


SYNTHESIS REPORT

Pre-Industrial Fire Regimes of the Western Boreal Forest of Canada

Synthesis Report

fRI Research Healthy Landscapes Program

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Informing Land & Resource Management

Disclaimer

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Executive Summary

The need for a better understanding of pre-industrial disturbance patterns over several centuries and tens of millions of hectares is shared by mangers, regulators, policy-makers, and researchers. Such knowledge is critical baseline information for so-called Natural Range of Variation (or NRV) management strategies as a requirement for (in some cases both) provincial policy and international certification. For researchers, having a natural, pre-industrial baseline of disturbance dynamics is invaluable for studying the time-space dynamics of anything from coarse filter landscape patterns (e.g., old forest levels), to species habitat dynamics, to climate change, to carbon budgets. For modellers, such information can be used as either input or as output validation. Unfortunately, the breadth and depth of existing published research studies, and the availability of pre-industrial wildfire datasets, are both insufficient to create a summary of pre-industrial fire regime attributes for more than a handful of relatively small areas in western Canada.

Towards addressing this gap, the goal of this project was to ***develop a first approximation summary of the pre-industrial (NRV) fire regime attributes of the western boreal forest of Canada based on the best available knowledge.*** The 125 million ha study area represents the western Canadian boreal forest, bordered by the Rocky Mountains to the west, (mostly) the 62nd parallel to the north, the Manitoba Lakes area to the east, and the US border and/or the grassland interface to the south.

This report captures, describes, and summarizes four distinct, but related elements that combine to deliver on this goal. Note that each element is designed to build on the previous one(s):

1) Local historical deep-dive identifying all types and sources of informal fire evidence in the Peace area of Alberta.
2) Fire regime literature review of the study area to provide a common baseline of existing direct knowledge of historical fire regimes in the study area.
3) A two-day workshop designed to elicit knowledge and advice from a national panel of fire regime experts, including a) the most reasonable zonation system for pre-industrial fire regimes, and b) defining fire regime parameters for each zone.
4) A series of follow-up consultations with the same group of fire regime experts to help further refine the workshop output.

The primary deliverable of this project was a map and GIS shapefile of western boreal Canada defining pre-industrial long-term-fire-cycles (LTFC) by zone. The zonation used for the map was based on a mixture of national and provincial/territorial ecozone definitions. The long-term-fire-cycle (LTFC) map was populated based on a combination of available direct and indirect evidence and expert opinion. The final version of the LTFC map in this report is a result of that process, including fully documenting any disagreements. In terms of specifics, LTFCs estimates for the continental part of the study area range between 45-130 years, and for the cordillera area, 30-250 years.

Disagreement with the LTFC map occurred on two different levels among a large and diverse group of national fire experts. More than 85% of the experts agreed with the final LTFC numbers to within plus or minus 5-20 years, depending on the location. These numbers were also consistent with most of the pre-industrial evidence from the literature review, and the majority of several validation and plausibility tests. A second level of disagreement from a minority of experts suggested that pre-industrial LTFC numbers were between 2-3 times longer than those in the final LTFC map for most of the study area.

The output from this project exceeded expectations in both breadth and depth, and included:

1) A first approximation of a pre-industrial fire regime zonation system for western boreal Canada based on a combination of the national ecozone system and the provincial/territorial ecozone systems from both Alberta and NWT.
2) A first approximation of a LTFC map based on the fire regime zones identified above. The process was comprehensive and inclusive and clearly meets the requirement of *best available knowledge*.
3) Knowledge gap analyses of pre-industrial fire regime attributes. This report describes where, to what degree, and in what way fire regime knowledge gaps exists in the western boreal. This information can be used to prioritize future research as well as to assign risk ratings (of the LTFC map numbers being wrong).
4) A demonstration of how different types of "knowledge" are defined and valued. The use of topic-based (fire regime) experts to help create some of the project output represented a new scientific method for the HLP, and proved both effective and informative.
5) The value and role of evidence beyond pure, published literature. There is clearly an enormous amount of legitimate sources of "evidence" beyond published papers that we should be acknowledging and including in our understanding of ecosystem dynamics. This is not to suggest that all sources of knowledge are equal, but rather they are all worthy of consideration.

The value of the project output is similarly broad. For managers and regulators, the pre-industrial zonation map and the LTFC numbers are new science-based tools than can be directly integrated into existing systems and frameworks. For non-fire researchers the LTFC map represents a new spatial stratum for sampling and testing. For fire researchers, the map represents not just a straw dog starting point (for adding in the details of new attributes such as fire size and severity), but a source of multiple hypotheses (of zonation and LTFCs) that can be continually upgraded as new knowledge becomes available, the details of which can be directed by the gap analyses details in this report. For all natural resource researchers, the project offers some alternative methodological tools as it relates to the use of expert opinion and multiple lines of evidence. For modellers, the LTFC map could be used as either input, or validation data with which to compare model output. And for all stakeholders and partners, this project is an excellent example of how we can and should better understand and deal with imperfect knowledge.

1.0 INTRODUCTION

Reconstructing historical disturbance regime attributes across the Canadian boreal forest has been one of the research priorities for forest industry, regulators, and certification agencies over the last 20 years. The impetus for this interest in disturbance dynamics is in large part due the shift towards using knowledge of historical disturbance regimes as guides for forest management. The logic of a so-called natural pattern approach is that while all boreal ecosystems are highly dynamic, they all have natural ranges and thresholds that are familiar to all resident species (Christensen et al. 1996). By keeping the patterns of managed ecosystems as close as possible to those experienced historically, we are more likely to maintain the historical levels of goods and services (Pickett et al. 1992). Moreover, because disturbance is both a) the principle agent of change for ecosystems, and b) our main tool for managing forested ecosystems (via forest harvesting, fire control, etc.) it is otherwise logical to use so-called *natural range of variation* (NRV) benchmarks to help guide for our own disturbance activities (Hunter 1996).

In the western boreal forest of Canada the primary disturbance agent is wildfire (Johnson 1992). Although highly variable over time and space, since the last ice-age, fire has occurred on all parts of the western boreal on average every 30-250 years. No other (insect, disease, geologic, or weather-related) disturbance vector comes close to having this level of influence on the boreal landscapes of today.

Beginning in the early 1990's, various versions of natural pattern indicators/guidelines/directives based on wildfire patterns were developed by individual forest management companies and provincial governments (e.g., OMNR 2001). The disturbance patterns of greatest interest included 1) seral-stage levels (with a focus on old forest), 2) disturbance event sizes, and 3) disturbance event residual levels. Although incomplete, these three indicators represent the most important elements of a *disturbance regime*; 1) ***how often*** (which drives seral-stage levels), 2) ***how big*** (which determines patch sizes), and 3) ***how severe*** (which determines fine-scale heterogeneity) (Hunter 1993, Angelstam 2009).

Regardless of the implementation mechanism (e.g., indicators, guidelines, policy, etc.), one of the underlying assumptions of a natural pattern approach is that NRV should be based on the *best available knowledge*. This is an important new – and more humble and realistic - standard. It suggests that developing or applying an NRV approach need not require perfect knowledge, but rather the best available at the time (Grumbine 1994). This is relevant because despite the huge investment in studying historical fire regimes across the boreal over the last 20 years, there are areas with little or no relevant data or direct knowledge. This places the focus of an NRV strategy on the defendability of the method(s) and interpretations used to define the associated management, regulatory, and policy choices. In other words, one way to evaluate an NRV strategy is the ability to answer this question: *Is the strategy based on the best available knowledge, and was it developed in a clear, reasonable and defensible manner?*

Towards addressing this, the goal of this project was to ***develop a first approximation summary of the pre-industrial (NRV) fire regime attributes of the western boreal forest of Canada based on the best available knowledge.***

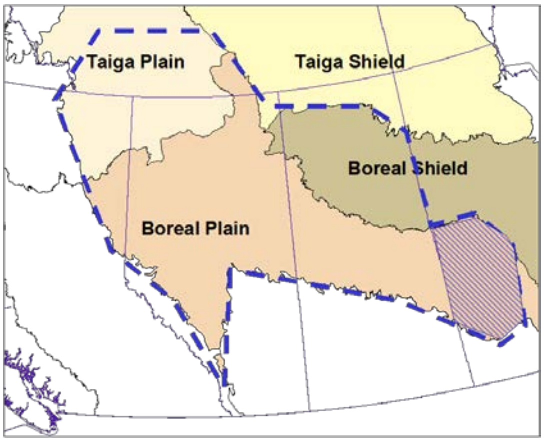
2.0 Background

2.1 The LandWeb Project

This project is part of a larger Healthy Landscapes Program (HLP) initiative called LandWeb (Landscape dynamics of Western boreal Canada). The objectives of the larger LandWeb project 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.***

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

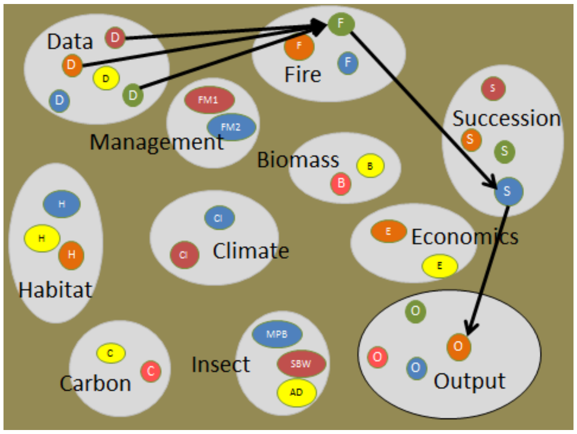


The ultimate goal of the LandWeb project is improve the quality and quantity of available landscape dynamic science, and develop tools for defining landscape-scale NRV benchmarks.

The study area for LandWeb was determined by the many industry, government, and non-government partners across parts of BC, Alberta, NWT, Saskatchewan, and Manitoba (Figure 1). The study area covers the western-most 125 million ha of the Canadian boreal forest and cordillera extending west from the Rocky Mountain foothills to the southwestern portion of the Manitoba forested area in the east, and from the southern boundary of the forest-grassland interface roughly to the 62nd parallel into the NWT – excluding the Taiga Shield. 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 transitional areas of the Prairie, Montane Cordillera, Taiga Shield and Boreal Cordillera (Wilken 1986) (Figure 1).

Building LandWeb is, and has been happening in parallel with this project. Its architecture and genesis are unique and worth summarizing briefly. Recall that the second of the two objectives of LandWeb is to create a *modelling framework* within which existing or new data, models, or output modules can be inserted, removed, or traded for others (Figure 2). 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 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 (Figure 2). Krueger et al (2012) refers to this approach as “ensemble modelling”.

Figure 2. A visual interpretation of SpaDES and LandWeb. The small coloured circles are various modules organized by topic (in large circles). SpaDES is the brown background that facilitates these modules talking to each other. The black arrows represent a likely configuration of module elements for LandWeb.



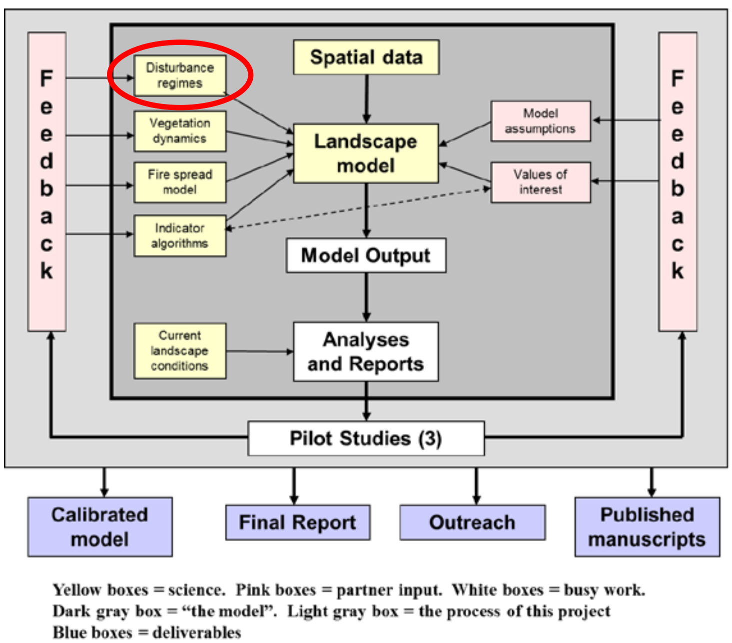
Within the SpaDES environment, it was recognized that multiple iterations of LandWeb would likely be developed over time, each one adding layers of sophistication and robustness. However, the vision for the first version of LandWeb was modest and simple. It included modules that would be relatively easy to develop and calibrate, including input data, output formats, and the assumptions and drivers behind both fire dynamics and forest succession (Figure 2). The presumed advantage of simplicity in this case was the speed with which such models could be built, adapted, linked, and run.

In support of the SpaDES modelling vision, the location, size, and attributes of pre-industrial fire regimes zones are either a) emergent properties of a mechanistic type of model, or b) input parameters for a statistical type of model (as per Figure 3). Thus having an independently derived fire regime map functions either as model input (in the case of a statistical model) or validation data for model output (in the case of a mechanistic model). Either way, such a map is one of the critical knowledge needs for the LandWeb project.

2.2 What is "Natural"?

The gold standard for defining historical, natural fire regime parameters would include no human influence. However, notwithstanding the argument that humans are a part of nature (*sensu* Nesbit et al. 2008), there is evidence that humans have been influencing otherwise "natural" fire regimes for centuries in many parts of the western boreal. Unfortunately, that influence varies by location and is difficult to verify or quantify with empirical data (Bowman et al. 2011).

Figure 3. Possible LandWeb Project Elements.



