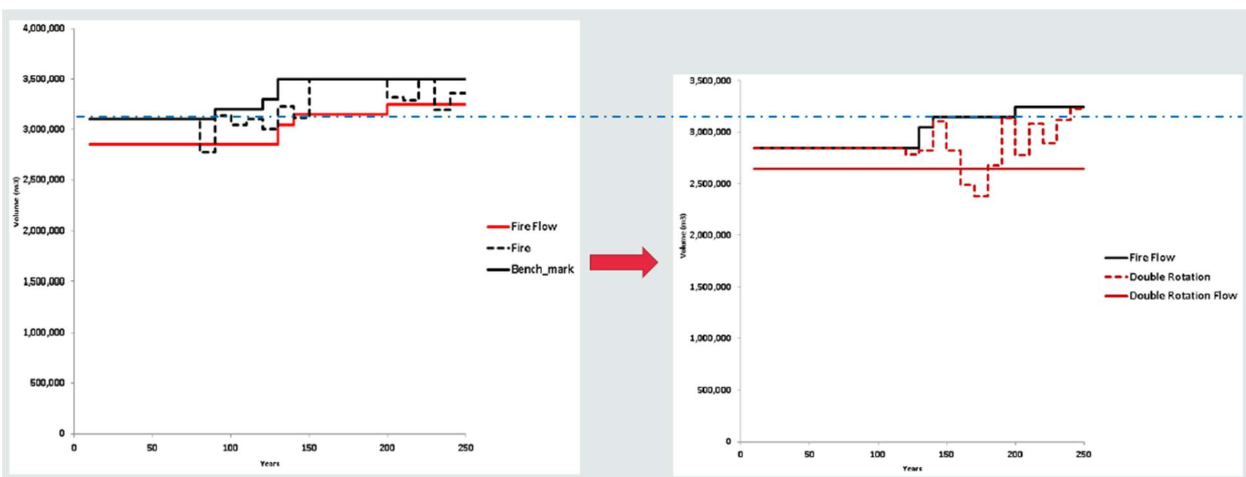


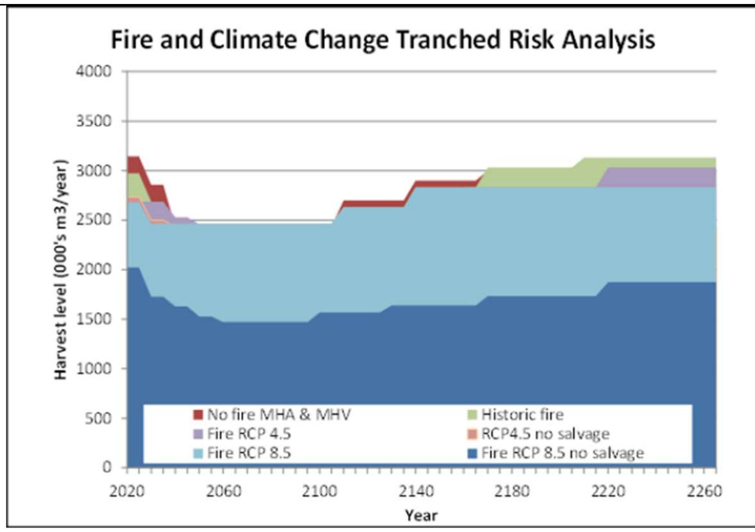
Figure 3 Timber supply results for analyses comparing explicit modeling of wildfire to a no-fire scenario (left chart) and for a gradual doubling of fire frequency over a 100-period (right chart). Note that the lower red solid line in the left chart becomes the uppermost black solid line in the right chart. Mackenzie timber supply review, 2022.

The choice of a gradual doubling of fire frequency was not entirely arbitrary since some research suggests changes of this magnitude or greater (e.g., Littell et al 2018); however, this parameterization was not developed through a formal process by wildfire experts. While functionality exists for modeling fire under climate change, parameterization of the models remains a challenge given the uncertainties associated with climate change.

The purpose here is not to explore the results in detail, but rather to indicate that existing model functionality allows for exploration of climate change impacts. Modeling fires explicitly would provide a more nuanced and realistic approach than the use of predetermined NRLs.

Risk tranche approach

The following figures show results of two tranche analysis for the Mackenzie TSA: the first related to wildfire risk, and second to risk associated with transportation cost.



- Risk class 1 (dark blue): 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 (light blue): 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 (orange): Assume a less severe fire regime under RCP 4.5 climate change (without salvage).
- Risk class 4 (purple): Assume a less severe fire regime under RCP 4.5 climate change (with salvage).
- Risk class 5 (green): Assume no climate change (historic fire regime and fire suppression, with salvage).
- Risk class 6 (red): Base case assumptions with no fire.

Figure 4 Fire risk tranche analysis from Mackenzie TSA TSR (BC MOF 2022)

This analysis explored the impacts of different emissions scenarios (RCP 4.5 and 8.5) and of salvage on the timber supply forecast. This kind of forecast could be used to partition an AAC according to risk. Use of partitions would be one way – potentially the only way – to incorporate potential climate change impacts while keeping options open to harvest in areas or forest types at higher risk. One challenge would be to identify implementable tranches, that is, areas that can be identified on the ground. Another would be to define management regimes to areas of higher risk; for example, establishment of forest types that would reduce future risks.

Figure 5 below shows results of a tranche analysis related to transportation methods and distance, which affect costs. While the categories identified for the Mackenzie TSA may not be directly related to climate change, other types of operational access classifications – for example, areas accessible for winter logging by ice bridges. Changes in winter temperature and length could affect the economically accessible timber supply. Identification of this kind of operational category would likely be more straightforward than defining risk categories for disturbance.

- About 40 percent of the total timber supply for the TSA over the mid- to long-term is supported by areas with good road access in the south-west partition (Tranche 1);
- An additional 12 percent is supported by other areas not involving water transport (Tranche 2);
- Approximately 33 percent is supported by areas that involve barge access, but with reasonably short road access (Tranche 3); and
- Approximately 15 percent is supported by areas that involve barge as well as relatively remote road access (Tranche 4).

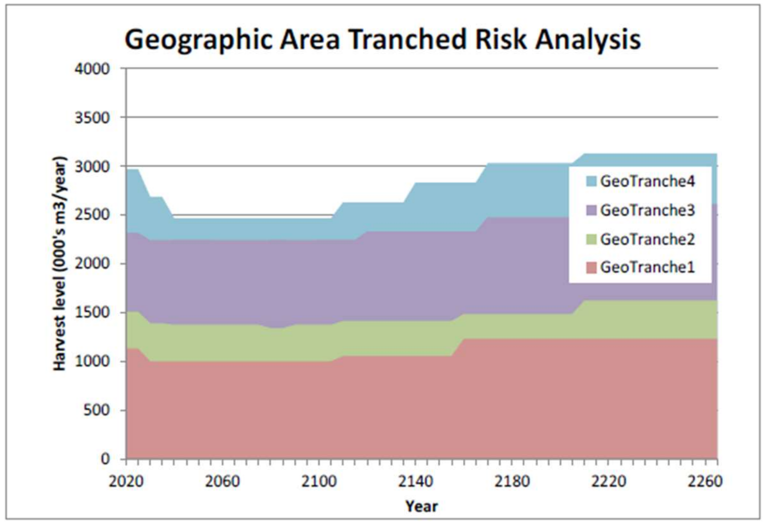


Figure 5 Geographic risk tranche analysis results for Mackenzie TSA TSR (BC MOF 2022)

Drought-risk modeling

Based on drought tool developed for BC (Delong et al. 2019; Foord et al. 2017), the contribution of different drought-risk classes to the timber supply projection was modeled for the Mackenzie TSA (Figure 6)

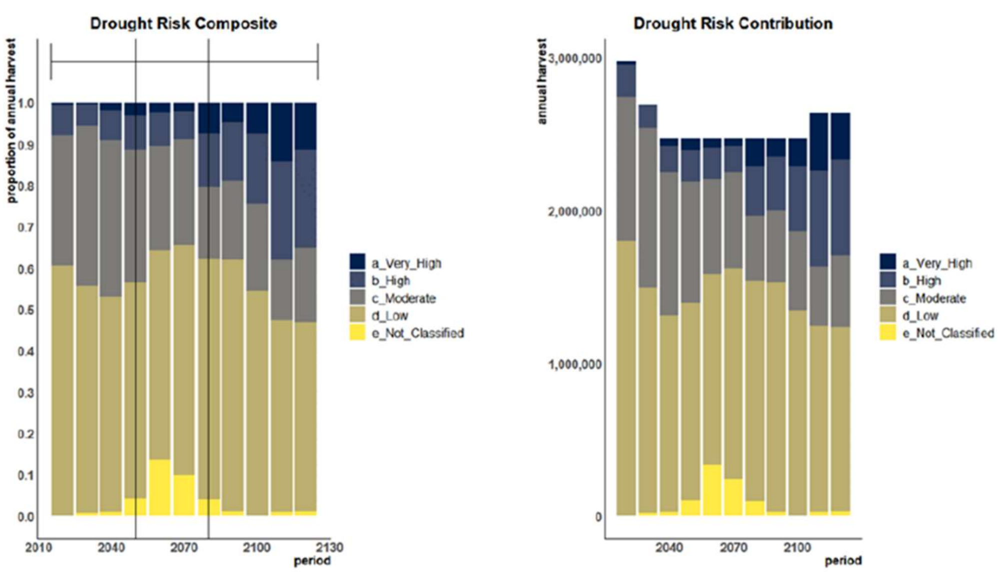


Figure 6 Contribution of various drought-risk classes to a timber supply projection (percentage contribution on the left and volume contribution on the right). Mackenzie timber supply review, 2022.

As for fire risk, identification of areas or forest types subject to different levels of drought risk could enable use of partitions so that options could be kept open to include high risk areas in the AAC subject to employment of appropriate management, while relieving pressure on lower risk areas. It must be noted that the chief forester does not control what kind of management are undertaken in specific areas or forest types, other than the stocking standards, which may create challenges in creating links between risk categories and climate-adaptive management practices.

Current practice in BC – other programs

Other programs in BC in which climate change is relevant include Forest Landscape Planning and Cumulative Effects.

At the time of writing, the focus in forest landscape planning appears to be on choosing areas for protection based on vulnerability to climate change. To date, there have not been substantial efforts to forecast or project long-term impacts as part of FLP (B. Snowdon, pers. comm. December 14, 2022).

Cumulative effects staff in the MOF Resource Stewardship Branch indicate that they are involved in projects related to climate and wildfire refugia (identifying risks to fire in different areas); and describing climate envelopes of wildfire (provides a basis for defining how fire behaviour changes with climate variables (D. Lewis, pers comm, February 8, 2023). The wildfire envelope work may be the most relevant for longer-term strategic work like TSRs. Identification of differential fire risk would assist in implementation of a risk tranche approach. As will be discussed later in this report, use of risk tranches and related partitions may be one of the few ways in which AAC determinations could be made more "robust" given climate change.

5. Work in other jurisdictions

Resource analysis staff in New Brunswick, Quebec and Alberta were contacted to discuss progress on incorporating climate change into timber supply analysis and harvest-level decisions in their jurisdiction.[8]

New Brunswick

The following is based on information received from the New Brunswick Department of Natural Resources and Energy Development (DNRED) (Chris Hennigar, pers comm, Jan 13, 2023)

DNRED staff have been examining potential impacts of climate change on fire and wind, but so far have not noted obvious concerns in need of immediate attention. The clearest example of reflecting climate change impacts into timber supply projections in New Brunswick is related to decline in the health of balsam fir in the south of the province. Representatives from the provincial and federal governments, industry, and academia have come together to reach consensus on adjustments to growth and yield estimates for balsam fir, based on *observed* decline. This is the first time in New Brunswick that climate change has been incorporated into forest planning. All parties agreed that fir decline was occurring and should be reflected in yield adjustments. In cases where evidence of climate change impacts is more equivocal or contentious, such consensus would likely not be achieved.

Other climate change-related efforts in the province include involvement in the Canadian Forest Service Climate Sensitive Growth and Yield Modelling initiative; developing relationships between tree development and climate correlation using North American tree data; and exploration of the suitability

[8] Staff in Ontario were also contacted; however, no direct response was received. Based on related discussions, in would appear that the progress in Ontario is similar to that in Alberta.

of different provenances of trees for climate change reforestation. The latter initiative will likely take 5 to 10 years to generate results.

