FINAL REPORT

Understanding Pre-Industrial Landscape Patterns on the Canfor FMA Area in Alberta

Final Report

fRI Research Healthy Landscapes Program

September 10, 2019

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fRI Research
Informing Land & Resource Management

DISCLAIMER

ACKNOWLEDGEMENTS

This project is a sub-project of the LandWeb initiative via the fRI Research Healthy Landscapes Program and funded by Canfor Company.

Many thanks to the LandWeb funding partners, including West Fraser Timber Co., Alberta Newsprint Company, Alberta Pacific Forest Industries Inc., Mercer Peace River Pulp Ltd., Weyerhaeuser Company, Millar Western Forest Products Ltd., Tolko Industries Ltd., Canfor Company, Louisiana-Pacific Corporation, Mistik Management Ltd., Vanderwell Contractors Ltd, Ducks Unlimited Canada, the government of Alberta, the government of Saskatchewan, and the government of the NWT. Thanks also to the Forest Resource Improvement Association of Alberta (FRIAA), and Mitacs for their generous support as well.

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EXECUTIVE SUMMARY

This project was a spatial modelling exercise that created coarse-scale pre-industrial landscape metrics of the Canfor Grande Prairie FMA area in Alberta. The primary goal was to understand if, or in what ways the current condition of the FMA area aligns with the historical range. The results suggest that much of this landscape is statistically already beyond its historical range. More specifically, the amount of mature (80–120 years) and old (>120 years) are in many cases currently very close to or beyond the upper natural range of variation (NRV) threshold and the overall amount of young (<40 years) forest is close to or beyond the lower NRV threshold. More detailed analyses revealed that the deviation from NRV was more pronounced in those parts of the landscape that are not actively managed for timber and black spruce dominated areas. This suggests that wildfire control efforts have been effective for many decades. However, the pattern of high levels old and low levels of young forest are evident on the 'active' land base as well, suggesting that historical disturbance rates have been higher than harvesting levels over the last few decades.

A large amount of old forest can provide positive benefits to a landscape in the form of a buffer against natural disturbance. On the other hand, the social, ecological, and economic risks of having old forest levels beyond NRV include increased risk of wildfires or insect and disease outbreaks – the impact of which is already evident in BC and Alberta during the 2017 and 2018 fire seasons. Moreover, this study also revealed that the ecological benefits of having large amounts of older forest on this landscape is likely compromised by the cumulative impacts of linear features such as roads, seismic lines, and pipelines right-of ways spatially divide what would otherwise be large contiguous patches of old forest into smaller patches.

A less obvious, but equally important implication of the deviation of the study area from NRV is the loss of young forest habitat. While we tend to focus on old forest as the ultimate measure of ecosystem biodiversity, a large number of specialized species are dependent on disturbance, creating a smaller, but unique diversity peak within a few years after fire thanks to the sudden physical, chemical, and environmental changes. This landscape has been experiencing disturbance levels near or at the lower end of NRV for several decades, which minimizes opportunities for disturbance-specialist species

Of perhaps greater concern is that the shift towards older forest in favour of young forest is a pattern that has been ongoing for many decades. The magnitude and degree of difference right now is such that it would take an increase of several times the current disturbance levels over the next 20 years to just prevent the gap between NRV-and current condition to widen.

Overall, the metrics from this study suggest that this is an unbalanced landscape that is headed in the wrong direction, due largely to decades of the inappropriate use of disturbance as a tool. This is likely already negatively impacting a) resilience (to climate change), b) the likelihood of maintaining a sustainable flow of all goods and services, and c) the risk of natural disturbance agents.

1.0 INTRODUCTION

The evolution of forest management in North America has been an ongoing process, but one that has inevitably been moving towards the goal of sustaining all forest values. Forest management is now expected to manage for a wide range of biological values including water and nutrient conservation, toxin filtration, carbon cycling, fish and wildlife habitat, food, pharmaceuticals, and timber (Davis 1993).

Under the auspices of this task, the concept of the using (pre-industrial) forest patterns created by natural processes as management guides is gaining favour in North America (Franklin 1993), and is one of the foundations of an ecosystem-based management (EBM) approach (Booth et al. 1993, Grumbine 1994, Long 2009). The theory is certainly attractive: by maintaining the type, frequency, and pattern of change on a given landscape, we are more likely to sustain historical levels of the various biological goods and services. So-called “coarse-filter” knowledge can also be applied directly and immediately to planning and management programs at virtually all levels and spatial scales. Thus, defining the historical range of various ecosystem patterns is a fairly fundamental requirement of a natural pattern-based approach to forest management.

Developing coarse-filter, pre-industrial knowledge is perhaps most challenging at landscape scales. Reliable pre-industrial landscape snapshots are rare to non-existent due to the combined impacts of fire control, cultural disturbance activities, and lack of historical records or data. What we do know about the disturbance history of Canadian boreal landscapes suggests that they are highly dynamic, and the age-class distribution from one time to another can vary widely over time (Turner and Dale 1991, Payette 1993) and space (Andison and McCleary 2014). This means that historical levels of old forest are likely to be both highly dynamic and spatially variable as well.

In the absence of detailed and multiple historical data and/or photos, the only means left to capture explore the dynamics of forest ecosystem patterns at the landscape scale is spatial simulation modelling. In its simplest form, spatial models allow one to explore how known (observed, known) probabilities of key variables intersect in time and over space to create multiple possible landscape scenes or snapshots. When a sufficient number of landscape snapshots have been created by the model, each one is measured in a number of ways to capture the desired metrics, and then summarized to generate NRV.

This report summarizes the results of a spatial modelling exercise designed to generate NRV summaries for the Canfor forest management agreement (FMA) area in the Upper Peace region of Alberta.

2.0 GOAL

The goal of this project is: ***to understand some simple pre-industrial landscape-scale patterns on the Canfor FMA area in Alberta relative to the current condition***. Note that this goal is both narrow (i.e., it will capture only landscape scale patterns) and humble (i.e., it will capture only a small number of simple metrics).

3.0 BACKGROUND

3.1 LANDWEB

This project is a pilot study of a larger Healthy Landscapes Program (HLP) initiative called LandWeb (Landscape Modelling in Western Boreal Canada). The objectives of LandWeb are to a) **Define the historical range of disturbance regimes and landscape conditions for western boreal Canada**, and b) **Create a spatial modelling framework for future scenario and hypothesis testing across western boreal Canada**. The ultimate goal of the larger project is improve the best available science and tools for defining landscape-scale benchmarks of NRV.

The study area for LandWeb (Figure 1) includes 15 partners across five provinces and territories. The study area covers the western-most 125 million ha of the Canadian boreal forest extending west from the Rocky Mountains to the Manitoba border in the east, and from the southern boundary of the forest-grassland interface roughly to the 62nd parallel into the NWT. The area includes 73 million ha of the Boreal Plain, 25 million ha of the Taiga Plain, 20 million ha of the Boreal Shield, and 7 million ha of transitional areas of the Prairie, Montane Cordillera, Taiga Shield and Boreal Cordillera (Wilken 1986) (Fig 1).

Figure 1. Map of the LandWeb Study Area (shown by the blue dashed line).

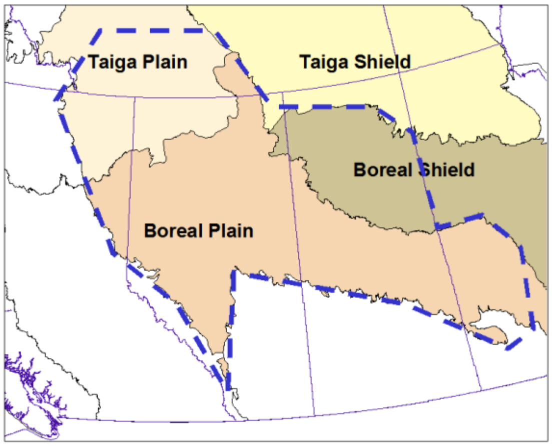
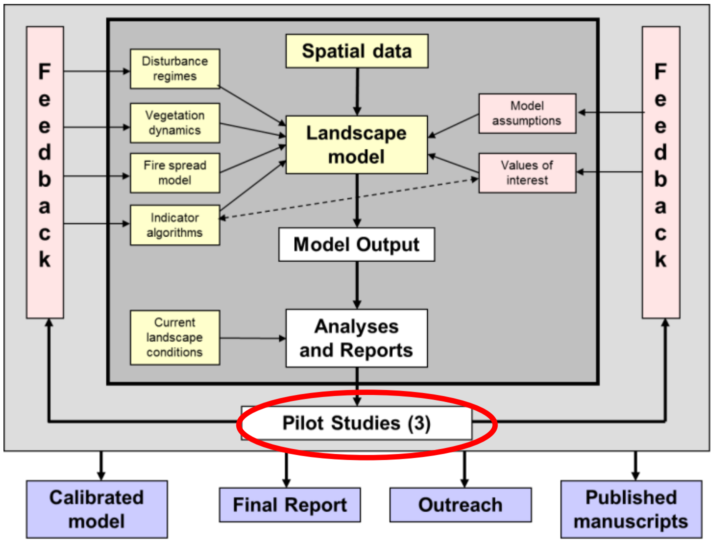


Figure 2. Overview of LandWeb Project Elements.



Yellow boxes = science. Pink boxes = partner input. White boxes = busy work.
Dark gray box = "the model". Light gray box = the process of this project
Blue boxes = deliverables

LandWeb has several linked research elements (Figure 2), all of which are built around the idea of creating a *modelling framework* within which existing or new data, models, or output modules can be inserted, removed, or traded for others. So LandWeb is not a model *per se*, but rather a *modelling configuration*. The larger framework within which the LandWeb configuration resides is called SpaDES (Spatially Discrete Event Simulator). SpaDES is not a model either, but rather a smart modelling environment within which new and existing model modules and datasets can communicate with each other (Chubaty and McIntire 2018). For example, a fire spread module from model A could be linked to the succession module from model B or C, and datasets from models D and E. Krueger et al (2012) refers to this approach as *ensemble modelling*.

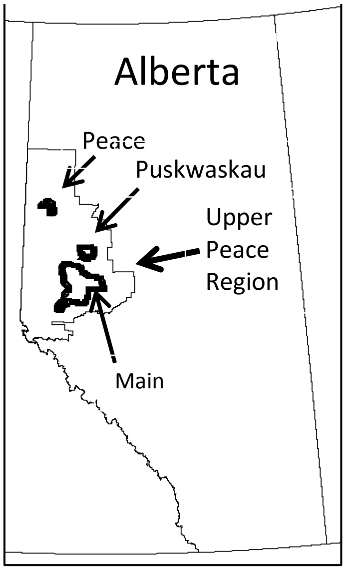
As one (of potentially dozens of possible) configuration of SpaDES, it was recognized that multiple iterations of LandWeb would likely be developed over time, each one adding layers of sophistication, ease of use, or robustness as the case may be. However, the original vision of the very first version of LandWeb was very modest and simple. It included largely empirical modules that would be relatively easy to develop and calibrate, including input data, output formats, and the assumptions and drivers behind both fire dynamics and forest succession. The presumed advantage of simplicity in this case was the speed with which such models can be built and run. In support of this vision, that part of LandWeb that determines the frequency, size, shape, severity, and location of fires (i.e., the fire regime) was originally assumed to be largely *input data*, as opposed to having these attributes "emerge" from a more process-based model architecture (as per Figure 2). This assumption thus required defining regime parameters for the entire 125 million ha study area.

This project, and the associated modelling architecture and assumptions, preceded Version 1.0 of LandWeb. The value of this particular pilot study to the greater LandWeb project was both a) to provide specific LandWeb partners with results sooner, and b) developing and testing techniques for dealing with the complexities of multiple regime zones in a spatial model.

4.0 STUDY AREA

The area modelled as part of this pilot study was the entire greater Upper Peace (land use framework) region of Alberta, covering over almost 7.5 million hectares. However, the summaries provided in this report are limited to the three distinct areas of the Canfor FMA area totalling just over 642,000 ha, partitioned into Main (551,000 ha), Puskwaskau (71,000 ha) and Peace (20,000 ha) (Figure 3).

Figure 3. Study area map showing the Canfor FMA areas of interest in Alberta.



Of the total area in the Canfor FMA area, just over 35,000 ha, or 6% is non-forested. Another 31% (almost 202,000 ha) is deciduous leading, 21% mixedwood leading (132,000 ha), 16% of black spruce leading, 15% white spruce leading, and 12% pine-leading (Table 1).

Table 1. Summary of Canfor FMA area by leading species type.

Leading Species	**Area**	
	Hectares	**%**
Pine	76,928	12
White Spruce	96,576	15
Black Spruce	99,888	16
Deciduous	201,576	31
Mixedwood	131,852	21
Total forested	606,820	94
Non-forested	35,330	6
TOTAL	**642,150**	**100**

Ecologically, almost half of the Canfor FMA area is represented by the central mixedwood natural subregion (NSR; 48%) followed by the lower foothills (31%), and the upper foothills 14%) (Table 2). The relatively small proportions of dry mixedwood (6%), subalpine (1%), and montane (<1%) NRSs in the Canfor FMA area are all ecotonal (i.e., mostly within close proximity to the other major NRSs)

Table 2. Summary of Canfor FMA area by Natural Sub-Regions (NSR)

NSR Name	**Area**	
	hectares	**%**
Central Mixedwood	307,662	48
Dry Mixedwood	40,934	6
Lower Foothills	199,749	31
Montane	9	0
Subalpine	4,412	1
Upper Foothills	89,338	14
TOTAL	**642,104**	**100**

The range of ecological conditions on the Canfor FMA area is noteworthy and highly relevant to NRV modelling and estimates. The 642,000 ha area of the Canfor FMA area is relatively small for the boreal forest, and it would otherwise be considered to be a homogenous study area based on size alone. However, this particular location spans an elevation from 200–1750 m, growing degree days from 900–1250, mean annual precipitation from 475–650mm, and flat to steeply sloped topography (Table 3). In other words, this is by no means a homogenous study area in terms of either biotic or abiotic elements. By association, nor is it likely not homogeneous in terms of historical (or future) fire behaviour or risk. In fact, the historical long-term fire cycle estimates for the Canfor FMA area range from 60–100 years (see ahead). Moreover, these different fire regime zones align strongly with changes in many critical wildfire behaviour elements. For example, shorter fire cycles are associated with low elevation (i.e., higher lighting ignition probability), longer growing (and fire) seasons, and more flammable fuel types.