For this project, *pre-industrial* serves as the historical benchmark, with *industrial* including any significant manipulations of either a) the patterns of the ecosystem directly (e.g., harvesting, land conversion, surface mining), or b) natural ecosystem processes (e.g. controlling wildfires). This avoids, but still acknowledges the relevance of the pre-industrial influence of humans, but still captures the influence of industrial activities on (mostly) the southern parts of the western boreal (Pickell et al. 2016).

Unfortunately, this definition discounts a large amount of the research and data available on western boreal fire regimes. In many areas of the boreal - particularly those of greatest interest to managers, regulators, and certification agencies – the last several decades are associated with forest harvesting, fire control, land conversion, urbanization, activities by the energy sector, and other anthropogenic land-use changes (e.g., roads, railways, power lines, pipelines, etc.). Each of these *post-industrial* activities influences various attributes of fire regimes in unknown and sometimes conflicting ways. For example, fire control creates higher levels of older forest associated with higher flammability levels, while linear features often create artificial edges for some species. The problem is that using fire regime attributes as management benchmarks as part of an NRV strategy assumes that both the patterns and processes are "natural" – and thus not influenced by significant levels of human activities associated with industrialization. If there is any doubt about the impact of fire control or other industrial activities, any hope of understanding the relationship(s) between fire regime attributes and climate, weather, fuel-types, and topography breaks down, as does the value of these data as historical benchmarks. In other words, when we include post-industrial evidence, we lose the link between pattern and process, which effectively voids the intended value of an NRV strategy. Thus, for this project, the primary filter - for all sources of evidence - is whether it is pre or post-industrial.

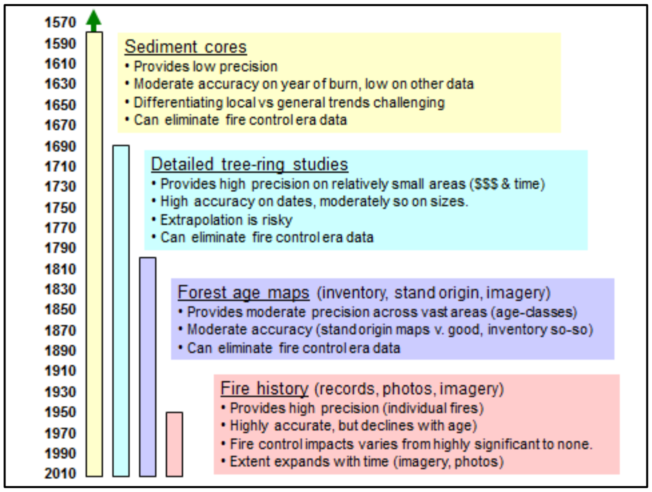
2.3 The Art and Science of Studying Fire History

The data and methods used for understanding historical fire regimes vary widely, each with strengths and weaknesses. In the end, there is no one best method of studying pre-industrial fire regimes. Meeting the requirement of *best available knowledge* is linked to a) the depth and quality of various forms of knowledge, and b) the degree to which multiple lines of evidence align with each other. In general, there are three types of evidence; 1) direct, 2), indirect, and 3) experiential.

2.3.1 Direct Evidence

Direct evidence is derived from empirical, direct sources of data and analytical activities associated with the primary question(s) which in this case is the understanding of pre-industrial fire history regime attributes. Direct evidence of fire history is generated using a range of techniques (Figure 4), most of which are associated with only one or two fire regime attributes. Direct evidence is the best in terms of quality, although it varies by method.

Figure 4. Overview of the sources of direct data types for studying fire history (The numbers on the left side are dates in years)



2.3.1.1 Provincial Fire Records

Most provincial and territorial governments map the outer boundary of individual wildfires (e.g. Strickland 1995). These data extend back as far as back as seven decades in the study area, although both the quality and quantity of these data decreases as one goes back further in time. For example, recording and/or mapping of fires less than 200 hectares in size did not begin in many provinces until the 1970's and even then with crude methods (e.g., visual-based mapping from small aircraft). This means that the chances of missing fires (because of small size, timing, or low severity) increases as one goes back in time. Thus, if anything, official fire records *underestimate* the historical level of fire activity. Moreover, provincial records tend to ignore mortality levels inside fires, and thus are of limited value for capturing low to moderate severity fires. Provincial fire data are most valuable for estimating fire cycles, and fire sizes and shapes over large areas.

The main limitation of fire records for the purposes of this project is that the timeframe of its availability (i.e., the last 40-70 years) which overlaps with industrialization. However, there are some notable and valuable exceptions. For example, the northern half of Saskatchewan, most of NWT, and some national parks have both 1) comprehensive fire records that go back up to 60 years and 2) include no significant industrial disturbance or fire control. These exceptions were some of the most valuable empirical data at our disposal for this project.

2.3.1.2 Other Fire Evidence and Records

Evidence of fire activity is often found in historical diaries, pictures, and maps. In Alberta, Rangers and surveyors travelled widely and took detailed notes and sometimes photos of wildfires, smoke, and freshly burned *brule* (Jackson et al. 2000). Local museums and municipal archives, and historical records and maps gathered by forest management companies are often good sources of these materials. Although usually general in nature, other evidence and records often prove valuable, particularly in areas where physical evidence of past fire activity is lacking. Efforts to gather these data from local sources have occurred in the study area on several occasions. As part of this project, the Peace area of Alberta was identified as one of the most challenging to understand in terms of historical fire regimes because it represents a critical grassland-forest interface settled many decades ago, and thus lacks physical evidence of fire.

2.3.1.3 Orthogonal Images of the Earth

Remotely sensed data from aerial photos and satellite imagery looking directly down (i.e., at right angles, or *orthogonal*) to the earth are valuable sources of fire history information. When properly interpreted, they track changes in vegetation type, height, and density, as well as patterns of fire. Orthogonal data sources fall into one of two groups: aerial photos, and satellite imagery.

Aerial Photos

Orthogonal aerial photos are commonly available across most of the study area, sometimes in multiple years, but they only extend back to *circa* 1950. Aerial photos tend to be flown in batches for a specific purpose, often focused on small to medium-sized geographic areas at photo scales ranging from 1:1,000 to 1:60,000. The exception to this is that the entire country of Canada was flown between 1947-1952 by the federal government at a scale of 1:15,840 (and some parts since then over large areas). These photo data are available as both negatives and positives (i.e., a photograph), both of which can be converted to digital format through hi-resolution scanning (e.g., Andison 2012). Over the last 20 years, digital, multi-scalar ortho-photo images (which are already corrected for curvature) have become common.

Aerial photos can be used in two different ways to help understand historical fire regimes. The first is to delineate fire boundaries across large to medium-sized areas. In this case, the quality of a fire boundary map largely depends on the age of photography relative to the year of the fire. Fire boundaries fade over time, but with training and practice, it is possible to differentiate not only older fire boundaries, but also areas of lower fire severity. A fire boundary map is useful on its own, but can also be used to guide field sampling to determine exact fire dates. When a fire boundary map is combined with the results from field sampling, it can create a time-since-fire (TSF) map (e.g. Rogeau 2003). TSFs are commonly used to calculate landscape-scale fire cycles (i.e., the average number of years it takes to burn the equivalent number of hectares in a given study area) and/or local fire return intervals (i.e., the average number of years between fires in a given, specific location) for medium-sized landscapes. Fire boundary map can also be used to direct more intensive field sampling to those areas with higher vegetation complexity (e.g., Naficy 2017). The limitation of TSFs is that it extends back only to the last fire, providing no information on the fire(s) that preceded the most recent one. The study area has several local TSF maps. Maximizing the value of this technique requires trained experts.

Aerial photos can also be used to create mortality maps of individual fires. The precision with which this is possible depends on a) the photo scale, b) the raw data format, and c) the timing of the photo relative to the fire. Ideally, mortality maps are created from hi-resolution scans of photo negatives taken at a scale of 1:15,000 or better and within two years after the fire (Andison 2012). Under these conditions, it is possible to delineate individual live and dead trees. The limitations of using aerial photos are 1) meeting the three conditions listed above, 2) the relatively high cost, and 3) the “naturalness” of both the fire (i.e., no fire suppression) and the vegetation (i.e., no anthropogenic features or salvage harvesting). Mortality maps can generate medium to fine-scale fire regime metrics such as fire shape and severity – which can be further broken down into more specific metrics such as the sizes and shapes of individual remnant patches.

The study area included 129 high-resolution fire mortality maps generated from aerial photos across most of Alberta and part of Saskatchewan (Andison and McCleary 2014).

Satellite Imagery

The second type of orthogonal data comes from satellite imagery. Satellites gather data by measuring the relative reflectance values of different (visible and invisible) band-widths signals sent to the earth’s surface. Over the last several decades, we have learned that specific bandwidths or combinations thereof are particularly good at capturing specific land cover types and conditions. For example, combination A is good at picking up soil moisture, combination B is good at differentiating hardwood from softwood, and combination C is good at identifying burned areas. Thus, unlike the manual interpretation methods required for aerial photos (requiring an expert interpreter), raw satellite imagery data can be interpreted via automated algorithms that look for known differences in band-width signals over space and/or time. However, satellites are "dumb" in that they are only capable of detecting signal differences – they do not know why. Thus, in most cases, satellite imagery data must be calibrated and trained to suit individual needs with the help of field-based data. More specifically, one develops models / algorithms that combine the influence of specific band-widths that capture the change detection of interest. In the case of fire, the majority of the effort thus far has been on detecting the change from pre-fire to post-fire conditions using what is known as the *differenced Normalized Burn Ratio* (dNBR) (e.g. Soverel et al. 2010, Burton et al. 2009). While dNBR is generally assumed to be the *defacto* technique for detecting fire patterns today (Key and Benson 2006),recent evidence suggests that dNBR is virtually incapable of detecting partial mortality (San Miguel et al. 2018), which is a common and important feature of historical wildfires (Andison 2004).

While several hosting services offer at a range of resolution, band-width, scene-size, and cost (e.g., SPOT, CORONA, Landsat, IKONOS, Quickbird, Worldview, Pleiades), the majority of published fire history studies use Landsat, presumably because it is free, available on a regular schedule around the globe, and one of the first available. Boreal fire history studies based on Landsat have been valuable at the local (Soverel et al 2010), regional (Burton et al. 2009) and the biome level (Pickell et al. 2016). However, using Landsat to help define pre-industrial fire patterns has three limitations:

1) It only became available in 1984. This limits its application to those parts of the study area with no industrial influence prior to that date. This eliminates most or all managed areas of the boreal.
2) The raw data are only available as 30m by 30m pixels. Any finer-scale patterns that may be relevant are either averaged or lost.
3) In its current form, dNBR cannot differentiate between pixels with partial mortality from those with full mortality (San Miguel et al. 2017). This represents a significant bias. More recent research has improved the ability of prediction – but only with the aid of pre-fire vegetation (San Miguel et al. 2018) which is not always available.

2.3.1.4 Oblique Images of the Earth

Oblique photos are taken at an angle between 0-90 degrees from the earth's surface from an elevated position (e.g., mountain tops). Early surveyors took advantage of this technique by taking photographs of the Rocky Mountain foothills area between 1861-1958 to help them create topographic maps of the area and define provincial and national boundaries. Fire history researchers have re-purposed these data by re-taking the photos from the same locations today (Sanseverino et al. 2016). This makes it is possible to compare vegetation patterns on the same area several decades apart, and help date and locate historical fires.

The fact that the photos are taken at an oblique angle means that the information on vegetation patterns may not necessarily represent the vegetation patterns of the greater landscape. What cannot be seen behind areas hidden by topography may be relevant (e.g. north vs south slopes), and thus there is some potential risk of bias. Recent methods convert oblique date to orthogonal data (Stockdale et al.

2016) which allow the application of standard spatial analyses and statistics. The southern foothills portion of the study area includes hundreds of historical oblique photos, although only a small percentage of the stations have had repeat photography and analyses.

2.3.1.5 Forest Inventory

Forest industry and/or provincial governments have been creating forest inventory maps for many decades in a more or less standardized format (Cumming et al. 2010). Such maps are key tools for forest industry to do both strategic and tactical planning. Inventories are generated via a combination of aerial photo interpretation and field-sampling. They typically include information on tree species composition, stand density, height, stand age, other vegetation types, soil moisture, and site capacity (Cosco 2011). The attribute of interest in these data for fire history studies is forest polygon age. The age data from forest inventory maps over large areas roughly translate into a TSF map which can be used to create rough estimates of fire cycles.

While informative and useful, there are several challenges associated with using forest inventory data to approximate fire historical fire activity. First and foremost, most areas of the boreal that have forest inventory data today have also had decades of fire control, and thus do not qualify as pre-industrial. Thus, we cannot rely on any of the current forest inventory maps to represent even a single historical snapshot of a pre-industrial age-class distribution. However, the age data from forest inventories can be adjusted backwards in time via “back-casting” using a combination of the actual (from maps and records) and most likely (from assumptions) age data to re-create a forest age map at one or more historical points in time (Taylor and Carrol 2003, Vilen et al. 2012). The main challenge with this technique is not so much the technical details of how to back-cast, but the year chosen as the pre-industrial reference point(s).

Another challenge associated with the use of forest inventory map ages as fire history information is a lack of precision as regards age estimates. Field sampling in the development of forest inventories is less intensive than that required for associated scientific studies, and focuses on the ages of co-dominant and dominant trees. Trees are also sampled at breast height, and then the total tree age estimated using a species-specific correction factor (Cosco 2011). Moreover, the ages of the majority of forest polygons in the final version of a forest inventory map are estimated without associated field data. Comparisons of actual stand age (since the last fire) to inventory stand ages suggests that inventory aging errors are fairly common, but relatively evenly distributed both positively and negatively (Andison 1999a, Andison 1999b). In other words, forest inventory ages are likely to be wrong for any given location, but less likely to be biased over larger areas. Forest inventory ages are thus useful for generating only rough estimates of broad fire regime attributes such as fire cycles, or as comparative evidence.

