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Complete List of Authors:	Nelson, Harry; University of British Columbia, Forest Resources Management Scorah, Hugh; The University of British Columbia Faculty of Forestry, Forest Resources Management
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How Should We Sustain Future Forests Under Extreme Risk?

Harry Nelson^{1*}

Hugh Scolah^{1,2}

¹ Forest Resources Management, Faculty of Forestry, University of British Columbia

²Phd. Candidate, Faculty of Forestry, University of British Columbia

*corresponding author:

20245-2424 Main Mall

Forest Sciences Centre

University of British Columbia,

Vancouver, BC V6 T 1Z4

Ph: 604.827.3478

Fax: 604.822.6970

Email: Harry.Nelson@ubc.ca

Abstract

In this paper we examine the implications of managing for sustained yield in a world characterized by growing risk and uncertainty. We review the history of sustained yield (SY) forestry in North America with its emphasis on economic benefits and the persistence of the SY paradigm today, despite a publicized shift towards managing for a wider range of forest values called Sustainable Forest Management (SFM). We show that current forest management goals around sustainability as well as SFM indicators are still predicated on maximizing harvest levels and timber flows. We build a simple model to explore the implications of SY under extreme (fat-tailed) risk assumptions to show that maximizing a level of harvest without adequately accounting for risk leads towards the depletion of the forest stock with a corresponding decline in the forest economy. We discuss these results in relation to real-world events such as the increase in catastrophic fires and pest outbreaks like the Mountain Pine Beetle in Western Canada. We then examine the theoretical and practical implications that flow from this model and analysis.

Keywords: forest management, sustained yield, risk management, fat-tailed risk

Introduction

In 1990 Gordon Baskerville wrote:

Sustainability will be the dominant issue in forestry over the next decade. Yes, we have sustained yield forest management in Canada by someone's choice of feature to be sustained. However, it is clear there is not sustainability for the things some of the public owners want sustained...It is foolish for a society to continue saying what it wants sustained, and what actions it will use or allow to achieve sustainability, without rigorous evaluation of the cause effect connections between the allowed or mandated actions and the features to be sustained. Only a minute portion of the national discussion of sustainability has come remotely close to facing technical reality. The predominant form of discussion runs along the lines "do these good things, and the following good things will result". Inadvertently, this soft approach to a hard problem has set our society up for an incredibly rude awakening to the realities of natural system dynamics.

One of the principal goals of forest policy in Canada has been to promote economic activity and support community development, yet across Canada (and especially in British Columbia) we find mills closing and communities struggling to deal with the consequences of timber supply falling at a much greater rate than ever anticipated. The purpose of this paper is to look at why by examining those natural system dynamics, the consequences of sustained yield and the consequences of climate change that for us to recognize that ecosystem stationarity no longer holds (Milly, Betancourt, Falkenmark, Hirsch, Kundzewicz, Lettenmaier and Stouffer 2008).

How to best sustain forests is not a new question. While there are numerous examples of collectively owned forests that have been managed successfully (in the sense of maintaining those forests) for several centuries or more (Ostrom 2015), these exist at the more local level and reflect the accumulation of local knowledge and cultural traditions. How to best accomplish this in a more formal and structured way arose with the introduction of modern forestry (as a way of thinking) that started in Europe in the mid-19th century and its application to state (publicly) owned forests. Modern (or scientific) forestry is based on a paradigm of forests as a productive system whose inputs could be manipulated with predictable consequences for outputs with a goal of maximizing the physical productivity of the forest to produce timber (Scott 1998). Industrial policy in a sustained yield paradigm encourages investment that makes use of the maximum level of harvest that can be maintained in perpetuity.