Table 3. Summary of the biotic and abiotic conditions across the Canfor FMA area.

Natural Region	**Natural Subregion**	**Elevation**	**Topography**	**Climate**	**Vegetation**	**Soils**	**Growing Degree Days $>5^{0}$C**	**Mean annual Precip (mm)**	**Relative Summer Moisture Index**	**Estimated LTFC**
Foothills	Upper Foothills	950-1750m	Rolling to steeply sloped	Short wet summers, snowy cool winters	Dense Pl forest (low el) to dense Sb, Sw forest (high el). Small area in wetlands.	Luvisols, with some brunisols	900	650	2	100 years
	Lower Foothills	650-1625m	Gently rolling with plateaus	Short summers with average precip, colder very snowy winters	Highly variable. Mostly mesic dense mixedwood forest (At, Pl, Sw, Pb, Ta, Fir, shrubs). Very little water or wetlands	Luvisols, with some brunisols	1100	590	2.7	75 years
Boreal Forest	Dry Mixedwood (Peace)	225-1225m (lower El in the Peace)	Level to gently rolling plains	Long, warm, dry summers, mild winters	At dominated, with some Sw, shrubs, and fens	Luvisols, with some solenetzics, gleysols, and organics	1300	475	4.1	60 years
	Central Mixedwood	200-1050m (lower El in the Peace)	Level to gently undulating	Short warm, moderately wet summers, long cold winters.	Upland mixedwood, Sw, Pj (50%) and Sb fen forests + wetlands (50%). Open water common	Luvisols with some brunisols and organics	1250	500	3.8	65 Years

5.0 METHODS

As previously (Section 4.0) discussed, the modelling described in this section was actually based on the entire Upper Peace region of Alberta. Thus, most (but not all) of the methods are the same, but the results (for Canfor) are unique.

5.1 MODELLING PRE-INDUSTRIAL LANDSCAPES

At the heart of any attempt to generate pre-industrial landscape conditions is the formulation and assumptions within a spatially explicit model. Thus, the defensibility of the output is intimately linked with the defensibility of the input mechanism (i.e., model), and the associated modelling assumptions. The model used to create multiple possible past landscape scenes for this project was LANDMINE (Andison 1998).

LANDMINE is a spatially explicit, cellular automaton, Monte Carlo landscape simulation model that was developed for landscapes dominated by stand-replacing disturbance events (Andison 1998). LANDMINE uses a dispersal algorithm to spread fires from one pixel to another in such a way that fire movement responds probabilistically to various input layers such as fuel-type, topography, and wind. Fire movement thus favours uphill movement, older forest, high percentages of conifer forest, prevailing winds, or other factors as defined by the user. Controlling layers can be added or removed depending on available data. The nature of the fire movement can also be calibrated to create different fire shapes and residual numbers, sizes, and locations to match empirical data as available. Fire size is controlled by an equation that represents the actual fire size distribution for each landscape. Ignition location probabilities can also be calibrated – usually using historical lightning probabilities or pre-defined long-term-fire-cycle (LTFC) estimates. Finally, the total amount of forest burnt in any single time step (10 years in this case) is established through another probabilistic equation capturing historical area burnt (in hectares).

Each of these steps is stochastic, meaning that LANDMINE never burns the same way twice. However, over the long term the output is consistent with internally defined probabilities. Clarke et al. (1994) also demonstrated that this method of growing disturbances created fractal images, meaning that the model could use spatial data at any scale of resolution. Finally, a succession module is available that includes a set of self-defined rules that governs successional pathways either probabilistically or deterministically depending on stand composition and age (Andison 1996).

In summary, LANDMINE is a powerful landscape *disturbance pattern model* (*i.e.*, it is good for exploring long-term disturbance regime trends over space and time). It is not meant to predict the patterns or spread of individual fire events. LANDMINE was developed in 1996 (Andison 1996), and has since been used eight times across Canada.

5.1.1 MODEL ASSUMPTIONS

By definition, a model is simple, incomplete representation of reality (Hammah and Curran 2009). There is a trade-off between complex models and simple ones. The “best” model is not necessarily the most complex or realistic one, but rather the one that best suits the purpose. The rule of thumb for any modelling exercise is, *as complex as necessary, but no more*. In other words, each modelling exercise should focus on achieving the desired objectives with the least possible number of explanations, equations, and assumptions (Hammah and Curran 2009). In this case the modelling objectives were simple and general in nature, as defined by Canfor:

1) To define the pre-industrial (NRV) percentages of each (of four) seral-stages in each (of seven) major vegetation types for each of the following geographic areas:
    - The Canfor FMA area as a whole,
    - The three major management units,
    - The provincial natural subregions, and
    - Woodland caribou range boundaries,
2) To define the pre-industrial (NRV) densities of 'old' forest patches for a) all old forest combined, and b) old forest of the major forest types for the following four patch size classes: 1) <100 ha, 2) 1–500 ha, 3) >500 ha, and 4) >5,000 ha.

Since the interest is in very broad patterns over hundreds of years, LANDMINE was run with minimal rules and assumptions. No topographic data was included and broad seral-stage and cover-type classes were adopted (see below). Furthermore, succession rules were turned off, and 400 years was adopted as a universal age at which any surviving pixels automatically convert to year zero based on the assumption that over such a long period of time, such areas would be subject to other disturbance agents such as pathogens, disease, wind, snow, or ice.

The most notable modelling assumption was ignition probability, which determines the average long-term fire frequency. The average, pre-industrial long-term-fire-cycle (LTFC) for the entire western boreal Canada was determined by a combination of a literature review, a two-day workshop of fire regime experts, and another four years of collaboration among fire regime experts to finalize the details. For a full description and explanation of the development of the western boreal pre-industrial LTFC map(s), see Andison (2019).

5.2 SPATIAL DATA

LANDMINE used a number of spatial data layers for both input and output, each one using 4 ha pixels (200m square).

5.2.1 PRE-INDUSTRIAL VEGETATION

Since the model runs capture NRV, they must represent "natural" (i.e., pre-industrial) landscape conditions with no obvious cultural features such as towns, roads, harvesting, or even fire control impacts. The elimination of the cultural influence on the spatial dataset required three steps.

1) *Create a single landscape snapshot with no cultural features*. The timing or date of this particular landscape was unimportant (see step two ahead). To create a pre-industrial landscape, we first obtained the oldest digital version of forest inventory (with the least amount of cultural

disturbance) for each jurisdiction. Then we used available digital data, records, and maps to replace existing cultural features with the attributes of the known pre-disturbed vegetation types. Any remaining culturally modified polygons were filled in with the age and cover-type attributes of the adjacent polygon with the greatest length shared boundary. Thus, all towns, roads, cutblocks, mines, and other human developments were replaced by attributes of the last known, or the most likely, polygon.

2) *Create an unbiased starting point for the model*. The "natural" pre-industrial snapshot created by step one may still include bias or inaccuracies from a) fire control b) using data from different eras, or c) aging errors from forest inventories, all of which could influence the subsequent model output for several centuries. To eliminate this risk, the model was run forward in time a minimum of 1000 years before landscape snapshots were collected and measured for NRV.

3) *Stratify the vegetation into major vegetation types*. The inventory data was used to define one of seven forest cover-classes, as per Canfor's direction:
    a. Conifer – pine leading
    b. Conifer – mesic (Sw and fir leading)
    c. Conifer hygric (Sb, L, Ta leading)
    d. Conifer Sw/Pl leading
    e. Deciduous leading
    f. Mixedwood Pl leading
    g. Mixedwood Sw leading

Note that if a polygon had a leading tree species, it was modelled regardless of whether or not it was productive, or 'active' forest. Non-forested land was included as a fuel type in the model, but not tracked and summarized for the output.

Age data was used to define four broad *seral* stages of stand development. Canfor agreed to adopt the seral classes defined by the Alberta government, as follows:

- Young ≤ 40 yrs.
- Immature = 41–80 yrs.
- Mature = 81–120 yrs.
- Old ≥ 120 yrs.

5.2.2 CURRENT CONDITION

The spatial data used to calculate current conditions for the various metrics was the most recent AVI (Alberta Vegetation Inventory) data for the Canfor FMA area. These data were provided by Canfor. The area in each of the four seral-stages X seven major vegetation types (as described above) were queried in ARC GIS using the same rules for defining each strata as used by the model. The calculation for the current condition for patch size included using any and all linear features available in the same AVI dataset.

5.3 MODEL CALIBRATION

The calibration required for this particular set of LANDMINE runs is largely related to fire regime attributes. A *fire regime* is a description of how often, how large, and how severe fires occur, and other details about seasonality and location. Fire regime attribute combinations tend to be landscape unique, and linked to major ecological, vegetation, topography, and climate factors. For example, there tends to be a universal inverse relationship between fire frequency, and fire size and severity (e.g., Falk et al. 2007, Steel et al. 2015). As part of the larger LandWeb project, an expert workshop and series of subsequent collaborative interviews suggests that the larger Upper Peace region of Alberta has eight distinct fire regimes (Andison 2019), which suggests a highly complex local fire history.

5.3.1 FIRE FREQUENCY

The frequency of disturbance can be captured in several different ways. At very broad scales, the long-term (average) *fire cycle* (LTFC) is the average number of years required to burn an area equivalent to the study area. Note this is not the number of years to burn the entire study area — just the equivalent number of hectares burned over time. For example, on a 100,000 ha study area, how many years (on average) does it take for the total area burned by all fires to add up to 100,000 ha? Thus, during any given fire cycle, some areas will burn more than once, and others not at all.

Based on an earlier version of the LTFC map generated by the fire regime workshop and subsequent solicitation process (Andison 2019), the overall average fire cycle for the study area is almost 73 years (derived from the data from Andison (2019) overlain with the Upper Peace study area). However, the same expert process determined that the LTFCs in the study area ranged from 30-140 years (Figure 4). On the Canfor FMA area alone, there are four different historical fire regimes, and the LTFCs range from 60-100 years.

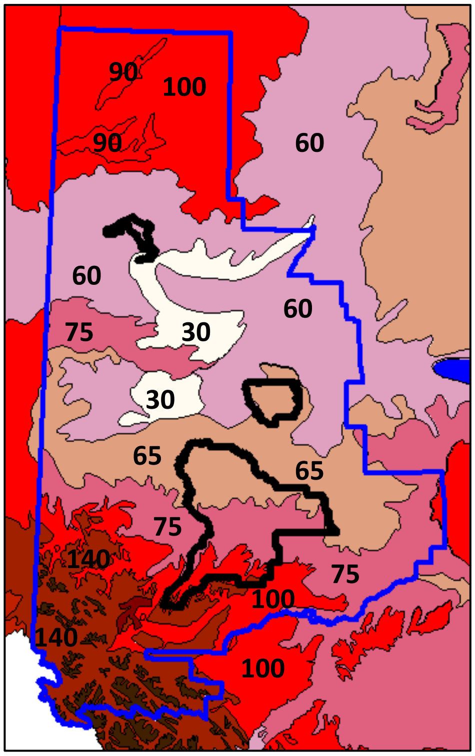


Figure 4. Study area map showing the long-term-fire-cycles (years).

Note that the final V4.0 LTFC map generated by the expert process described by Andison (2019) differs from Figure 4 in two ways. First, the Dry Mixedwood NSR area LTFC as 45 years in the final report instead of 60, and the Peace River Parkland NSR LTFC was 20 years instead of 30. These difference will mean some minor changes to the results, but not the conclusions, and only for the very small Peace area of the FMA (see ahead for details).

Using the average LTFC estimates in the model would be inappropriate. We know that long-term fire cycle estimates include highly variable fire activity from one decade to the next. Thus, what the model required was an equation representing decadal probabilities of fire activity, based on historical data. In this case, decadal variability in the LTFC was captured by an equation representing historical decadal levels of historical fire activity in the Alberta foothills using a back casting technique (*sensu* Vilen et al. 2012). Essentially, this technique peels back the most recent age-class, and assumes that the age of the forest underneath is proportional to the age-class distribution of the remainder of the landscape. Keep in mind that the LTFCs become the targets, so the only function of this model parameter is to approximate (historical levels of) variability around the LTFC.

In order to accurately reflect the range of LTFCs in the study area, the LTFC estimates were used as targets for the average level of disturbance in each of the eight major fire regime areas in the larger modelling area. This was accomplished by adjusting fire ignition probabilities in each fire regime zone, using the original, statistical ignition probabilities as the starting point based on LTFC alone. The focus of this part of the model calibration was getting the numbers in the *LTFC Achieved in Model* column to match those in the *LTFC Targets for Model* column. Due to the complexity of the study area, this calibration took more time and effort than anticipated. Study areas with multiple fire regime zones are far more challenging to calibrate for LTFCs because ignition probability alone cannot account for fire activity in that zone. Fires regularly ignite from one area and spread to another, particularly when they are so close to each other geographically. The only way to capture this dynamic is to model it in space and time – thus the calibration exercise.

After several weeks of this iterative calibration process, 100 landscape snapshots were taken, measured, and summarized to represent NRV (Table 4).

Table 4. Summary of the area modelled in this project, showing how ignition probability was manipulated to achieve the desired LTFC averages.

Natural Sub-Region	Total Land Area		Forest Area							
			Forest			Targets for Model			Achieved in Model	
	Area (ha)	% of Total	Area (ha)	% of Forest	% of Total	% of Ignitions	LTFC (years)	Area Burned per Decade (ha)	LTFC (years)	Area Burned per Decade (ha)
Alpine	159,456	2.1	10,584	0.2	6.6	0.04	300	353	213	496
Central Mixedwood	999,392	13.5	907,796	15.3	90.8	17.1	65	139,661	70	129,749
Dry Mixedwood	2,128,680	28.7	1,595,580	26.9	75.0	32.5	60	265,930	61	263,094
Lower Boreal Highlands	890,636	12.0	769,252	13.0	86.4	12.5	75	102,567	76	101,266
Lower Foothills	1,259,804	17.0	1,134,164	19.1	90.0	18.5	75	151,222	71	159,519
Montane	48,408	0.7	43,652	0.7	90.2	1.2	45	9,700	44	10,031
Peace River Parkland	307,248	4.1	63,744	1.1	20.7	2.6	30	21,248	33	19,567
Subalpine (low elevation)	662,920	8.9	522,544	8.8	78.8	4.7	135	38,707	127	41,065
Upper Boreal highlands	290,384	3.9	276,852	4.7	95.3	3.4	100	27,685	100	27,817
Upper Foothills	680,152	9.2	615,736	10.4	90.5	7.5	100	61,574	96	64,209
TOTAL	**7,427,080**	**100**	**5,939,904**	**100**		**100**		**818,647**		**816,814**

5.3.2 Fire Size

The output from the same LandWeb workshop referred to above concluded that there was not yet enough data or evidence to define or defend specific, unique fire size distributions for the majority of the western boreal (Andison 2019). This group agreed on some maximum fire size numbers for some landscapes relevant to this study area, including 1,000 ha in the Peace River Parkland, 3,000 ha in the Montane, and 5,000 ha in the Dry Mixedwood (Andison 2019).