It is also possible to use forest inventory data to map individual fire mortality patterns (e.g. Delong and Tanner 1996). This effectively negates the problem of the lack of precision of the exact fire date, and is most useful in areas with high age contrast. However, a) the accuracy of the mortality map relies heavily on the interpreter’s skill, and b) there will be a precision trade-off with respect to scale since many forest inventories do not capture smaller polygons.

Forest inventory data is available for most of the southern portion of the study area and selected areas in the north.

2.3.1.6 Tree-Ring Data

Information on the count, width, scarring and the density of tree rings from field samples is gathered by researchers and managers for a number of reasons. As regards this project, tree-rings store valuable information on both the location and date of individual fires. Tree-ring data can be either formal or informal, depending on the methodological rigour and the original purpose.

Informal Tree-Ring Data

Information on tree-rings (from cores, wedges, or disks) is often collected for purposes other than fire history (e.g. forest inventories, sample plots, other research projects). Such data can still be useful for fire history studies, particularly when such data are available on a grid.

In most such cases, field-based methods for collecting tree-ring data make simplifying assumptions for speed and efficiency. For example, ages taken for forest inventories and most PSPs/TSPs are limited to tree cores taken at breast height and the physical samples may or may not be retained. Regardless, tree-ring counts are often made in the field and later amended to the estimated year of origin using species-specific correction factors. Polygon /plot age is then calculated as the average or maximum of individual tree ages. While these age data lack the precision and accuracy of the more formal fire history studies (see ahead), they can still provide valuable information on broad scale patterns of fire years, frequencies, and boundaries.

Formal Tree-Ring Data

When tree-ages are taken specifically for fire history studies, the sampling depth and breadth, and analytical rigour increase significantly (e.g. Rogeau 2005). For example, (preliminary) age polygon maps created from aerial photos are both populated and validated by locating field sampling locations on the boundaries of the mapped polygons (e.g. Rogeau et al. 2016), which increase the chances of identifying (at least) stand origin dates at multiple, independent locations. Field protocols for these plots usually require taking physical samples from as many as 20 trees, either as cores, wedges, or full cookies – taken as close as possible to the origin point of each tree. Each sample is then sanded, tree rings counted and/or measured, and the dates of stand origin and/or all fire scars noted. This information is then superimposed back on the original fire polygon map, creating a high resolution fire return interval (FRI) map, as well as some information on fire sizes and severity. It is even possible to identify the season of burning from tree-rings (e.g. Stokes and Smiley 1968).

The highest standard as regards tree-ring methods is better known as *dendrochronology* (Douglas 1941). Dendrochronology involves cross-referencing tree-ring patterns between individual tree samples using automated statistical software (Holmes 1983). When this process is duplicated over many trees and sites, it creates what is known as a *master chronology*, which is a standardized relative tree-ring width sequence over tens or hundreds of years. While the sampling, processing, and analytical effort involved in dendrochronology are high, there are two significant benefits. First, it virtually eliminates the chances of either the stand origin or fire dates from any single sample being wrong. Even regular biological anomalies such as *false rings* are detected and corrected. The second benefit is that it allows the master chronology to pre-date the year of origin of the oldest living trees by cross-dating (often incomplete) tree-ring samples from dead trees, stumps, or even old logs and lumber. This is particularly useful in the boreal where trees are relatively short-lived.

Dendrochronology methods are very precise, but also very expensive and time-consuming. The necessary high sampling intensity also means that it tends to create only site-specific (i.e., less than 10,000 ha) knowledge of localized fire activity. However, more recent techniques have expanded dendrochronological methods beyond local scales by combining tree-ring data with broader spatial methods (e.g. Naficy 2017).

A number of different types of tree-ring studies exist in the study area.

2.3.1.7 Sediment Coring

It is possible to extend fire history information back more than two thousand years using sediment cores taken from the bottom of lakes and ponds. Sediment in smaller, quiet water bodies tends to settle in annual layers, much like annual tree rings. Embedded in each annual layer is physical evidence of forest fires in the form of ash, and information on tree species in the form of pollen (Denis et al. 2012). Thus, it is possible to use sediment cores to track very broad-scale landscape dynamics of fires and changes to tree composition (Davis et al. 2016). Using sediment cores is expensive and time-consuming, and the technique is limited to areas with suitable water bodies for sampling. A small number of sediment core studies exist in the study area.

2.3.2 Indirect Evidence

Indirect evidence is that which is not observed first-hand through empirical techniques (as described in Section 2.3.1), but rather from inferred, secondary sources of evidence. Indirect evidence is less accurate and less precise than direct evidence, but can still be valuable guides where no other evidence exists, either in combination with other sources of knowledge, or as a validation source.

2.3.2.1 Related Observations

Historical fire regimes can and do leave observable legacies in vegetation patterns. For example, very short fire return intervals (i.e., less than 20 years) rarely support vegetation communities with trees, and tend to have chernozemic, or solenzetic soil types, while the transitional parkland zones have slightly longer fire cycles and both grassland and forest (Bailey and Wroe 1974). Similarly, Parisien and Sirois (2003) found a strong relationship between fire cycles and the percentages of both white spruce (positive) and jack pine (negative). Very long fire cycles (2-400 years) will create a forest dominated by spruce and *abies* (Lesieur et al. 2002). It is also relatively well known that fire regimes are strongly associated with regional climate, which makes climate a potential proxy for fire regime zonation.

As a knowledge source, this type of indirect evidence lacks both precision and accuracy, and is thus rarely referenced. However, it can still provide some general thresholds and/or broad ranges that can be logically compared with other evidence.

2.3.2.2 Emergent Model Behaviour

Models are approximations of reality (Hammah and Curran 2009) and as such they generate output that is essentially hypotheses of the behaviour patterns of natural phenomenon. And while model output should not be confused with direct evidence, even the most simplistic models provide valuable insights. For example, we rely heavily on models to predict climate change because it is not possible to move forward in time to compare our predictions with reality. As it relates to the larger LandWeb project, we employ models to predict multiple pre-industrial landscapes because no other method of doing so exists. Thus the primary role of spatial models as it relates to NRV is to predict hundreds or thousands of pre-industrial landscape time-slice “snapshots”, which can be measured for various pattern metrics of interest, such as old forest levels or patch sizes.

So models generate new knowledge by extrapolating *what we think we know* in time and space, but they also generate new hypotheses (by universally acknowledging that all model output as one form of *what we think we know*). In other words – all model outputs are hypotheses, and not necessarily truth.

The ultimate measure of confidence for data generated from a model is consistency with other available evidence. This process is generally known as *validation* (Krueger et al. 2012). For example, a model of the spread of an insect infestation might include a) an estimate of the population size based on over-wintering mortality, and b) the quality and quantity of the available food. Model output is then compared to actual spread measurements. When the two are in agreement, we gain confidence that we have identified, codified, and calibrated the appropriate ecosystem elements. If and when model output is inconsistent with other evidence, it generates new and important hypotheses. For example perhaps the model was missing or misrepresenting a critical ingredient, or the methods used to measure insect spread are faulty. Regardless, the value of the modelling exercise in this case lies in the fact that a) new hypothesis were generated, and b) it is possible to evaluate and test them. Both scenarios serve the needs of the advancement of *best available knowledge*.

It is possible to evaluate fire regime knowledge across the study area in this way in this study, but only after the completion of the final model runs.

2.3.3 Experiential Evidence

The third and final type of evidence is experiential, which is knowledge of system behaviour and patterns gained through specific training, and/or observations and experiences over extended periods of time (i.e., decades to generations). Knowledge of natural systems gained through experience is not just a useful way of dealing with knowledge gaps, but can offer novel insights and perspectives. For example, indigenous peoples’ understanding of when and where to use fire to encourage the production of berries and habitat preceded the formal documentation of these phenomena by several centuries (Lake 2013). The two main forms of experiential evidence discussed here are *traditional ecological knowledge*

(TEK) and expert opinion. Although the two are not normally linked, I did so here because they share many of the same opportunities and challenges.

2.3.3.1 Traditional Ecological Knowledge

Traditional ecological knowledge (TEK) includes knowledge and insights acquired through generations of local observation and experience (Berkes et al. 1995). It is now well recognized that indigenous peoples managed natural ecosystems for the purposes of sustaining local livelihoods for thousands of years across virtually all of the earth's biomes (Mason et al. 2012). Closer to home, we know that indigenous peoples in Canada used their understanding of wildfire to manage habitat, food production, and species movement for many centuries (White et al. 2011).

The primary vector for capturing TEK is verbal, passed on to subsequent generations through experience and stories (Huntington 2000). The challenge has been to extract, translate, and integrate traditional knowledge into a format that can be integrated and applied by managers and regulators (Rist et al. 2015). The response has been an increasing reliance on social science techniques such as workshops, interviews, collaborative field trials, and questioners to extract traditional knowledge, which is daunting for some since it adds another layer of information gathering and processing (Huntington 2000).

Accessing TEK would be invaluable for understanding pre-industrial fire regimes. Notwithstanding the value of this information to this project, time and resources did not allow for it. The sheer size of the study area is such that this would have been a formidable, long-term task that extended beyond the original scope of the project. ***However, this does not, and should not preclude this from happening in the future, perhaps using the outcome from this project as a starting point for local TEK discussions.***

2.3.3.2 Expert Opinion

The second form of experiential evidence is the opinions and advice of (topic specific) *experts*: individuals that possess unique and substantive knowledge of a particular topic gained through formal training, experience, education, or training (Kuhnert et al. 2010). While less well recognized and documented than other forms of scientific evidence, virtually all aspects of natural resources science rely on expert input, including conservation biology (O'Neill et al. 2008), habitat modelling (Store and Kangas 2001), environmental modelling (Krueger et al. 2012), forest harvest planning (Kangas and Leskinen 2005) and wildfire behaviour (Gonzales et al. 2006).

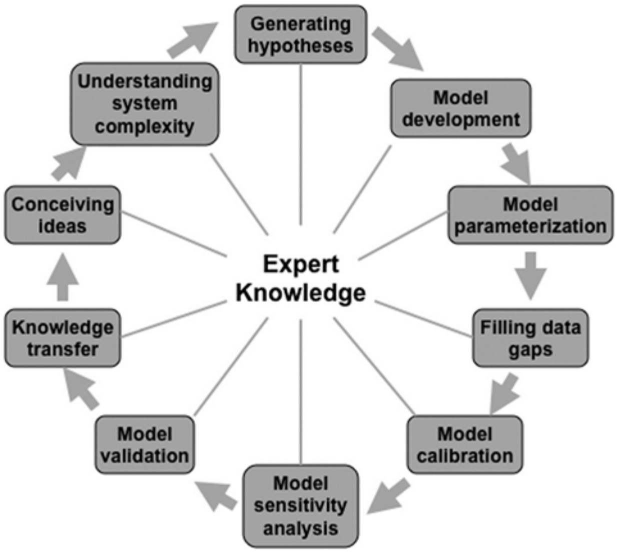
The reason that expert input is so ubiquitous in the natural resource sciences is the sheer size of the problem to be solved. In a perfect world, we possess detailed and well documented knowledge of every ecosystem pattern and process of the western boreal. In reality, natural ecosystems are far more complex than we are likely to ever comprehend, and our direct and indirect understanding of the dynamics of natural ecosystems has, and always will have, many gaps (Drew and Perera 2011). Not surprisingly, experts are regularly used to complement or substitute for scare knowledge (Drew and Perera 2011).

Drescher et al. (2013) offer a useful summary of the various ways in which expert knowledge is currently used in natural resource management (Figure 5).

Whether formally recognized or not, the standard of providing the *best available knowledge* almost always includes expert opinion (Jacobs et al. 2015). Rykiel (1989) goes further suggesting that "***the best available information on complex environmental systems may be expert opinion".*** Unfortunately, the gathering and integration of expert knowledge tends to be informal and poorly documented (Drescher et al. 2013). It is thus both overlooked and under-valued as a legitimate source of knowledge – even by scientists, although that trend is changing (Drescher et al. 2013).

The role of expert opinion in this project is considerable, and will be discussed further below.

Figure 5. Summary of how expert knowledge is used in natural resource management (from Drescher et al. 2013)



3.0 Objectives

The objective of this project is to: ***Develop a first approximation summary of the pre-industrial (NRV) fire regime attributes of the western boreal forest based on the best available knowledge.***

This objective was deliberately general and flexible in nature. As described above in Section 2.1, knowledge of fire regimes will be either input into, or an external validation source for output for, the LandWeb model. However, that objective aside, creating a map of western Canada fire regimes has other benefits. First, it provides a *best available knowledge* scientific foundation for defining pre-industrial fire regimes, which could otherwise be used for establishing benchmarks for climate change studies, natural disturbance risk assessments, stratum for species habitat studies, or future range of variation predictions. A second benefit is that it provides a large number of testable hypotheses for future research. Lastly, the exercise, and this final report, provides a detailed gap analysis of where and what baseline knowledge of pre-industrial fire regimes is lacking. *There are no known similar research initiatives in Canada at this scale.*

4.0 Methods

This project involved four separate but linked elements:

1. Local historical summary of all types and sources of informal fire history evidence in the Peace area of Alberta (Section 4.1).