At the end of 19th century, these techniques and ideas of modern forestry were manifesting themselves in North America (Weirsum 1995; Morgenstern 2007) but for the first half of the 20th century government efforts were focused on conservation of the forest resources (to prevent over-exploitation). It was not until the second half of the century that the North American government agencies started establishing the policies and mechanisms on how to best regulate timber harvesting while promoting employment and economic development (goals that remain today). Policy-makers and managers arrived at a rule that the level of timber harvests would be determined by the productivity of the forest and annual growth. Choosing the age at which growth rates reached a maximum would provide the maximum amount of timber that could be harvested without depleting the forest stock over time. This annual rate, or sustained yield, became both the organizing principle and paradigm used by Federal and state governments in the US and provincial governments in Canada in determining harvest levels. Sustained yield was

justified by pointing to the positive socioeconomic outcomes, which included community stability and it was assumed maintaining the forest stock would provide the other non-market values (Weirsum 1995).

Sustained yield as a concept and practice drew criticism for its emphasis on productivity and physical yield. Early on Faustmann had pointed out the economic opportunity cost of focusing on biological criteria to determine harvest levels; subsequent authors also pointed out that forests produced more than just timber and it was unclear whether we should simply be sustaining the existing harvest level or something else completely (Stillman 1949; MacDonald 1954; Behan 1978; Baskerville 1990; Walker 1990). North American politicians (and policy-makers) eventually started responding to the growing public demand for other forest values (i.e., recreation, wildlife habitat), with a series of policy changes and the introduction of what was termed a new paradigm. On US public lands it was initially Multiple Use, before joining Canada in adopting Sustainable Forest Management (SFM), which promised a better balance of timber and non-timber values from the forest over time (Morgenstern 2007). Today this phrase is embedded in high level commitments, policy as well as being supported by forest certification schemes that explicitly acknowledge SFM in Canada (and elsewhere). However sustained yield is a stubborn concept and does not give ground easily: in many jurisdictions although SFM may provide the surface veneer, underneath the hood the legislation, regulation and timber supply planning models that drive harvest regulation still employ sustained yield as the underlying principle. In Canada, this is expressed through the determination of the Allowable Annual Cut (maximum annual harvest level and abbreviated AAC) that continues to be determined based on the productivity of the forest (Luckert, Haley and Hoberg 2011; Morgenstern 2007; Natural Resources Canada 2020). Despite higher-level efforts to promote SFM, at best that simply

becomes the introduction of non-timber constraints around which sustained yield management is wrapped (Luckert and Williamson 2005; Elbakidze, Andersson, Angelstam, Armstrong, Axelsson, Doyon, Hermansson, Jacobsson and Pautov 2003; Mönkkönen, Burgas Riera, Eyvindson, Le tortorec, Peura, Pohjanmies and Triviño 2018). The remainder of this paper addresses the implications of continuing to rely on sustained yield as part of our industrial policy given the increasing risks associated with climate change, using a simple model to explore the interaction between our policies and system dynamics.

A Brief History of the Introduction and Persistence of Sustained Yield in North America

Modern (technical) forest management was introduced into North America in the early 20th century through the efforts of individuals such as Bernhard Fernow and Gifford Pinchot and the forestry schools that were being set up in Canada and the United States (Morgenstern 2007).¹ These forestry schools adopted models and practices of forest management that had been widely embraced in Germany and other parts of Europe (Ker 1962). At the time, these schools were seen as highly progressive, introducing the idea of sustainability where previously the focus had been on cut and run, and highlighting the success of this approach in ensuring maximum productivity of the land while also sustaining the forests themselves. Some, however, saw the introduction of this paradigm as more of an outcome of the modern state with its approach towards a single-minded focus (in this case maximizing timber flows) that simplified the task for ease of

¹ Bernhard Fernow, who had immigrated from Germany where he had trained as a forester, played an important role in promulgating these principles as he was instrumental in helping shape what would become the US Forest Service along with his disciple, Gifford Pinchot (Fernow later became Dean of the School of Forestry at the University of Toronto)(USFS, nd).

management in a highly-centralized governance system rather than progressive concern for the maintenance of the forest (Scott 1998; Prudham 2007).

