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Dealing with uncertainty in strategic forest management planning

Highlights

- Forest managers are often challenged by uncertainty when making decisions.
- Decision support tools that account for uncertainty are available for use by forest managers.
- Frequent re-planning can also address uncertainty.
- Managers can and should incorporate risk analysis methods in their forest management planning procedures.

Forest management is often complicated by uncertainty that may be associated with the data used to develop plans (e.g., forest inventory, growth and yield curves), incomplete understanding of ecological processes (e.g., succession and natural disturbance) and changing markets (e.g., changing product demands or prices).

Fire: A major source of uncertainty

Fire is a major source of uncertainty for boreal forest managers. The annual area burned by forest fires in Canada ranged from 165,000 to 7.5 million ha over the period 1959 to 1997. Fire activity also varies across Canada; while some areas experience very little fire activity, fire may be very common in other areas.

Dealing with uncertainty in forest management planning

The simplest, but not necessarily the best way to deal with uncertainty, is to assume the future will unfold in some predictable way (e.g., no fires will burn) and plan accordingly. Another approach, ingrained in the practice of forest management is to re-plan every 5 or 10 years, or after some significant event such as a large fire has occurred. Re-planning involves creating an initial plan, implementing it (i.e., harvesting and regenerating according to the plan), observing what happens for 5 or 10 years (e.g., fire, insects, policy changes or market fluctuations), observing the resulting forest condition, and then developing a new plan. This iterative process of re-planning occurs continually with some decisions made before the random events and some after. Re-planning shares many similarities with formal adaptive management processes because it allows managers to adapt to changing conditions and to incorporate new science and policy in their revised plans. A third way of dealing with risk is to use models or other decision-making aids that account explicitly for uncertainty.

Forest management planning models

Canadian forest managers use a variety of planning models for strategic planning purposes. Linear programming (LP) optimization models are the most common and are usually formulated so that planners can maximize harvest volume or economic returns subject to constraints. Constraints can be economic (e.g., silvicultural budgets), ecological (e.g., age class distribution), or social (e.g., employment targets) factors. LP models are deterministic in that they assume no random events, and most are aspatial (no spatial relationships). Aspatial LP models can easily be formulated to address uncertainties by assuming natural disturbance processes (e.g., area burned), stand-level succession, or regeneration occur at "average" rates.

One strategic planning LP model, often referred to as Model III, can account for such uncertainties. Fire is incorporated in the planning model by using the estimated average annual burned area (burn fraction) as a model parameter. When a burn fraction of zero is used, a manager essentially ignores fire or assumes that no fires will occur over the planning horizon.

The results described in this research note were developed using an aspatial LP planning model that was embedded in a simulation model of a managed flammable forest. We simulated harvesting and fire in our landscape over a 200-year period. The modelling process for each 200-year scenario began by running the LP planning model with the initial state of the forest at the start of year 1 to develop a harvest schedule which was then implemented in the simulated forest (i.e., the simulated forest was harvested as specified by the LP model). The forest was then randomly burned using parameters that are representative of the forest's fire regime. A new harvest plan based on the modified age class distribution which was produced by the simulated harvesting, burning, and forest growth was then developed on a regular interval of either 1, 5, or 10 years. The iterative planning, harvesting, burning and forest growth continued until the end of the 200-year scenario and mimics the planning, implementation and re-planning processes currently used by forest managers. The 200-year modelling process was repeated 1,000 times to produce 1,000 scenarios or simulated futures that are representative of outcomes that might be observed in an uncertain world. We then carried out statistical analyses of those scenarios and presented some of our results graphically. Our results can be used by managers to explore the "side effects" of their planning methods as they illustrate how a simulated flammable forest might develop over time if a specific LP model is used to schedule harvesting activity in our simulated flammable forest.