2. Fire regime literature review of the study area to provide a common baseline of existing direct (and in some cases indirect) evidence (Section 4.2)
3. A two-day workshop designed to elicit historical fire regime input from experts (Section 4.3)
4. A series of follow-up consultations with historical fire regime experts to help refine the workshop output. (Section 4.4)

4.1 Local Fire History of the Peace Region of Alberta

By. K. MacLean

The Peace area in Alberta was thought to be the most complex with respect to historical fire regimes. In this area, elevation, vegetation types, and topographic complexity all change rapidly within very short distances, which means that historical vegetation types and patterns are particularly sensitive to small changes in historical fire regime attributes. This is further complicated by the fact that this same area was targeted more than 100 years ago for land conversion activities, which means that there are very little direct sources of evidence of historical fire regimes.

As part of this project, any and all available evidence from local municipal, provincial, and external data (i.e. local museums) was identified by an independent expert (MacLean 2014).

4.2 Literature Review

By: C. Stockdale

The next step element was a literature review of the available knowledge on fire regimes of the study area. This was contracted out to an independent expert (Dr. Chris Stockdale), and included any and all available sources of *direct evidence* (as per 2.3.1) relevant to fire regimes in the study area, plus the information found by the MacLean (2014) report. In other words, the review included; a) all relevant published, internal, and 'grey' (i.e., unpublished) literature, b) relevant studies on a national scale or beyond, and, c) some (but by no means all) relevant historical records, photos, maps, and data.

A summary of this comprehensive review is available at https://friresearch.ca/fire-regimes/western-boreal-canada-and-foothills-alberta) (Stockdale 2014). The review generated some key insights relevant to the project objectives.

1. There is a significant amount of direct knowledge of various aspects of fire regimes available in and near the study area. However, most of it was *post*-industrial.
2. The variability in the quality and quantity of knowledge and data varies by location. Intensive and high-quality fire research and data tended to focus on specific and often smaller areas, leaving some areas with little or no direct evidence.
3. The overall level of understanding of pre-industrial historical fire regimes across the western boreal is moderate, and relatively consistent. However, there still exist both disparities (i.e., conflicting evidence) and knowledge gaps.
4. A literature review of direct evidence of this topic is not enough on its own to define all aspects of the pre-industrial fire regimes for the entire study area.

4.3 Expert Workshop

By: D.W. Andison, K. McCleary, and J. Leboeuf

To this point, considerable effort was spent to gather and summarize what was believed to be the most defensible direct and indirect evidence of historical fire regimes for the study area. However, that same effort made it clear that it was not enough to generate and populate a fire regime attribute table for the study area. Ideally, such a table would include three elements: 1) a geographic zonation for capturing regions of homogeneous historical fire regime parameters (the columns in Table 1), 2) a ranked list of the most important fire regime parameters to capture (the rows in Table 1), and 3) the details of the chosen fire regime parameters (the matrix cells in Table 1).

Table 1. Example of Desired Workshop Output. (Regime Zones A, B, C, etc. would be identified on an associated map)

Attribute	Regime Zone			
	A	B	C	etc.
Attribute 1	Mean = 80 95% CI = 70-100			
Attribute 2	Mean = 500 95% CI = 30-2,000			
Attribute 3	Mean = 25 95% CI = 5-45			
Etc.				

Knowledge gaps in this fire regime table could certainly be addressed by a coordinated and dedicated research program. However, the cost of this would be tens of millions of dollars and likely take several decades to complete. Moreover, the need for at least a first draft of Table 1 is imminent for the purposes of policy, practices, and management. Waiting for universally acceptable, high-quality evidence to inform policy and practices with respect to pre-industrial fire regime knowledge in the study area is unrealistic given the timelines and costs involved.

This scenario - where direct, empirical data are scarce or unavailable, but decisions involving a complex ecological system are required in the near term – is one for which expert opinion is widely regarded as the best available option (Sutherland 2006, McBride and Burgman 2012). The idea of designing and hosting a fire-regime workshop with experts in fire behaviour, fire pattern, fire managers, and fire modelling emerged from this logic. Thus, the primary goal of the workshop was to: ***<u>Create a preliminary version of a fire regime description (i.e., Table 1) of western boreal Canada based on a combination of direct and indirect evidence and expert opinion</u>.***

4.3.1 Who is an "Expert"?

Experts are "*qualified individuals that are defined as a result of their technical practices, training, experience, and peer recognition"* (McBride and Burgmann 2012). Thus, experts are usually scientists, but may also be practicing ecologists and natural resource managers who have accumulated considerable knowledge of a specific topic area through decades of experience (Drescher et al. 2013).

The difference between *expert opinion* and *opinion* is subtle, but worth discussing. Opinion is "*a preliminary state of knowledge of a topic for which claims are not necessarily justified or agreed upon*" (Krueger et al. 2012). On the other hand, an expert is one who "*possesses unique and substantive knowledge of a particular topic gained through formal training, experience, education, or training*"

(Kuhnert et al. 2010). Thus, experts can be scientists, managers, or members of the public – but only those formally recognized as having special knowledge acquired through training, study, peer-recognition, and experience (Drew and Perera 2011). Both forms of input are valuable for natural resource management, but differently so. Opinion can and should be a part of decision-making processes, but only expert opinion is recognized as a form of *evidence*.

In an effort to be inclusive and objective, we adopted a liberal definition of an expert for the workshop by invited 34 academics, consultants, provincial / territorial fire and forest management personnel from across Canada (Table 2). This was a risky decision. Experience from others suggests that groups larger than 12 are unlikely to create any new knowledge because the chances for disagreement increase significantly (Knoll et al. 2010). However, a) this topic was broad and of great interest to a number of agencies, b) the study area was massive, and c) we wanted to include, address, and document any disagreements directly and openly. The workshop team believed that a broader, larger invitation list would be appropriate for this scenario in the interests of objectivity and openness.

Of the 34 invited, 21 attended (Table 2) including the three people on the workshop committee.

Table 2. Invitation List for the fire regime workshop.

Name	Affiliation	Attended?
Dave Andison	fRI Research	yes
Jules Lebeouf	Facilitator	yes
Kris McCleary	Facilitator	yes
Chris Stockdale	University of Alberta/CFS	yes
Steve Cumming	University of Laval	yes
Yan Boulanger	Natural Resources Canada	yes
Craig Delong	Ecora Environmental Resource Group	yes
Tom Lakusta	Government of NWT	yes
Cordy Tymstra	Alberta AF	yes
Soung Ryu	University of Alberta	yes
MP Rogeau	University of Alberta	yes
John Stadt	Alberta AF	yes
Dave Smith	Parks Canada	yes
Douglas Turner	Saskatchewan Environment	yes
Dave Finn	Alberta AF	yes
Matt Carlson	ALCES Group	yes
Jacque Tardiff	U Winnipeg	yes
Robert Kruus	Saskatchewan Environment	yes
Kelsy Gibos	Alberta AF	yes
Franco Nogarin	Government of NWT	yes
Larry Nixon	Government of NWT	yes
Matthew Smith	Alberta Pacific Forest Industries	yes
Jeff Weir	Parks Canada	no
Sylvie Gauthier	CFS	no
Phil Burton	UNBC	no
Dennis Quintilio	Consultant	no
Mike Flannigan	University of Alberta	no
Ed Johnson	University of Calgary (retired)	no
Chris Dallyn	Saskatchewan Environment	no
Margaret Donnelly	Alberta Pacific Forest Industries	no
Jean Morin	Parks Canada	no
Mark Heathcott	Parks Canada	no
Brad Stelfox	consultant / modeller	no
Colin Bergeron	U of Alberta	no
Marc Parisien	CFS	no
Matt Conrod	Government of Manitoba	no
Rob Rempel	Ontario MNR	no

4.3.2 What Type(s) of Expert Knowledge Was Needed?

We used experts to elicit both qualitative and quantitative knowledge. More specifically:

1) What is a reasonable geographic zonation for the western boreal that represents an internally homogeneous pre-industrial fire regime classification?
2) Identify and rank the relative importance of the various historical fire regime attributes in the western boreal, by zone if necessary (as per #1), and,
3) Quantify the pre-industrial fire regime parameters for each zone as per #2.

To be clear, the intent of the workshop was to complement and/or supplement the available direct evidence. Thus, the result was intended as a mix of all types of evidence, although the experts were expected do the heavy lifting of filling in gaps, translating, and summarizing as required (*sensu* Drescher et al. 2013).

4.3.3 How Was Expert Opinion Elicited?

As previously noted, although the use of expert knowledge is regularly used to inform scientific studies and modelling exercises, these contributions are rarely documented or acknowledged, which has contributed to the mistrust of and disrespect for expert input in general (Huntington 2000). Thus, the elicitation process must be neutral, fair, open, clear, accountable, non-threatening, well-documented, and align with the original question (Kuhnert, et al. 2010, Krueger et al. 2012). The design of this workshop was intended to honour all of these requirements. In service of this, the workshop team developed six guiding principles:

1) **Limit the scope**. We went to great lengths to specifically advertise this as a technical workshop with narrow, specific goals.
2) **Self-determination and neutrality**. We developed and shared three guiding questions for the participants; A*) What can we live with*?; B) *What can we not live with?;* and, C) *What is missing*? In other words, the participants were to be given full control over if and how they created a fire regime map, and what information or data it contained.
3) **Consensus is not required**. Disagreement was anticipated, documented, and incorporated.
4) **Be humble and realistic**. We accepted that "success" would be any new information we end up with, but not necessarily the full version of what we hoped for.
5) **Define a "fire regime"** In the interests of narrowing the technical scope of the exercise, we tried to focus participants on a) fire regime boundaries, and b) the most important elements of a fire regime including 1) frequency (how often), 2) size (how big) and 3) severity (how much dies).

The workshop team used these principles to design the agenda for a two-day workshop that was held on Feb. 19-20, 2014 in Edmonton Alberta. The workshop agenda (Figure 6) was designed to offer multiple opportunities for expert input and maximize the input of the participating experts within a safe, neutral space, but also to allow for participant feedback on process.

The speakers during the "Open Speakers Box" on day 1 included Dr. Marie Pierre Rogeau, Dr. Jacque Tardiff, Dr. Steve Cumming, Dr. Yan Boulanger, Craig Delong and Dr. David Andison (Figure 6). These opening talks were very broad in nature, and designed to "prime the pump" as opposed to influence opinions.

Figure 6. Invitation and agenda for the Healthy Landscapes Program fire regime workshop.

HISTORICAL LANDSCAPE CONDITION BENCHMARKS FOR WESTERN BOREAL CANADA: FIRE REGIMES

A WORKSHOP

February 19 and 20 2014

Edmonton, Alberta

Purpose:

- To co-create robust historical fire regime input assumptions for a western boreal Canada landscape modeling exercise.
- To develop shared understanding of the input assumption specifics and how they will be utilised.
- Identify knowledge gaps (e.g. the impacts of fire control, areas where regime knowledge is unavailable, limited or conflicting) and how we might manage these potential dilemmas.

Outcomes:

To obtain a mutually shared understanding of the landscape we inherited from Mother Nature so that we may begin to manage it with a greater awareness and appreciation for its complexity. This outcome will minimize second guessing on how we manage the land together and increase our chances of success in managing the land to provide a continual flow of all ecosystems goods and services (i.e., species at risk).

Assumptions:

- Co-creating robust historical fire regime input assumptions does not rely on achieving 100% agreement amongst workshop participants.

DAY 1

8:30 am	**Welcome and & Overview of the Workshop** – *Kris McCleary* **Opening Address-** *Dave Andison* • Presentation of the Historical Landscape Condition Benchmarks for Western Boreal Canada project **Opening Group Dialogue** – *Jules LeBoeuf*
10:00 am	BREAK
10:30 am	**State of the knowledge on fire regime parameters in Western Boreal Canada** - *Chris Stockdale*
11:15 am	**Approximating changes in forest age in Alberta from 1910 and 2010**- *Matt Carlson*
11:35 am	**Open Speakers Box: New knowledge on fire regime parameters in Western Boreal Canada** *(Various Speakers)*
12:00 pm	LUNCH
1:00 pm	**Open Speakers Box,** continued
1:30 pm	**Dialogue – Table Top Conversations** – *Jules LeBoeuf*
3:00 pm	BREAK
3:30 pm	**Table Top Report and Debrief** - *Jules LeBoeuf*
4:30 pm	**Closing Conversation** – *Jules LeBoeuf*
5:00 pm	Adjourned

DAY 2

8:30 am	**Opening Remarks & Reflections-** *Jules LeBoeuf*
9:00 am	**Dialogue – Table Top Conversations, continued-** *Jules LeBoeuf*
10:30 am	BREAK
11:00 am	**Four Key Questions Worth Asking** - *Jules LeBoeuf*
12:00 pm	LUNCH
1:00 pm	**Four Key Questions Worth Asking** – Continued
3:00 pm	BREAK
3:30 pm	**Next steps** - Jules LeBoeuf
4:00 pm	**Closing Conversation** - *Jules LeBoeuf*
4:30 pm	Adjourned

4.3.4 Workshop Results

4.3.4.1 Day One Output

As hoped, the presentations and discussions from the morning session generated valuable conversations about fire regimes, methods, and regime zone boundaries. However, the conversation ultimately strayed into more strategic topics including spatial modelling approaches in general and the LandWeb model specifically. The workshop team heard the following messages from participants:

1) <u>Spatial modelling architecture is relevant</u>. While this discussion provided some valuable input into the larger LandWeb project (which at this point was still in the process of developing model architecture), and provided more background information for participants, it did not advance the workshop objectives.
2) <u>Context matters</u>. The workshop participant list was broad and deep. It included folks intimately involved in the larger LandWeb project, some who were only marginally involved in one or more elements, and some who had no knowledge of it at all. The group felt that this created an uneven understanding of the desire to create a historical fire regime map that was highly relevant to the workshop expectations. For example, what level of assumed or required confidence is required?