Regardless of the reason, sustained yield flourished as a concept and was widely adopted and enshrined as a principle in Canada (Morgenstern 2007) where it still forms the basis for the major timber-producing Provincial forest jurisdictions even though actual harvest levels have remained below the AAC.²³ Sustained yield also formed part of the original legislation for managing harvests on Federally-owned lands in the US (Weirsum 1995) and in theory still underlies the calculation of what could be harvested on those lands (Youtz and Vandedriesche 2011), even though harvest levels have remained below those levels for over two decades because of litigation and conflict over how those lands should be managed.⁴ The paradigm of sustained yield also exists outside of North America. In countries such as Sweden and Russia, management is still fundamentally sustained yield despite the adoption of SFM (Elbaidzke, Andersson, Angelstam, Armstrong, Axelsson, Doyon, Hermansson, Jacobsson and Pautov 2013) and in some cases maximizing productivity is seen as a way to better achieve SFM outcomes

² The four largest timber-producing Provinces are BC, AB, Quebec and Ontario that account for over 80% of all timber harvested in Canada. Sustained yield may be explicit (as directed by statute or regulation) as is the case in BC or Quebec or implicit (built into the modeling of timber supply and processes for determining AAC. In BC and Quebec it is explicitly part of the overarching legislation: it can be found in the Forest Act []Part 2(8)5.8); in Quebec it is Section 53.5 of the Forest Act. In Alberta it forms part of the timber supply planning analysis process and requirement to generate even harvest flows as is also the case in Ontario (van Damme 2020).

³ The discrepancy between what in theory could be harvested and is actually harvested typically lies in the fact that the calculations of AAC will typically include parts of the timber profile and timber land base that while in theory are merchantable, in fact are economically undesirable; as a consequence, harvesting pressure then becomes concentrated on those areas and species for which there is a positive economic margins as those areas and timber types are left unharvested (Van Damme 2020; Betts and Girvan 2017).

⁴ In some cases in the US, such as state-owned lands it is still explicitly the management objective. See, for example, Oregon state lands: <http://www.oandc.org/o-c-lands/sustained-yield-forestry/>.

rather than being in tension (Lindahl, Sténs, Sandstrom,, Johansson, Lidskog, Ranius, and Roberge 2017). It also lies at the heart of the various processes used to define sustainable forest management employed by many certification schemes. Under the Montreal Process, the definition for whether a forest is being managed sustainably depends on the:

“total growing stock and annual increment of both merchantable and nonmerchantable tree species in forests available for wood production

Rationale: This indicator measures the growing stock and annual increment of forest area available for wood production to meet society’s needs. The annual increment and growing stock can be related to the volume harvested each year to provide a means to demonstrate the sustainable management of forest resources.” (indicator 2b, C& I).

Arguably, one of the reasons sustained yield remains so important as an organizing principle is that it provides a simple objective for managers and decision-makers in a complex environment while also promising sustainability (Prudham 2007) despite the issues noted by Baskerville and others. We return to this point in the next section.

Why Uncertainty Matters (and Extreme Risk is Increasing)

We now turn our attention towards the effect of this industrial focus and reliance on sustained yield management practices on publicly-owned forests and why we are facing a ‘rude awakening’-and why the consequences of that awakening may be more severe than policy makers and planners anticipate. Part of the reason is one Baskerville and others identified earlier: the assumption that sustained yield can generate the harvest flows to support our economic goals while maintaining the forest stock simplifies the complexity of the forest system

in such a way that does not incorporate other important forest values people care about. Further contributing to the problem is the creation of systemic risks created in part by our tendency towards centralized forest policy practiced on public lands where practices in one area may not be ecologically appropriate in others (Haley and Nelson 2007). More importantly, however, our approach fails to fully recognize the implications of this growing risk and uncertainty and how it affects the dynamics of the system we are trying to manage. The consequence is that natural disturbances can have catastrophic, wide-spread and long-term effects on a forest and the communities that rely upon it. One prominent example of how policy has failed to anticipate or incorporate these risks include wide-spread fire suppression in the inner mountain forests of the US and parts of British Columbia (BC) that has increased the susceptibility of those forests to fire and the increasingly catastrophic fires throughout the US West that are now being experienced in Canada as well (Kirchmeier, Young, Gillett, Zwiers, Cannon, and Anslow 2019; Tymstra, Stocks, Cai and Flannigan 2020). Another well-known example is that of the Mountain Pine Beetle epidemic in BC (now extending across Alberta and into Saskatchewan), where policy combined with climatic changes to create favourable conditions for the epidemic (Nelson 2007).