Forest fires and timber supply

The decision of whether or not to account for fire and how to do so also depends on the anticipated fire regime (i.e., how much area is expected to burn over the planning horizon). In general, when fire is accounted for in the planning model, less volume will be harvested over time in comparison to when fire is ignored in the planning model (Figure 1). However, the lower volume is compensated for by a much more stable (i.e., less variable over time) harvest flow. Forest managers can harvest more volume from their forest if they choose to ignore fire while planning but if they choose to do so, the harvest volumes that result will be variable and sometimes highly variable. In areas with low burn fractions (e.g., less than 0.45% per year) fire will have little impact on harvest flow variability and can likely be ignored. However, in areas with burn fractions in the range of 1-1.5%, fire should be explicitly accounted for in the planning model. By doing so, managers will minimize the likelihood of experiencing erratic harvest flows like those depicted in Figure 1.

We found the use of different re-planning intervals (1, 5 or 10 years) had little impact on the variability in timber supply. Similarly, area-burned thresholds of 1.5% and 2.5% (which were used to trigger re-planning) had little impact on the variability in timber supply. These results suggest that re-planning alone is not effective at reducing the variability in harvest volume in areas where large fires are common. However, re-planning remains an essential component of the adaptive management cycle and is important for incorporating new science and policy into forest management planning.