The *Table Top* discussions in the afternoon of day one were intended to provide the group with the power to a) self-identify four key questions that they believed would be required to address the workshop goals, and then b) a chance to participate in one or more of those discussions. The questions chosen by the participants were broader than originally envisioned by the workshop team, not all of which were of direct value to the goal of this project. To follow is a summary of those four discussions, as captured by the collective notes of the workshop team.

Table 1 Summary:

Question: ***What is the best model integration approach? Are the outputs evidence based? Are the model outputs useful?***

Table 1 chose to focus on model outputs without being constrained by individual models or their design. They agreed that a model must, in general, be credible, defensible, and usable. More specifically, the group suggested that model output in this case should address two scales. At the landscape scale, model output should include disturbance event size, seral stage distribution, and interior forest. At the operational level model outputs need to provide information on structural attributes that could be used for field compliance and monitoring cumulative effects. The group also agreed on a list of needs and wants for model output, including:

- Preferably in the form of distributions,
- Compatible (with planning metrics),
- Transportable (from one region or landscape to another),
- Adaptable and flexible to changing socio-economic drivers,
- Able to incorporate climate change,
- Robust enough to handle scenario planning,
- Sensitive where needed to capture spatial influences (i.e., topography), and
- Auditable.

Table 2 Summary:

Question: ***What are the information gaps and research opportunities for the filling knowledge gaps (wrt historical fire regimes)?***

This table focused their discussion on compiling a list of fire regime knowledge and data gaps in general. This group agreed in the end that they were only able to ‘scratch the surface’ of this topic.

- Seasonality. We have good recent data on this, but no data on past seasonality. This is important because seasonality of fires affects post fire vegetation composition structure.
- Frequency. Provincial fire records pre-1980’s are very poor. Significant underreporting is evident prior to 1980, which only increases the further back you go in time. In other words, fire frequency is increasingly under-estimated from fire records alone.
- Fire size. As above, provincial fire records have a negative bias since small fires were not recorded until quite recently.

- Older fire record precision. Most old fire records only recorded event perimeter, which affects severity estimates.
- Fire suppression impacts. Data collected and used for analyses during the fire suppression era are biased in unknown ways, which means a) overall fire frequency is under-estimated, and fire-size distribution is biased.
- Forest age data. Many parts of the boreal (e.g., northern Saskatchewan and Manitoba, outside of forest management agreement areas (FMAs) in Alberta and NWT) have no forest inventory data, and thus no age-class distribution information. In these areas, these data cannot be used to reconstruct fire regimes.
- Grasslands. We have very poor evidence of fire regimes in these areas, as well as the forest-grassland interface(s).
- Relationship between frequency, size and severity. If we have severity wrong, do we have the greater fire regime relationship(s) wrong?
- How do / should we track severity (as an indicator)? Frequency distribution of percent mortality for individual fires? Frequency distribution of areas of different mortality levels overall? Something else?
- Relationship to fire weather. Do we have enough information / research to include fire weather index parameters in a model?
- Fire severity methods. Photos methods are successful, but expensive and limiting. Can we use alternative methods and data (e.g., satellite imagery, lidar, wet areas mapping, etc).
- Long term fire history. In general, the quality and quantity of records deteriorate with age. Is it possible to use more recent fire –climate relationships to model those of the past? If not, what is the direct and nature of the bias(es)?
- Fire and soil. There are few studies that capture the impacts of fire intensity at the soil organic level.

Table 3 Summary

Question: ***What are the possible model inputs, and how practical are they?***

This group also tackled the problem of knowledge and data gaps, but more specifically as it related to a spatial modelling exercise.

- Fire cause. Older fire records tended not to record this information, although it is more important to capture for more recent fires. Cause (i.e., “naturalness) is also confused by fire suppression.
- Fire frequency. It is defined in several different ways. Need to make sure the method is clear and consistent (rather than being the only “right” method).
- Fire size. There is increasing error in data as one goes back further in time in fire data and records.
- Severity. Also many different approaches and definitions of this, and none are simple.

In terms of the practicality of the model inputs, the group offered the following observations:

- The local-scale fire weather for the vast majority of historical fires is not known.
- There are many different approaches to calculating most metrics (see above).

- Definitions (of terms and metrics) are not standardized.
- Budgets are limited – need to separate needs from wants.

Table 4 Summary

Question: ***How do we best define homogenous units (fire regime boundaries) we are going to use for this process? Do units change over time and if yes, what time period do we use for our units?***

The last group tackled the problem of how to define spatial units that represent homogeneous fire regime units. The list of guidelines they came up with includes the following:

- Size. Suggest there should be a minimum size unit. Some literature suggests that an area of at least 3 times the maximum fire size is a suitable minimum requirement. This process could be iterative between forming units and parameters, and testing them to ensure they are large enough to capture the required components of each unit (i.e., age class distribution).
- Management relevance. The units should be relevant to management capacity to consider and manipulate age class distribution, retention levels, wildfire threat, mountain pine beetle (MPB) threat, habitat suitability, and patch size distribution – *as largely independent output*. The spatial units and parameters can be tested for this purpose (i.e. discriminate analysis).
- Ecological relevance. Existing ecological classifications (both provincial and federal) are available and relevant to fire regimes via vegetation, climate, and topography. Could the (workshop) participants agree that this is good starting point? A new version of the ecological land classification could consider climate as the driving element – which would assume that climate is the primary driver of fire regimes.
- Key drivers of fire regime sizes and boundaries should include:
    - Climate (precipitation and temperature and possibly seasonality and number of fire weather days greater than 95th percentile),
    - Vegetation (fire resistance of trees, fuel continuity) which can affect stand level survival levels and fire size,
    - Macro topography (e.g., elevation, topology),
    - Exposure (north, south facing) important, but the scale is not appropriate for this analysis,
    - Meso-topography. Very wet sites and/or water bodies can affect both fire size and stand level retention levels, and
    - Lightning density (may be important in certain areas, not so much in others).

4.3.4.2 Day Two Output

The opening conversation on the morning of day two revealed a concern of some participants that much of day one was spent discussing issues that were broader than the original workshop goals. The workshop team responded with a brief presentation meant to help focus the group on the task at hand:

1) A reaffirmation that the workshop goal was an expert opinion driven first approximation of some pre-industrial fire regime parameters for the western boreal. While input and advice on the larger LandWeb project and/or the modelling is, and always be welcome, any further questions or discussion on these larger topics should be saved for a more appropriate forum.

2) There was no preconceived idea in terms of workshop process by which the team would generate the desired output. The nature of if and how the process develops the desired zonation and fire regime attributes is entirely at the discretion of the workshop participants. The agenda, the process flexible we discussed, and any of the suggestions provided by the workshop team and day one speakers were intended to inspire and help create a common foundation for discussions, not to direct or influence opinion.

The ensuing discussion of the workshop participants not only confirmed a shared desire to develop a first approximation fire regime map by the end of the day, but generated some critical guiding principles for the work yet to be done:

1) Defining fire regime information as proposed by this workshop has value regardless of the modelling approach, platform, and/or output. It can be used as input for empirical models, or output validation for process-based models. On a more general level, consistent with the spirit of the larger LandWeb project, creating a first approximation fire regime map is intended to generate healthy debate, identify knowledge gaps, and generate hypotheses for future research.

2) The size of fire regime zones should reflect the confidence in and quantity of the available knowledge. In areas where a lot of information exists and fire regimes change over short distances (e.g., the Rocky Mountain foothills) regime zones may be much smaller than in areas where very little data or knowledge exists.

3) Despite the wide range of fire regime attributes available across the study area, the list of those that participants should focus on in this initial workshop should be those that are the most commonly available and understood. The group agreed that the two most commonly studied and relevant aspects of fire regimes in the study area were: a) fire frequency (expressed as fire cycle), and b) fire size. The group agreed that other attributes such as fire severity, fuel-type burn probability, ignition probability, timing, and the relative influence of various biotic and abiotic factors were not necessarily less important, but less well understood and documented.

Although the afternoon agenda was originally designed to provide participants an opportunity to identify and discuss critical topics of interest via break out groups, the workshop participants proposed that a group discussion would be a more effective way to identify and discuss this topic. The sub-headings below capture the discussion of the major topics, that were used to help set the stage for the next round of group discussions. As above, these results are a summary of what was heard based on the collective notes of the workshop team mixed with relevant references where possible and appropriate.

4.3.4.2.1 Regime Variability

Consistent with the discussion about modelling approaches, unique fire regimes could be generated either a) based on emergent properties from a model, or b) using deliberate zonation. While a process-based approach (in support of option (a)) is preferable in theory, the workshop participants did not feel there was enough fire regime knowledge to develop a defensible series of such parameters. However, there was agreement that a first approximation of a pre-industrial version of a fire regime map of the western boreal was possible based on pre-defined zones. Towards this, the group further agreed that some combination of national and provincial/territorial ecozones is likely the best place to start in terms of capturing historical fire regime differentiation. The group also agreed that the Canadian ecological zones align well with several key fire regime drivers, including climate, length of fire season, fuel-type and continuity, physiography, distance to (and influence of) mountains, latitude, and elevation.

4.3.4.2.2 Fire Regime Attributes

As discussed above, the group agreed that the most important details of pre-industrial fire regime attributes included (in order of priority) fire frequency, size, and severity. However, the participants also agreed that the time and effort required developing first approximations of either fire size or severity estimates across the study area was beyond the available time and resources. Thus the group agreed on the following:

1) The default for fire size in the absence of other data / knowledge would be the fire distribution used for adjacent areas, and/or local, available provincial fire records.
2) The default for fire severity levels (captured as tree mortality), in the absence of other evidence would be and the spatial definitions of “fire event” and “remnant”, would be those suggested by Andison (2012), and Andison and McCleary (2014) for the entire study area.
3) In terms of fire frequency, there was an agreement that a first approximation of a fire regime map should first and foremost include *fire cycle*. The classic definition of a fire cycle is the average number of years required to burn the number of hectares in the landscape / area of interest (Johnson 1992). The group agreed on this definition.

The main limitation of the use of fire cycle as a measure of fire frequency is that it presumes that most fires are high severity, resulting in even-aged landscape mosaics (Johnson 1992). While there is growing evidence of lower to moderate severity fires in the western boreal (e.g. Amoroso et al. 2011), the details of how often, where, or why lower to moderate severity fires occur remain unanswered. This is further complicated by the fact that lower severity fires are more likely to be suppressed by fire control activities. The group agreed that these caveats should at least be documented, and at best further explored via directed research.

The other challenge with the use of fire cycle as a pre-industrial NRV metric is that it can, and does, change over and through time. A single fire cycle number representing the average or median over X years can be misleading or biased. The group agreed to deal with this in two ways: First, the group agreed to use single fire cycle numbers to reflect *long-term fire cycle* (LTFC) averages to represent the fire cycle over the longest possible timeframe. The LTFC is thus a centroid, but the collective understanding was that the range varied over shorter periods of time (i.e., 1850-1950 vs 1910-1950). Second, in areas where there was either a) lower confidence in LTFCs, or b) areas where LTFCs changed over short distances, the group would suggest a range, with an explanation (e.g., sharp changes to LTFC in the Rocky Mountain foothills due largely to elevational gradients).

For the remainder of the day, the group worked together to develop historical fire regime estimates by region using several key assumptions and questions as a guide:

- The boundary definitions of homogenous fire regime zones should use a combination of the ecoregions of Canada (Wilkens 1986) and the natural regions of Alberta (NRC 2006).

- Overview of climate, vegetation, and topography for each zone
- Openly reveal and discuss the quality and quantity of available evidence for each zone
- The most realistic outcome from the workshop was to define a pre-industrial LTFC map, but including the following additional information;
    - What are the chances of being wrong? (i.e., confidence levels)
    - What are the risks of being wrong? (i.e. potential impacts)

The discussion to follow focused almost entirely on pre-industrial LTFCs, with a few exceptions (see ahead). This exercise was captured on a map of the study area as a group exercise. Before starting, the group agreed on the following:

1) In the interests of not having any data gaps, given the location and size of the areas with very little fire history information, adopt a default LTFC average of 90 years.
2) Where possible, a range of LTFC values would be used instead of a single average. This was intended to incorporate both disagreement (among participants) and uncertainty.
3) Capture the details. Even within the major biome areas, topographic complexity, elevation, vegetation type, and distance from mountains all create relevant ***fine-scale*** changes in LTFCs, sometimes over very short distances. Although this may not be reflected in the map, it should be captured in the discussion.

A summary of the group discussion is summarized in Table 3.

Table 3. Summary of workshop results from the afternoon of day two.

Biome Area	LTFC	Fire Size	Severity	Chance of Being Wrong	Risk of Being Wrong
Grasslands	10	1,000 max	n/a	Low	Low
Grassland-Forest Interface	30	3,000 max	??	Moderate	Moderate
Montane	40	5,000 max	mixed	Low	Moderate
Foothills	70-100	200,000 max	mixed	Low to High	Low to High
Alberta Subalpine	150-250	50-200,000 max	??	Moderate	Moderate
Boreal Plains	50	??	mixed	Low to High	Low to High
Boreal and Taiga Plains (BC)	100	??	??	Moderate to High	Moderate
BC Subalpine	150-250	??	??	Moderate	Low
Boreal Shield	60-70	??	??	Low to Mod	Low to High
Manitoba	40-60	??	??	Low to High	Mod to High
NWT	??	??	??	n/a	n/a

GRASSLANDS

This area encompasses the southern fringes of the boreal forest, plus some smaller areas in the Peace area of northern Alberta. Historical grasslands boundaries are well-preserved by the existing boundary of chernozemic soils (www.sis.agr.gc.ca/cansis/nsdb/slc/index.html). This area is typified by high fire ignitions and a long, dry fire season, although it is fuel-limited. Little or no physical, local evidence of historical fire exist, but there is some written and verbal fire history evidence of these areas on which to draw. Grasslands also tended to be more heavily influenced by pre-industrial burning by Indigenous Peoples. The workshop experts estimated a LTFC average of 10 years and a maximum fire size of 1,000 ha. Severity (in terms of tree mortality) is not applicable. Despite the lack of local physical evidence, the chances of being wrong are low. The risk of being wrong was felt to be low as well since getting these fire regime parameters correct was not critical for the purposes of the modelling exercise.