A notable observation relevant for BC is that the work related to balsam fir went relatively smoothly because of tangible evidence upon which there was broad agreement.

Alberta

The following is based on information received from the Alberta Ministry of Forestry, Parks and Tourism (G. Greidanus[9], pers comm, January 24, 2023).

Annual overview surveys are used to document disturbances caused by abiotic and biotic agents. The province is beginning to undertake climate assessments along with forest health monitoring to record weather anomalies and issues that could be attributed to climate change (e.g., increased blowdown events and aspen die back due to drought).

Alberta is engaged in ongoing work coordinated by the Canadian Forest Service to develop a climate sensitive growth and yield model.

Development of a business case to increase capacity to allow for climate change analysis is ongoing.

An Aspen Risk Tool was developed along with the CFS over the last 20 years (Climate Impacts on the Productivity and Health of Aspen initiative). This tool allows identification of stands that are at risk of decline and mortality. It is currently being revised by CFS to improve its utility.

Forest management planning is undertaken on a 10-year cycle to update plans based on new information. Harvest levels are reassessed in the event of large natural disturbances.

Approved forest plans in the province contain objectives to increase harvests in pine stands susceptible to MPB attack to pre-emptively use at-risk timber and to reduce the amount of susceptible forest. Implementation of the pine objectives in the plans will require timber supply analysis to quantify increases.

Alberta currently does not have a climate change strategy. However, improvements to climate change capacity in the Forestry Division of the Ministry of Forests, Parks and Tourism and development of a forestry-specific adaptation strategy are being explored.

In summary, Alberta is employing monitoring as an early warning tool; regular replanning and analysis updates to incorporate new information including disturbances; identification of stands at risk of decline and mortality; collaboratively developing a climate sensitive growth and yield model with the CFS and other provinces; and developing a forestry climate strategy and a business case to enhance resourcing for incorporating climate change into forestry work, including forest analysis.

Ontario [10]

The following points outline ongoing forestry-related efforts in Ontario to address potential climate change impacts.

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[9] Senior Resource Analyst, Forest Resource Management Section, Ministry of Forestry, Parks and Tourism

[10] This section is based on discussion following a presentation on the process used in Ontario to determine AACs on January 24, 2023

- There is interest in developing approaches to address climate change in analyses, but currently there is no policy that requires incorporation of climate change in wood supply analyses and AAC calculations.
- Climate change-related sensitivity analysis may be done for wood supply analysis, but currently there are no specific methods or guidance.
- It is expected that sustainable forest management practices such as reforestation with diverse tree species will help mitigate some potential negative impacts of climate change.
- Efforts are underway to ensure the simulated range of natural variation calculations (used as inputs to planning and analysis) are updated regularly to account for changing climate.

Quebec

A pilot study undertaken by the Quebec Office of the Chief Forester (Quebec 2021) involved a detailed timber supply analysis that incorporates climate impacts on disturbance (fire, budworm), forest growth and yield, and regeneration success. This study likely provides a relevant example of efforts that could be pursued in BC to develop inputs and modeling approaches for climate change impacts.

To begin, some prerequisites for the project and related organizational and process factors will be summarized before summarizing technical features of the work.

The pilot began in 2018 when funding from a federal program became available and the Quebec chief forester agreed to host a project to explore analysis approaches to integrate climate change into timber supply analysis and AAC determination. Quebec's Sustainable Forest Development Act has required that AACs reflect the impact of climate change on forests (section 48(2)) since 2013. In 2017, the province's auditor general noted that this requirement had not been met in AACs determined up to that time.

Funding supported a project leader for 2 years. The project leader reached out to researchers in academia and government who had published on climate change impacts on forest productivity, post-harvest and natural disturbance regeneration, wildfire, and insect pests. He constructed a team of experts who worked together on the pilot to develop inputs for use in a timber supply model. The project report (Quebec 2021) provides details and references for the scientific work used in developing the inputs.

As suggested in the foregoing, legal requirements, pressure from the auditor, available funding for dedicated staff, and experts with relevant knowledge and willingness to engage in developing inputs all helped to advance the project. In addition, the fact that the project was a pilot rather than a process supporting a decision helped to remove pressure on participants that would likely have been present had there been a need to generate information and resolve uncertainties in ways that a broad range of interests would find agreeable.

The project report emphasizes that for some processes, only one scientific source was used, which simplified the work in the pilot, but that the scientific knowledge base would need to be broadened to strengthen the analysis framework for use in decision support.

The BFEC-CC (Bureau du Forestier en Chef – Changements Climatiques) model used for the analysis was built using SELES.

The analysis used information from three climate models (CanESM2: Canadian Earth System Model, version 2; MIROC-ESM-CHEM: Model for Interdisciplinary Research – Earth System Model; and HadGEM2-ES: Hadley Global Environment Model 2 - Earth System) and three emissions scenarios (Historical – 1980-2010; RCP 4.5 – moderate climate change; and RCP 8.5 – intense climate change).

Impacts on disturbance and stand development

Academic and government researchers provided inputs related to climate change impacts on wildfire, spruce budworm, growth and yield, and succession. The approaches are discussed in some detail in Section 6 on current knowledge about key dynamics. The modeling approaches and parameters were developed by single researchers. There was no formal external review process for the pilot project specifically, however, the research publications were peer reviewed.

Analysis approaches and decision support

The climate change analysis report and related documents were designed to help decision makers interpret large amounts of information related to different climate scenarios and timber supply options.

One table (see Figure 7 below) displays results for timber supply, regeneration failure, salvage percentage and area planted for each climate scenario and assigns general preference ratings – preferred (green), uncomfortable (yellow), and unsatisfactory (red). Boundaries between these preference categories are shown in the bottom three rows of the table. The process used to develop these preference categories was not specified in the report; however, to be meaningful in any specific decision context, such categories would need to be developed in consultation with the decision maker.

Scenarios	Indicators and periods	Mean harvest rate (m^3/year)			Percentage of forest in regeneration failure (%)			Portion of harvested volume from salvage (%)			Mean annual area planted (ha)		
	RCP	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
Status quo	2020 - 2050	6 240 704	3 685 506	2 077 021	1%	4%	3%	12%	71%	84%	17 945	19 021	18 658
	2051 - 2075	7 140 787	3 794 267	2 181 075	1%	10%	11%	8%	82%	83%	15 629	20 100	20 100
	2076 - 2120	6 611 750	4 014 677	2 288 178	2%	19%	25%	9%	67%	79%	14 395	20 100	20 100
	2121 - 2170	6 528 624	4 267 888	2 496 041	3%	28%	38%	11%	38%	58%	15 713	20 100	20 100
Intensive	2020 - 2050	7 631 472	5 556 630	3 060 931	0%	2%	2%	11%	44%	78%	38 259	51 836	36 851
	2051 - 2075	8 313 743	5 513 926	3 234 274	0%	7%	8%	7%	54%	81%	26 117	44 181	50 653
	2076 - 2120	7 075 474	5 360 662	3 199 945	1%	14%	19%	7%	36%	74%	29 753	47 587	56 719
	2121 - 2170	7 162 519	5 635 537	3 197 532	1%	21%	29%	13%	26%	49%	28 195	45 420	52 533
Intensive_F50	2020 - 2050	7 500 692	5 888 581	3 820 348	0%	2%	2%	11%	47%	68%	37 564	46 651	40 075
	2051 - 2075	8 211 570	5 903 769	3 995 346	1%	7%	7%	7%	44%	82%	26 196	41 271	52 662
	2076 - 2120	7 072 322	5 761 068	3 955 604	1%	11%	14%	7%	32%	65%	27 883	47 366	54 751
	2121 - 2170	7 314 333	6 168 369	4 107 319	1%	13%	18%	12%	22%	32%	28 154	41 798	51 292
Intensive_F50 _Plant2	2020 - 2050	7 620 185	5 967 500	3 910 841	0%	1%	1%	12%	42%	68%	44 272	58 057	54 003
	2051 - 2075	8 326 704	6 035 906	4 139 909	0%	5%	3%	6%	44%	80%	32 339	57 189	57 535
	2076 - 2120	7 148 825	6 058 382	4 083 925	0%	7%	8%	7%	30%	66%	31 317	51 246	64 702
	2121 - 2170	7 492 227	6 487 404	4 367 095	0%	8%	10%	11%	25%	33%	31 101	47 432	53 430
Intervals	Preference		greater than 6.0 M (+/- 5%)			less than 3%			less than 10%			less than 35000	
	Discomfort		5.5 to 5.9 M (+/- 10%)			3 to 5 %			10 to 25 %			35000 to 40000	
	Rejection		less than 5.5 M			greater than 5%			greater than 25 %			greater than 40000	

Figure 7 Results matrix from Quebec climate change analysis. Intervals for preference (in green), discomfort (in yellow), and rejection (in red) Table 18, from Quebec, Office of the Chief Forester 2020

Another approach is used to display results for four different values on a single "radar" graph (see Figure 8, below; these can be generated in Excel). These types of charts would likely be most useful in planning exercises where trade-offs among values are being explored but could be informative in TSRs as well.

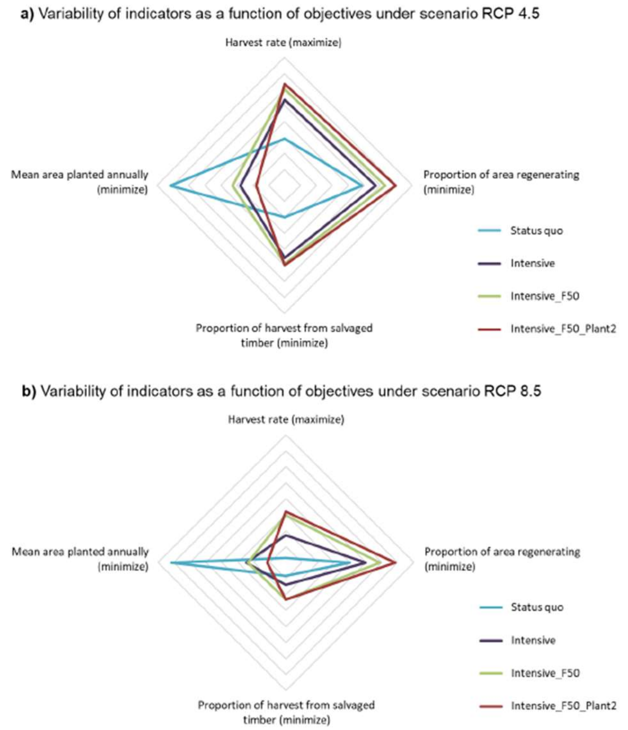


Figure 8 Radar graphs to illustrate effects on different values of interest under different climate scenarios and management options. (Figure 33, from Quebec, Office of the Chief Forester 2020)

Clearly, substantial work has been done in Quebec to develop modeling functionality and parameters for assessing potential impacts of climate change.

As noted in the introduction of this section on Quebec's work, funding allowed for dedicated work (half-time) by a project leader for two years. Work was facilitated by the building of a team of researchers in academia and government who had published on climate change and forests, and who were willing to assist in developing parameters for modeling climate change impacts. The work with researchers on parameter development is particularly notable and may be worth discussing more with representatives from Quebec. However, as the project report emphasizes, only one scientific source was used to develop each set of climate change parameters, which simplified the work in the pilot, but resulted in a narrow knowledge base that would likely need to be broadened to ensure that the parameters were robust to criticism. Finally, the fact that the project was a pilot rather than tied to a specific decision helped to remove pressure on participants that would likely have been present had there been a need to meet tight timelines and to generate information that a broad range of interests would find agreeable. While parameterization and modeling ultimately need to be well enough developed, reviewed and validated in some way to be sufficiently robust for decision making, a pilot project setting allowed for freer exploration and collaboration.

Cross-jurisdictional summary

Discussions with analysts from provincial forestry or natural resource ministries or departments, and review of relevant documents indicated that there are ongoing efforts to develop strategies and obtain resources for climate change work (Alberta, Ontario), recent and ongoing efforts to develop adjustments to growth and yield in response to observed climate-related impacts (New Brunswick), and detailed work on incorporating climate change into timber supply analysis and AAC determination (Quebec). All jurisdictions are involved to some extent in a CFS-sponsored initiative to develop climate sensitive growth and yield models. While it would be worthwhile to remain in communication about climate change with all jurisdictions, the analytical and decision support efforts in Quebec are advanced and would be worth following closely. There would likely be potential for collaborative work with Quebec, since it is likely that work in both BC and Quebec could be mutually useful.