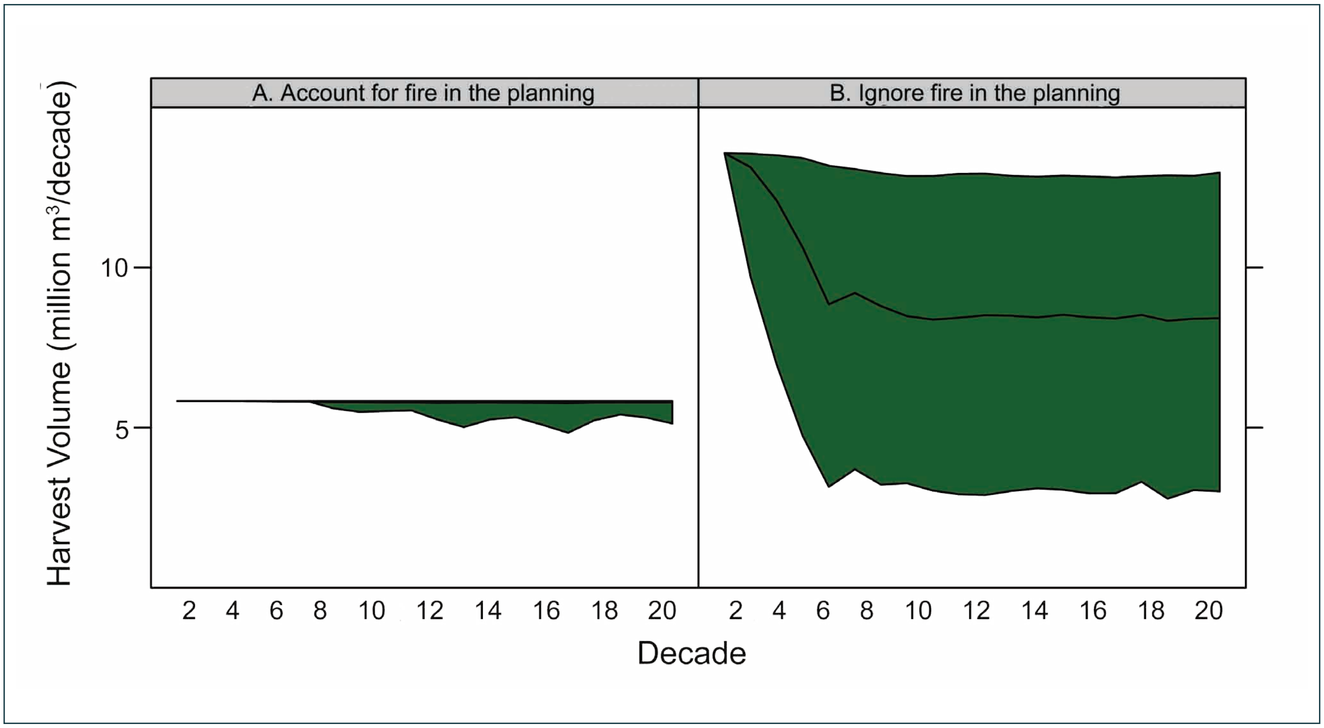

Figure 1. Graphs that illustrate how accounting for fire in the planning model (A) or ignoring it (B), can affect variability in the harvest volume. The upper and lower bounds are the 2.5th and 97.5th percentiles (i.e., the green areas contain 95% of the simulated harvest volume runs) and the middle line is the median. Ignoring fire can result in considerable variability in the harvest volume.

Risk analysis

The term ***risk*** is used in many different contexts. Formally, risk is the product of the probability that some event will occur multiplied by the consequences of that event. For example, if there is a 2% chance that a 100,000 ha fire might occur next year, the risk (or expected area burned by a large fire) would be 0.02 x 100,000 or 2,000 ha. Risk is sometimes used to denote probability alone, particularly when referring to a well defined event, for example, that it might rain tomorrow.

One of the graphs that we produced showed the risk of not being able to harvest a minimum volume over the 200-year planning horizon (e.g., a mill capacity). For each scenario we calculated the volume harvested in each of the 20 decades modelled and the decade with the lowest harvest volume was identified. We then repeated the low decade identification process for all 1,000 scenarios to find the lowest volume harvested during each of the 1,000 simulated futures and those 1,000 lowest harvest volumes were sorted from smallest to largest. We then calculated the empirical cumulative distribution function (ECDF) for the 1,000 lowest harvest volumes which provides the probability of being able to harvest a minimum of x m^3/decade. To simplify the interpretation of the risk analysis graph (Figure 2) we plotted 1-ECDF rather than the ECDF.

Risk analysis methods can be used to enhance decision-making under uncertainty. Figure 2 shows the probability of being able to harvest a minimum volume over a 200-year horizon when fire is accounted for or ignored in the planning process. To demonstrate the use of this figure, red dashed lines were added to show the probability of being able to harvest at least 5 million m^3/decade when either accounting for or ignoring fire while planning. For example, if a manager wanted to determine the probability of being able to harvest at least 5 million m³/decade when they accounted for fire in the planning, they would find 5 million m³ on the x-axis and then follow a vertical line up to the account for fire in the planning line (black solid line); they would then move horizontally to the y-axis and find the corresponding probability value. The hypothetical risk analysis curves presented in Figure 2 show that there is roughly an 85% chance of achieving at least 5 million m³/decade throughout the entire 200-year planning horizon if fire is accounted for in the planning. If fire is ignored, the chance of that happening decreases to roughly 22%.