Grassland-Forest Interface

This area includes smaller ecological zones adjacent to grasslands such as the Peace Lowland, Dry Mixedwood, and Peace River Parkland and Peace Lowland in BC. Ignition probability and fire season are both on the high end, but more rainfall and Luvisolic soils (with some Solonetzic soils) supports a moisture limited hardwood forest likely mixed historically with grassland. Physical evidence of fire history in these areas exists only on a limited basis. Very little research or data is available on fire regimes in this area. Estimate a maximum fire size of 3,000 ha and a LTFC average of 30 years, although the LTFC for areas closer to foothills are likely to be longer. Grassland-forest interface areas are among those most likely to be influenced by Indigenous Peoples and climate change. Since these areas are grassland-forest transition zones, the chances of being wrong is only moderate, and the risk of being wrong on the potential output from a modelling perspective also moderate. However, given the importance of these areas in terms of understanding the influence of climate on fire regime shits, this may represent a critical knowledge gap in the bigger picture.

Montane Forest

The Montane natural subregion in Alberta occurs only in or near valley bottoms in mountainous areas, and is typified by high lightning ignition probability, longer fire seasons, and highly variable climate. Despite being one of the smallest fire regime zones, Montane areas are disproportionately represented as regards fire history research. Workshop participants estimated a LTFC average of 40 years, maximum fire size of 5,000 ha (limited by topography), and mixed severity (from low to high). Recent research in Montane areas has shifted our perspective from assuming most fires were stand-replacing, to understanding that at least some were stand-maintaining. The influence of Indigenous Peoples on many Montane areas is widely accepted, but not well documented. The chances of being wrong about LTFC are low overall, but there are still some local gaps. The biggest risk of being wrong in this area is not necessarily linked to errors in LTFC or fire size, but rather fire severity and its relationship to other regime parameters. This remains a knowledge gap.

Rocky Mountain Foothills

This area includes the Foothills natural region in Alberta and the Sub-Boreal Foothills in BC. The Foothills is essentially a transition zone between the Boreal Plains and the Mountain Cordillera. In general, this zone becomes narrower moving north to south, reflecting sharper changes in elevation, topographic complexity, the growing /fire season, species composition, lighting ignition probability, and climate. The group agreed that the LTFC in this area was a gradient from 70 to 100 years from east to west and the maximum fire size was *circa* 200,000 ha. The group debated, but did not agree on the degree to which this area was influenced by low to moderate-severity fires (and thus remains a notable knowledge gap).

The chances of being wrong vary across this zone, with the southern half being better represented by both research and data than the northern half. In particular, in areas where the Rocky Mountain transition zone widens as it tracks into BC, the available fire history information and/or data is unlikely to capture the subtitles of regime complexity. However, it was felt there was little chance that the group has the direction of the LTFC transition wrong (i.e., that it increases as one moves from east to west). The risks of being wrong vary from low (in the south-central foothills) to high (in the north).

Alberta Subalpine

This includes all areas that lie between the Foothills and the high elevation Alpine areas. These areas tend to be dominated by dense conifer forest, including *abies*, and have the shortest growing and fire seasons, the most complex terrain, and the lowest ignition probabilities in the study area. However, as with all Cordillera areas, the sharp rise in elevation from east to west means that there is a range of these conditions from east to west. It was agreed that the eastern edge of this zone had a LTFC average of 150 years, and the western-most edge 250 years. The maximum fire size in the lower subalpine areas was circa 200,000 ha, and in the upper subalpine circa 50,000 ha. The differences between lower and upper Subalpine reflect an increase in topographic roughness, a decrease in fuel continuity, and a shorter fire season. The chances of being wrong are moderate (i.e., fewer local studies and data), and the risks of being wrong are only moderate since only the lower elevation areas of the Subalpine are commercially relevant.

Boreal Plains

This is the largest ecological zone of the study area spanning from BC to Manitoba, but excluding the Foothills natural region of Alberta. Much of this area is classic boreal mixedwood forest with a mix of softwood, hardwood, and non-forested fuel types, including significant areas of bogs and fens. The climate is continental with long cold winters, but winter snowfall can vary from high to low - the latter of which can be responsible for long-term drought conditions that significantly influence the subsequent fire season. In the summer, high-pressure weather systems are not unusual, which both a) make the available fuel more flammable, and b) generate significant ignition probabilities via lighting strikes. Knowledge of historical fire regimes in this area is moderate, but fragmented, depending on the data and methods used, and/or location. Participants expressed concern over this very large zone being representing a single fire regime. The experts suggested applying an initial LTFC average for the entire area of 50 years, but tempered with other geographic factors such as changes in elevation and/or distance to mountains. For example, higher plateaus and areas closer to mountains tend to have longer fire cycles. Participants had less confidence around these estimates in northern Alberta, northern Manitoba, and the NWT, where fewer studies and less data exist. The chances and risks of being wrong in this area vary from low to high by location.

Boreal Plains and Taiga Plains in northeastern BC

As the influence of the Rocky Mountains spreads out, and as climate changes as one moves north, the definition of this large transition zone becomes more challenging. These areas are neither classic cordillera nor purely continental. Moreover, the climate, physiography, and vegetation continually change from east to west, and north to south. The LTFC estimates for this area was assumed to be an average of 100 years across the entire region, with 80 years in the southern tip to align with estimates from the Alberta Foothills region, and longer LTFCs closer to the NWT border due to a shorter fire season. As above, latitude and the elevation and distance to mountains could and should be used to fine-tune this, with longer fire cycles in higher plateaus and areas closer to mountains. Fire size was assumed to be similar to the Boreal Plains. The chances of being wrong (in this case plus or minus 25 years) are moderate to high, and the risks of being wrong moderate.

Subalpine in northeastern BC

This is known in BC as the Boreal Foothills NDU (Natural Disturbance Unit) but shares many attributes with the subalpine areas in Alberta. This area is typified by environmental, vegetation, lighting ignition, and climatic gradients from east to west, and low to high elevation. The workshop group agreed that the LTFC ranged from 150-250 years from east to west. There was thought to be only a moderate chance that NRV does not lie in this 100 year range, and the potential risks of being outside this 100 year range were considered low given the lack of industrial activity in this area.

Boreal Shield

This area includes a large part of northern Saskatchewan, and a small part of northeastern Alberta, but excludes the shield area of Manitoba. The climate in this zone is continental, which means it is prone to long-term droughts and blocking-high weather systems that bring both high fire ignitions via lighting activity and occasional extreme fire weather conditions. However, fuel continuity in this area is intermittent due to the presence of both exposed bedrock and open water. LTFC in this area was thought to be longer than the 50 years in the Boreal Plains, but not significantly so. The group suggested increasing LTFC by at least 10 years, and perhaps more further north (due to a shortened fire season).

Given the good availability of both recent and pre-industrial fire records for this area, most of the participants felt that this estimate could be out by 10-20 years at most, and thus the chances of being wrong are moderate to low. The risks of being wrong vary depending on one’s perspective. From a forest management perspective, the risk is low because there is no management activity in this area. From a wildlife perspective, the risk is high because this area has woodland caribou, and if we are wrong about historical fire regimes in this area, it could have a significant impact on our understanding of the historical habitat requirements of this species. This is thus a significant knowledge gap, and the outcome could have a significant impact on how caribou habitat is managed everywhere in the boreal.

Manitoba

The partnership arrangement of LandWeb is such that only a relatively small section of Manitoba lies within our area of interest for this project; only that portion of the Boreal Plains that lay to the east and south of Lake Winnipeg and Lake Winnipegosis. However, this relatively small area is another one that likely has a complex fire history because of the influence of the lakes on climate, physiography, vegetation, and the proximity to the grassland-forest interface. Given that this area is moderately well represented by local fire regime research, participants agreed to LTFC averaging 30-60 years, and generally corresponding to elevation, major soil types, and both distance and direction to major water bodies. No estimates of fire size or severity were suggested. While there is excellent local knowledge available on historical fire regimes, some geographical gaps remain. Confidence in the mapped estimates thus varies from low to high depending on the location of local studies. The potential risks of being wrong are moderate to high, only because of the short the LTFC estimates.

Northwest Territories

This region captures all areas of the study area north of the 60th parallel (Figure 1). This is another area that the workshop participants suspected of having a moderately complex fire history because of the influences of Great Slave Lake on climate, soil and forest development, and physiography. It is also the only landscape in the study area with intermittent areas of permafrost, and the highest proportion of wetlands. Not surprisingly, this is the geographic area for which the group had the least confidence in making historical fire pattern estimates. The default position was to either a) use the 90-year default LTFC value, or b) extend the best information available from BC, Alberta, and Saskatchewan to the north, with the following caveats: 1) the fire season is very short, and 2) there will be a moderating and (directional) weather influence from the lake. Given the many knowledge gaps, the group was reluctant to offer even an initial estimate of LTFCs for this area - beyond agreeing that LTFCs would extend north from three provinces using the ecological zones as guides, and with the 90-year default in mind.

Although no specific LTFC estimates for NWT were offered, the group did agree that LTFC would be influenced by a) distance and direction from the lake, b) elevation, and c) distance to the mountainous areas to the west. This area has significant knowledge gaps in terms of all aspects of historical fire regimes, and both the chances and risks of being wrong cannot be evaluated without LTFC estimates.

4.3.5 Workshop Summary

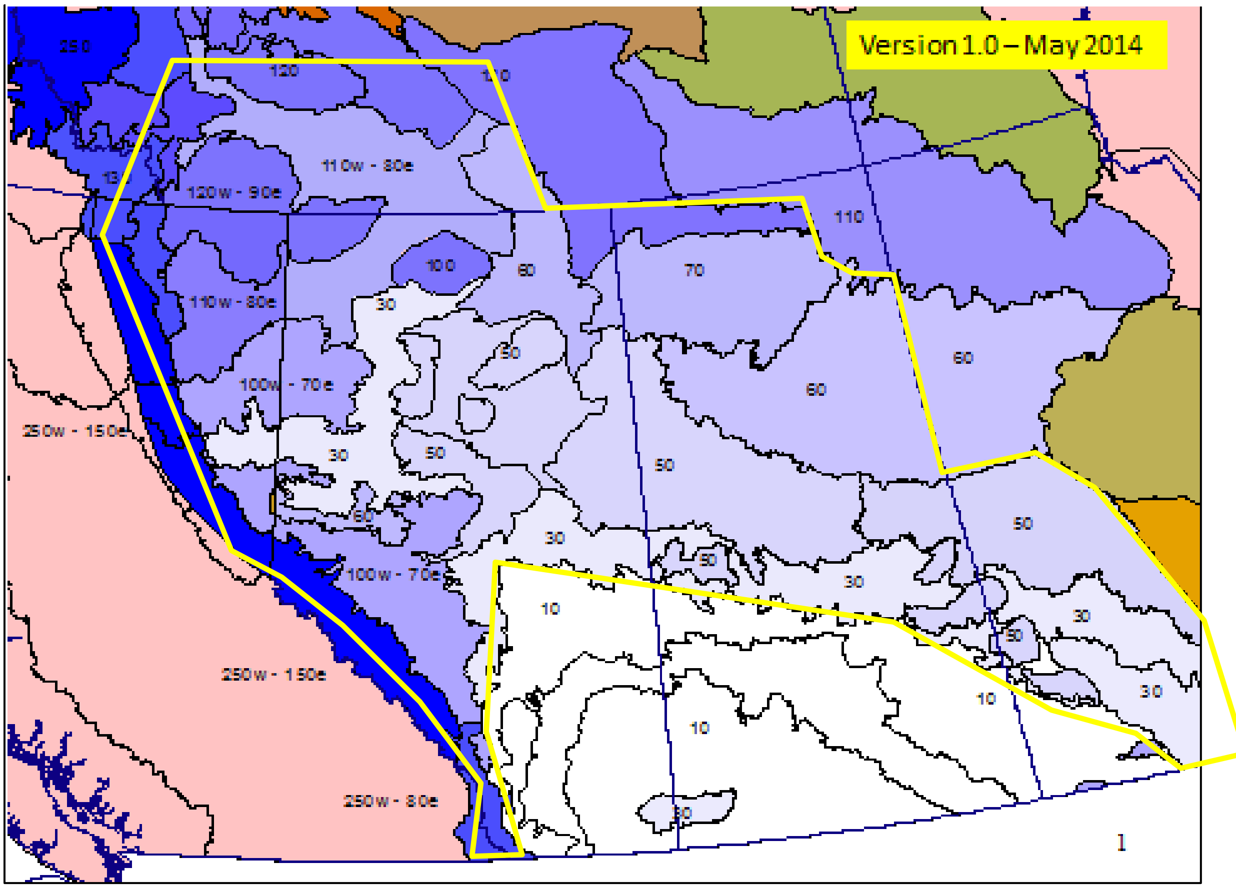
The second day of the workshop generated a significant amount of qualitative and qualitative data, all of which we wanted to record and summarize. It is noteworthy that some of the workshop output was based on consensus (i.e., there was no disagreement), while other output was based on agreement (i.e., most, but not all agreed).