The strategy for fire size in the model was to reflect both the agreement on general trends, and that of specific fire regime zones. First, an edited version (accounting for missing small fires and fire control) of the Alberta provincial historical fire database was used to generate the following cumulative equation for fire size, in hectares:

$$FireSize = 10^{\left(1.85\times(-\log(1-RN))^{.65}\right)} - 0.14$$

Where RN = a random number between 0 and 1. This equation allows for a very high probability of very small fires and very low chances of very large ones — consistent with the pattern of fire sizes observed across the majority of the Canadian boreal (Ward and Tithecott, 1993, Taylor *et al.* 1994). The consistency of this pattern across the boreal and among scientists suggests that the details are less important than the trend: Very large fires, although rare, are highly influential.

The second layer of filtering of fire sizes included limiting maximum fire sizes in the Peace River Parkland to a maximum of 1000 ha, 3000 ha in the Montane, and 5000 ha in the Dry Mixedwood, as per the fire regime workshop results.

5.3.3 Fire Severity

One of the strengths of LANDMINE is the ability of the model to create realistic fire pattern details, including fire shape and residual levels (Andison 1996). However, as with all other fire spread models today, LANDMINE does not capture partial severity in residuals. Research suggests that partial severity is quite common in natural wildfires accounting for an average of 10% of fire event area in the foothills, and over 25% in fires in the boreal plains (e.g., Andison 2004). LANDMINE was originally calibrated to leave an average of 10% as interior island remnants using the disturbance event definition (*sensu* Andison 2012).

5.4 Running Landmine

For each of the 100 landscape snapshots generated by the model, non-spatial summaries of area each of the seven vegetation X four seral stage classes were compiled for a) the entire Canfor area, b) the three different spatial areas of the FMA, c) woodland caribou herd areas, and d) natural subregions. Results were also summarized by the passive and active land bases (as defined by Canfor) for the combined Canfor areas.

Spatial summaries of each landscape snapshot were also captured in the form of old forest patch sizes. Pixel membership in a "patch" of old forest was defined only by adjacency. Thus, any "old" pixel (as per the age rules defined above) is grouped with any other old pixel that was one of its eight neighbours. Old forest patch sizes were calculated two ways; 1) all old forest pixels combined, and 2) old forest pixels from one of the seven forest types. If an old forest patch crossed the FMA boundary, only that portion of old forest patches within the FMA boundaries was counted. This created a negative bias of the actual size of old forest patch sizes regionally, but it allowed the output to be compared directly to management planning scenarios applicable to the study area boundaries.

6.0 RESULTS

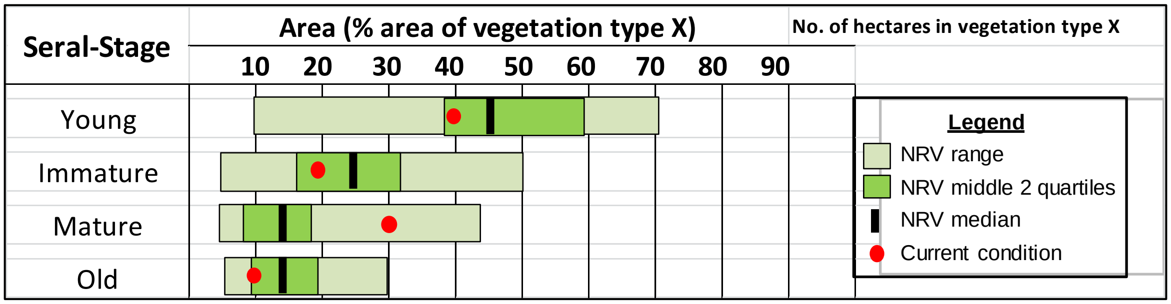
There are both non-spatial and spatial results.

6.1 NON-SPATIAL RESULTS

The non-spatial results from the NRV modelling results are presented as *quartiles*. As the name suggests, quartiles gather dozens, hundreds, or thousands of measurements into four evenly spaced groups, each one representing 25% of the total number of measurements. So, for example, if the observations of the metric of concern were 2, 3, 4, 5, 9, 11, 16, 23, 25, 26, 27, 30, 40, 50, 70, and 100, the first quartile would be 2–7, the second 7–24, the third 24-35, and the fourth 35–100.

Quartiles not only simplifies the output into a more visually intuitive form, but also allows viewing all seral stages of a given vegetation type at the same time. Reading the example shown in Figure 5 is as follow: First, each set of four quartiles represent all seral-stages of a specific vegetation type. Recall there are seven vegetation types, plus one that combines all forest into a single ‘forest’ class. The associated area (in hectares) of the vegetation type being shown is in the upper right hand corner of each graph in small font. So, if the total area of the veg type is 100,000 ha, and vegetation type X is pine leading, that means there are 100,000 ha of pine leading forest across the four seral-stages.

Figure 5. Example of how the non-spatial modelling results are presented.



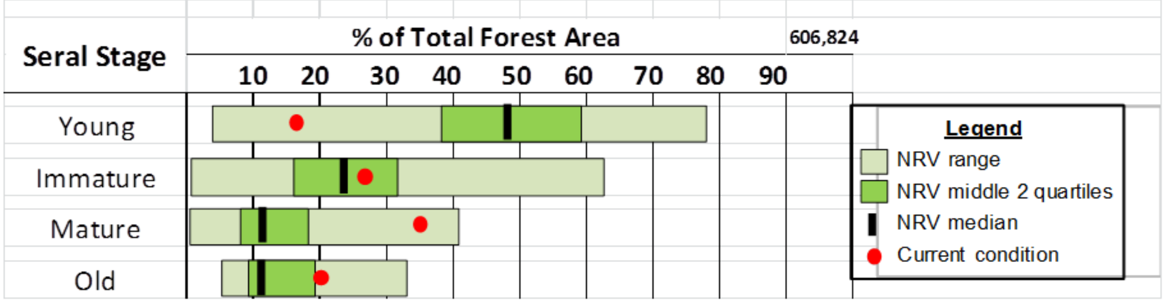
In terms of the details of the graph, the width of the green bands (regardless of shade) captures the 100 model runs representing NRV, and the red dot is the current condition. So, as per above in Figure 5, the red dot at 40 for *young* forest represents 40% of the 100,000 ha of (in this case) pine — or 40,000 ha. Similarly, the red dots represent 20% (or 20,000 ha) of immature, 30% (or 30,000 ha) of mature, and 10%) or 10,000 ha) of old forest, for a total of 100,000 ha of forest.

The NRV model run output are captured in *quartiles*, interpreted as follows. Each set of horizontal green bars represent the full range of the model output. For example, in Figure 5, no model runs created less than 10% and no more than 70% of young pine. The quartiles (bands within which exactly 25% of the data lie) are represented by the different shades of green (Figure 5). Quartiles are numbered in order from lowest to highest. So quartile 1 (Q1) is the light green band on the far left of each bar, quartile 2 (Q2) the dark green band immediately to its right, the third quartile (Q3) the second dark green band to the right of that, and the fourth quartile (Q4) the light green band to the far right (Figure 5). The dark black line between Q2 and Q3 is the *median,* which is the 50th percentile of the NRV data. Note that the medians in each figure will approximately (but not always exactly) add up to 100%.

6.1.1 CANFOR OVERALL

Overall, the Canfor areas are currently all within NRV in terms of seral-stage distribution. However, there are some notable trends that, if left unchecked, could cause this landscape to track outside of NRV in the near future. Most notably, the current amount of young forest (17%) is within NRV, but on the lower end of the first quartile (Figure 6). However, the graphic is misleading. The 17% of young forest represents just the 3rd percentile of NRV. In other words, less than 17% young forest was only generated by the model three percent of the time.

Figure 6. Historical Range of Total Forest Area on the Alberta Canfor FMA

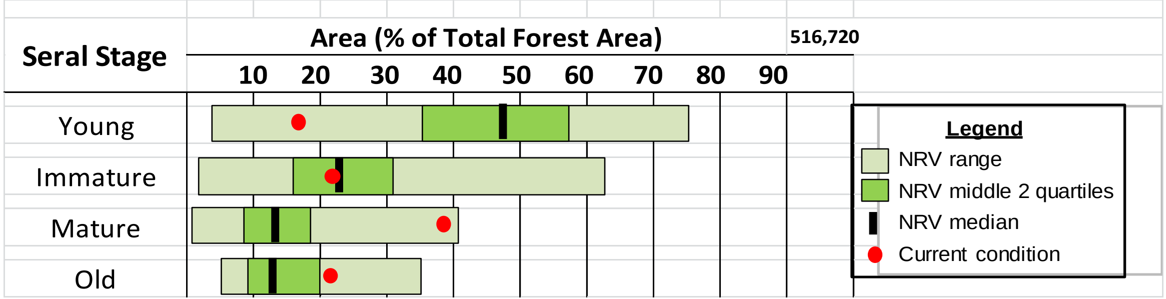


At the other end of the age-class spectrum, current old forest levels within the Canfor areas are on the high side of, although still well within NRV. The current level of old forest (20%) is higher than the NRV median (12%), and just beyond the 75th percentile (19%). However, of greater concern is that the 36% of forest currently in the mature seral-stage is also at the extreme end of NRV. In fact, only one of the 100 NRV model runs created mature forest levels in excess of the 36% observed today. In other words, statistically, the current amount of mature forest on the Canfor FMA area is already beyond NRV.

6.1.2 CANFOR FMA AREAS

The patterns noted for the largest part of the Canfor tenure area (the *Main*) are very similar to those of the overall results. This is not surprising given the large influence of these data in the summaries of the overall picture for the Canfor FMA area. As above, the current level of young forest (17%) is far below the NRV median (47%) and represents just the 5th percentile of NRV (Figure 7). In contrast, the current

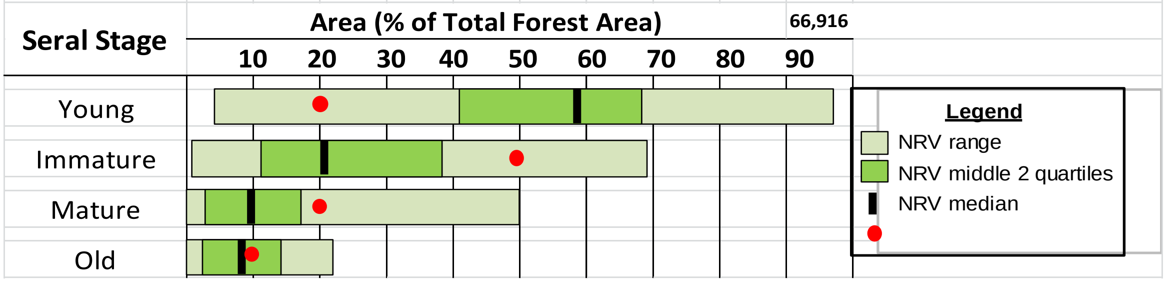
Figure 7. Historical Range of the Canfor FMA Main Area



level of 36% of mature forest was only exceeded once by the NRV modelling data.

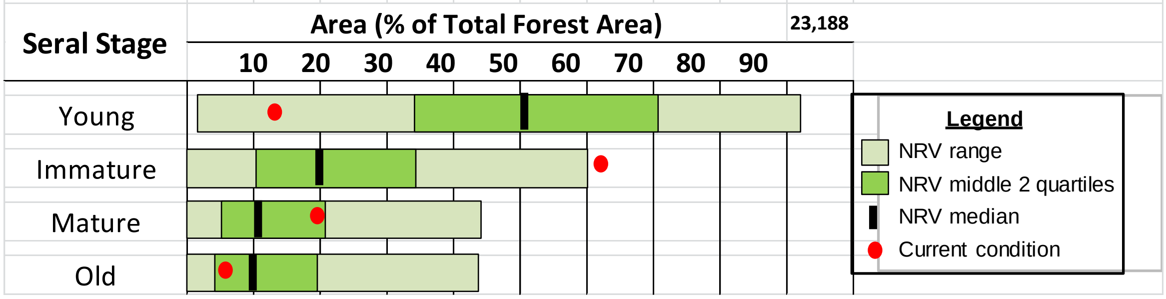
In the Puskwaskau Canfor area, the relationship between NRV and CRV is similar to that noted above, but less acute. Twenty percent of the Puskwaskau forest is young, compared to 59% for the median of NRV (Figure 8). However, only 11 of the 100 NRV model runs produced less than 20% young forest. Moreover, while both mature and old seral stages are on the high side of NRV, neither is within the upper 90th percentile extremes. It is also noteworthy that the current immature seral-stage represents 50% of the total forest area in the Puskwaskau area, which represents the 90th percentile of NRV (Figure 8).

Figure 8. Historical Range of the Canfor FMA Puskwaskau Area



The third, and smallest part of the Canfor FMA area in the Upper Peace region is the *Peace*. Relative to NRV, this area currently has very low levels of young forest, average levels of old forest, high levels of mature forest, and very high levels of immature forest relative to NRV (Figure 9). However, this is an extremely small area on which to be considering managing for landscape-scale patterns independent of the surrounding landscape and is thus included only for information.