6. Knowledge about key dynamics – disturbance and productivity

The following sections provide an overview of some of the research and perspectives on climate change impacts on disturbance – wildfire and other abiotic dynamics, insects and diseases – forest productivity, and succession. During early phases of this study, literature on climate change impacts on forest disturbance and productivity was reviewed with a view of potentially providing guidance on parameter development. However, it quickly became apparent that the scientific literature was very extensive and diverse, and the findings were often qualitative (i.e., referred to increases or decreases without assigning magnitudes) and when quantitative, the results differed among studies, among ecosystems, and among management regimes. Conversations with research scientists in the BC Ministry of Forests and the federal government also suggested that while there was interest in finding ways of enhancing how climate change impacts are incorporated into decision making, there are no definitive answers to the complex problems of defining parameters and determining approaches for modeling climate change impacts in timber supply analysis.

The overall conclusion reached from these reviews and conversations was that it would not be possible to derive definitive parameters in almost any case; and that trends in impacts and categorization of risk would most likely be achievable goals. The best way forward then would be for FAIB to collaborate with experts to determine what dynamics are most prevalent in the management unit being assessed, set priorities for which ones to explore in detail, and then work together to develop model parameters and highlight research needs.

This section provides an outline of some of the literature reviewed and conversations with experts to provide some basis for the conclusions just described. This does not constitute a comprehensive review – content experts would be better positioned to undertake such reviews – but rather an initial exploration of the current state of knowledge. While work is ongoing in these areas, substantial uncertainty remains. A further conclusion based on this partial review is that the available literature and scope of impacts is very large. Collaboration with experts will be helpful to prioritize which dynamics to explore in different management units, to find relevant information sources, and to develop modeling approaches.

Wildfire

Abatzoglou and Williams (2016) estimated that climate change contributed to a near doubling of the area of forest being burned in the western US from 1984 to 2015.

Boulanager et al. (2014) defined fire regime zones for Canada based on annual area burned and fire occurrence (number of fires) and used them to model future fire activity. Their models projected that annual area burned could increase by 3.7 times and fire occurrence by 3.0 times by 2100 relative to 1961–1990, with much variability across fire regime zones. For fire zones in BC, projected increases in the interior range from 2 to 4 times for area burned and up to 3 times for number of fires, and on the coast, from 2 to 3 times for area burned and 1.5 -2 times for number of fires. Yan Boulanger of the Canadian Forest Service, the lead author on these reports, worked with the Quebec Office of the Chief Forester to develop fire regimes for the climate change analysis described earlier (Quebec 2021). He may be worth contacting to help interpret this research and provide advice on fire modeling in BC.

Halofsky et al. (2020) summarize findings from research based on both empirical and mechanistic models applicable to the Pacific Northwest US. Empirical climate-fire models involve developing statistical relationships been historical climate and fire and using them to predict fire behaviour based on climate projections. They often do not account for decreases in burn probability in recently burned areas, or for long-term changes in vegetation (and thus flammability) with climate change. Their review of studies involving empirical models included the following:

- McKenzie et al. (2004) projected that, with a mean temperature increase of 2°C, area burned by wildfire will increase by a factor of 1.4 to 5 in the PNW.
- For the 11 western states[11] Kitzberger et al. (2017) projected a 5-fold increase on average in annual area burned for the 2010-2039 timeframe compared to 1961-2004.
- Littell et al. (2010) suggested that for Idaho, Montana, Oregon, and Washington, area burned will double or triple by the 2080s, based on future climate projections for two global climate models. For drier forest types (Western and Eastern Cascades, Okanogan Highlands, and Blue Mountains ecosections), they projected the mean area burned was projected to increase by a factor of 3.8 in the 2040s compared to 1980 to 2006.
- Barbero et al. (2015) projected that the annual probability of very large fires will increase by a factor of 4 in 2041 to 2070 compared to 1971 to 2000.
- Parks et al. (2016) suggested that fire severity in a warming climate may not change significantly in the Northwest, because fuels limit fire severity. However, altered fire severity will depend partly on vegetation composition and structure (as they affect fuels), and climate change is expected to alter vegetation composition and structure/

Halofsky et al. (2020) also summarized research findings involving mechanistic models that include interactions between vegetation and fire under changing and potentially novel climate and can account for elevated carbon dioxide concentration which could increase vegetation productivity and fuel load. Their findings included the following:

- For western Oregon and Washington, Rogers et al. (2011) projected a 76 to 310% increase in annual area burned and a 29 to 41% increase in burn severity by the end of the twenty-first century, depending on climate scenario. Projected changes were largely driven by increased summer drought.

- Sheehan et al. (2015) projected increasing fire activity in Idaho, Oregon, Washington, and western Montana. Projected decreases in mean fire interval (i.e., increased frequency) were as high as 82% in the interior subregions without fire suppression; projected decreases in mean fire interval for the westernmost subregion were as high as 48% without fire suppression.

[11] Montana, Wyoming, Colorado, New Mexico, Arizona, Utah, Idaho, Nevada, California, Oregon, and Washington.

- For western Washington, Halofsky et al. (2018) projected a 400% increase in annual area burned in the twenty-first century compared to 1980 to 2010.
- Using the LANDIS-II model and its fire module, Creutzburg et al. (2017) found that area burned in the Oregon Coast Range over the twenty-first century may not increase significantly with climate change compared to historical levels, but fire severity and extreme fire weather would likely increase.
- Using the Fire-BioGeoChemical model for the northern US Rocky Mountains, Keane et al. (1999) projected that under warmer, wetter climate scenarios, there was an increase in vegetation productivity, which led to greater fuel accumulations, and ultimately to more intense crown fires and larger fire sizes. Fire rotations shortened from 276 to 213 years, and reburns also occurred over a greater proportion of the area than historically. This paper highlights the potential interactions between forest productivity, fuel, and fire behaviour.

Littell et al. (2018) highlight how fire dynamics are affected in different ecosystems depending on the relative importance of fuel or flammability. At either end of a spectrum there are fuel limited ecosystems and flammability-limited ecosystems. In fuel-limited ecosystems – many of which are non-forested areas – fire occurrence depends on production of fuels in the recent past. In flammability-limited ecosystems, fire occurrence depends more on hot, dry weather since sufficient fuels are generally present. Many ecosystems have hybrid qualities. In wetter forests, weather must be unusually warm for fuels to be available for burning. Conversely, in drier ecosystems, fuels are dry enough to burn most years, and fire size depends on how much fuel is available to carry fires over large areas – which means that moist weather and hence greater vegetation growth in one year can create conditions for larger fires in a following dry year. Generally, expected future trends in area-burned range from large increases in flammability limited systems, to substantial decreases in fuel-limited non-forested systems. The notion of fuel and flammability limitation on fires adds further complication to the challenge of predicting future fire behaviour. It is possible that the Natural Disturbance Units (Delong 2011) and Biogeoclimatic Ecosystem Classification[12] systems may overlap with the fuel and flammability typology outlined by Littell et al. (2018) and provide a good baseline for developing climate change-related parameters. Wildfire experts in BC would be the best source for guidance on this.

Brown et al. (2017) used pollen, mollusks and charcoal in lake sediment to reconstruct fire history for the Chilcotin Plateau in BC. Their finding suggested that given climate change projections, non-treed and open-forest communities may become dominant on the plateau, as they once were, and that land management strategies may need to be developed to manage that transformation.

These citations suggest that there will likely be increases in fire frequency, extent and in some cases severity in many western North American forest ecosystems where increases in temperature, more evaporative stress, longer summers, and greater temperature and precipitation extremes are projected. However, while there is general consistency in the overall narrative, the quantitative findings vary substantially among researchers and among ecosystems. Still, there clearly is research that could be used to explore plausible changes in fire frequency, extent, and severity, as well as potential ecosystem transformation, in BC. Development of parameters for modeling climate change impacts in the various

[12] https://www.for.gov.bc.ca/hre/becweb/resources/classificationreports/index.html

ecosystems in BC should involve wildfire experts and will need to account for the variability of fire behaviour changes across ecosystems.

For the Quebec case study (Quebec 2021), a fire probability map was constructed based on fire history data to condition fire initiation. Area burned under different climate change scenarios was based on Boulanger et al. (2014 and 2017) and updated for the pilot project by the lead author of those studies. These fire inputs were applied to three 30-year periods in the model (2011-2040, 2041-2070, 2071-2100) with the regime remaining constant after 2100. One hundred fire regime replicates were provided by the researcher, but only the median replicate was applied for the project. The effect of forest composition (old/young and deciduous/conifer) on the annual burn rate developed in the Boulanger papers was removed by applying a correction factor of 1.64 (Bernier et al., 2016 Extents of individual fire events were drawn from the Canadian National Fire Database. Random samples of the history of fire sizes for the project region were taken to build 250 fire-size sequences to allow for stochastic modeling. The work of Bernier and others (2016) was then used to reintroduce the effect of forest composition at each modeled time step based on the emerging forest landscape composition. The BFEC-CC model controls fire spread, and fire initiation and spread stop once the area-burned target is met. The effects of fires were assumed to be a reset to age zero, with eligibility for salvage being zero for stands less than 50 years old at the time of the fire, 50% for stands 50 to 80 years old, and 70% for stands older than 80 years, with a window of two years. More details are available in Quebec (2021).

Finally, BC Wildfire Service staff (N. McLoughlin, pers. comm., January 24, 2023) provided information on fire models. There are two types of fire models: fire scale and landscape scale. Fire-scale models are best suited to operational decision making about fire management and control, since they focus on fire behaviour and spread based on detailed spatial and temporal information on weather, fuel, and topography. Landscape fire succession models simulate multiple fire events and fire regimes over the long term and account for dynamic interactions among wildfires, vegetation and climate at large time and spatial scales. BC Wildfire Service advice is that landscape fire succession models are best suited for TSRs, the long time horizons and large spatial extents. BC Wildfire Service currently has more expertise with operational fire growth models but is interested in using landscape fire succession models to explore questions about the impacts of climate change on future fire regimes.

According to Neal McLoughlin (pers comm, January 24, 2023) at least three landscape fire succession models have been used in Canada. Numerous journal articles are available on each of these models. It is likely that there are other currently unpublished landscape-scale fire models (e.g., ongoing work in FAIB by E. Kleynhans).

- LandWeb: Developed through the fRI Research Healthy Landscape Program and used to simulate natural range of variability across large landscapes (https://friresearch.ca/project/landweb-simulation-modelling). LandWeb has been used primarily by forest companies operating in Alberta, Saskatchewan, and Manitoba. LandWeb has been incorporated into the Spatially Discrete Event Simulator which is an open-source framework for spatial explicit models used for predictive ecology (https://spades.predictiveecology.org/).
- BFOLDS (Boreal Forest Landscape Dynamics Simulator): An extension of LANDIS II intended for simulating large-extent and long-term fire regimes mechanistically as a function of land cover,

terrain, and climate (https://sites.google.com/site/landismodel/extensions/bfolds). BFOLDS has been used primarily by the Government of Ontario.

- SELES (Spatially Explicit Landscape Event Simulator): A tool for constructing and running spatio-temporal landscape models that integrate natural and anthropogenic processes and track indicators over long time frames and large spatial areas (http://www.gowlland.ca/about_gowlland/index.html). This model has been used more by Canadian researchers and academics and has been used to build natural disturbance modeling capacity for FAIB.

Other abiotic dynamics (drought, wind, winter ice)

A drought-risk prediction tool has been developed for BC to inform forest harvest and silvicultural decisions at the stand level (Delong et al. 2019; Foord et al. 2017). The authors used an annual water-balance approach to assess the relative risk of current and future drought-induced stress and mortality for tree species in BC. Findings suggest that seven tree species (western larch, lodgepole pine, western redcedar, western hemlock, interior spruce, Douglas-fir, and ponderosa pine) could be at risk of drought-induced stress and/or mortality due to climate change in at least some ecosystems where they currently grow, depending on climate, and site moisture and nutrient conditions. This tool was used for the tranche analysis in the Mackenzie TSA and is an example of the type of parameterization for climate change impacts that could be useful in BC.

The FPInnovations operational tool discussed earlier[13] mentions that winter roads and bridges that have been used to access some areas may become unusable due to climate change. This kind of dynamic is amenable to monitoring, which would enable relatively rapid reflection in AAC determinations, likely though establishment of a partition, or adjustment to the area available for timber harvesting.