How much of these impacts can be directly attributed to climate change, to management practices or other factors remains a debate in the academic literature; however, there is wide-spread agreement that the impacts of climate change are expected to increase over time and it is anticipated that many of these impacts will have negative consequences (Lemprière, Bernier, Carroll, Flannigan, Gilsenan, McKenney, Hogg, Pedlar et al. 2008; Daniel, Ter-Mikaelian, Wotton, Rayfield and Fortin 2017; Halofsky, Andrews-Key, Edwards, Johnston, Nelson, Peterson, Schmitt, Swanston et al. 2018; Spittlehouse and Nelson forthcoming). Lindenmayer,

Messier and Sato 2016 worry about ecosystem collapse in managed forests associated with climate change and argue for a more conservative approach. However, they fail to define what collapse looks like. Given the focus of forest policy in Canada on the economic benefits that accrue from timber harvesting, we define collapse as the rapid, indefinite shutdown of industry. In many regions of the country, timber supply is expected to decline in part due to climate change even while there is still a great deal of uncertainty as to how climate change will impact/affect those ecosystems in the future (McKenney, Yemshanov, Pedlar, Allen, Lawrence, Hope, Lu and Eddy 2016; Brecka, Shahi and Chen 2018). Although policymakers have made some adjustments to timber harvest levels, overall they still seeking to maintain timber harvest levels close to their maximum level despite evidence that these levels are becoming difficult to sustain.⁵ This has meant there is no margin or additional timber stock available to mitigate the effect of these extreme events.

The typical approach to managing risk is to deduct a certain amount of losses based on past history in practice (Brown, Bancroft, Nelson and Robinson 2013): in theory such as in the case of wildfire some authors have argued for a similar buffer based on average or anticipated losses (Peter and Nelson 2005; Raulier, Dhital, Racine, Tittler and Fall 2014). However, these either assume that the past is an accurate predictor of the future or that the variability around the expected annual loss is assumed to be well-behaved, that is tightly clustered around the average (in the case of Raulier, Dhital, Racine, Tittler and Fall 2014). But what if the losses from wildfire, disease and pests can be realized as losses that are orders of magnitude larger than the

⁵ An example of this paradigm can be found in future timber supply projections for BC where the Province projects long-term harvest levels are expected to dip for a few decades but then rebound and remain stable for the next 250 years (Spittlehouse and Nelson forthcoming).

historical average? The evidence suggests this is true for losses from wildfire (Schoenberg, Peng and Woods 2003; Scotto, Gouveia, Carvalho, Monteiro, Martins, Flannigan and Borrego 2014) and is certainly the case for the losses experienced from the MPB epidemic in BC (which were orders of magnitude higher than had ever been previously experienced)(Nelson 2007). While Peters and Nelson (2005) do explore the consequences of more extreme risk in their model of choosing a harvest level, they fail to consider the implications for this in terms of how policy adjusts to losses and where the magnitude of losses depends on the scale. We address these by exploring the implications of fat-tailed loss behaviour for harvest at the local mill level and the incentives for policy adjustment in the following section.

A Simple Model of Forest Growth and Investment

The most commonly used models of forest growth typically envisage an even-aged forest (or cohorts made of even-aged stands). We start with a stock of timber in cubic meters S . This stock of timber grows according to a logistic function (S-curve).

$$\Delta S = S_{t+1} - S_t = rS_t \left(1 - \frac{S_t}{\bar{S}}\right) \quad (1)$$

The change in stock (or Mean Annual Increment, MAI), $\Delta S = S_{t+1} - S_t$ depends on the growth rate r , the current stock and the maximum achievable stock $\bar{S}$. When humans enter the picture they cut a certain volume of the forest every period $0 \leq \kappa_t \leq S_t$.