Figure 9. Historical Range of the Canfor FMA Peace Area



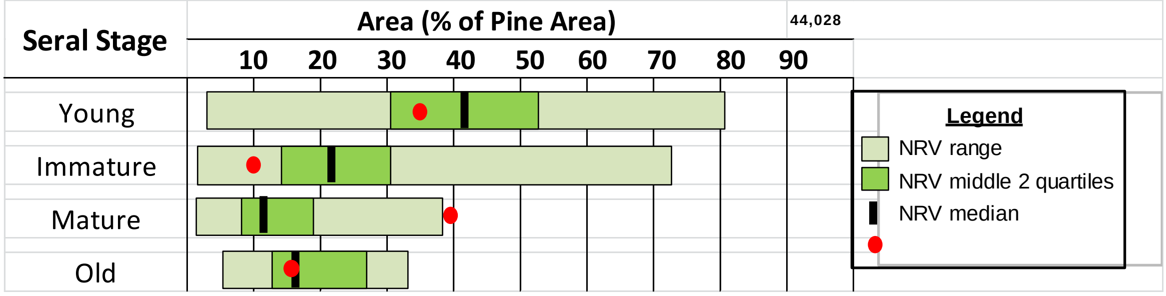
6.1.3 MAJOR VEGETATION TYPES

The following results break down the Alberta Canfor FMA area by leading forest types, as defined by Canfor (see section 5.2.1).

Current levels of pine-dominated forest levels are not within NRV for every seral stage, but the pattern of deviation is an unusual one. The current 40% of mature forest is beyond the 38% maximum generated by the NRV modelling snapshots, and the level of immature forest is well below the median

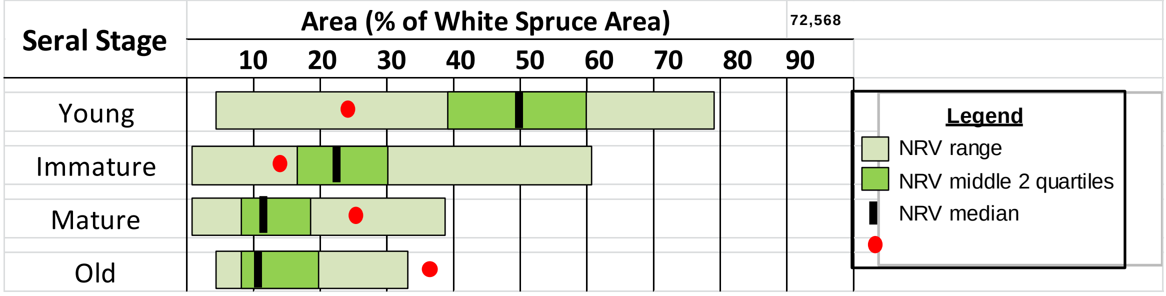
NRV level (Figure 10). However, both young and old forest levels are within the middle two quartiles of NRV, and the current level of old pine forest is very close to the NRV median (Figure 10).

Figure 10. Historical Range of Pine Forest on the Alberta Canfor FMA Area



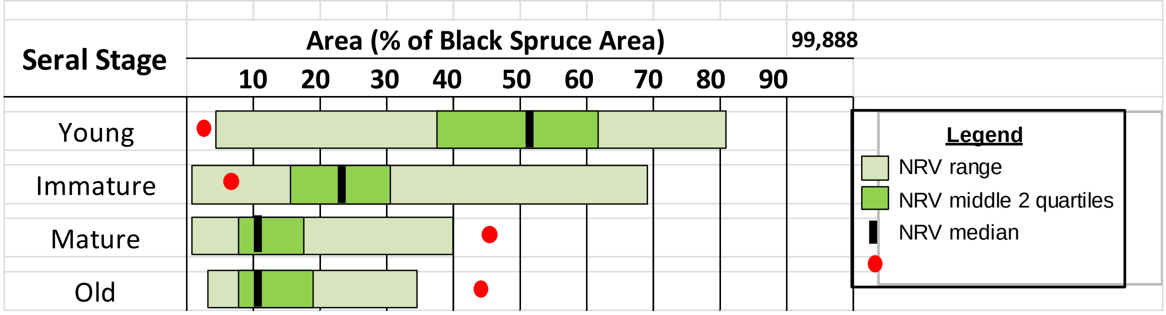
The current level of white spruce dominated forest on the Canfor FMA area has far more older forest than the NRV data suggests for the pre-industrial benchmark. For example, the 38% of old white spruce forest is well beyond the 33% NRV maximum observed, and the current level of 26% mature forest was only observed 5% of the time with the NRV landscape snapshots (Figure 11). However, keep in mind that the succession module was turned off in LANDMINE. In mixedwood forests, young stands often start out as hardwood and become mixedwood or even white spruce as they age. Thus the NRV results are likely under-estimating the historical levels of old white spruce, which means the deviation between the current and historical old forest levels noted decreases.

Figure 11. Historical Range of White Spruce Forest on the Alberta Canfor FMA Area



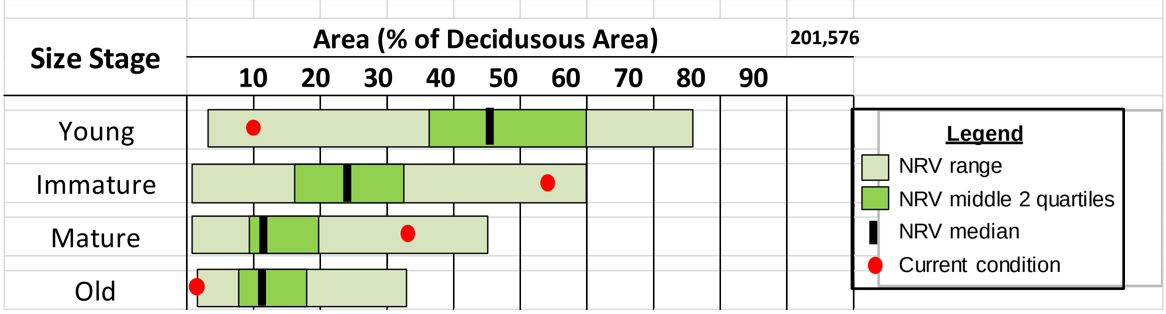
The current level of black spruce dominated forests on the Canfor FMA area is well beyond NRV in the same manner as previously noted for other species, but the degree of difference is unprecedented. The current 3% amount of young black spruce forest is not only significantly lower than the 52% median, but also below the 4% minimum observed from the NRV simulation exercise (Figure 12). The current level of immature black spruce forest is within, but near the lower end of NRV. The amount of mature Sb is currently well beyond the maximum level observed by the NRV modelling exercise (46% vs 40%), and the current level of old Sb forest (44%) is also beyond the 40% observed from the NRV snapshots.

Figure 12. Historical Range of Black Spruce Forest on Alberta Canfor FMA Area



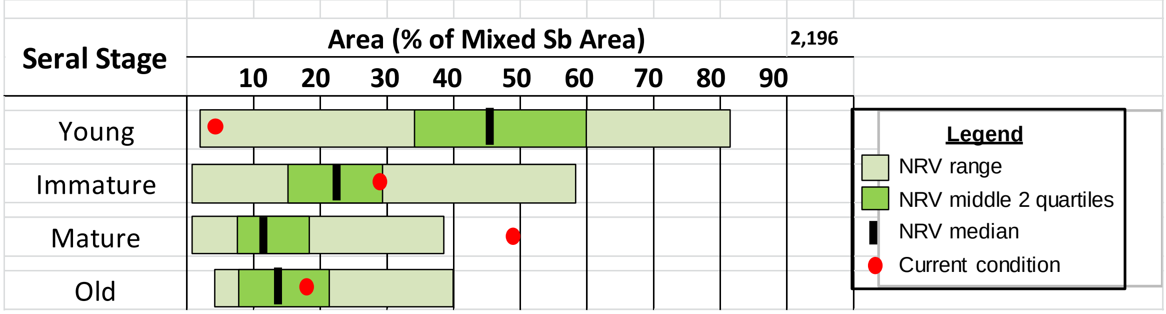
The pattern of the seral stages of deciduous forest on the study area is unique, and suggests that old hardwood-dominated areas are currently significantly under-represented on the landscape today. For example, the current level of old deciduous is 2%, which makes it statistically impossible given that a lower level was only observed once in the NRV data (Figure 13). Yet, the current levels of immature and mature deciduous forest are on the high end of NRV, and the young seral-stage is almost beyond the lower threshold of NRV (Figure 13). However, recall that the succession module in LANDMINE was not turned on for these runs. Thus, the fact that there is very little old deciduous today is likely due to the fact that older stands dominated by hardwood tend to become mixedwood or white spruce as they age. The model thus over-represents the historical levels of old deciduous forest, so the low current level is not likely a legitimate concern. However, the massive current level of mature deciduous forest is a significant and likely a true deviation from the NRV data (Figure 13).

Figure 13. Historic Range of Deciduous Forest on the Alberta Canfor FMA Area



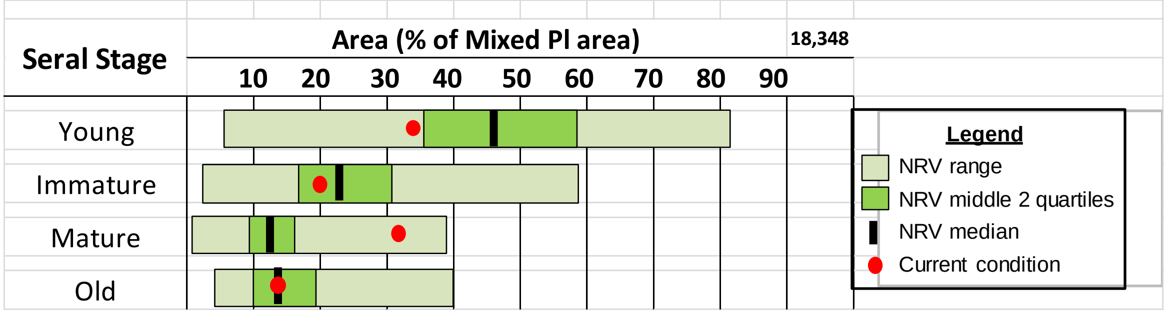
The current levels of mixedwood-black spruce forest on the study area are similar to those noted previously; currently very low young forest, and extremely high levels of mature forest relative to NRV (Figure 14). However, this forest type represents a very small component of the greater study area. Applying landscape-scale NRV results to very small parts of the landscape is inadvisable.

Figure 14. Historical Range of Mixedwood-Black Spruce Forest on Alberta Canfor FMA Area



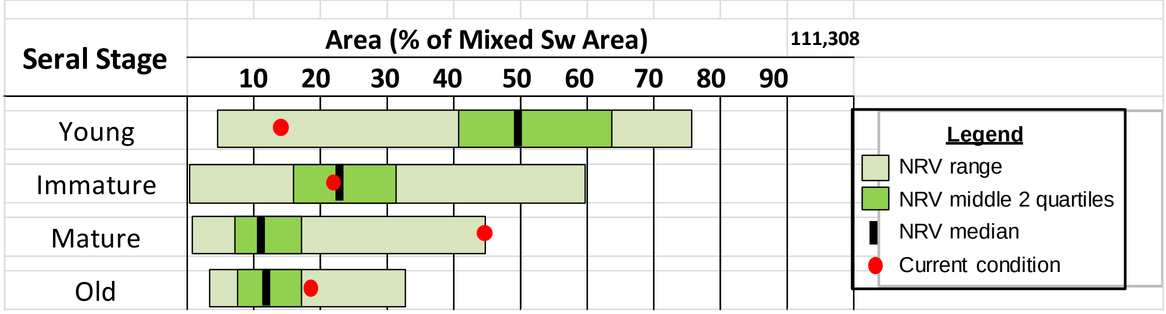
The comparison of current conditions to NRV for the mixedwood-pine suggest that current conditions are mostly well within NRV, with just one exception; the current level of mature forest (32%) lies on the extreme high end of NRV — and was only twice exceeded from the NRV landscape snapshots (Figure 15). However, note that this forest type includes just over 18,000 ha, which is not large enough to consider applying coarse-scale NRV patterns.

Figure 15. Historical Range of Mixedwood-Pine Forest on the Alberta Canfor FMA Area



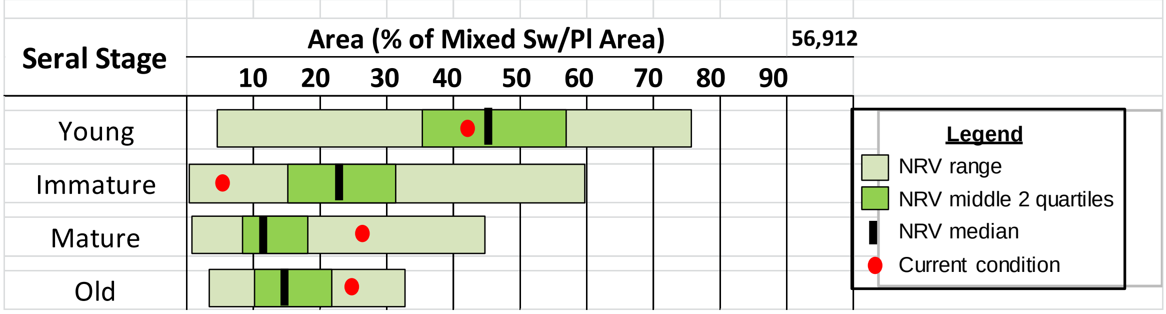
The patterns of the mixedwood-Sw areas of the study area are similar to those described above several times now. Current conditions of young forest (14%) is only the 4th percentile of NRV (i.e., only three NRV model runs produced less than 14% young forest) and the current level of 45% of mature is at the very high end of NRV (Figure 16). Immature forest levels are currently very close to the median NRV, and current old forest levels are just beyond the third quartile of NRV (Figure 16).

Figure 16. Historical Range of Mixedwood-White Spruce Forest on the Alberta Canfor FMA Area



Lastly, mixedwood Sw/Pl show seral stage patterns similar to that for pine and mixedwood-pine. Current levels of young forest (42%) are very close to the median (45%). The current level of old forest is just above the 75% percentile, but the amount of mature mixed Sw/Pl forest is at the 95th percentile, almost beyond NRV (Figure 17).