Windthrow damage is expected to increase in some areas due to climate change (Haughian et al. 2012; Saad et al; 2017). In areas subject to significant risk of damaging wind it could be useful to consider modeling windthrow as a stand replacing disturbance. Windthrow risk mapping and systematic projections of potential changes to risk under climate change do not appear to be readily available for BC.

Biotic disturbance (Insects and Disease)

Given the diversity of forest insects and diseases, a summary of research findings like that presented for fire is less practical. For example, Haughian et al. (2012) list 12 important forest insect pests in BC, and numerous root rots, blights, and rusts. These various organisms respond differently to climate and climate changes. Generalizations about the impacts of climate change are possible for types of organisms but overarching generalizations about how insects and diseases will respond to changes would not be accurate. This section summarizes some relevant literature and personal communications related to biotic disturbances. However, it is suggested that given the diversity of biotic pests, content experts should be sought when attempting to develop modeling parameters and approaches for TSRs.

The dynamics of forest insects and diseases are affected by climate, weather, ecosystem type, and the condition of forests (H. Kope, pers. comm. January 11/23). In addition, abiotic and biotic disturbances can positively reinforce one another by increasing the susceptibility of trees to disturbance and forest

[13] https://storymaps.arcgis.com/stories/be140461a0874d9cb9c3e0aebe69d4cf

pests L. Maclauchlan, (pers. comm, January 26/23). For example, drought can increase the likelihood, extent and intensity of fire, which can leave surviving trees with weakened immunity, increasing their susceptibility to insect attack and the likelihood of tree mortality. Therefore, modeling disturbance particularly under a changing climate is difficult due to complex interactions, which differ in different ecosystems. An understanding of the underlying biology of each organism will be necessary to enable the development of modeling parameters.

Woods et al. (2010) summarize the potential effects of climate change focusing on insects and pathogens in BC. In terms of insects, they discuss bark beetles (mountain pine beetle, Douglas-fir beetle, spruce beetle), spruce leader weevil, and defoliators (western spruce budworm in dry Douglas-fir, western hemlock looper). Anticipated climate change will likely increase the potential for repeat infestations, intensification of insect activity from endemic to epidemic levels or moderate to high hazard, migration of infestations to new areas, more frequent infestations. Insects are more affected by changes in temperature than precipitation.

Woods and colleagues describe potential climate change effects on foliar diseases (*Dothistroma*), stem rusts (western gall rust in young pine, white pine blister rust, comandra, stalactiform blister rust), root diseases (*Armillaria*, *Phellinus, Tomentosus, Annosus*), and dwarf mistletoe. Pathogens are generally more affected by changes in precipitation than temperature, and since precipitation changes are generally more difficult to predict, future potential changes in pathogen populations and behaviour are difficult to predict.

Trees that are already stressed by endemic insects or pathogens will likely be more susceptible to alien invasive pests. Cold winters historically have been a good defense against the survival and spread of alien pests, but this may change as climate changes.

The discussion in the Woods et al. paper is mostly qualitative, so provides limited insight into how timber supply models could be parameterized to explore impacts. As highlighted here, there are manty forest health agents that could be considered. While not all will be active in a particular management unit, keeping a TSR process manageable focus would most likely need to be on a small number that are potentially most damaging.

Carroll (2012) suggested the climate change is more likely to lead to increased disturbance by bark beetles than by defoliators, mainly because bark beetles respond more readily to host tree stress and have less strict requirements for phenological synchrony (correspondence between seasons and life cycle). Carroll suggested that more priority be given to development of predictive tools for bark beetles than for defoliators. He also highlighted threats related to currently innocuous, and both native and alien invasive species that could erupt unpredictably and migrate northward as climate changes.

Haughian et al. (2012) suggest that root rots, blights, and rusts are likely to expand where climate becomes warmer and wetter, while they may decline or remain unchanged in severity where conditions become drier.

Hennon et al. (2020) developed a conceptual framework for evaluating climate effects on tree diseases. Climate affects pathogen biology, including reproduction and infection processes, and some climatic changes can increase the success and virulence of diseases. Climatic conditions can also cause direct stress on trees (e.g., drought), which can kill them or weaken their ability to withstand pathogens, or mortality when trees' physiological limits are exceeded.

Hennon et al. (2021) examine seven forest health factors: Dothistroma needle blight in BC, Swiss needle cast in the Pacific Northwest, hard pine rusts in BC, hemlock dwarf mistletoe, sudden aspen decline, Western white pine pole blight, Yellow-cedar decline. They demonstrate links between the increased prevalence of these forest health issues and climate change. While the authors provide management guidance, they do not provide specific guidance that would facilitate parameter development for timber supply modeling. They note the need for collaboration among pathologists, physiologists, ecologists, entomologists and others to understand the causes of tree mortality or decline. Presumably this kind of collaboration would assist with parameter development.

For the Quebec case study (Quebec 2021) the effects of spruce budworm under climate change were modeled based on Bouchard et al. (2015) and on recommendations made by the first author of that study. Modeling budworm involved inputs related to the periodicity and probability of mortality of infestations, and to the effect of stand species composition, stand age, and mean annual temperature during the simulation year. Probabilities of high mortality were provided for various classes of the latter three variables. Infestation intensity was provided as a time series of outbreaks on a 35-year cycle.

An understanding of the physiology of spruce budworm suggests that climate change may result in a northward migration of the insects. This migration is expected since currently the northern extent of budworm is limited by cold temperatures. The southern limit of budworm is connected to interferences with the insect's life cycle by warm winter temperatures, and that boundary is expected to migrate northward (Quebec 2021, pp. 6).

The spruce budworm module is based on the methodology presented in Bouchard et al. (2015) and also on recommendations by Bouchard related to (i) the effects of climate change on the insect and (ii) adaptation of the methodology for the purposes of the project.

For modeling, spruce budworm infestation was assumed to occur on a 35-year cycle, with outbreak intensity peaking during each infestation (see Figure 9). The probability of mortality in this figure is linked solely to infestation intensity. Ultimate probability of death is the product of this probability and probability linked to stand species composition; stand age; and the mean annual temperature for the year of simulation (Quebec 2021, pp. 20-21).

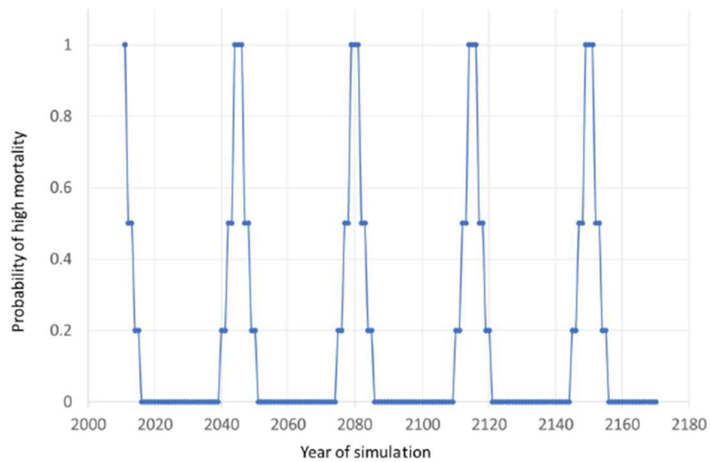


Figure 9 Intensity of spruce budworm outbreak (indicated by probability of high mortality) (Figure 7 from Chief Forester [Quebec], 2020.

While the periodicity and intensity of budworm outbreaks was assumed to stay consistent over the modeling horizon of 150 years and therefore does not appear to be climate sensitive, the mortality probability is sensitive to mean annual temperature, which bring climate sensitivity to the budworm module.

Experts within the forest health community in the Ministry of Forests are willing to develop estimates of disturbance periodicity, amplitude (severity) and longevity under climate change that could be used in timber supply analysis (L. Maclauchlan, pers comm, January 26, 2023). There is scientific literature that would support parameter development related to forest insects and disease (e.g., Kliejunas et al. 2009; Hennon et al. 2020, Woods et al. 2010); however, monitoring will be important to strengthen knowledge about the changing dynamics of pests and their impacts on forests (A. Woods, pers comm, February 3, 2023). Given the deep uncertainty, this task will not be straightforward and will require considerable collaboration between forest health experts and timber supply analysts. Nevertheless, it is likely that climate change will increase the damage of forest insects and diseases on timber volume and value.

Forest productivity and succession

Sattler et al. (2023 under review) developed climate-based transfer functions for lodgepole pine survival using data gathered from a provenance trial in BC. This research continues the work of O'Neill and Nigh (2011) and Nigh (2014). Transfer functions are increasingly being studied for their potential to modify climate-static models of growth and survival. The transfer functions developed by Sattler et al. predicts annual survival as a function of changes in both temperature and precipitation. The interactions between climate at the seed source and the transfer across temperature and precipitation gradients were included in the model and suggest that rates of survival under climate change will vary according to the climate of the provenance. In the short-term, areas where the contemporary climate is cold and dry are likely to benefit the most in terms of the effect of climate change on survival. However, long-term predicted warming trends will lead to a decrease in survival for all populations of lodgepole pine in BC. This result corresponds with findings of D'Orangeville et al. (2018) in Quebec. Transfer functions are currently available only for lodgepole pine.

The Canadian Forest Service (CFS) is leading a Climate Sensitive Growth and Yield Modelling Initiative. The goal of the initiative is to build model functionality so that growth and yield models can account for the impacts of changes in climate and other environmental conditions, such as temperature, precipitation, water balance, increases in atmospheric CO2 concentration and atmospheric nitrogen deposition (Metsaranta et al., 2022). Most Canadian provinces, including BC, are involved in the initiative, and most provinces do not currently have a climate sensitive GY model (J. Metsaranta, pers. comm., February 2, 2023). Some pilot projects are ongoing within the CSGYM initiative to integrate climate and environmental relationships into existing GY models, which requires that CFS be given access to the model code. Therefore, this initiative does require open access to code, which had required negotiations in some provinces.

An exception to the lack of climate sensitive GY model is Quebec, where climate sensitivity was built into the Artémis model for the pilot study discussed earlier in this report (Quebec, 2020). To reiterate, that model was modified to incorporate influences of climate on diameter growth, stem mortality, and stem recruitment, based on work by D'Orangeville et al. (2018). In this case, adjustment factors for merchantable volume were calculated to reflect yield changes under the different climate change scenarios for 5-year stand age classes of various species groups, and for each 20-year establishment periods. It could be argued that the need to use adjustment factors signifies the model is not strictly climate sensitive, however, there is nevertheless functionality that allows development of climate sensitive parameters.

For the Quebec case study (Quebec 2021) the Artémis-2014 stand-scale model was modified to build in sensitivity to climate on merchantable volume development (Power and Auger, 2019). Power and Auger (2019) built climate sensitivity into the stand model using work by D'Orangeville et al. (2018), which simulates the basal area growth of many species as a function of temperature and precipitation, while using temperature and precipitation to predict mortality for certain potential vegetation types. The Power and Auger (2019) work was undertaken specifically for the pilot project and involved simulating regional sample plots under historical and climate change projections, and incorporating the differential effects of climate changes on stands at different developmental stages. This work provided adjustment factors to apply to merchantable volume for the different climate scenarios for the various species groups (balsam fir, shade-intolerant deciduous shade tolerant deciduous, shade-intolerant conifer, and shade-tolerant conifer) for every 20-year establishment period and 5-year stand age classes.

As with other dynamics important for projecting timber supply, there is important ongoing research into the effects of climate change on forest growth and survival in the CSGYM Initiative and on transfer functions (Sattler et al, 2023 under review). At the time of writing this report, there is a lack of consistency in research results related to climate change impacts on forest productivity (D. Sattler, pers comm, March 22, 2023). Therefore, there is a need for collaboration among researchers with a view to achieving better understanding of the relationship between climate change and forest growth and survival. Ongoing research on climate-productivity linkages will assist in parameterizing GY modeling for TSRs, and GY experts in FAIB should remain involved with them.

Another impact of climate change related to stand development is ecosystem transformation or succession. These changes could occur as new assemblages of species regenerate after natural disturbance, or in response to decline of one ecosystem due to maladaptation to new climate conditions. In terms of the volume of timber supply, the implications of ecosystem transformation may be captured in the modeling of disturbance and forest health issues. However, ecosystem change may also involve changes to the amount of area available for timber harvesting and to tree species. For example, the Brown et al. (2017) paper referenced above suggested that currently forested areas may transform into grassland. In some locations, frequent disturbances could lead to forests being dominated by disturbance tolerant or resistant species, such that the types of timber on which current industries are based may decrease in extent. Analysis was undertaken in Quebec on post disturbance succession linked to reforestation strategies to focusing on reforestation strategies to reduce future wildfire risk (Quebec 2021); this resulted in large increases in the modeled area of deciduous-dominated forest, which may present adaptive challenges for industry.