So that the change in stock⁶ is

$$\Delta S = rS_t \left(1 - \frac{S_t}{\bar{S}}\right) - \kappa_t \#(2)$$

Humans harvest trees to do useful things with them and they use tools to do it. We will call this collection of tools the capital stock, K_t . The amount that can be cut in any period is a function of the capital stock and the mean annual increment.

$$\kappa_t = f(K_t, \Delta S) \#(3)$$

For now, we assume that one unit of capital allows us to cut one unit of forest stock and the most we will cut in any given year is the change in stock $\kappa_t = \text{MAX}(K_t, \Delta S)$ when $K_t \geq \Delta S$. Using this as a harvest rule leads to a flow of timber that in theory can be sustained in perpetuity or sustained yield. This rule has been used (and continues to be used), to determine harvest levels on public land in Canada and other jurisdictions.

Our forest is publicly owned and the government has decided that industrial development will be encouraged so that the harvest rate equals the change in stock or MAI. A key point is that we are modeling this at a scale where the impacts of these events can have serious consequences at the scale of a timber catchment area for a given community, a point we return to later. To achieve this, the capital stock grows at a rate g , less depreciation, δ , if the cut is less than the MAI, otherwise no investment occurs and capital depreciates at the rate δ , $g > \delta$. Depreciation is

⁶ Silviculture is absent from this model. For the purposes of modelling the impacts of wildfire on a capital investment in a timber catchment area silviculture is not going to significantly affect the modeled outcome. If I increase the growth rate, investors will increase the size of the capital stock to capture the potential fibre. We can imagine approaches to silviculture that reduce the potential for catastrophic wildfire, but that is not, for the most part, the situation we are faced with currently.

included because it allows capital to decline when there is a forest disturbance and the allowable cut drops.

$$\Delta K = (g - \delta)K_t \quad \text{if } \kappa_t < \Delta S \#(4)$$

$$\Delta K = (-\delta)K_t \quad \text{if } \kappa_t \geq \Delta S \#(5)$$

Now we have all the pieces of a simple, deterministic forestry model. When step through this model using a computer simulation, we approach a steady state amount of capital equal to the MAI. We can see this in Figure 1.

So far in this mathematical description we have relied on the forest to regenerate itself, but it is possible that through silvicultural practice the output of forest products could be boosted. To do this we define a new rate of forest growth $r' = r + \zeta$, where ζ is the incremental growth from silvicultural investments. Now the change in stock is $\Delta S = r'S_t\left(1 - \frac{S_t}{\bar{S}}\right) - \kappa_t$. The maximum stand volume $\bar{S}$ also increases to a higher level $\bar{S}'$. If we run the computer simulation again, we observe higher growth, higher MAI and higher equilibrium cut levels (See Figure 1).

This all works as we would expect but living in a deterministic universe is not interesting. What happens to this model if we introduce damages from wildfire that follow a Pareto distribution⁷? Wildfire damages are given by ω_t , which is a random event drawn from a bounded Pareto distribution so that the highest possible damage is equal to some fraction of the total forest stock.

⁷ A Pareto distribution has been selected because studies in the past have found it to be an appropriate model for the distribution of wildfire sizes (Schoenberg Peng and Woods, 2003; Malamud, Millington, and Perry 2005)). It is not necessary, however, for the result of this paper, other one-sided distributions (log normal, Levy, Frechet) with the potential for low-frequency, catastrophic fires will give similar results.