1) There was consensus that ecological zones of Canada were the most likely to represent unique fire regime zones.
2) There was consensus that most important fire regime parameter to capture was the long-term-fire-cycle (LTFC).
3) The group generated LTFC estimates for the entire study area, starting with areas of high confidence from direct evidence, and working towards those areas with the most gaps.
4) Agreement on the LTFC numbers was high (80-90%), but not unanimous. A minority of experts felt that the LTFCs were as much as 300% higher, depending on the area.
5) There was consensus that while some evidence exists on fire size and severity within the study area, time and resources were insufficient to attempt including either parameter in the creation of the fire regime map at this time.

6) There was consensus that a first approximation of a pre-industrial LTFC map of the western boreal was an important contribution to both science and management.

In an attempt to standardize and summarize the workshop output, version 1.0 of a LTFC map of western boreal Canada (Figure 7) was generated by the author based on a) the workshop notes from the mapping exercise, and b) the collective notes of the workshop team. This required some assumptions and interpretations to translate a combination of data and narrative into a hard map format. In the case of missing data (e.g., NWT) data were extrapolated from other areas, presented as ranges, and kept close to the 90-year default as suggested by the workshop participants. Where possible, the author also integrated and interpreted decisions by the group regarding how LTFC varies with elevation, latitude, longitude, and topographic complexity within the ecological zonation.

Figure 7. Version 1.0 of the long-term fire cycle (LTFC) map for western boreal Canada that was generated from the workshop participants.



Note also that Figure 7 also includes LTFC estimates from outside the main study area. This was done only to provide some spatial buffers for a model that will (likely) need to account for how fires burn into and out of the study area. The chances are high that the LTFCs being wrong in any and all areas outside of the main study area.

4.4 Developing a Collaborative LTFC Map Using Experts

By D.W. Andison

The logical next step in the expert workshop process would have been to a) summarize and distribute the LTFC output based on the workshop input, and then b) ask the participants to provide feedback on the map as interpreted (*sensu* Delbecq et al. 1975). More specifically; Did the map accurately reflect the discussions and points of agreement?; Were the interpretations appropriate?; Did the interpretations accurately represent the intent of the advice? In theory, integrating this feedback into the Figure 7 would create a LTFC map that would meet or exceed the standard of *best available knowledge*. However, there was an opportunity to do better.

Stopping at an edited version of V1.0 of the LTFC map assumes;

a) The workshop output accurately represented the thinking of the entire group (*sensu* McBride and Bungmann 2012) none of whom were influenced by more vocal participants. As Drescher et al. (2013) suggests "*Group think and individual personalities prove powerful in group settings*".
b) The opinions, advice, data, and knowledge of experts unable to attend the workshop offer no additive value to the output, and
c) There is nothing more to be learned from a better understanding of disagreement among experts. Krueger et al. (2012) suggests that disagreement among experts is critical information.

Thus to take full advantage of the workshop output, the final stage of this project was designed to expand the feedback request from workshop participants to a broader, anonymous, and inclusive feedback mechanism designed to generate multiple versions of the LTFC map.

This process describes an adapted version of the *Delphi* method (Clayton 2006) which is designed to collect, process, and resubmit information to and from experts multiple times (Winzenired, 1997). In this case, the process of summarizing, requesting and integrating new perspectives, data, and opinions was repeated several times over the next four years using the same list of 34 experts (Table 2), and using the LTFC estimates from Figure 7 as a baseline. The idea was to keep the conversation going (from the workshop), hopefully towards an even more defendable, accurate, and precise outcome.

4.4.1 Methods

Time and resources allowed for four versions of the LTFC map. The instructions to the list of 34 experts each time were to provide any specific evidence (that may have previously been overlooked) and/or their opinion in support of or against the LTFC estimates on the most recent fire regime map.

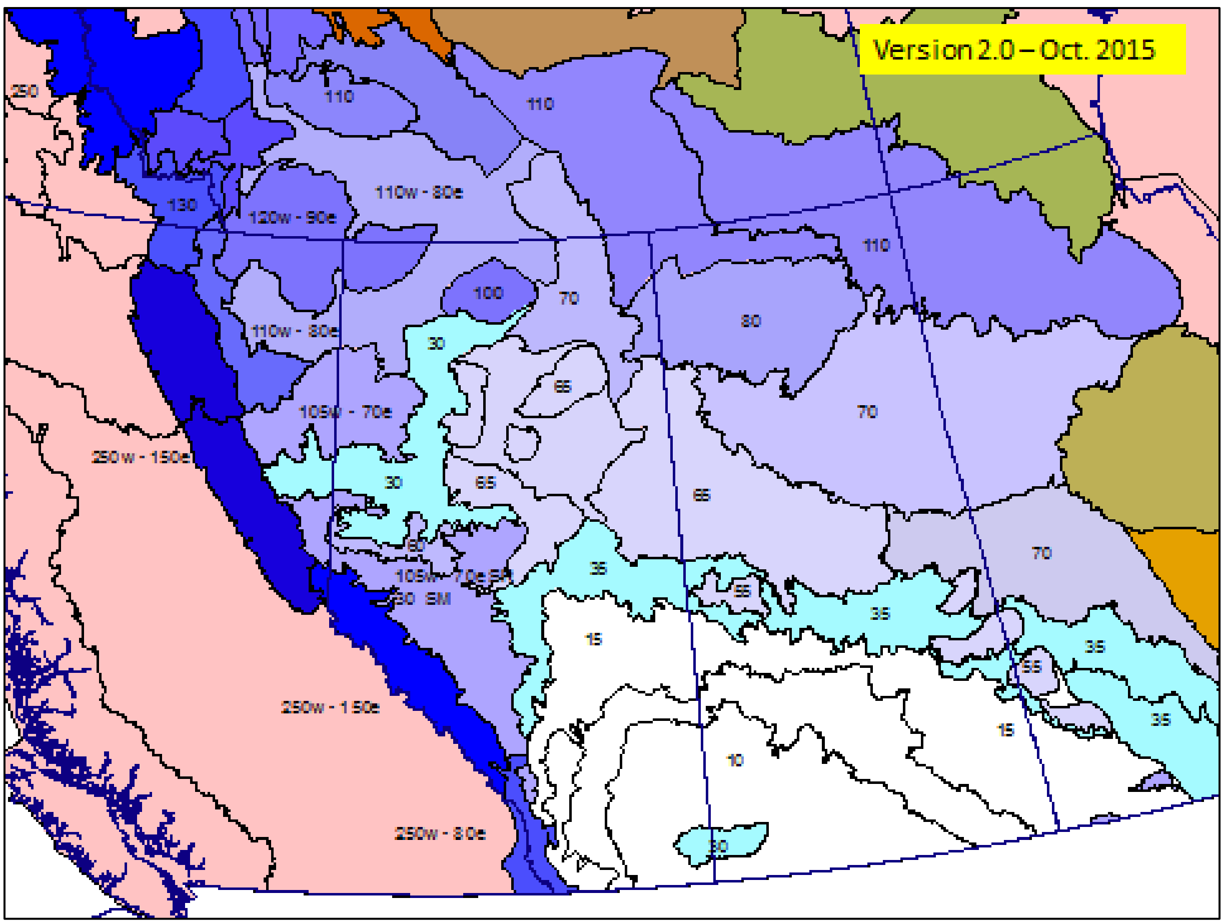
4.4.1.1 LTFC Map V2.0

In May of 2014, a shapefile and image of version 1.0 of the LTFC fire map was distributed to the full list of 34 workshop invitees (Table 2). The file was accompanied an explanation of the project objectives, an overview of the workshop process, and an explanation of how the workshop process arrived at V 1.0 of the map. Also included was an invitation to provide feedback on any and all aspects of the map that they were comfortable commenting on, along with any explanations and/or new evidence they were willing to provide. This gave workshop participants the opportunity to anonymously consider the interpreted map product over several weeks, and a chance for other experts who did not participate in the workshop to offer their opinions and evidence.

The main objectives of this second iteration of the LTFC map were to a) ensure that the information from the workshop participants was reflected accurately by the map, b) ensure that outstanding questions and interpretations from the workshop were addressed in the map, and c) integrate expertise and input from those not in attendance.

Over the next 10 months, there was considerable feedback to the LTFC map from both workshop participants and other experts. Most of the changes between versions 1 and 2 were relatively small, involving shifts of no more than 25 years. However the changes were ubiquitous and most resulted in *increases* to LTFCs (Figure 8).

Figure 8. Version 2.0 of the long-term fire cycle (LTFC) map for western boreal Canada generated from feedback to Version 1.0.



Some of the more notable changes between V1.0 and V2.0 of the LTFC map included:

- Increasing LTFC by 10-20 years across much of Saskatchewan, and parts of Alberta and Manitoba. This was a result of both feedback from experts who were not at the workshop, and new feedback from some original workshop participants. It was also pointed out that the LTFC of northern Saskatchewan - based on 60+ years of pre-industrial fire history records - averaged 72 years, which fundamentally changes both the chances and risk of being wrong for this area.
- Some changes were made to the LTFCs of the forest-grassland interface, but based on (often conflicting) opinions. As the literature review revealed, this ecotone remains one of the bigger knowledge gaps in terms of direct evidence.

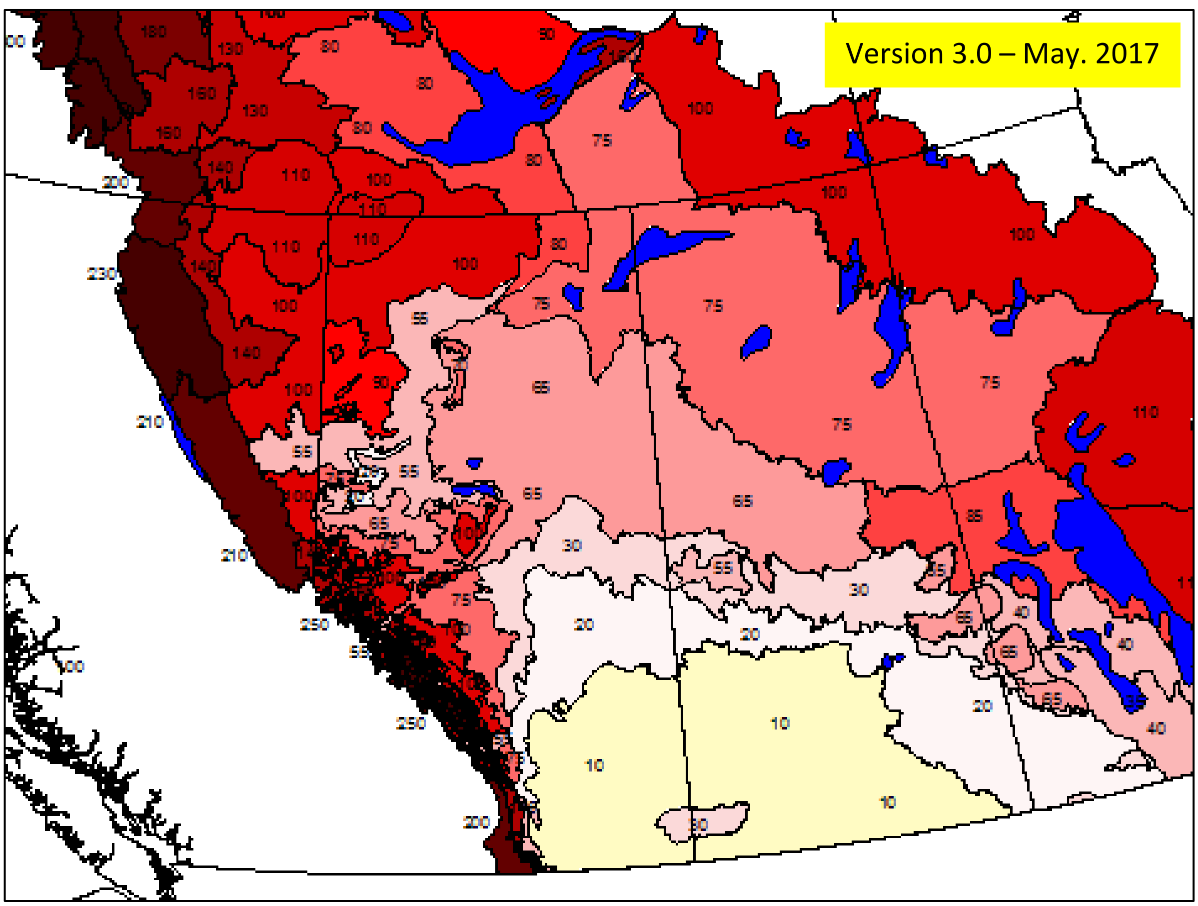
4.4.1.2 LTFC Map V3.0

After compiling all of the comments and input from Version 1.0, a shapefile and image of V2.0 of the LTFC map was sent out to the same group of experts in October of 2015 with the same instructions to offer expert advice and opinion on any or all of the LTFCs suggested, and/or the zonation system.

The changes to the LTFC map for this round (Figure 9) were largely refinements to the ecological / fire regime zones:

- In the NWT, the national ecoregions were replaced with the most recent ecological units defined by the territorial government and local LTFCs adjusted downwards based on local fire record data and expert opinion.

Figure 9. Version 3.0 of the long-term fire cycle (LTFC) map for western boreal Canada.