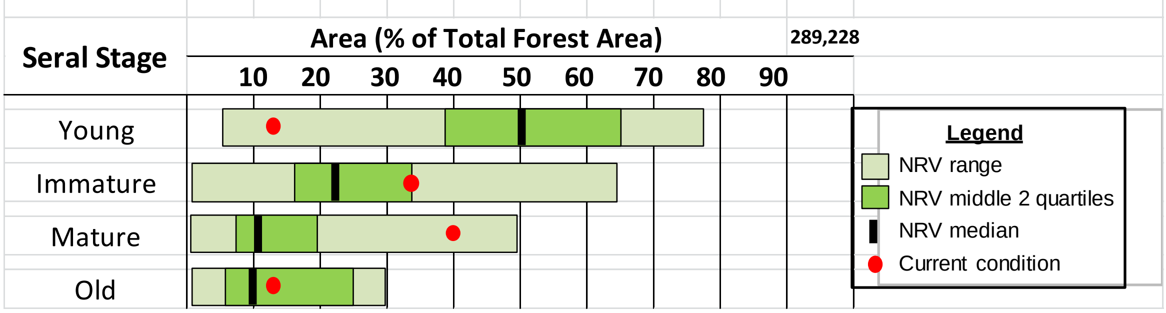
Figure 17. Historical Range of Mixedwood-White Spruce / Pine Forest on the Alberta Canfor FMA Area



6.1.4 ECOLOGICAL NATURAL SUBREGIONS

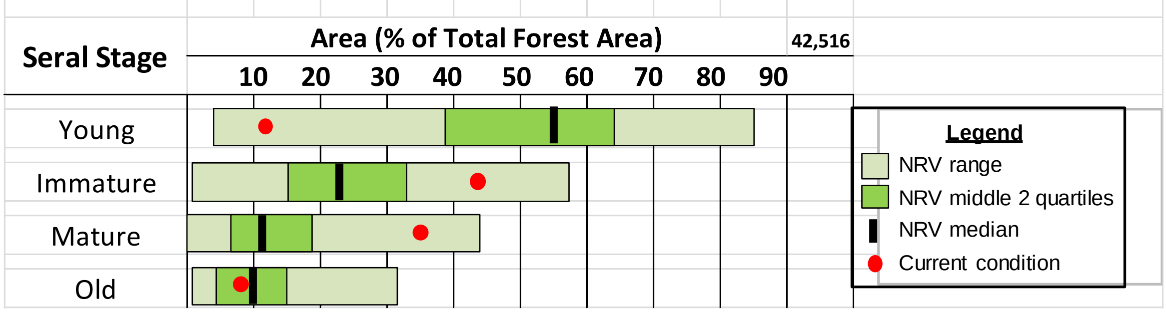
The patterns within each natural subregion (NSR) are similar to those noted in the previous section, although there are some notable differences. The central mixedwood (CM) area has a historical LTFC of 65 years (Table 4), which creates a significant amount of young forest. Young NRV in the CM averaged 50% with a median of 51% (Figure 18). The current level of young forest in the CM area is 13%, which represents just the 3rd percentile. The current old forest level (13%) is close to the median NRV level (10%). However, the current mature forest level (40%) is well beyond the 11% median for NRV, and statistically beyond NRV (i.e. it was only exceeded once in the NRV model runs). The 34% currently in immature forest in the CM is exactly the 75th percentile (Figure 18).

Figure 18. Historical Range of the Central Mixedwood Natural Subregion on the Alberta Canfor FMA Area



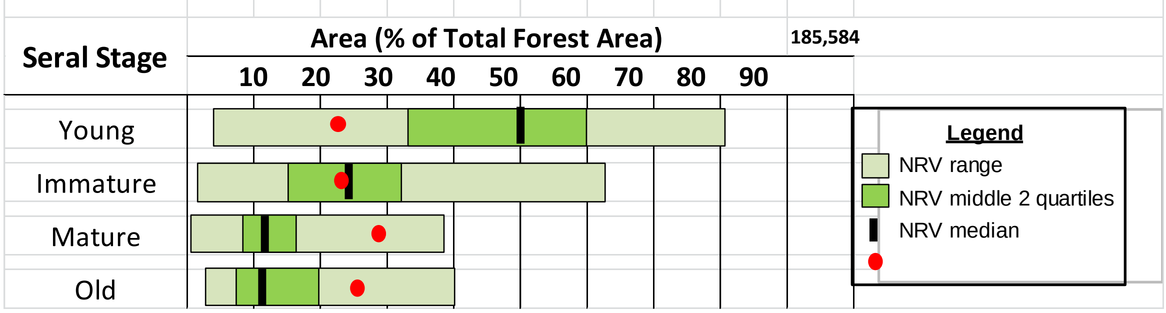
The average amount of young forest in the dry mixedwood (DM) NSR was 52%, with a median of 55% (Figure 19). The current level of 12% is almost beyond the lower end of NRV, representing just the 4th percentile. The current levels of both immature and mature are close to, but not yet beyond the upper end of NRV. The current level of old forest in the dry mixedwood (8%) is well within NRV — just below the median (10%).

Figure 19. Historical Range of the Dry Mixedwood Natural Subregion on the Alberta Canfor FMA Area



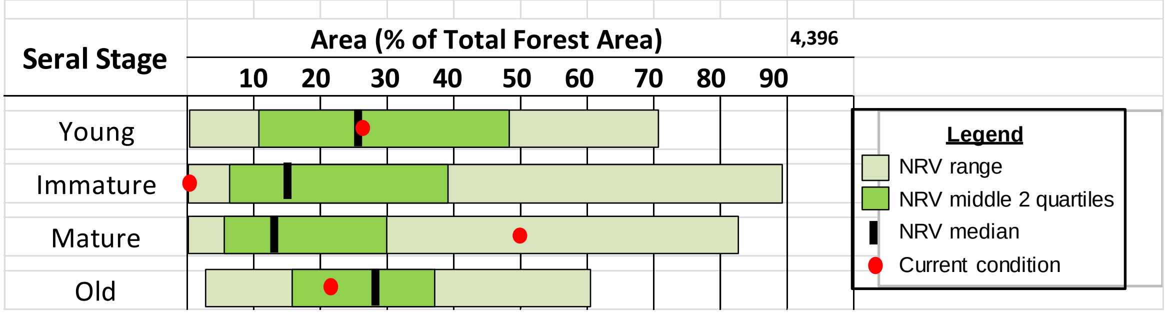
The lower foothills (LF) part of the Canfor FMA area also currently has low levels of young forest, and high levels of both mature and old relative to NRV (Figure 20). However, the pattern deviates from the other NSRs discussed so far. More specifically, T = the 23% currently in young forest is well within the first quartile. Of some concern is that the current level of old forest (26%) is already at the 85th percentile of NRV, which coupled with the current level of mature forest in the 97th percentile of NRV suggests some future challenges (Figure 20).

Figure 20. Historical Range of the Lower Foothills Natural Subregion on the Alberta Canfor FMA Area



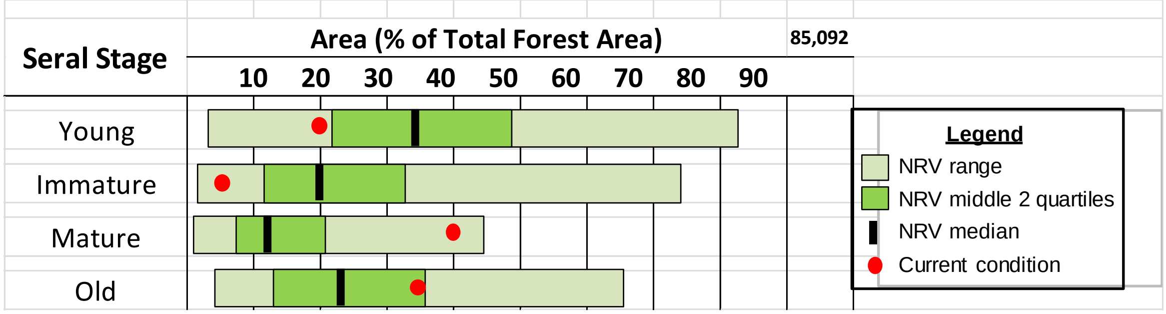
The current seral stage condition of the subalpine area of the Canfor FMA area shows some, but not all patterns similar to those discussed above. For example, the current level of young forest (27%) almost lands on the NRV median (26%), and the current mature forest level is close to the upper end of NRV (Figure 21). However, this is very small area (4400 ha), and thus the value of considering or managing this portion of the study area in isolation is questionable.

Figure 21. Historical Range of the Subalpine Natural Subregion of the Alberta Canfor FMA Area



Young upper foothills (UF) forest on the Canfor FMA area currently sits at 20%, which is well below the NRV median of 34%, but close to the 25th percentile of NRV (Figure 22). Of greater concern is that the current level of immature forest is only 5%, which is very close to the lower end of NRV. In contrast, current levels of mature forest (40%) are in the 98th percentile of NRV, and the 34% of old forest is at the 73rd percentile. However, when the mature and old seral stages are combined, the current levels are at the 90th percentile of NRV.

Figure 22. Historical Range of the Upper Foothills Natural Subregion of the Alberta Canfor FMA Area

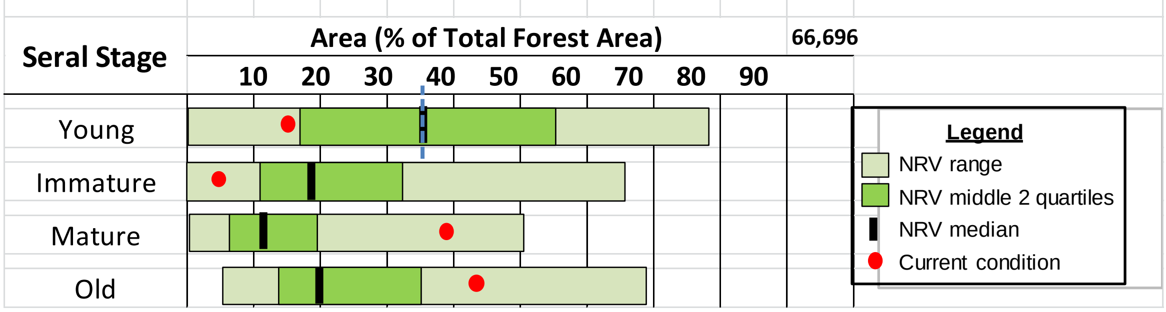


6.1.5 WOODLAND CARIBOU RANGES

The only caribou range that intersects with the Canfor FMA areas in the Upper Peace to any meaningful degree is the Little Smoky (LS). The Canfor FMA area includes less than 1000 ha of the A La Peche range, which is virtually meaningless in the context of landscape-scale metrics.

In any case, the median NRV for young forest for the LS range was 36% and the average 35% (Figure 23), which means that exactly half of the runs created young forest levels in excess of the guidelines. The current level of young forest (14%) is well within NRV, and also well below the 35% threshold. The current level of immature forest (5%) is very close to the lower end of NRV. As a result, the amount of older forest in the Little Smoky area is very high. Both the mature and old forest levels are in the 4th quartile of NRV, and the total amount of forest greater than 80 years of age is at the 99th percentile of the data (Figure 23), which is statistically beyond NRV.

Figure 23. Historical Range of the Little Smoky Caribou Range on the Alberta Canfor FMA Area. **(The vertical blue line in the Young seral-stage represents the upper threshold for acceptable caribou habitat from Environment Canada)**



6.1.6 PASSIVE VS. ACTIVE LAND BASE

Most forest management agencies in Canada must identify those parts of the forested area within an FMA area that is eligible to be harvested, versus those that are not. In Alberta, these are known as the *active* and *passive* land bases respectively. For this study, we obtained the active-passive map directly from Canfor and used it to calculate NRV versus current condition (Figures 24 and 25).

Figure 24. Historical Range of the Active Land Base on the Alberta Canfor FMA Area

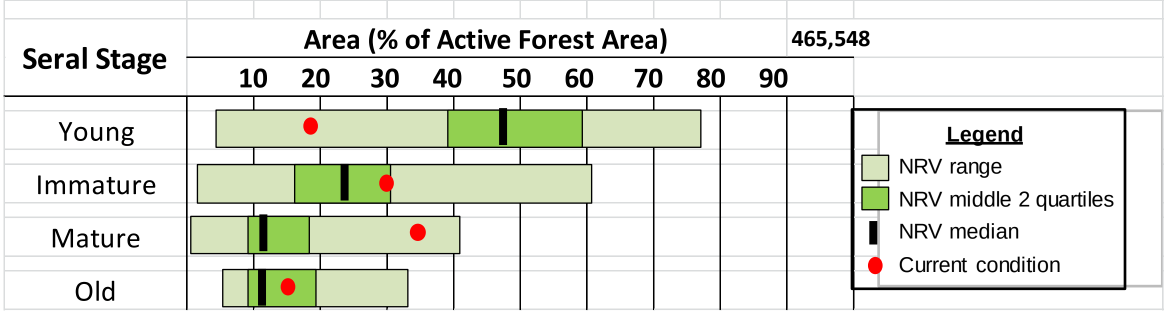
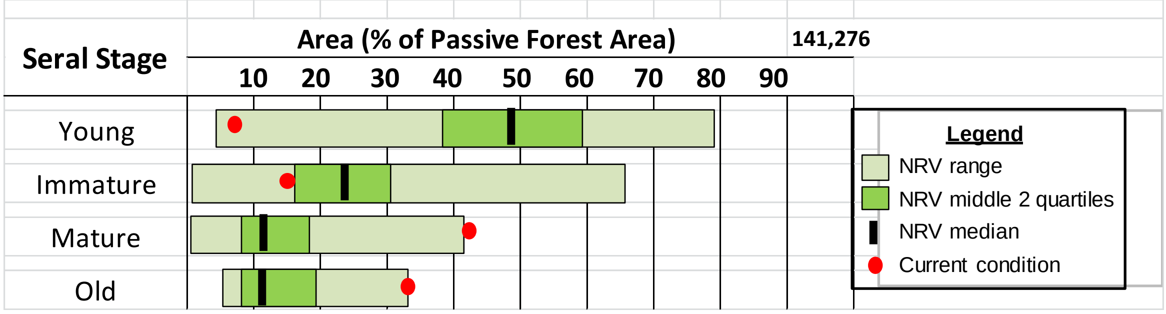


Figure 25. Historical Range of the Passive Land Base of the Alberta Canfor FMA Area



Note that the NRV patterns for the two forest types are similar but not identical. This is interesting because neither one represents a single fuel-type, but rather a combination of several different ones – representing a number of different unique fire regimes.