The change in stock is now

$$\Delta S = r'S_t \left(1 - \frac{S_t}{\bar{S}}\right) - \kappa_t - \omega_t \#(6)$$

And the probability density function that describes the distribution of risks from fire is given by:

$$\omega(x) = \frac{\alpha L^\alpha x^{-\alpha-1}}{1 - (L/H)^\alpha} \quad L \leq x \leq H \#(7)$$

Where $L \geq 0$ is the lower bound of the distribution and $H = \gamma S_t$ (the upper bound) with

$$0 \leq \gamma \leq 1.$$

In Figure 2 we see a single, example run of the model with fire disturbances⁸. The model parameterization is not intended to capture the dynamics of any particular fibre basin but some general features of capital accumulation and harvest under a sustained yield regime within the supply area of a mill (or group of contiguous mills). The capital accumulation parameters implicitly assume that the available AAC is economic to harvest and that capital will grow until it is sufficient to harvest all of the available fibre. When the AAC drops the capital adjusts without friction (which is not true in reality, making the real situation worse than the model suggests). The distributional parameters chosen to model the risk of damages are taken from a data set examining wildfire in a region of the BC Interior over a 20 year period (Scorah, Nelson and Daniels 2021). The distribution does not have to be Pareto, a log-normal distribution (or any other asymmetrical distribution) with a wide variety of parameter choices will give the same

⁸ This abstraction could be used to model any fire or insect disturbance. Notably, BC's forests have been severely disturbed by an endemic pest (the Mountain Pine Beetle) that led to extensive losses of standing timber and where the beetle has expanded into the neighboring jurisdiction (Alberta), also leading to significant timber losses and downward pressure exerted upon the timber supply.

result. When there are asymmetric shocks to the forest stock (from pests, pathogens, or fire) the AAC will continually decline over time if there is no refractory period where harvest is below AAC. The frequency and magnitude of these shocks will affect the rate of decline but not the fact that it will happen.⁹

No matter how many times this model is run, the forest stock always heads down to the minimum value set in the model where a forest industry is no longer viable. This always happens because once the capital stock is built up the cut is equal to the MAI. When the MAI drops because the stock has dropped, the capital drops with depreciation to accommodate the reduced MAI but the cut is still equal to the new growth each year. Without a refractory period where cutting is less than growth it is impossible for the system to recover to previous harvest levels. The system inevitably trends towards the minimum values.

If we introduce silviculture again in this Pareto random world, we get some recovery but continue to trend down to the minimum bound (See Figure 3). Even with silviculture there is no avoiding a refractory period. In the real world, this is what we are likely to see. Not because government policy demands a refractory period, but because the mills are unable to operate without access to fibre. We are most likely to see this when there are *discontinuous changes* in operating conditions. In this model the only operating condition that matters is ΔS . Small ΔS are easy to adjust to on the margin. Staffing can be changed, and product mixes can be adjusted over time. It is the large, discontinuous changes that really disrupt the industry and forest-based communities. When high volatility events, like catastrophic wildfire, occur a very large gap can

⁹ We also note that even if we account for how much growth is assumed to be available to be harvested (for example, deducting annual expected losses or set asides), the problem still remains that we are still practicing sustained yield, albeit sustained yield minus these adjustment factors.

suddenly open up between marginal benefits and marginal costs. Investors who had calculated a positive return on investment given current harvest levels find their discounted cash flow models to be a poor fit for realities of large loss events. In other words, we are long ways from equilibrium analysis being applicable (Farmer and Geanakoplos 2009).

Discussion

BC offers an example of how this dynamic plays out in terms of harvest levels and the forest sector. Despite public pressure and efforts to move towards an approach that de-emphasizes timber flows, management paradigms and process still firmly hew to the sustained yield paradigm (Lertzmann, Rayner and Wilson 1996).¹⁰ As long as there are downward shocks to the cut level without balancing shocks upwards or a capital re-balancing there will be continuous crisis in BC forests. The capital re-balancing could happen in a steady, negotiated manner that could reflect depreciation or all at once. In 2019-2020 we are observing rapid, painful change as forestry companies try to rebalance their asset portfolios in the face of abrupt changes to the cut level that are a consequence of biotic and abiotic disturbances (Kurjata 2019). The current pain is a direct consequence of trying to maximize the value of stands damaged by disturbances without giving much consideration to the consequences for the dynamics of the capital stock, future cut