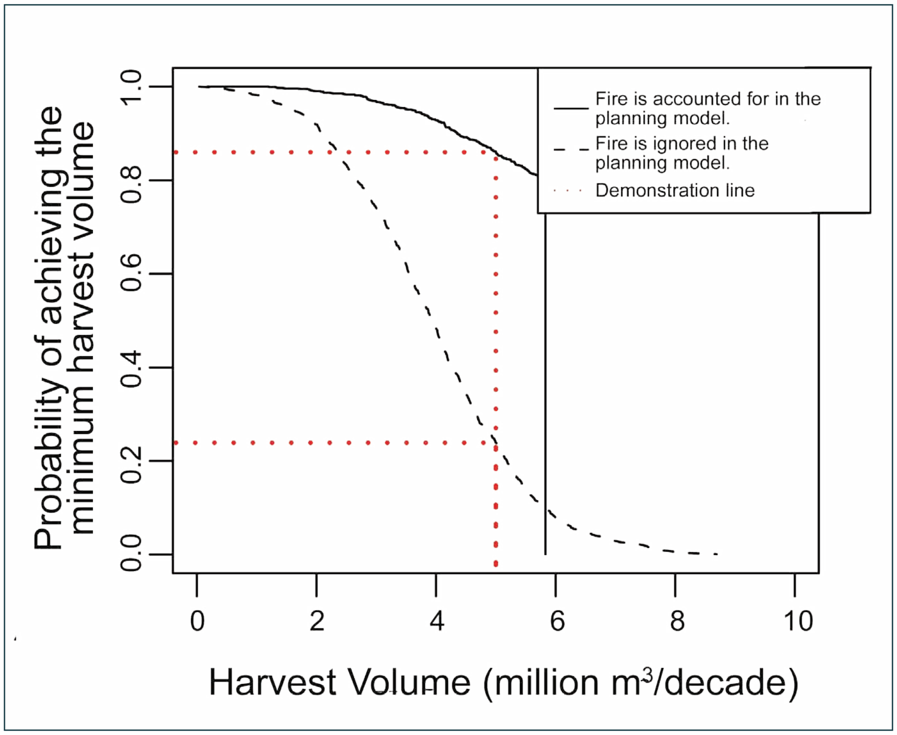

Figure 2. Risk analysis curves that show the probability of being able to harvest at least 5 million m³/decade during every decade in a 200-year or 20 period planning horizon when fire is accounted for or ignored in the planning model. The solid black line shows what might happen if fire is accounted for in the planning model. The dashed black line shows what might happen if fire is ignored. The red dotted lines are used to determine the probability of being able to harvest a minimum of 5 million m³/decade during every period over 200 years. The probability that will happen is roughly 25% if fire is ignored and 85% if it is not ignored when planning.[1]

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[1]The solid and dotted black lines are *1- ECDF(h)* where the *ECDF(h)* is the empirical cumulative distribution function of the lowest decadal harvest level. They therefore indicate the probability that the lowest decadal harvest level will be greater than or equal to *h* for the entire 200 year planning horizon, using strategies under which fire is or is not accounted for in the planning model.

Discussion

The best strategy for dealing with uncertainty will depend on the risk preference of the decision-maker and the degree of uncertainty involved (e.g., the amount of area that might be burned). The risk preference of a manager will influence how much risk he or she is willing to assume. For example, risk-averse managers will usually opt for a strategy under which there is little chance of failure (e.g., they may want to harvest a consistent harvest volume over a long period of time). A risk-seeking manager may choose to adopt a strategy that will allow higher harvest volumes in the short-term but may have a high probability of significant decreases in harvest volume over time. A challenge in forest management is to reconcile different risk perceptions that might be held by forest management companies, government regulators, or members of the public.

These hypothetical results illustrate that forest managers can incorporate uncertainty in some of their planning models. Risk analysis methods like those described here can be used by forest managers to develop and evaluate a variety of strategies with respect to their potential impact on forest sustainability. Some of the forest sustainability issues that could be investigated using such methods include:

1) Economic questions such as: what is the risk that timber harvest costs will exceed a certain value?
2) Ecological questions such as: what is the risk of losing a large proportion of old growth forest?
3) Social and economic issues such as: what is the risk of a large portion of the timber supply burning and forcing the closure of a mill?

Further reading

Armstrong, G.W. 2004. *Sustainability of timber supply considering the risk of wildfire.* For. Sci. 50: 626-639.

Martell, D.L. 1994. *The impact of fire on timber supply in Ontario.* For. Chron. 70: 164-173.

Savage, D.W, D.L. Martell and B.M. Wotton. 2010. *Evaluation of two risk mitigation strategies for dealing with fire-related uncertainty in timber supply modelling.* Can. J. For. Res. 40:1136 - 1154.

Management Implications

- As the likelihood of a particular risk such as fire increases, so does the importance of incorporating it explicitly in the planning process.
- Managers need to reconcile their risk preferences with those of their government, industry and societal stakeholders when resolving decisions under uncertainty.
- Risk analysis methods can be used to assess a variety of economic, ecological, or social values. For example, risk analysis could be used to estimate the chance that some minimum area of old growth forest would persist throughout the planning horizon.

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