The difference in current conditions between the two areas is far more significant. Active young forest on the Canfor FMA area currently sits at 19% (Figure 24), compared to just 8% for the passive land base (Figure 25). Similarly, immature young forest in the active land base currently accounts for 30%, double the 15% of immature forest in the passive areas. However, the 35% of mature forest in the active land base is significantly lower than the 43% currently in the passive land base, and the 16% of forest currently in the old seral-stage in the active land base is more than twice the amount of old passive forest (Figures 24 and 25). The fact that the deviations between the two types of forest are so large for both the young and immature seral-stages suggests that disturbance levels have been consistently lower in the passive forest areas for several decades.

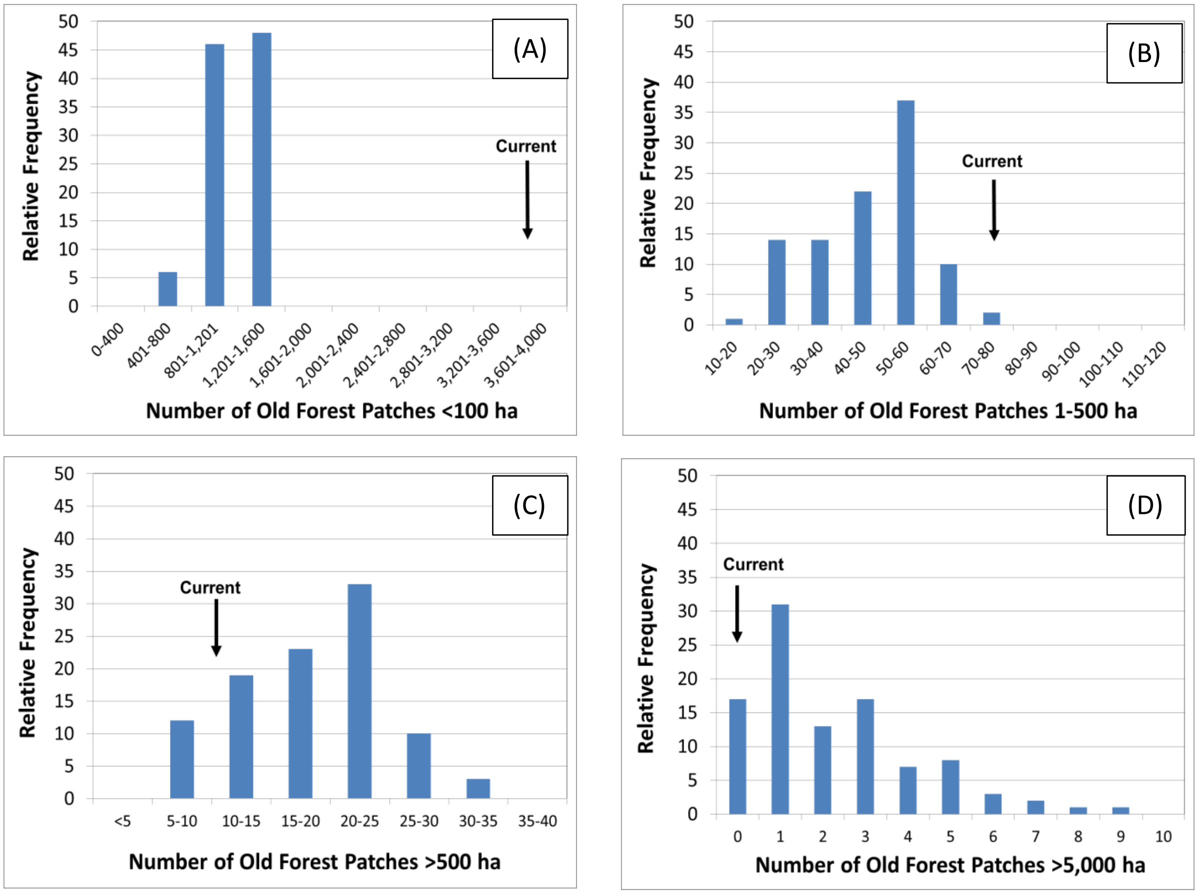
6.2 SPATIAL RESULTS

As a reminder, as per Canfor's requirements, the results for four patch sizes of old forest are presented here: <100 ha, 100–500 ha, >500 ha, and >5,000 ha. Moreover, a "patch" in this case captures only that portion of NRV or current condition that lies within the boundaries of the Canfor FMA area defined by any and all available linear feature data available at the time. In other words, the only standards for calculating current condition were the availability of data, and with no filters on feature origin, width, or date. Large forest patches that extend beyond the boundaries of the Canfor FMA area were captured by the model, but not reported. Results are reported here for the total Canfor area, and the three distinct management areas.

6.2.1 CANFOR FMA AREAS COMBINED

The number of small (i.e., <100 ha) old forest patches on the Canfor FMA area ranged between 668 and 1576 historically, which is well below the 3678 observed today (Figure 26A). The 76 old forest patches currently observed between 1 and 500 ha is at the very high end (i.e., the 99th percentile) of NRV (Figure 26B). Old forest patches larger than 500 ha range from 6–34 historically, compared to the 11 currently observed (Figure 26C). And finally, the NRV of old forest patches >5000 ha ranges from 0–9, compared to zero (0) currently observed (Figure 26D).

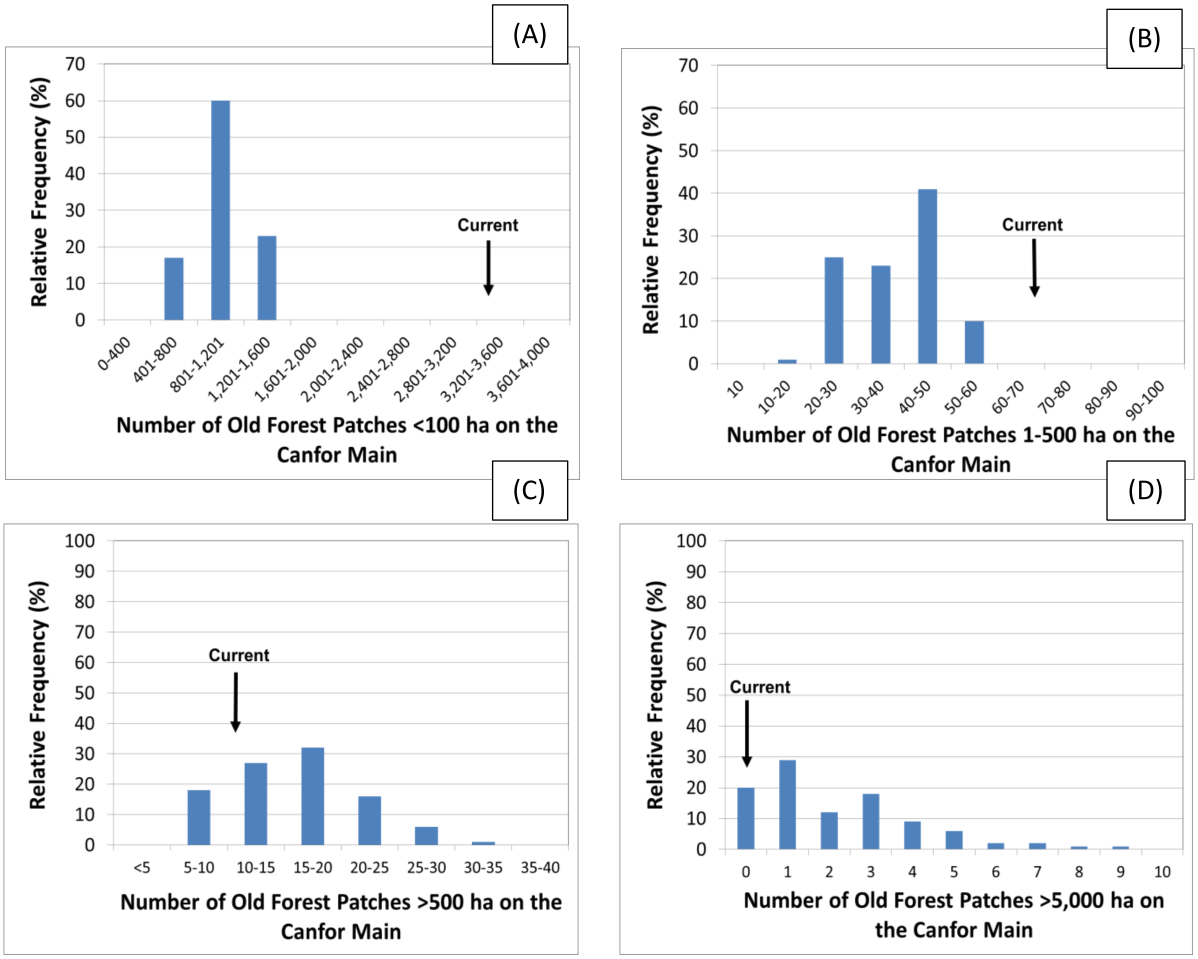
Figure 26. NRV (blue bars) and current condition (black arrow) of old forest patch sizes on the Alberta Canfor FMA area. Upper left (A) is all old forest patches <100 ha. Upper right (B) is all old forest patches 1–500 ha. Lower left (C) is all old forest patches >500 ha. Lower right (D) is all old forest patches >5000 ha.



6.2.2 THE MAIN MANAGEMENT AREA

At over 516,000 ha, the Main management area is by far the largest of the three spatially separate management areas of Canfor FMA area in the Upper Peace. Not surprisingly, the spatial results are similar to those noted above for all three Canfor FMA areas combined. The number of small (i.e., <100 ha) old forest patches on the Main ranged between 647 and 1,362 historically, which is well below the 3273 observed today (Figure 27A). The 69 old forest patches currently observed between 1 and 500 ha is also beyond the maximum of 56 generated by the NRV modelling (Figure 27B). Old forest patches larger than 500 ha range from 6–31 historically, compared to the 11 currently observed (Figure 27C). And finally, the NRV of old forest patches >5000 ha ranges from 0–9, compared to zero (0) currently observed (Figure 27D).

Figure 27. NRV (blue bars) and current condition (black arrow) of old forest patch sizes on the Alberta Canfor FMA Main management area. Upper left (A) is all old forest patches <100 ha. Upper right (B) is all old forest patches 1–500 ha. Lower left (C) is all old forest patches >500 ha. Lower right (D) is all old forest patches >5000 ha.

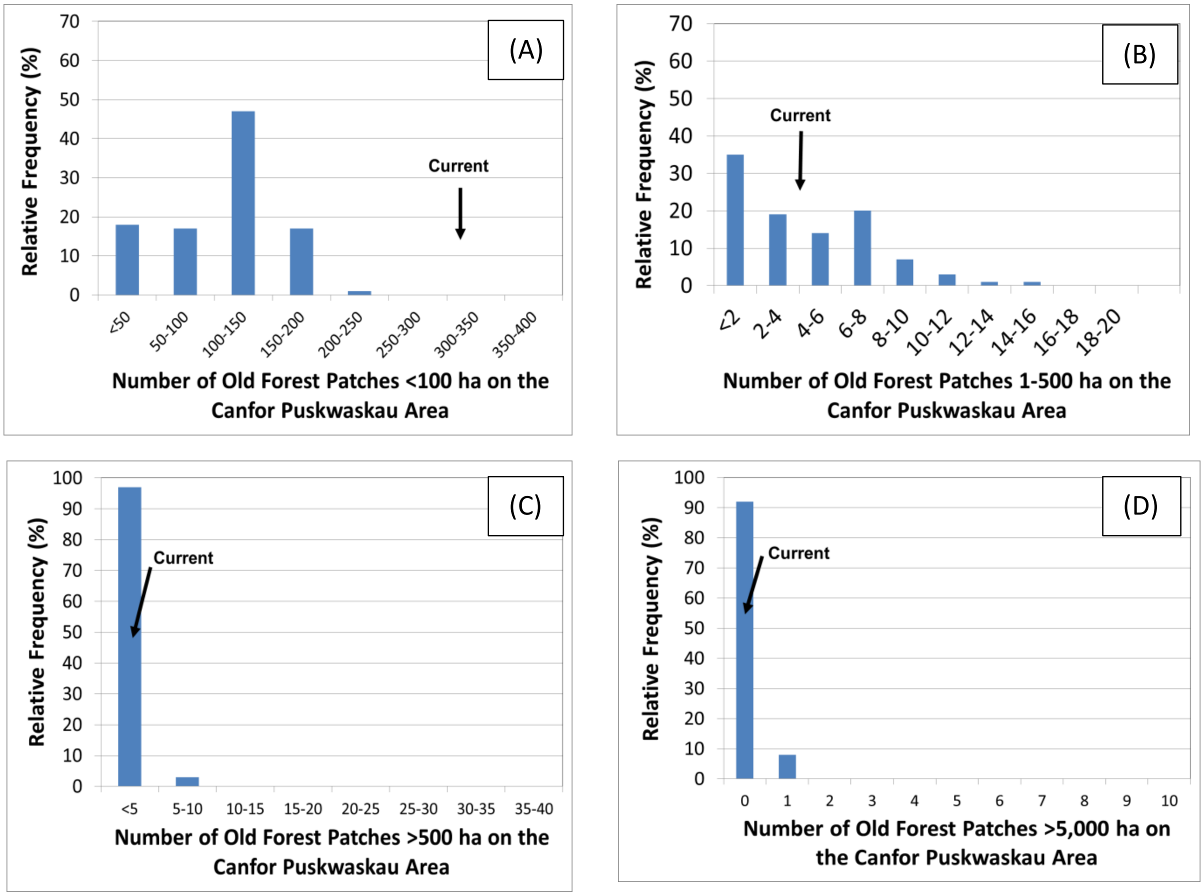


6.2.3 THE PUSKWASKAU MANAGEMENT AREA

Canfor's Puskwaskau management area is only 67,000 ha, which is a very small to be considering significant spatial pattern planning for large patches in isolation of the larger landscape pattern context. Nevertheless, for context, the comparison of NRV to current condition for the Puskwaskau area is as follows.