The LANDIS-II landscape-scale model has been used to explore climate change related succession (e.g., Laflower et al, 2016). Haupeng Chen of FAIB is undertaking research on succession using LANDIS-II. At the time of writing this report, this research is still in its early stages, and it may be some time before results may be available for incorporation into TSRs.

Although the short-term implications of succession may be small, fundamental changes in the nature of the timber inventory over time would be worth exploring to enable proactive adaptation.

For both stand-level and landscape-level models, it would be worthwhile to encourage focused collaboration between researchers and FAIB analysts to explore options for incorporating climate change impacts into GY estimates and succession. As noted elsewhere in this report, the utility and practicality of such collaboration would likely be highest if done as part of time-limited pilot projects. Soft commitments to collaborate are often less successful due to competing demands on time and resources.

7. Readiness

Organizational, individual, and broader social or cultural factors can affect the readiness of FAIB and the OCF generally to more fully incorporate climate change impacts into TSRs and AAC determinations.

Organizational factors include requirements of, direction from, or limits set by legislation, service plans, the Canadian constitution, minister mandates, and budgets. For example, legislative requirements to complete AAC determinations within set timelines while undertaking thorough engagement with Indigenous communities require significant resources. Adding climate change considerations, which necessitates learning about a new and complex scientific area, on top of the other requirements and limitations may be overwhelming to the program. These challenges will never be resolved completely; however, they should be recognized explicitly, and if possible, additional, adequate resourcing must be provided and mechanisms such as efficient training and well-documented tools for analysis and decision support should be developed and made easily accessible.

Individual readiness overlaps with the organizational factors just discussed. Climate change presents numerous challenges to analysts. Their jobs will be made much more straightforward if they have sufficient knowledge, skill, and resources including: an understand the general features of the dynamic they are modeling; readily available information and modeling tools; and understanding of methods for accounting for inevitable uncertainties. As noted for organizational factors, individual readiness will be enhanced with focused training and well-documented and easily accessible tools for analysis and decision support. The intention of describing training as “focused” is to recognize that timber supply analysts do not require expertise in all areas of climate modeling, wildfire behaviour, climate effects on forest health, etc. Analysts need just enough information to get beyond the overwhelm potentially caused by the shear amount of available information and its diversity. For example, an hour-long training module that describes the different types of climate models, why they differ, and considerations in choosing climate models or ensembles could be useful in addressing initial confusion. A multiday training that attempts to develop in-depth knowledge would not be required and relevant for a timber supply analyst.

The main social or cultural factor affecting readiness is the general discomfort that most people have with uncertainty. Addressing climate change impacts in forestry decisions is effectively making decisions under deep uncertainty. Uncertainty is usually seen as something that should be eliminated. Culturally, there are substantial challenges in acknowledging it as reality, and developing common language and creative analysis and decision-making approaches. With AAC determinations, the diversity of values further complicates having to acknowledge uncertainty, since climate change and management efforts to adapt to it can create different and sometimes opposite risks for different values.

Some interests may be averse to findings that the future could be very different due to ecosystem transformation and changed disturbance regimes and advocate that technology and innovation will allow for continuation of current business. In developing approaches for incorporating anticipated climate change impacts into analyses and AACs, FAIB should recognize these cultural realities and generate relevant information. For example, when presented with a timber supply projection showing much lower potential harvest levels, a common question will be: How can that impact be alleviated? Directly incorporating climate change impacts into AACs will likely require explorations than can respond to such questions.

Having outlined factors that could challenge readiness to more fully incorporate climate change, research undertaken for this report suggests that FAIB is well-positioned to address the challenges in some ways and will likely need to undertake some innovative work to improve decision support for robust AAC determinations.

FAIB already possesses analytical tools to enable incorporation of climate change impacts to stand-replacing disturbance regimes and to forest productivity. This modeling functionality can almost certainly be modified to permit modeling of other dynamics that affect forest health (i.e., insect and disease) and landbase availability (e.g., changes to terrain stability due to changes in precipitation patterns). Existing model functionality can also handle issues such as geographic access challenges due to changes in winter ice.

Remaining challenges include developing parameters for timber supply models to reflect climate change impacts, and implementing mechanisms that would increase the robustness of AAC determinations, namely partitions the recognize differential risks in different forest types and areas.

Prior to exploring these issues in more detail, it will be worthwhile to outline some definitions for, and approaches available to manage in the face of uncertainty.

8. Uncertainty

Even in the absence of climate change, forest management is almost always subject to uncertainty due to the long lifespans of forests, unknown timing and severity of biotic and abiotic natural disturbances, changing social values, technological and new-product development, and other factors. Adding climate change to the mix creates deep uncertainty, which occurs under the following circumstances (Marchau et al. 2019b):

- Scientists, decision makers and stakeholders do not know or cannot agree on the likelihood of different future scenarios
- There is a lack of agreement or knowledge about the outcomes of management decisions, since there is a lack of knowledge about the relationships among system components (e.g., weather and forest health, or responses of insects and diseases to climate changes)
- There is a lack of agreement on how the various values being managed for should be weighted, and
- The lack in knowledge and agreement cannot be resolved within the timeframe of a decision, or perhaps at all (e.g., it will most likely never be possible to know for certain what climate and weather will exist, or how human values may shift decades into the future). It is also uncertain what choices people will make in attempting to respond to climate change through mitigation or adaptation actions (Swart et al., 2009)

Still, decision makers like the chief forester must make decisions that have immediate and longer-term effects on ecosystems, cultures, communities, and the economy. While there will always be some degree of discomfort in making decisions under uncertainty, some approaches are available that can either reduce uncertainties for future decision processes or increase the chances that desired objectives will be achieved. Measures that acknowledge and to some extent address uncertainty consist of actions within the following categories (Fletcher 2015):

- Enhance information and knowledge
- Implement practices that help adapt to or buffer against uncertainty and change
- Develop responsive decision-making processes, institutions, and regulatory frameworks

Table 1 (next page) provides examples of each category.

AAC rationales almost always speak to gaps in knowledge – either data or process understanding – and ask that efforts be made to improve information to strengthen future decisions. This falls within the first category of tools discussed above (enhance information and knowledge). AAC rationales also virtually always reference the fact that the *Forest Act* requires new determinations at least once every 10 years and could be made more frequently if new information highlights an urgency. Therefore, the idea of maintaining responsive decision-making processes is embedded in the legislative framework.

However, neither of those approaches – asking for improvement in information and ensuring regular and relatively frequent decisions – fully acknowledges the challenge of making decisions that perform well in a plausible range of uncertain futures. One approach that appears applicable to AAC determinations is the identification of risk “tranches” (slices in French) (Fall 2019b). Risk categories could be based on susceptibility to fire, insects, disease, drought, lack of usable ice bridges or other factors that are relevant in the area. The utility of categorizing the timber supply forecast in terms of differential risks would be to keep options open for harvesting in all areas, subject to applicable management requirements; acknowledge uncertainty about when the risk-causing dynamic will occur, and its intensity or duration; and ensure that timber supply from at-risk areas, which may ultimately be lost, is not harvested from other areas.

Table 1 Approaches to address uncertainty.

Enhance information and knowledge	Practices that help adapt to or buffer against uncertainty and change	Responsive decision-making processes, institutions, and regulatory frameworks
○ Collect information (inventory) ○ Research ○ Adaptive management (experimentation, learning and adjustment) ○ Monitor – look for early warning signs and feedback about the impacts of decisions and actions ○ Analysis, scenario development and strategic scanning (explore what could be coming) ○ Sensitivity analysis ○ Anticipate and project an array of plausible futures ○ Clarify language and definitions of important concepts and terms	○ Prepare for a range of conditions; diversify ○ Safety factor (buffer, insurance, design for extreme events, redundancy, precautionary principle ○ Leave options open ○ Avoid irreversible actions ○ Be adaptable and flexible ○ Resist or defend against influence of change agents. ○ Enhance recovery and resilience ○ Facilitate response to change. Support adaptation to new conditions	○ Revisit decisions regularly ○ Avoid making irreversible decisions ○ Leave options open ○ Be adaptable ○ Share risks ○ Develop incentives ○ Promote organizational capacity – enable flexibility, decisiveness (rapid response) ○ Clear and transparent assumptions to facilitate direction changes ○ Decision rules such as: no regrets, robustness; maximin (minimize the maximum loss); minimax regret (minimize the worst-case regret)

Forest management practices, such as creating diverse stands and landscapes during reforestation (Crowe and Parker 2008; Hof et al 2017), selecting species more likely to be adapted to future climate (MacKenzie and Mahony 2021), and assisted migration (O'Neill et al. 2008) can also be used to address uncertainties about future forest health, survival and growth under uncertain future conditions. While practices such as these may assist in adapting to climate change, at this time AAC determinations can only reflect their use, not require their implementation.

Common approaches to uncertainty

Hoffman et al. (2014) outlines four common approaches to uncertainty in natural resource management.

1. Proceed as though there is no uncertainty
   Given the complexity, perceived intractability, and cost associated with uncertainty, some ignore it. While this allows for faster decisions, they will be based on incomplete understanding and may lead to undesirable outcomes since important dynamics of the management systems have not been considered.

2. Await more certainty before acting
   This approach avoids errors, but implies action based on past approaches and conditions (i.e., passive or inactive with respect to uncertainty).

3. Frame the problem as being a lack of information
   This is action focused, but can lead to analysis paralysis, and failure to think about how to make good decisions under uncertainty.

4. Focus on better-understood problems or parts of the problem
   This approach can lead to false sense of achievement and divert attention from more important issues.

As is hopefully clear from these descriptions, common approaches often do not perform well in addressing the challenges presented by uncertainty. They focus on filling knowledge gaps or on working with existing knowledge and approaches, rather than acknowledging the uncertainty and working to make decisions that achieve desired objectives in the face of uncertainty.

Acknowledging and working with uncertainty is challenging for several reasons (Hoffman et al. 2014):

- It can appear to be inefficient, extending the time taken to make decisions, and requiring additional scarce resources for decision support.
- Implementing strategies to address uncertainties – such as diversification, monitoring, frequent decision making, and identifying and protecting at-risk values – are often costly in the short term and divert resources from activities seen to be more focused on achieving objectives.
- There may be fears of appearing incompetent, lacking the knowledge and skill to clearly resolve scientific and technical unknowns.
- There usually are no clear answers, which can be deeply troubling and unsatisfying for researchers and professionals accustomed to using their expertise and skill to get things done.

Notwithstanding these challenges, consciously acknowledging uncertainty in decision making and exploring strategies for reducing risks to important values increases the chance of achieving desired outcomes. It also enhances the capacity for flexible thinking, which can be helpful when facing future uncertainty and complexity. Table 1, above, summarizes some general approaches for addressing uncertainty, many of which can be adapted for timber supply analysis and AAC determination. TSR processes already encourage gathering of information to improve future decisions, and the legislative requirement for regular AAC determinations helps to ensure updated information and knowledge are continuously incorporated into analyses and decisions, which can act as a kind of monitoring (i.e., checking if the existing AAC is still reasonable given changing circumstances). As will be explored in later sections of this report, it may be worthwhile to consider how actions in the middle column of Table 1 (Practices that help adapt to or buffer against uncertainty and change) could be implemented in AAC determinations. It may be worthwhile to explore how risk categorization and related partitions could serve to acknowledge potential climate change impacts while leaving options open for use of at-risk forests under appropriate conditions (e.g., implementation of practices to enhance climate change adaptation).

Importance of constructive relationships

Challenges associated with building and maintaining constructive working relationships are not frequently discussed in climate change literature. Nevertheless, it is difficult to envision how a world characterized by diverse viewpoints and values will be able to address a challenge as consequential – both socioeconomically and ecologically – as climate change without the willingness and ability to work together across difference. Still, this concern may appear to be beyond the scope of TSR. However, it should be acknowledged that developing inputs and approaches to account for potential impacts of uncertain climate change will require cross-disciplinary efforts, which will not be straightforward. Experts are usually attached to and believe in the benefits of the language, methods and conceptual frameworks of their disciplines. Working across disciplinary boundaries will be frustrating, feel inefficient, and involve conflicts. This is all unavoidable *even without considering uncertainty*. Developing inputs and approaches for incorporating climate change will require nuanced navigation of the cultural differences of disciplines. At times it may be worthwhile to engage outside experts who can serve as a sort of tribunal to evaluate the different positions and information sources and provide recommendations to the chief forester. If conflicts are particularly strong, engagement of conflict facilitation expertise may be warranted.