¹⁰ The Forest Act states that “In determining an allowable annual cut under subsection (1) the chief forester, despite anything to the contrary in an agreement listed in section 12, must consider (a) the rate of timber production that may be sustained on the area, taking into account: (i) the composition of the forest and its expected rate of growth on the area, (ii) the expected time that it will take the forest to become re-established on the area following denudation, (iii) silviculture treatments to be applied to the area, (iv) the standard of timber utilization and the allowance for decay, waste and breakage expected to be applied with respect to timber harvesting on the area, (v) the constraints on the amount of timber produced from the area that reasonably can be expected by use of the area for purposes other than timber production, and (vi) any other information that, in the chief forester's opinion, relates to the capability of the area to produce timber.

and the impacts this would have on communities. The most recent wildfires in the BC Interior provide the most salient example: in these cases in several regions the losses from fire were large enough (up to 22.5% of the timber harvesting land base available to local mills) to project that the midterm timber supply would need to fall by half (Ministry 2018). However there is still pressure to keep cutting at pre-fire levels (or at levels sufficient to keep the mill open) such that there was no change in allowed harvest levels.¹¹ However, mills run out of timber eventually and start shutting down as is currently happening in that region (Hamilton 2019).

We also observe similar patterns elsewhere in Canada where long-term harvest levels have been reduced (Ontario and Quebec are the two most prominent examples, but the same pattern can also be found in the Maritimes as well) along with associated widespread mill closures (McKenney, Yemshanov, Pedlar, Allen, Lawrence, Hope, Lu and Eddy 2016).

Silviculture is often looked to as a way to offset these downward pressures on harvest levels. In the model we see that while it buys time, it does not change the fundamental dynamic. Policy makers have also struggled to find ways to encourage firms to invest in silviculture as a way to mitigate downfalls in timber supply: not only does the model show absent a refractory period, in practice these efforts have been disappointing at best (Mitchell, Nelson, Larson, Griess, DeLong, Melton and Sheppard 2017).

While the model is a simple one, it captures the essential dynamics that underpin our approach to timber supply planning in which we continue to emphasize the highest modeled timber harvest

¹¹ “These updated projections suggest that the current AACs do not need to change; however, current partitions may need to be reconsidered to protect mid-term timber supply.” Ministry 2018, p. 2).

levels we can sustain on an ongoing basis, and why we can expect this pattern of decline with periodic crisis. Once an investment is made with the expectation of a sustained fibre flow and that flow becomes unattainable because of catastrophic disturbances we cannot expect a lagged downward adjustment or afforestation to make up for this. Political necessity will push the cut to be maintained above sustainable levels for as long as possible to maintain employment. This risk exposes the structural weakness of this approach. Given these incentives how do we approach managing forests in a world with these types of extreme risks?

We need to recognize that our current approach is inadequate for several reasons. First, deducting average historical loss from expected annual increment is insufficient to account for losses in a fat-tailed risk regime. The losses, when an event occurs, will be far greater than the average loss (again, see the example of wildfires-the vast majority of wildfires are small and put out at very little cost and it is the cost of the extreme ones we really care about). There are also other risks that we may not be aware of at this time that could have equally significant consequences. These could be from other impacts: changes in hydrological regimes resulting from salvage logging and affecting flooding; or some unknown unknown we still do not know about yet.

There is a collective need to re-think how we can shift from managing the flow of timber to managing the forest stock. A necessary part of that will be bringing the harvest level more in line with what can actually be achieved, while also exploring what it would mean to manage with buffers to absorb the impacts of these extreme risk events when they occur. This is challenging: aside from the political difficulties associated with reducing harvest levels, sustained yield as a concept has been persistent because it provides a powerful organizing principle, whether it is through how we model timber supply, the rule we employ to set harvest levels or report out on

sustainability. How to modify it or find an alternative concept is not a straightforward task. The same is true even if we approach the challenge focused on conservation values with the goal of protecting forest stock: this is unlikely to work in a world that is more complex and more uncertain than we account for in our existing models (Messier, Puettman, Chazdon, Anderson, Angers, Brotons, Filotas, Tittler et al. 2015).