The number of small (i.e., <100 ha) old forest patches on the Puskwaskau ranged between 6 and 211 historically, which is below the 319 observed today (Figure 28A). The four old forest patches currently observed between 1 and 500 ha is well within that observed by NRV (Figure 28B). Old forest patches larger than 500 ha range from 0–7 historically, compared to zero currently recorded (Figure 28C). Historically zero old forest patches larger than 500 ha were observed 30% of the time, so this is not necessarily outside of NRV. Similarly, while there are currently no old forest patches >5000 ha in the Puskwaskau management area, the modelling exercise suggested that zero old forest patches >5,000 ha occurred 92% of the time, putting the current condition well within NRV (Figure 28D).

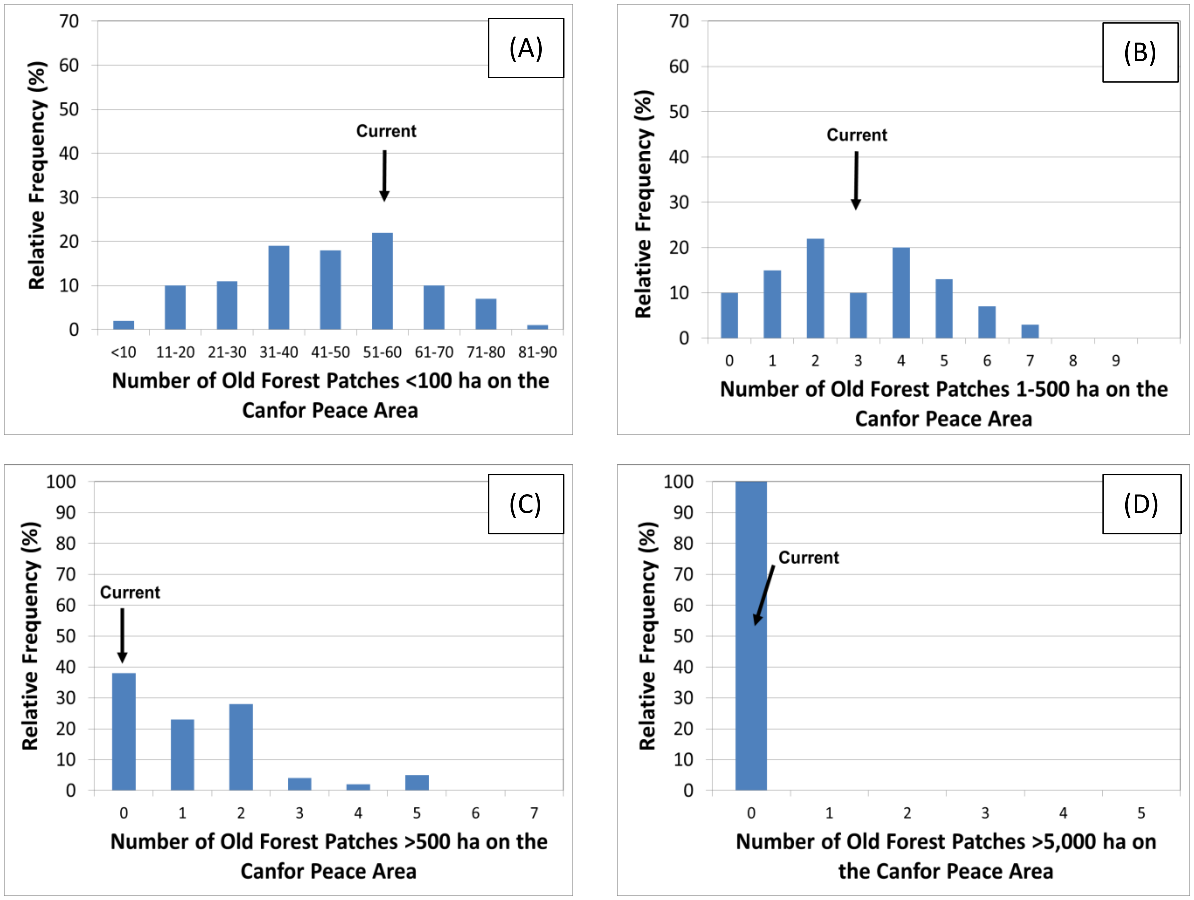
Figure 28. NRV (blue bars) and current condition (black arrow) of old forest patch sizes on the Alberta Canfor FMA Puskwaskau management area. Upper left (A) is all old forest patches <100 ha. Upper right (B) is all old forest patches 1-500 ha. Lower left (C) is all old forest patches >500 ha. Lower right (D) is all old forest patches >5000 ha.



6.2.4 THE PEACE MANAGEMENT AREA

Canfor's Peace management area is just over 23,000 ha, which is a far too small to be considering doing any significant spatial pattern planning for large patches in isolation of the larger landscape pattern context. Figure 29 is given as information only.

Figure 29. NRV (blue bars) and current condition (black arrow) of old forest patch sizes on the Alberta Canfor FMA Peace management area. Upper left (A) is all old forest patches <100 ha. Upper right (B) is all old forest patches 1–500 ha. Lower left (C) is all old forest patches >500 ha. Lower right (D) is all old forest patches >5000 ha.



7.0 DISCUSSION

7.1 OVERALL RESULTS

Spatial modelling exercises such as this generate such a large amount of output. This is an extraordinary opportunity to be able to explore pre-industrial landscape patterns in detail, but also a challenge to identify the most relevant signals. Towards the challenge, the results in this study tell a single, consistent story: ***disturbance rates have been low for several decades, which have created very low levels of young forest, and high level of mature and old forest today relative to historical conditions***. The overall current level of old forest is actually within NRV, and creates a modest buffer against the inevitable natural disturbance events such as wildfire and insect outbreaks. Thus — *considered in isolation* — current overall old forest levels are at or near the 3rd quartile, which is not a concern. However, old forest levels for some parts of the landscape are already beyond NRV (i.e., old passive forest). Of greater concern is the fact that the current level of mature forest is beyond or very close to the upper bound of NRV for the entire study area. Consider that, barring significant increases in disturbance levels, the majority of mature forest will shift to old forest in the next 10–20 years. In other words, this landscape is unbalanced relative to historical conditions. These findings are consistent with those found in previous NRV spatial modelling exercises in the western boreal including Sundre Forest Products, Hinton Wood Products, Alberta Newsprint Company, Weyerhaeuser Grande Prairie, Tolko, Alberta Pacific, and Mistik Management.

The degree to which the shift from mature to old forest from this point forward depends on a) how much disturbance will take place, and b) where and how. For the sake of argument, let us start with a business-as-usual scenario in which nothing changes as regards policies and practices and project forward another 20 years. Recall that the 17% of young forest (<40 years of age) represents the 3rd percentile of NRV. For context, the NRV median is almost three times higher at 48%. If we use the disturbance levels of the last 40 years as a benchmark for the future, we know that an average of (17%/40 years =) 0.425% of the landscape has been disturbed each year over at least the last 40. So, under this disturbance scenario, in another 20 years, that will convert (20 x 0.425 =) 8.5% of mature and old forest to the young seral stage. Even under this idealistic scenario (i.e., not including any harvesting restrictions in caribou zones), once the shift from young to immature, immature to mature, and mature to old are taken into account over the next 20 years, the amount of old + mature forest will be much further beyond NRV than it is now.

Admittedly, the above simplistic scenario is not very realistic. For example, climate change predictions suggest that it is likely that wildfires will become more common, and more severe in the future despite our best efforts to control them (Flannigan et al. 2000), which will a) increase the overall level of disturbance, and b) negate the assumption that disturbance will only occur in mature and old seral-stages. A simple non-spatial mathematical exercise confirms that even if future wildfire + harvesting levels on this landscape are triple that of the last 40 years, the amount of old + mature forest will still be beyond NRV in 20 years. However, under this scenario one must account for the likely catastrophic social and economic cost of those additional fires. So if anything, a more realistic future scenario for this landscape poses far greater challenges and risks than a simplistic one.

It is interesting to consider the spatial results and the non-spatial results together. Under natural conditions, as the amount of old forest increases, the probability of finding larger patches of old forest should increase. Based on that logic, one would expect the number of old forest patches today to be on the high end of NRV. However, despite the large amount of old forest, the current number of large old forest patches is very low relative to NRV.

There are several possible reasons for this discrepancy. One possibility is the nature of *all* anthropogenic disturbance patterns over time and space over the past several decades. We know that anthropogenic disturbances on this landscape take one of four main forms; 1) settlement (e.g., roads, towns, land conversion, and various rights of way), 2) forest harvesting, 3) activities from the energy sector (e.g., roads, seismic lines, well sites, and other infrastructure), and 4) other industry (e.g., borrow pits, surface mining). Research suggests that the impacts of the energy sector on landscape patterns far outweigh those of forestry in Alberta, despite the fact that the physical footprint of the energy sector is much smaller (Pickell et al. 2013). Moreover, historical provincial harvesting regulations mandated multi-pass “checkerboard” patterns for several decades, which tended to artificially spread out disturbance patterns — which would ultimately create less opportunity for large old forest patches (Pickell et al. 2015). However, in the end, the only way of understanding the impact of each of these vectors on old forest patch size is to conduct a more comprehensive spatial analysis than this study was intended to provide.

7.2 THE DETAILS

The specifics of how NRV compares to current condition for the Canfor landscape are highly informative. For example, the results between the active and passive forest types were unexpected in two ways. First, the degree to which the passive (i.e., unharvestable) part of the landscape is already beyond NRV was surprising. The amount of passive forest older than 80 years was well beyond NRV suggesting decades-long fire control policies and practices have been extremely successful. ***The only way to that the passive part of the landscape could shift back into NRV over the next 20 years is if the disturbance rate on the passive land base increased <u>at least eight-fold,</u> relative to that of the last several decades.*** Since these areas are currently not economically viable for the forest industry, this means either allowing more wildfires to burn under controlled conditions, more wildfires will burn under uncontrolled conditions, more prescribed fires, introducing alternative forest product streams for passive forest areas (e.g., pellets), or non-commercial mechanical disturbance. Otherwise, the gap between current and historical conditions will only continue to widen in this part of the landscape.

The second surprise was that even on the so-called *active* portion of the land base, old and mature forest levels are still very high and young forest levels very low. One of the long-held tenets of forest management in Canada is the concept of sustained yield, which proposes an annual harvest volume equivalent to the annual growth of the forest. The large amount of mature and older forest on the active land base could be due to 1) lower than planned for harvest levels, 2) harvesting restrictions based on fine-filter requirements (e.g., caribou) or 3) higher LTFC assumptions than used in this study. The low level of young active forest suggests that harvesting levels on this part of the land base has for several decades been much lower than the average disturbance levels that occurred historically.

The details of NRV and current condition for the single caribou range in the study area were also informative. The amount of “recovered” forest (>40 years of age) was 86%, which is well beyond the 65% minimum required by federal guidelines (Environment Canada 2012). However, it is important to understand that this only captures habitat from a non-spatial perspective, and does not include the impact of linear features and the associated buffering. Having said that, the pattern of NRV for this caribou range is informative. For example, the median NRV falls almost exactly on the 35% threshold. This suggests that about half of the time, the area of this range did not support woodland caribou over the last several thousand years — assuming the Environment Canada (2012) habitat model correctly captures caribou requirements.

The possible explanations for this inconsistency include a) caribou historically did not stay in ranges but rather moved across the landscape in response to wildfire activity, or b) the assumption that forested areas cannot support caribou until at least 40 years after any and all wildfires is in error.

7.3 POSSIBLE SOURCES OF ERROR IN THE MODEL

One of the most widely known quotes about modelling is from George Box (1979): "*all models are wrong, but some are useful*". What he meant by that is, a) models are only representations of reality, b) every model (should) has a very specific purpose, and c) precise models are not necessarily "better" than accurate ones (Hammah and Curran 2009). This leads nicely to the concept of parsimony: The best models should have the minimum number of parameters and assumptions necessary to address the objectives and explain the phenomenon, but no more (Haag and Kaupenjohann 2001). Thus, it would be inefficient to identify every possible source of modelling error in this study, as opposed to focusing on those that matter the most.

Recall that the purpose of this modelling exercise was to define some broad and simple landscape-scale pre-industrial pattern metrics. Thus, the question is not whether the model simulated fire pattern, probability of vegetative sprouting, or the inclusion/exclusion of specific fire behaviour patterns in the model are "right", but rather which factors, parameters, or assumptions are mostly likely to *significantly* alter the desired output. Thanks to the simplicity of the model — and its purpose — the possibilities are limited.

The most significant factor driving the area in different seral-stages is the frequency of disturbance. To illustrate, using a simple negative exponential mathematical model that is broadly associated with representing age-class distributions in the boreal forest (Johnson 1992), the average amount of forest older than 120 years with a 65 year long-term fire cycle (LTFC) is 16%, compared to 20% for a LTFC of 75 years, and 26% for a landscape with a LTFC of 90 years. The process for identifying pre-industrial LTFCs in the study area was through and extensive, including a) an informal review of historical local records, b) a literature review, c) a two-day expert workshop, and d) four iterations of a LTFC map from anonymous expert opinion over four years (see Andison 2019). It should be noted that this modelling was done prior to the completion of the final LTFC map produced from the iterative exercise. However, the LTFC numbers used for this project were not significantly different.

In the end, the LTFC maps clearly represent the *best available science*, given the breadth and depth of effort. Having said that, one of the advantages of a spatial modelling exercise is the ability to test input assumptions (including LTFCs) via a sensitivity analysis. Aptly named, a sensitivity analysis allows one to test the impact of model output on different input assumptions, which in this case would be the LTFC numbers.

Another possible source of significant error could be the under-representation of low and moderate severity fires in the model. As with every other landscape-scale model today, LANDMINE captures and represents severity in a simplistic, binary fashion; either a pixel burns, or it does not. However, evidence suggests that some percentage of historical fires left behind significant areas of partially burned forest (Andison 2004).

Although the inclusion of low to moderate severity fires in a spatial model is likely important, their influence on the output of this project is unclear. The first issue is the potential lack of documentation of such fires. Smaller, lower intensity fires could easily be missed by historical mapping methods. The result is that the historical LTFCs may actually be *higher* than empirical data suggest in order to capture lower intensity fires (e.g. Amoroso et al. 2011). A second, related issue is if or how we define a seral-stage. The boreal has for decades been considered to be a stand-replacing ecosystem (Johnson 1992) that can be represented spatially by the date of the last disturbance. The introduction of low to moderate severity fires challenges, and suggests expanding on, these simpler definitions to capture more complex forest age structures. In the end, there is no evidence to suggest how, or in which direction, the inclusion of low and moderate severity fires might impact the output from this study. Moreover, there currently exists no spatial model that accounts for partial mortality.