9. Robustness in timber supply analysis and AAC determination

This section outlines two types of robustness relevant for TSR and AAC determination.

- The first sense of robustness corresponds to ***decisions designed to perform satisfactorily over a wide range of plausible conditions, in both the near and far terms*** (Lempert et al. 2013; Radke et al. 2017).
- The second sense of robustness refers to the ***quality of the body of information used to support a decision***.

These two frames of robustness are related: making a decision that meets objectives satisfactorily in both the near term and a range of plausible long-term futures would be difficult without having a robust body of information on which to rely.

The scientific literature on robust decision making under deep uncertainty is growing (e.g., Marchau et al. 2019; Munoz et al. 2022; Radke et al. 2017). The approaches in the literature usually involve computationally intensive searches for management regimes that minimize regrets relative to either a desired outcome or to outcomes of the regime that performs best. These approaches appear to be best suited to planning exercises in which an appropriate balance of activities is sought to meet multiple objectives. In the context of AACs as currently conceptualized in BC – that is, harvest levels that are consistent with the current management and land use regimes as formalized in land use zones, legislative or regulatory requirements, and operational plans – the search for least regret regimes given multiple objectives does not seem applicable, since the chief forester does not define objectives and management requirements for values other than timber.

The challenge for AAC determination in relation to climate change of uncertain magnitude, rate, and ecological impact, and where scientific knowledge indicates trends in changes and impacts, may be to reflect those trends, while to the extent possible keeping options open for managing and utilizing types of forests that are most at risk of climate change-related impacts. A further challenge is to determine how to reflect climate change trends in quantitative decisions (how many cubic meters of timber can be harvested). Deciding on types of management direction to take – for example, the kinds of tree species to be planted or the types of areas that warrant highest protection from wildfire risk – given climate trends is somewhat more straightforward.

The second type of robustness, related to the quality of information, affects the level of confidence that a decision maker like the chief forester has in reaching decisions that will affect multiple objectives while acknowledging uncertainties about climate change. Once an AAC decision is made, there is always the risk that its reasonableness will be challenged by negatively affected interests. Therefore, it may be worthwhile to prepare for such challenges. This is the topic of the following section.

10. Parameter development under uncertainty

As highlighted in the introduction to this report, development of parameters for modeling climate change impacts was beyond the scope of this study. However, review of some literature on climate change impacts on forests led to the conclusion that while many research studies indicate that climate change will affect ecosystems, there are few examples of guidance on how to factor research results into resource use decisions. In addition, the impacts are usually stated as trends and ranges. This is not surprising given the uncertainty about the specific nature, magnitude, and timing of climate change due to uncertainty about emissions scenarios, ecosystem responses, and extent of future mitigation and adaptation measures. Therefore, the TSR program is faced with a situation of a wide variety of research with a diversity of scientific results, that normally outline trends and ranges of impacts.

It would be possible for FAIB analysts to consult on an *ad hoc* basis with single experts in key dynamics such as wildfire, forest health and stand growth to help to navigate this situation and to develop modeling inputs to reflect climate change impacts. Working with single researchers or small existing teams of researchers was the approach taken in the Quebec pilot study discussed earlier (Quebec 2021). However, as outlined at the end of the previous section, this approach could leave the chief forester open to challenges of reasonableness, since there may be diversity of scientific opinion.

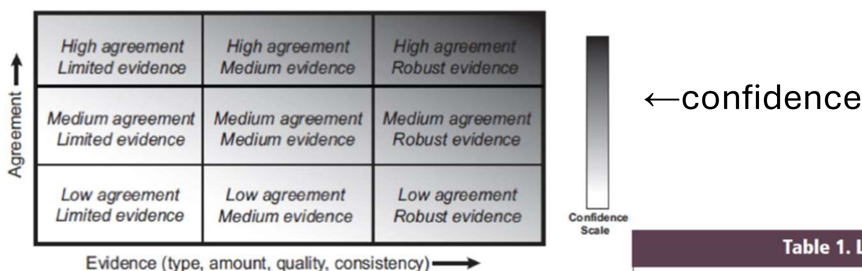
One approach would be to work to ensure model parameters[14] developed to reflect climate change impacts are supported by scientific consensus. Work to achieve scientific consensus could involve seeking input from several relevant experts on initial work by one expert, or through more formal processes like workshops or time-limited initiatives. As outlined earlier in the section the importance of relationships, this type of process may not always be straightforward given the level of uncertainty and the likely diversity of preferred approaches to parameter development among experts. Investigation of approaches for expert elicitation (e.g., Bolger et al. 2011; Bolger and Wright 2011; Morgan 2014; Rowe and Wright 2011) and working with uncertain climate change information (e.g., Roussos et al. 2022; Swart et al., 2009; Thompson et al. 2022) could assist with the design of processes to convene experts to assist with parameter development.

Using group approaches could have the benefit of reflecting approaches used by the IPCC, which involve broad groups of experts. For example, the Summary for Policymakers for the report on impacts, adaptation and vulnerability for the Sixth Assessment Report of the IPCC (IPCC 2022) cites 11 editors and dozens of drafting and contributing authors. The benefit here could be that the IPCC is an established body working on climate change. If FAIB were to use approaches informed by those used in the IPCC, including acknowledging and working to address some of the shortcomings of the IPCC approach, the

[14] To be clear, frameworks that describe risk categories related to disturbance and productivity are a type of parameter.

information and the process used to develop it will likely have more credibility than if more *ad hoc* processes were used.

The most current guidance on treating uncertainties for IPCC report is Mastrandrea et al. (2010). The guidance is to develop confidence ratings and where statistical information is available, likelihood statements that reflect research consensus (see Figure 10, below). Confidence refers to the validity of findings, based on the type, amount, quality, and consistency of evidence and the degree of agreement. Confidence is expressed qualitatively. Likelihood is a quantitative measure of uncertainty expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment). The uncertainty framework has received much criticism due to ambiguity, vagueness, overlap among terms, and varying levels of understanding and interpretations across disciplines (Adler and Hirsch Hadorn 2014; Aven and Renn 2015; Kause et al. 2022; Wüthrich 2017). For example, the guidance lacks clear definitions for terms like “agreement”, “evidence quality”, and “likelihood.” However, although the guidance framework has shortcomings, clear definitions and a structured framework for collaborative parameter development by a range of experts could add credibility to decisions.



likelihood→

Table 1. Likelihood Scale

Term*	Likelihood of the Outcome
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33 to 66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

Figure 10 Confidence and likelihood scales from guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties (Mastrandrea et al., 2010)

11. Analysis responses to uncertainty

Given the prevalence of uncertainties associated with climate change, several types of analysis could be undertaken to shed light on decision options:

Sensitivity analysis

Sensitivity analysis is used to help understand the sensitivity of outcomes to changes in the magnitude of a variable. Often in TSRs, sensitivity analyses are runs with specific inputs changed in both directions. In TSRs, the main function of this type of analysis is to highlight the importance of the variable to timber supply. This approach would not provide substantial decision-relevant information on climate change to the chief forester, since it would mainly communicate that there is uncertainty but that actual timber supply could equally be lower or higher than the base or reference case.

Unidirectional uncertainty (sensitivity) analysis

This approach is similar to bidirectional sensitivity analysis; however, it would apply in cases where the potential direction of change in a variable is known with some confidence. For climate change this approach could be used for modeling potential changes in disturbance regimes or productivity under different climate change scenarios.

The challenge would be to assist the chief forester in interpreting the results, since sensitivity analysis does not outline which decision should be made. When making decisions under uncertainty the utility of sensitivity analyses would be to increase understanding of the effects of climate change on timber supply and other values, and to assist the chief forester in assessing risks on all values affected by AAC determinations. As an example, near term socioeconomic benefits can conflict with longer-term benefits. Regret is a concept that may be useful in this context. That is, if some analysis results indicate outcomes that the chief forester believed were unacceptable, the decision would be to make a decision that avoids that outcome. This approach is common in timber supply analyses and AAC determinations, where large disruptions in the timber supply projection are believed to be unacceptable. The challenge with climate change is that one climate change scenario may indicate satisfactory timber supply results, while another climate scenario may lead to unacceptable timber supply outcomes. In such a circumstance, the chief forester might need to make a choice about whether adjusting an AAC to avoid the outcome associated with the latter scenario warrants the costs associated with the adjustment.

A hypothetical way to circumvent the challenges just discussed would be to reach agreement that a specific climate scenario represents a reasonable “best guess” on which to base an assessment of climate change impacts. This approach would simplify analysis and parameter development. However, it also effectively denies the uncertainty about what climate scenario will occur.

None of this discussion is meant to imply that sensitivity analysis based around one or more climate scenarios is not useful. Such analysis is critical to develop understanding of how climate change could affect forests, timber supply and other values. However, while analysis can inform decisions it cannot make them. Additional information and clarity on risk attitudes is needed to help interpret how such analysis can be factored into a decision. For example, consider Figure 7 in this report (pg. 16 in the section on Quebec). The table shown there displays categories of preference for, or discomfort with, timber supply results under different climate and management scenarios. This kind of information is helpful for understanding relationships between different dynamics and timber supply. However, its utility for making decisions depends on the risk attitude of the decision maker, the decision maker’s belief about the likelihood of the different future scenarios, and the decision maker’s beliefs about the effectiveness and implementation feasibility of any available tools for mitigating risks. Tools in this sense could be forest management practices or decision options such as partitions. Even if the decision maker were to believe that a particular future climate scenario is plausible, they would still need to weigh whether the costs of a decision such as reducing an AAC were worth the future benefits given uncertainties about the future. Therefore, it is worthwhile to consider the extent to which decision tools are available to hedge – that is, acknowledge potential impacts while keeping options open. This is the topic of the next section.

Tranche analysis

Tranche analysis identifies the contribution of identified risk classes to the timber supply forecast. As discussed previously, such classes could be associated with wildfire, drought, insects, forest pathogens, regeneration success, wind damage, and potential ecosystem change and changes to accessibility (e.g., loss of ice roads and bridges). The benefit of this approach could be to facilitate reflecting potential but uncertain climate change impacts while at the same time keeping options open to utilize timber from higher-risk forests or areas. The approach could be used to define a base timber supply level consisting of timber at lower risk that can likely be achieved with confidence under a range of plausible climate change scenarios. This approach would reduce pressure on the base timber supply and could also provide a frame for implementing adaptive forest practices such as establishing more climate change-resilient stands as a condition of access.

Underlying this discussion of the potential benefit of using risk tranches as a hedge against uncertainty is an assumption that maintaining a managed or conditional opportunity to gain economic benefits from higher-risk areas in the present and near future is desirable. It will be up to the decision maker – the chief forester – to decide on the weight that this kind of hedging deserves. If risk categories were to be used as a basis for excluding types of forest or areas from contribution to the AAC, the definitions of the boundaries of the categories would likely become more controversial and would require effort to ensure they are defensible. Furthermore, it is acknowledged that the chief forest currently does not have the authority to link management conditions to partitions. The effectiveness of the risk tranche / partition approach in addressing climate change impacts would be greatly enhanced by (perhaps even dependent on) the ability to link access for harvesting timber in higher-risk forests with management practices that either reduce risk of disturbance and timber loss or rehabilitate and enhance forest productivity. It will be up to the provincial government to decide if enabling this type of linkage is feasible.

Risk categories relevant to climate change and timber supply cannot be identified without considering what types of climate change impacts may occur. Further, since there are practical limits on the number of risk types that could be factored into an AAC determination, priorities would need to be set, which also would require deliberation on what climate scenario(s) may be more likely. The point of using a risk classification is to acknowledge that the future is uncertain and to develop decisions that are reasonable under a range of plausible futures. Deciding on a particular climate scenario or scenarios on which to base analysis and decision making aligns more closely with the deterministic framework that has often been used historically for analysis and decision making. However, this approach does not acknowledge the deep uncertainties associated with climate change. While undertaking analysis based on multiple climate scenarios may be one approach to acknowledging uncertainty, it runs the risk of providing a large body information that the decision makers is left to interpret. The risk tranche approach does not preclude the need to consider climate change scenarios – that is, creating risk categories requires ideas of what types and magnitude of changes may occur – however, it would assist in addressing uncertainties related to which climate scenario will occur. Use of the tranche approach as a framework for exploring the use of partitions may be the best approach for making robust AAC decisions, given the likelihood that the best information on climate change impacts in many cases may be trends and risk categories. However, the tranche approach may not be suitable for all dynamics.