Second, we need to be cautious about our ability to use management practices that aim at increasing the annual increment. Rather than relieving the constraints we may have placed upon ourselves from the pursuit of sustained yield, they can have the effect of increasing the worst possible loss from wildfire and insect loss. These are hard to quantify but some kind of worst-case analysis of side-effects of management decision should be included in management decisions.

Finally, encouraging the development of an inflexible capital stock that requires high-throughput of a uniform product at the modeled annual increment to be profitable is only going to be profitable over the short-run. This forest management strategy and economic development model accentuates the boom-bust nature of the business. Indeed, this is what we see taking place in the BC forest sector today. There is no reason why this has to be the predominant business model (Nelson and Hotte 2016).

Conclusions

We can return to the quote with which we started the paper and complete it. Baskerville 1990 noted that:

“The expectations of the public owners of the forest resource, and the realities of what is achieved, or is indeed achievable in that resource, are so out of line that major

adjustments will occur in the next decade. The problem can only be addressed by changing the expectations, changing the reality, or changing both. Before making changes, it would be wise to consider what it is that needs to be changed.”

Baskerville was only wrong in his timing. We now face that challenge. Sustained yield no longer serves our purpose and, indeed, our approach to towards trying to do it has arguably exacerbated the risks we face. If instead we recognize the nature of those fat-tailed risks, this has profound implications for how we approach forest management. Rather than trying to run the system at its limits, with an unrealistic margin for error, this approach entails acknowledging the underlying natural productivity of the ecosystems we rely on and riding along with the ebb and flow of those systems-and then taking advantage of the opportunities to harvest the surplus when we can, while having the reserves to ride through the negative shocks.

We should also be willing to take our lessons from elsewhere. The idea of maximizing sustained yield relative to a given stock has been powerfully influential in fisheries management-and has also had a poor track record. The most notable example is that of the Northern Cod where a combination of incorrect models and poor policy decisions led to overharvesting (Ludwig, Hilborn and Walter 1993; Steele, Andersen and Green 1992; Walters & Maguire 1996); the stock still has yet to recover even after a two-decade moratorium (Canadian Science Advisory Secretariat 2016). It is disconcerting to think that we may be making the same mistake all over again. Paradoxically, the issue is not whether hewing wood in itself can be a long-term profitable and sustainable endeavour, the challenge posed by Harold Innis 1930; instead, we should focus on the rules that decide how we go about hewing the wood. There is every reason as to why a resource that is renewable and should be sustainable, with all the opportunities that provides,

should continue to enrich our communities and society in the future as they have in the past. In order to do so, however, we have to make sure that our mistaken models and beliefs are not leading us down a path of impoverishment.

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Figures

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Figure 1

Figure 2

Figure 3

Figure Captions

Figure 1. The deterministic model of growth and harvest. The blue line is natural re-growth and the red line is with silvicultural treatments. Equilibrium is reached when the annual cut equals the mean annual increment. As expected, in this model without disturbance, silviculture increases the equilibrium cut level. The parameter values used in the model: $K_0 = 1$, $r = 0.01$, $\zeta = 0.005$,

$$\bar{S} = 10,000, \overline{S_{silv}} = 12,000, g = 0.1, S_0 = 5,000, \delta = 0.05.$$

Figure 2. In this model, we have the same starting parameters except the stock is exposed to fires each year. The fire events are drawn from a Pareto distribution with $\alpha = 1.005$, $L = 1.0$ and H

equal to a fraction of S_t equal to 0.25. The stock inevitably travels to the minimum as we continue to cut all of the growth in the forest while facing repeated random negative shocks in total volume.

Figure 1. Using the same growth model as Figure 1 this introduces shocks drawn from the same distribution as in Figure 2. The redline includes silviculture and the blue line is without. No matter what is done, the stock

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