The last potential source of error in the model output is that the current condition estimates — both spatial and non-spatial. With regards to current condition for the non-spatial results (i.e., the red dots), the ages are taken from the most recent forest inventory. While AVI captures age data for every forest polygon, identifying the exact stand age is not a high priority for forest inventories. Comparisons suggest that accuracy is more of a concern than bias (Andison 1999a, 1999b). Moreover, inventory age estimates of older stands decreases in accuracy, and increases in bias (Andison 1999a, 1999b).

As regards the calculation of current condition for patch sizes, there are two challenges. The first challenge is tracking, classifying, and dating each disturbance feature. As with age data, AVI does not prioritize capturing details on all types of these data as part of its primary purpose. Fortunately, other agencies (e.g., Alberta Biodiversity Monitoring Institute) have more recently been making significant progress on a province wide database of disturbance features that could be used to re-calculate the current conditions for this project.

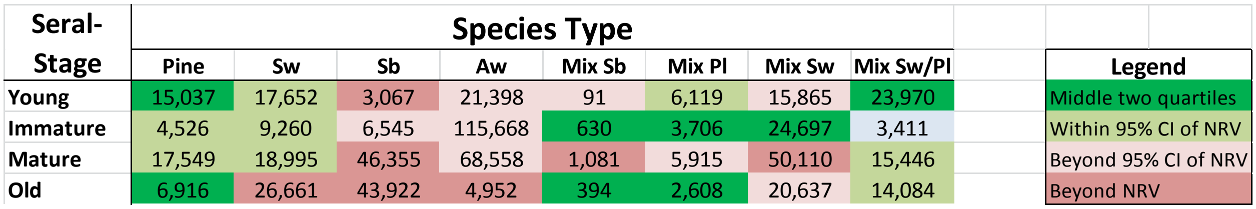
The second challenge of the current condition estimate for the patch sizes is more daunting; how does one integrate and compare the impacts of forest edges of different sources and vintages? For example, if/how do we different edges associated with highways to that from a bush road, to that from a large, new seismic line, to that of a small and/or very old seismic line? For this study, any and all disturbance features were used, but this could easily be augmented by a sensitivity analysis that creates 4–6 different “edge” scenarios, perhaps using the new ABMI data.

7.4 IMPLICATIONS

In theory, a landscape that has moved / is moving beyond NRV creates greater risks to the sustainable flow of goods and services, and is less resilient to the impacts of future perturbations (Christensen et al. 1996, Hunter 1996). One of the more obvious risks is the increased threat of natural disturbance. Towards that, the current level of forest >80 years of age is more than double that of the average NRV level, which means a higher than average amount of dense, continuous fuel that is more susceptible to wildfire, insect, and disease. We are already seeing some of the potential social, economic, and ecological costs of this fuel buildup in other parts of western Canada in the form of large wildfires that threaten communities and infrastructure, and the unprecedented eastward spread of the mountain pine beetle. As the large amount of mature forests shifts to old forest on this landscape, these risks will only increase. Note that this risk translates into a lower probability that existing woodland caribou ranges will survive intact over the short term.

Perhaps less obvious, but just as important is the risk associated with significant loss and/or shifts in ecological/habitat types. To demonstrate, Table 5 shows the current area in each of the four seral-stages for each of the eight major forest types – a combination often used to represent generic *ecotypes*. The four colour codes denote where each lies today within the associated NRV ranges; the middle two quartiles in dark green, the 95th percentile in all green, beyond the 95th confidence interval in light red, or beyond NRV in red (Table 5). Thus, Table 5 is a simple way of summarizing the differences between NRV and current condition for the entire study area both quantitatively and visually.

Table 5. Comparison of NRV to current condition for 32 ecotypes for the Canfor FMA area. The area in each cell represents the current number of hectares in each type, and the colour code represents how it relates to NRV from the model.



Seral-Stage	Species Type							
	Pine	Sw	Sb	Aw	Mix Sb	Mix Pl	Mix Sw	Mix Sw/Pl
Young	15,037	17,652	3,067	21,398	91	6,119	15,865	23,970
Immature	4,526	9,260	6,545	115,668	630	3,706	24,697	3,411
Mature	17,549	18,995	46,355	68,558	1,081	5,915	50,110	15,446
Old	6,916	26,661	43,922	4,952	394	2,608	20,637	14,084

Legend
Middle two quartiles
Within 95% CI of NRV
Beyond 95% CI of NRV
Beyond NRV

The visual patterns alone are telling. Of the 32 different ecotypes, only eight (or 25%) are within the middle two quartiles (dark green cells in Table 5), and another eight within the 95th percentile of NRV (light green cells). The other 50% of the cells are already statistically beyond, NRV (either beyond the 95% confidence interval, or beyond NRV). In terms of total area by ecotype, only 27% of the Canfor forest area is within the 95th CI of NRV, compared to 32% of the forest that is already beyond NRV, and another 41% that is on the verge of NRV.

From an ecological perspective, Table 5 represents a fundamental imbalance of landscape scale diversity. Biodiversity is widely recognized as being partitioned into two parts; 1) Richness (the absolute number of ecological elements), and 2) Evenness (the relative proportion of each element; DeJong 1975). In this case, the number of elements (i.e., richness) has not changed relative to NRV, but the current proportion (i.e., evenness) of each has, and in some cases dramatically so. At landscape scales, species and ecosystem functions have evolved over thousands of years, relying on a natural range of ecotype proportions over time and space. EBM theory suggests that pushing a landscape system beyond this natural range is likely to create some unexpected and very likely negative outcomes for the resident species and services (Pickett et al. 1992). For example, as discussed above, a large amount of older forest will create a higher risk to wildfire, insects, and disease. This demonstrates the risks of *over-represented* ecotypes on a landscape.

A less obvious, but perhaps equally important risk is *under-represented* ecotypes. For example, young black spruce stands averaged about 50,000 ha (or 12%) historically in the study area, compared to an unprecedented 3000 ha (or 0.5%) today, which is well below minimum NRV levels. Similarly, immature black spruce, young hardwood, young mixed Sb, mixed Sw, immature mixed Sb-Pl, and all young forest combined are all below, or very close to the lower end of NRV. The under-representation of one or more ecotypes across a large landscape should be cause for concern. For example, although not widely discussed, biological diversity peaks 1–5 years after wildfire, creating unique and critical habitat conditions, environmental conditions, and soil nutrient profiles necessary for the foundation and existence of a large number of boreal species (Coop et al. 2010, Yeager et al. 2005). Designing future landscapes that include levels of young forest below those experienced historically is likely to negatively impact the health, integrity, and resilience of the landscape ecosystem.

The likely implications of the lack of large old forest patches identified in this study are more straightforward. Similar to the logic from above for ecotype distribution, there are a range of species that favour forest edge and those that favour forest interior (Magura 2002). We also know that the amount of forest edge currently in the study area exceeds anything ever experienced historically — which is why there are very few large old forest patches relative to NRV. Unless the interior forest dependent species are able to adapt, it is reasonable to presume that the population levels of such species will decline. The decline of contiguous old forest patches in the boreal is neither a new pattern, nor a surprising one (i.e., Pickell et al 2016).

What is less well understood are the specifics of a) what constitutes an edge, and b) what defines a patch (and for whom or what)? As discussed above, the measurement of current condition used in this study was a simple GIS exercise based on all existing available spatial layers, including forest inventory, roads, water features, and seismic lines. The calculation did not differentiate among edges generated from highways bush roads or large new seismic lines, or that from an old narrow seismic line. An otherwise contiguous old forest patch size assessment in this study was likely biased by treating all forms of edge creation as equal. It is not difficult to imagine different species responding differently to each edge forms.

7.4 BOTH TIME AND SPACE MATTER

It is important to emphasize that the results from this project do not just tell the story of how the current landscape compares to historical ones at one point in time and space, but also the direction of travel for this landscape. Projecting the study area seral-stage patterns forward in time over several decades suggests that current policies and practices will only take this landscape further beyond NRV in the not too distant future. Existing requirements that limit harvesting in caribou zones will only magnify this trend. In other words, the most likely scenario is that in 20 years Table 5 will be mostly red. From an ecosystem-based management (EBM) perspective, this is not just an unbalanced landscape today, but one that is ultimately headed in the wrong direction in terms of resilience and sustainability in the absence of significant changes to policies and practices as regards how we manage all forms of disturbance activities. Lastly, the longer we avoid making changes to policies and practices, the more difficult, risky, and costly it will be to reverse this trend.

7.5 NEW QUESTIONS

The ultimate measure of a research project is the number and quality of new questions that it creates. This study generated no shortage of new questions:

1) **Do we fully understand the ecological (and associated social and economic) implications of under-represented ecotypes?** The most obvious knowledge gap here is the ecological (and by association economic and social) value of disturbance in non-forested areas, including wetlands, but more generally the so-called 'passive" landscape. Although well recognized that wetlands provide significant ecological benefits to the boreal ecosystem, we have very little understanding of the details of those dynamics over time and space, particularly as it relates to wildfire. Given that wetlands account for up to 40% of the study area, our collective ignorance of these details contrasts sharply with our lack of research investment in this area.

2) **What are the potential (new, increased, decreased) risks of staying the course with respect to policies and practices?** It is not difficult to project what this landscape will look like 20 years in in the future in terms of disturbance planning under business as usual policies and practices – relative to NRV. The forest will continue to age, the risk of natural disturbance threat will increase, and the negative social, ecological, and economic implications will only increase. What we are less clear on is if or how future landscapes might look like under alternative policy/practice assumptions. Spatial modelling technology now allows us to explore such alternatives, and it would be a worthy extension of this project.

3) **What is the potential for forest management and fire management to work together?** One could argue that the key to the future for boreal sustainability is a collaborative between forest and fire management. In the short term, any steps towards collaboration between these two otherwise independent government agencies can only be a positive contribution as regards addressing many of the regulatory / management challenges discussed in this study. This could / should include pilot studies, high-level policy discussions, and demonstrations.

4) **What is the ecological impact of defining "patches" in different ways?** How a patch is defined, and by what linear or polygon features, will no doubt be different for different species and values. More specifically, for this study, it would be useful to (re)calculate current condition of old forest patch size based on a range of assumptions. This simple GIS calculation is likely to reveal critical information in terms of sources and degree of anthropogenic impact. In the bigger picture, initiating technical standards through collaborative discussions with all stakeholders would be wise.

5) **(How) Will climate change modify the nature of any of the challenges noted above?** Recall that all of the results and discussions captured here were based on historical fire activity, which is intimately linked to historical climate patterns. The fact that future climate is likely to be different does not invalidate these results. Rather, understanding past climate conditions and fire activity is a necessity in preparation for the consequences of climate change on fire regimes — regardless of whether the past represents the future. In the bigger picture, there exists no alternative defensible landscape-scale benchmark for sustainability than (even adapted) pre-industrial conditions.

8.0 RECOMMENDATIONS

The following are the opinions of the author, and do not necessarily reflect the opinions of either fRI Research or the Healthy Landscapes Activity Team.

1) **Use the results from this study as an early warning system for ecosystem health concerns.** Landscape patterns have momentum that can take several years or decades to shift beyond their historical range. The responses of the resident species to such deviations may take even longer to be observable. As a result, the implications of policies and practices based on fine-filter values are — almost always — only obvious to us many years or decades later. In other words, value-based management systems force us to continually be responding to known, existing threats. Shifting to a more pro-active management paradigm lies at the heart of an NRV strategy. Notwithstanding climate change implications, in the absence of perfect understanding of how ecosystems function, an NRV strategy assumes that the historical range of patterns is a relatively safe range within which to manage that minimizes the degradation of ecosystem function and resilience while providing for a sustainable flow of goods and services. In other words, an NRV strategy is the ultimate manifestation of the precautionary principle. For example, when we first notice landscapes deviating from pre-industrial (NRV) patterns, that is a critical red flag — and one that is observable far ahead of the associated fine-filter red flags. We can be more proactive by paying attention to coarse-filter red flags. This project has identified several such critical NRV red flags, some of which already have observable fine-filter red flags (e.g., lack of very large old forest patches), but others than do not (e.g., scarcity of young black spruce forest type).

2) **Change the channel on the role / importance of disturbance**. For too long, disturbance has been associated with mostly negative social, economic, and ecological consequences. From an ecological perspective the boreal is now, and always will be, a disturbance-dependent ecosystem. This means one of the ultimate measures of a healthy ecosystem (and thus sustainability, and thus social and economic values as well) is the *quality* of disturbance activities, not the *existence* of them. Within and beyond Canada this message is becoming more common, but all forest land management agencies should be highlighting the necessary and positive role of disturbance — *of the appropriate quality*.

3) **Move towards co-management**. The challenges of adopting an NRV strategy through the information in this report are far from trivial, and are beyond that which any single agency (private, government, Indigenous Peoples, forestry, fire, etc.) can or should attempt to manage on their own. Assuming all parties agree that the results of this project are concerning (as per the red flags in point #1), this creates a foundation for working together across both jurisdictional boundaries and agency-specific objectives.

4) **Support proactive research**. Natural resource research priorities tend to shift over time, largely in response to the degree to which species or values get attention — in a negative sense. We should, and now have the ability to get ahead of that curve by understanding and anticipating funding future challenges as per the argument in point #1. The five questions posed in the previous Section (7.5) are an excellent starting point.

5) **Share, listen, and be humble**. This project generated a large amount of new and valuable information. The results can and should be a part of the next generation of planning. However, the results also challenge what we believe about old forest, resilience, sustainability, and even value-based management approaches. Thus, the results, and their potential implications (including these recommendations!), should also be part of any future stakeholder dialogue.

6) **Accept and present the results in this report as the best available evidence.** The output from this project represents a rigorous, innovative, and well-documented process from a multi-disciplinary team over several years in terms of model design, model assumptions, and spatial data. In other words, the results represent the best available science. There will always be arguments for further / better evidence, and no doubt the results from this project will be superseded in 5–10 years. However, this is the nature of how knowledge grows, and should never be used as an excuse to avoid making policy and practice decisions today.

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