Stochastic disturbance analysis

Stochastic analysis allows for assessment of the ability to achieve harvest targets under uncertain fire regimes. This kind of analysis was undertaken in the Quebec case study (Quebec 2021) and has also been done in preparing analysis inputs for the Mackenzie TSA in BC. In Quebec, analysis was done to determine the percentage of stochastic simulations of a fire regime for which a variety of timber supply targets were achieved (see Figure 11 below). Such an approach provides the decision maker with an understanding of risks associated with various timber supply levels. Underlying assumptions and sensitivities would need to be clearly documented. The challenge, as outlined under the discussion of unidirectional sensitivity analysis, is supporting the decision maker in interpreting the results. Again, such results are most useful in the context of clear attitudes about how to treat unacceptable future outcomes that could occur due to uncertain future events.

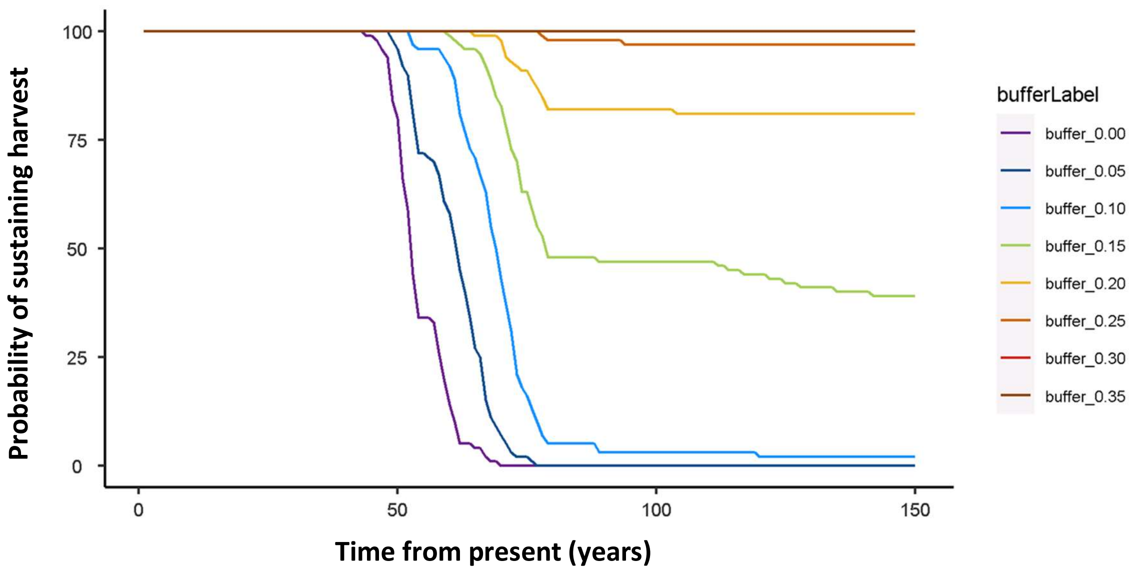


Figure 11 *Effect of reducing projected harvests on the ability to sustain the harvest target over various timeframe (from Yamasaki, 2022). "Buffer" is used here to denote the percentage reduction relative to a no fire scenario ("buffer_0.00").*

Exploratory analysis

Exploratory could be used to examine questions such as:

- What would the timber supply projection look like if an AAC were maintained, and climate change impacts turn out to be greater than expected?
- What effects would risk-based partitions have on timber supply projection; that is, given that risk classes have been identified, how would timber supply outcomes differ between cases where partitions are and are not implemented?
- How could adaptive forest practices affect timber supply projections? This has normally been outside of the scope of TSRs, but it is nevertheless an option.

It is possible that the kinds of analysis outlined here, particularly exploration of adaptive practices as described in the last bullet, may be more suitable for Forest Landscape Planning than TSR. Maintaining forest productivity and health to the extent possible under climate change will most likely require changes in forest management. Therefore, regardless of the program in which it is undertaken, this kind of analysis is needed to increase planners' and managers' understanding of the relative effectiveness of management options, and in which forest types and ecosystems they are best suited.

Retrospective view of recent major disturbance events

Using a past time as the starting point for an analysis and using known disturbances, such as the 2000s MPB infestation or the 2017/2018 and 2021 fires, could help explore how timber supply would be assessed and AAC decisions made if we knew in advance that major disturbances would occur. Such analyses could be complemented with experience with the uplift decisions made in response to those disturbances. We are now reasonably certain that major disturbance events will occur and likely with greater frequency and extent. This may provide a hypothetical case study for using risk tranche-based partitions. This may be worth exploring as a non-TSR project to provide a more open-ended frame for exploring options but could also be done as part of a TSR. A potential benefit of using such an approach would be that asking questions about what would happen if recent events occurred more frequently could provide more grounding in lived experience.

A question that arose in some conversations during research for this report is whether long-term timber supply sustainability is feasible to achieve given the probability of major disturbances. This question could also be explored in the kind of retrospective analysis just described. Businesses usually seek certainty of access to resources, and communities and governments desire some understanding of what economic activities can reasonably be relied upon to support their activities. Therefore, it would be worthwhile to increase understanding of long-term implications of major disturbances on sustainability – that is, the level of forestry activity that can most likely be maintained over the long term given potential disturbances – as well as the type and amount of resource management capacity (e.g., for salvage and rehabilitation) that may be required to respond to plausible future disturbances.

12. Potential responses in AAC determinations

As discussed at several points in this report it will not be possible to provide clear, quantitative estimates of future climate change and associated impacts due to irresolvable uncertainty about future human actions, and very challenging uncertainties related to how climate systems will respond to emissions and other climate drivers and how ecosystems will respond to those changes. Given these types of uncertainties, the chief forester could respond to information on climate change impacts in three general ways:

- Note the risks (hazards) associated with key uncertainties and highlight the need for further research and analysis. This approach could apply reasonably to impacts for which researchers and experts cannot provide confident insight regarding the direction and potential magnitude.
- Partition the AAC based on risk categories. Such decisions would most likely be based on tranche analyses.
- Change AACs. Such an action would require confidence on the part of the chief forester in the direction of impacts and general magnitude of impact. This confidence might come from monitoring information or other types of studies.

Monitoring of forest existing conditions could provide relatively clear sense of impacts in some cases; however, there will still be uncertainty about how forests will respond in the future. For processes such as wildfire, future dynamics cannot be so readily deduced from existing information. In any case, uncertainty about the future trajectory of climate change will always create uncertainty about impacts. Therefore, decision makers like the chief forester will need to decide how to consider impacts about which the best available information will likely be a trend and a general sense of magnitude.

Trend responsive decisions

The challenge for the chief forester and those supporting the AAC decisions may be to gain comfort in making decisions in response to climate change impact trends as opposed to relying on point estimates.

If experts are unable to agree that there are trends –for example, that there will likely be more (or less) disturbance – and that the potential magnitude is substantial, it may be difficult for the chief forester to conclude any more than the issue should be monitored, and new information incorporated in the next determination.

Some people may invoke the idea of precaution with respect to this challenge. That is, in the face of uncertainty, it would be better to be safe than sorry, so some kind of action is warranted. The following section provides a discussion of precaution and proposes the use of an alternative term for AAC determination: trend responsive decisions.

Precaution *versus* trend recognition

Input received by the Office of the Chief Forester during a recent TSR process suggests that some would claim changing an AAC by any amount based on uncertain information on climate change constitutes a precautionary approach (BC MOF 2022). It is recognized that this characterization of precaution supports an assertion that uncertainty is not a good reason to avoid acting when there may be negative impacts (United Nations FCCC 1992; Gardiner 2006). However, the precautionary principle has shortcomings when applied to decisions like AACs.

First, the precautionary principle is most straightforward to conceptualize and implement when a decision is binary: should a pharmaceutical or a genetically modified organism be permitted for use? In cases like these, if the precautionary principle were applied, the response would be that if there is any risk to human health, those drugs or organisms should not be permitted. AAC determination is not a binary decision.

Second, adopting a precautionary approach – that is, agreeing that it's better to be safe than sorry – falls short of providing guidance on how to employ it in terms of weighing different, potentially competing values relative to one another and quantifying the magnitude of precaution.

Third, it is unclear that it would strictly be precautionary, for example, to apply an arbitrary reduction to yield estimates to account for potential reductions in plantation success and productivity that scientists believe may occur but are unable to quantify. One could argue that a precautionary approach in this context would be to err strongly on the side of caution by applying a very severe reduction, or even to assume that at-risk areas will not produce any merchantable trees.

Rather than focusing on whether or not precaution is warranted, it may be useful to focus first on reaching agreement on whether or not there are identifiable trends, then discussing how or if to apply a quantitative adjustment based on the trends. This kind of a process would most likely involve substantial dialogue among scientists to clarify any trends and to describe the breadth of uncertainty, realizing that it will almost always be impossible to define statistical confidence intervals. As discussed earlier, a robust process for dialogue among experts would help the decision maker to develop confidence that action is warranted. The next step would be for the decision maker to consider the relevant values, to reach a decision on how to weight them, and to explore any management or decision approaches that acknowledge the trend, while potentially keeping options open for values that would be affected by adjustments. For example, if it were determined that many stands are at risk of drought-related mortality or productivity reduction, an option would be to identify a partition applicable to a core of sustainable timber supply from less at-risk stands, and defining another partition for higher-risk stands that would allow harvests and ideally climate-adaptive reforestation in them.

This kind of decision would be responsive to a trend, but not necessarily precautionary for all values. This approach could be labelled as trend responsive decision making. Some may believe the approach just outlined is fundamentally precautionary, and that using a new term would be merely semantic. The intention here is to recognize that given the diversity of values in forest management, precaution for one could be highly risky for another. The notion of trend responsive decision making may more accurately describe the challenge faced by decision makers like the chief forester.

It is acknowledged that AAC determinations in BC have accounted for unquantified directional risks for many years. However, reasoning presented in AAC rationales indicates that these kinds of risks were sometimes used to add support to a decision based on other quantifiable factors but were virtually never a key reason underlying a decision. Trend responsive decision making as conceptualized here would involve applying quantities based on trends outlined by scientists and could act as substantial factors in AAC determinations. It is likely that there would be resistance to the idea of applying quantities where magnitudes are unknown; but if climate change is to be accounted for in AACs – which are numbers – quantities will need to be assigned to uncertain future impacts, even if they are somewhat arbitrary.

Arbitrariness

It is common to label as arbitrary any assignment of a quantity when acknowledging that an event of uncertain timing and magnitude may cause an uncertain impact, even if there is confidence that the event will occur. There are several definitions of arbitrary, related to exercise of power, discretion, and choice. The online Merriam-Webster dictionary[15] defines arbitrary as “existing or coming about seemingly at random or by chance or as a capricious and unreasonable act of will” and “based on or determined by individual preference or convenience rather than by necessity or the intrinsic nature of something.” Similarly, the online Cambridge dictionary [16] defines it as “based on a desire or idea or chance rather than reason.”

Using these definitions, it may be accurate to label as arbitrary some parameter for which no clear rationale has been provided. It would not be accurate to say that the parameter is arbitrary if it has been based on scientific research, if the full range of relevant scientific knowledge has been considered, differences in opinion discussed, uncertainty recognized, and a collective recommendation provided. Further, it would not be arbitrary for a decision maker to use this information along with an understanding of the various relevant interests to make a decision that weighs risks and benefits based on the scientific advice. There may be disagreement about the decision, but it would not be accurate to label it as arbitrary if the types of steps described in this paragraph were taken.

[15] https://www.merriam-webster.com/dictionary/arbitrary
[16] https://dictionary.cambridge.org/dictionary/english/arbitrary

13. Exploring implications of climate change adaptation

If timber supply analyses indicate that AAC adjustments may be warranted due to climate change impacts, there will be questions about whether anything can be done to mitigate[17] those impacts. Normally TSRs do not engage substantially in exploring management options since the chief forester cannot make decisions on management for other resource values. However, there is some history of examining the implications of potential changes to management regimes to help inform other processes and to provide information on the risks to timber supply. So, undertaking some analysis of climate change adaptation would not conceptually expand TSRs, but would add to workload. The chief forester and other interests will most likely want to have some sense of options for cases where analyses indicate substantial climate change related impacts on timber supply.

Analyses could explore the following.

- The implications of not adjusting AACs, that is deferring action until better information is available. For example, what would happen to timber supply if current AACs were maintained and stands began to fail or natural disturbance increased? This has already been done to an extent in the Mackenzie TSA TSR.
- The current guiding principles regarding uncertainty about whether creating a buffer against uncertainty by reducing AACs or maintaining flexibility to access damaged or at-risk timber is the better approach. Use of risk-based partitions could effectively remove the need for this existing principle since partitions could be used to outline high-risk areas where proactive harvesting and rehabilitation may be warranted, and other areas at lower risk where there is greater confidence in the ability to sustain a timber supply level. However, it would still be worthwhile to understand the conditions under which different kinds of AAC determinations – reduction, maintenance, use of partitions – would be suitable. Ideally, TSRs would include analysis that would address these questions for each management unit, although broader exploratory analysis could assist in developing climate change policy for forest management and AAC determination.
- The effects of adaptive measures such as planting more diverse stands and/or focusing harvests in at-risk forest types (Dymond et al. 2014). Clarity on the kinds of benefits of adaptive measures and the types of climate conditions and forest types in which they could be most effective would be useful for informing AAC determinations. This type of analysis may be more suited to research projects and could be encouraged or sponsored by FAIB.

Choices about whether to engage in these types of assessment will likely depend on available resources. However, there are few examples of this type of work, so they should be seriously considered.

14. Engagement with Indigenous communities and the general public

One aspect of this study was to develop recommendation on the presentation and communication of analytical results to support effective engagement with Indigenous communities and the general public. These topics received less attention than those related to analysis approaches and parameterization discussed in previous sections. There were two reasons for this attention differential. The first is that

[17] Mitigation in this sense is not related to managing forest carbon and greenhouse gases, but rather to reducing the impacts of climate change on timber supply.

thorough and respectful conversations related to how best to engage with Indigenous nations and communities should be undertaken directly by the provincial government. It is recognized that the First Nations Leadership Council (FNLC) sponsored development of a BC First Nations Climate Strategy and Action Plan (FNLC 2022), which highlights First Nations' concerns, which are closely linked to the values and well-being of their communities. This document provides broad-scale information; however, Nation and community-specific concerns still need to be discussed at those levels. Engagement with First Nations on preferred approaches to communicating about climate change could be facilitated and documented by a third-party consultant, but to be respectful of Indigenous people's limited time and resources – and Nationhood – it should be undertaken as or at least initiated through government-to-government dialogue.

The second reason for less attention on engagement is that considerations related to communicating about climate change are not fundamentally different from communicating about other technical forestry issues that are inherently linked to values of Indigenous people and others. Two considerations are relevant here: first, it should be recognized that some people may not be technical "experts" in climate change; and second, concern about values is the reason Nations, communities and groups feel compelled to engage in forest management decision making processes. Based on these considerations, the following suggestions are provided.

- Focus on values rather than technical procedures
  First Nations and others engage because they are concerned about how their values are being or will be affected. Listening to concerns, and where practical, designing analyses to provide information on current and projected conditions of important values (beyond simply explaining that a modeling constraint deals with them) could help build some confidence that values are being taken seriously. Targeted analysis could also provide information to improve understanding of the dynamics of values over time. This could consist of providing graphics on temporal and spatial dynamics of the value, as contrasted with simply communicating a forest cover requirement.
- Avoid defaulting to technical terms and acronyms, such RCP, SSEP, GCM, stochastic modeling, risk tranche. When communicating with non-technical audiences, consideration should be given to demonstrating to people that concerns have been heard and relevant information generated, rather than focusing on the technical aspects of climate modeling, and risk analysis.
- For First Nations in particular, do some research ahead of time on what the Nation has said before with respect to climate change and impacts on their values.
- Recognize the importance of agency. People want to know what can be done to protect and improve their values (this is relevant for decision makers as well). It may be worth providing analysis that helps people to understand options that are within the purview of TSR and AAC determination – such as harvest levels and partitions, and even changes to cover requirements. It may be useful to ground potential climate change impacts in experience. For example, when discussing potential changes in wildfire regimes it may be worth referring to recent years in addition to providing information on technical aspects, like fire rotation and patch-size and intensity metrics. For instance (and hypothetically), it could be communicated that a modelled fire regime would be like 2017 and 2018 fire years occurring every 25 years as opposed to every 100 years.

- Work toward decision orientation as opposed to information orientation. This may be more relevant for decision makers like the chief forester, however the notion of attending to how information affects the decision rather than simply providing a broad range of information may also assist in engaging with First Nations and other communities and groups. Undoubtedly, technical information is fundamental to AAC determination. However, information does not on its own accrete into a decision. Decision makers need assistance in navigating through the information to understand implications and options. This type of assistance could also support First Nations and others to engage in TSR processes.

15. Recommendations

This section outlines several steps FAIB and the OCF could consider to improve incorporation of climate change impacts into TSRs and AAC determinations

Undertake a process to identify specific forest dynamics to focus on in developing climate change-related parameters

- This report has focused on potential impacts of climate change on disturbances due to fire, insects, and disease, and on forest productivity. Wind damage could also be substantial in some areas. Practically speaking, priorities will need to be set for parameter development and modeling for different parts of the province, and potentially for different types of disturbance agents. For example, as noted in the discussions in this report on insects and disease, many organisms could potentially affect forests in an area. For practical reasons, priorities will need to be set on which ones to explore in detail.
- Priority setting could be done at the provincial scale; however, given the potentially steep learning curve in designing and undertaking collaborative efforts to reach scientific consensus, it may be worthwhile to focus efforts on a region or management unit. Based on the research for this report, it is likely that disturbance will be important in all areas of BC, however, the dynamics with the largest potential impacts will vary across ecosystems. Pilot projects in one or two management units could develop and revise collaboration processes, including setting priorities on what dynamics to explore.

Build a robust process for developing analysis parameters, including risk categorizations

- Explore how best to convene groups of experts to assist with developing and implementing parameters for modeling climate change impacts. Options could include workshops, time-limited initiatives involving collaboration between FAIB and researchers, or potentially structured expert elicitation processes. As discussed in the section of developing parameters, it would be possible to maintain the practice of consulting with single experts to develop modeling parameters; however, this could create risks to challenge from affected interests, which structured, collaborative processes could reduce. In addition to creating robust information, structured processes help avoid duplicate work and build a cohesive and readily accessible body of knowledge to inform TSR analyses and AAC determinations.
- While much of this report has focused on developing group processes for expert collaboration with a view to generating robust information to inform decisions, this is not meant to imply that these processes should be data or evidence free. Drolet et al. (2015) assert that evidence-based tools out-perform experts in some cases. It seems self-evident that development of parameters to enable modeling of climate change impacts should be based on as much evidence as possible,

and that experts should engage in weighing the evidence and using judgment to help navigate uncertainty.

- Since there will be uncertainty about any parameters developed to model climate change impacts, participants should follow a consistent approach to describing and communicating uncertainties. The IPCC uncertainty guidelines could provide a starting point for developing an uncertainty communication framework (see Section 10, pp. 32-33 of this report).

Expand use of risk tranche analyses and link to partitions

- Use of risk-based partitions may be the clearest way to reflect likely types of climate change impacts while keeping options open for utilizing timber from forests at higher risk from impacts under appropriate circumstances. Partitions would reduce the chance that timber supply based on higher risk forest would be taken from lower risk forests, and also provide a focus for development of climate change adaptative measures in higher risk areas.
- The challenge will be to develop risk categories that can be defined on the ground and are implementable in terms of administration. This will likely require consultation with researchers and those working in timber administration.
- It is acknowledged that partitions have met with resistance in the past due to difficulties in on-the-ground identification of the stands or areas to which they apply, as well the extra administrative challenges and financial costs associated with implementing them. The Ministry of Forests and the forest sector generally will need to make choices about whether or not they wish to take action in the short term to attempt to alleviate costs that future generations will bear, as well as to make AAC decisions more robust to uncertainty. At this time, identifying forest types and areas that are at higher risk to climate change, and implementing partitions with a view to recognizing the likelihood of climate change related impacts while keeping options open to utilize at-risk forests and areas under appropriate circumstances appear to be one of the best approaches to making robust AAC determinations.

Trend responsive decision making

- For the chief forester to incorporate climate change impacts into AAC determinations, there will need to be a willingness to base decisions on information about trends and general magnitudes of impacts. Use of partitions will not eliminate the need to be trend responsive, since the boundaries of risk categories are ultimately choices.
- It may be worthwhile to develop guiding principles for trend responsive decision making. This concept may provide a more accurate description of the decision-making challenge than the concept of precaution, as discussed in section 12. Guiding principles could speak to the reliance on scientific consensus developed through collaboration of researchers and practitioners and analysis that demonstrates there are no clear management responses that would mitigate likely impacts.

Undertake exploratory analysis

- This could include assessment of the implications of not adjusting AACs (that is deferring action until better information is available); and gaining increased understanding of the potential effects of adaptive measures such as planting more diverse stands and/or focusing harvests in at-risk forest types, and the types of climate conditions and forest types in which they could be most effective.

Basic training on climate models, climate change impacts

- Only cursory attention has been given to training in this report. Training to provide general knowledge of climate change, climate modeling, impacts on forests, and uncertainty (including decision making under uncertainty) could assist in increasing individual analysts' ability to undertake climate change related analysis. This could include information on:
    - Climate models. The idea would not be to develop detailed knowledge but simply to move beyond climate projections being a "black box". This could include overview information on climate models: types, scales, downscaling.
    - Why are climate model projections different? Is it just knowledge uncertainty or are some models better for specific purposes or geographic areas and ecosystems?
    - Impacts on forests – provide links to summary resources such as regional extension notes (which likely require updating).
- A general suggestion is to consider ensuring that a body of relevant information is curated and made readily available to analysts. This could include information on climate models, climate change and associated emissions scenarios, shared socioeconomic pathways, best practices related to climate models and scenarios, timber supply model functionalities available, regional extension notes, and existing TSR examples to use as guidance for developing management unit specific approaches.
- Ultimately it would be useful to develop a guidance document on incorporating climate change into timber supply analysis and AAC determination processes, based on the types of information listed in the bullet above.

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Appendix 1: Current and potential tools to support incorporation of climate change

<u>Climate change:</u>

- temperature
- precipitation
- extreme events
- season length

<u>Tools:</u>
- Climate models & ensembles
- RCPs
- Climate trends (V. Foord)
- Extension notes (outdated)

<u>Ecosystem impacts:</u>

- Forest productivity change
- Hydrology (e.g., drought)
- Disturbance and health (fire, insects, disease)
- Successional shifts (change in dominant species)

<u>Current tools:</u>
- STSM functions allow modeling of fire and productivity change
- Drought vulnerability model (identify at-risk areas and/or stand types)
- Link GY to future BEC

<u>Potential tools.</u>
- Fire models linked to temp & precip (Tyler's group)
- GY models linked to temp & precip (Quebec)
- Insect and health models linked to temp & precip or other climate variables (Some basic work in Quebec)
- Succession (LANDIS-II – Huapeng Chen, Quebec)

Note: Impacts on wildlife and biodiversity (changed population dynamics, vulnerability, etc.) are acknowledged but for this study, will assume existing requirements remain applicable for TSR and that developing new regimes is outside TSR scope

<u>Navigating uncertainty:</u>

Models will provide information but the future remains uncertain. How can be AAC determinations assist in managing forests sustainably recognizing uncertainties about the amount and rate of climate change and ecosystem responses to those changes?

Relevant principles:
- Insurance – diversity, buffers
- Robustness – satisfactory under full range of plausible futures
- Responsiveness – monitoring, frequent decisions

<u>Currently available tools and approaches:</u>
- Partitions related to different levels of risk (risk tranche approach) – both insurance and robustness
- "What if" analysis related to buffers *versus* maintaining options for salvage
- "Future-trend responsive decisions" (acting on trend information with clear point estimates can't be provided) – like Mackenzie TSR

<u>Potential timber supply management or exploratory approaches</u> (less detail on these, just mentioning for potential exploration)
- Scientific consensus on levels of confidence and likelihood (patterned on IPCC approach to uncertainty)
- Seeking sustainable timber supply that can be maintained with confidence given knowledge of potential ecosystem changes, coupled with partitions to allow for salvage
- Analysis related to adaptation – benefits of diversified planting and at-risk focus

Figure 12 Summary of tools for incorporating climate change, ecosystems impacts and uncertainty into timber supply reviews and AAC determination