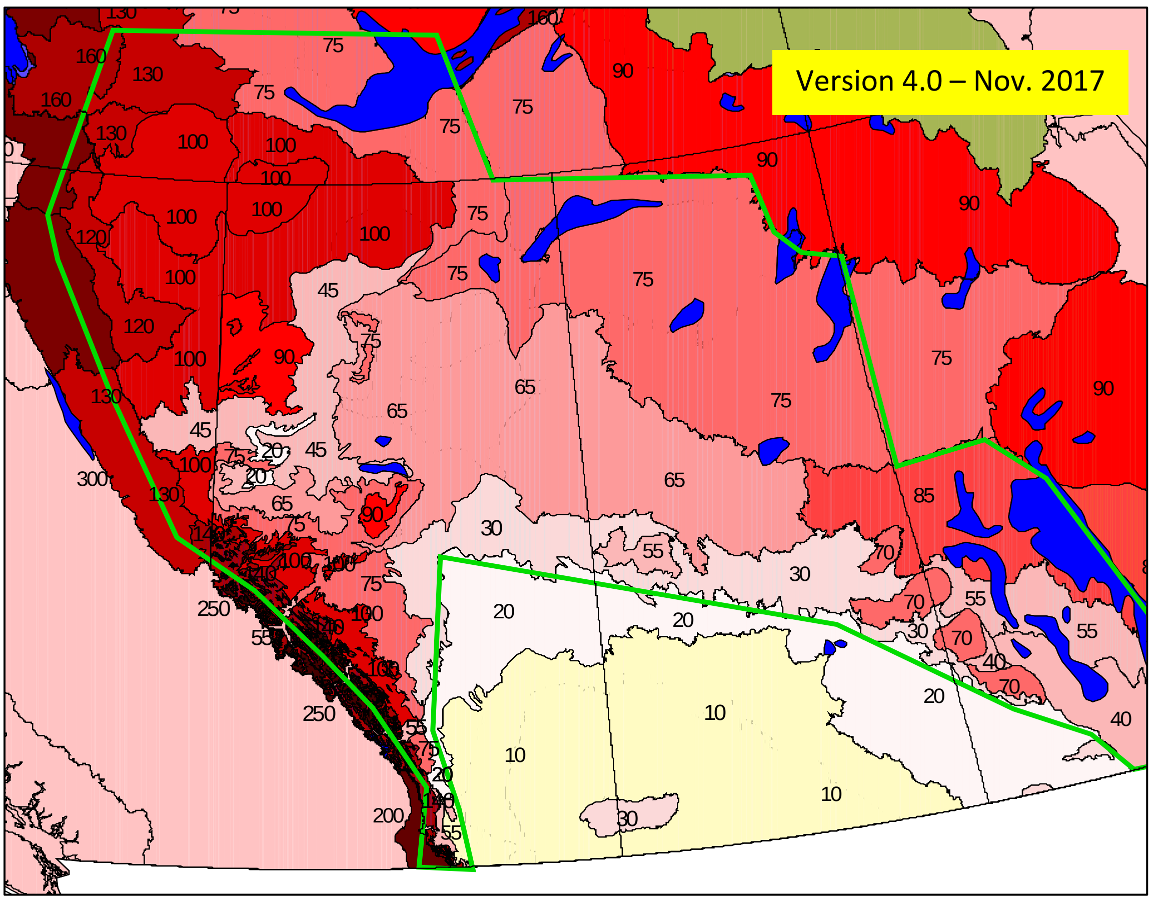


- In Alberta, the Foothills natural regions (NRs) were further refined into natural subregions (NSRs) and the ranges used in previous versions replaced with long-term averages.
- LTFCs in Manitoba were all increased slightly.
- Other adjustments to LTFCs in this round of comments gathered areas together with lower confidence levels into single estimates rather than give a false sense of precision (particularly in the northwestern bits of the study area).

4.4.1.3 LTFC Map V4.0

In May 2017, a shapefile and graphic of V3.0 of the LTFC map was distributed to the same team of fire regime experts with the same instructions. The fourth version of the LTFC map was compiled in November of 2017 based on the feedback to that point (Figure 10).

Figure 10. Version 4.0 of the long-term fire cycle (LTFC) map for western boreal Canada.



Version 4.0 of the LTFC map had the least number of comments and thus the fewest adjustments of any previous map. It mostly further amalgamated areas of similar LTFCs for areas in which there was lower confidence (e.g., NWT, northeastern BC, and northwestern Alberta), although some minor, mostly downward shifts in LTFCs were noted.

This was the first map in which most of LTFC changes were reversed from previous LTFC changes. This suggests that most of the experts were at this point only in disagreement around some small range. This phenomenon is common in Dephi studies (Drew and Perera 2011), and suggests that while further iterations may result in subtle changes, the chances of those changes contributing to a significantly higher level of confidence is minimal (Drescher et al. 2013).

4.5 Evaluating the LTFC Map Output

Evaluating expert knowledge is challenging when no other forms of evidence are available. However, remember that in this case there exists a substantial amount of other evidence, and the LTFC maps generated are an amalgamation of expert opinion and direct and indirect evidence. To evaluate such output, the standard of *validation* is often augmented with *plausibility* – which addresses whether the elicited knowledge aligns with expectations based on related and/or more fundamental rules or laws (PItchforth and Mengersen 2013). In other words, is the output consistent with other evidence that is borrowed, extrapolated, or apply on a more general level (Drescher et al. 2013)?

We were fortunate to be able to evaluate the output from this project using both validation and plausibility criteria.

4.5.1 Validation

Despite many gaps, we are not bereft of direct evidence of pre-industrial LTFCs for the study area. For example, it would be difficult to argue with several decades of pre-industrial fire activity in both northern Saskatchewan and the southern NWT – except to note that if anything they underestimate historical fire activity. There also exist several smaller-scale TSF maps in the central Alberta foothills, the western edge of the forest-grassland interface in central Saskatchewan, and north-eastern Alberta. There also exist a large number of small dendrochronology studies in Manitoba, central Saskatchewan, and the Alberta foothills. The details of these data and the findings from the literature review will not be repeated here, but Version 4.0 of the LTFC map is generally supported by most of the available pre-industrial evidence - within a 5-20 year window.

4.5.2 Plausibility

The standard of *plausibility* is less rigorous than that of *validation,* although multiple lines of evidence can make plausibility more powerful. Recall that plausibility is primarily concerned with consistency of evidence. In this case, there are several possible relevant plausibility tests.

4.5.2.1 Major Vegetation Types

Existing vegetation types in part represent long-term disturbance history by way of the interaction of species characteristics and fire activity (Wirth 2015). For example, *populus* and *pinus* species dominate on landscapes with relatively high fire frequency (i.e., <90 years) because of their aggressive and specific evolutionary attributes, including root sprouting and serotinous cones (Larson 2010). Black spruce (Sb) can regenerate both through layering and direct seeding, and tends to peak on landscapes with LTFCs of around 90 years (Bouchard et al. 2008). On the other hand, white spruce are only able to dominate on landscapes with longer fire cycles (ie.>200 years) and *abies* species dominate only when LTFCs are in excess of 300 years (Lesieur et al. 2002).

While much of the study area is dominated by mixedwoods (which can and do associate with a range of LTFCs) the patterns of species dominance changes over space are informative. The entire southern boundary of the study area, and parts of northwestern Alberta, border grasslands with chernozemic soils. We know with high certainty that grasslands have LTFCs of 10-20 years, and only in rare cases do they support forest (Strange and Parminter 1980). Immediately adjacent to grasslands is an ecotone between grassland and forest (i.e., parkland), much of which is considered marginal for growing forests, and largely dominated by hardwoods (Bailey and Wroe 1974). These areas have LTFCs of 30-45 years on Version 4.0 of the LTFC map.

The next section will discuss how major vegetation types interact with climate and geography.

4.5.2.2 Climate and Geography

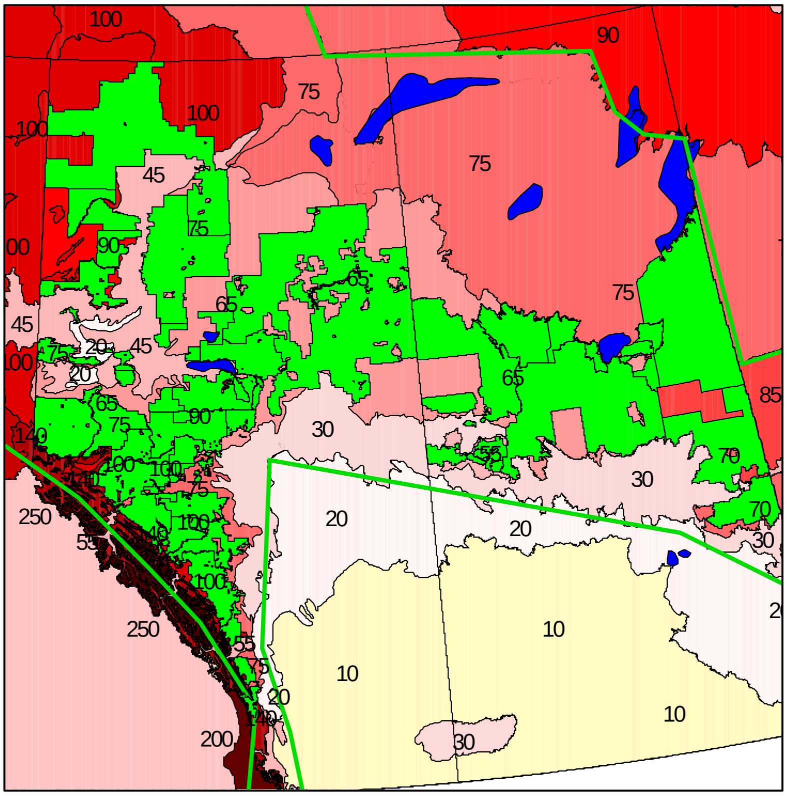
The study area is represented by two major climatic - geographic types; Cordillera, and Continental. The western edge of the study area includes the eastern edge of the *Cordillera* region, which in this case includes the Rocky Mountain foothills. Climate in the cordillera can change rapidly over very short distances. As one moves from east to west the fire season is longer, lighting activity decreases, and topography becomes more complex – all of which suggest that one would expect LTFCs to increase significantly across this same gradient. Consistent with this, the LTFC map show LTFC estimates of 140-250 years (from east to west). Note that the direction and magnitude of this LTFC range is also consistent with observed species shifts from pine to white spruce to *abies*.

Most of the study area is *Continental*, associated with large, flat to rolling land areas with hot summers and cold winters (in North America that is). Across the continental portion of the study area, there is little or no *abies* (<1%) very few pure white spruce stands (5%), a modest amount of pure hardwood (11%) and lowland Sb (21%), with the rest in mixedwoods, very broadly suggesting LTFCs of no less than ~40 years, but no more than ~140 years. We also know that changes in elevation, precipitation, temperature, growing season, major vegetation types, and fire season in Continental areas are often quite subtle. All other things being equal, one would not expect dramatic changes to historical fire regimes across Continental areas, and those that do occur would be in response to relatively modest changes in elevation (i.e., highlands and plateaus) fuel-continuity (e.g., the Canadian Shield), or adjacency to major water bodies. The LTFCs from Figure 10 in the boreal plains and boreal shield in the study area range from 55-100 years, which is consistent with these plausible observations.

4.5.2.3 Forest Productivity

Forest management agreement areas (FMAs) are ultimately defined by their viability in terms of providing a sustainable timber supply. As such the location and size of FMA areas must provide sufficient wood fibre to one or more mills. Such calculations are based on the best available knowledge of past and future growth and yield. Neither a government, nor a private company would propose or agree to FMA boundaries that could not sustain a forest of reasonable growth and mature tree size potential. In support of this notion, an overlay of the FMA map for (only) Alberta and Saskatchewan with Version 4.0 of the LTFC map reveals very few parts of any FMA areas include regime zones with LTFCs of less than 50 years (Figure 11), presumably because such areas would be unsustainable in terms of wood supply.

Figure 11. Overlay of V4.0 of the LTFC map with forest management area boundaries for Alberta and Saskatchewan.



4.5.2.4 Forest Inventory ages

As described above, all forest inventories collect information on stand age. As a part of background information gathered for previous spatial modelling exercises in the study area, ages from forest inventory data have been used to estimate a one-time, pre-industrial (circa 1950-1970) landscape snapshot. This is done using the *roll-back* technique, which a) back-casts the entire landscape to a point in time where fire control and harvesting impacts are minimal, and b) replaces all of the disturbance activity after that point in time with either the known, or the most likely, pre-disturbed age (Vilen et al. 2012). As previously discussed, forest inventory ages lack precision, but have minimal bias (Andison 1999a and 1999b) and thus serve, at the very least, as reasonable plausibility tests.

The average (pre-industrial) ages have previously been calculated for a total of seven management areas within the study area, including Mistik Management (59 yrs), Hinton Wood Products (76 yrs), Alberta Newsprint Company (75 yrs), AlPac (62 yrs), Tolko (92 yrs), Sundre Forest Products (78 yrs), and the Peculiar-Merton forest area in BC (96 yrs) (references available upon request, and only with permission). Note that all of these re-constructed average forest age estimates are consistent with, but slightly shorter than their respective LTFC estimates in V4.0 of the map.

4.6 Confidence Levels in LTFC Output

This project revealed two levels of disagreement among experts. Most (~85%) of the experts, along with the vast majority of the direct and indirect evidence, generally supported the LTFC numbers in Version 4.0 of the map. The second level of disagreement represented a small number of experts who believed that the LTFCs of the study area were two to three times higher than those captured in Figure 10.

The second, more significant level of disagreement is difficult to capture in terms of confidence levels. Unfortunately, the opportunity to explore this divergence of opinion was limited by the lack of participation in the collaborative mapping exercise from those individuals who expressed fundamental disagreement with the larger group on LTFCs at the workshop. However, the sheer size of the disagreement suggests that the possibilities are limited, and relevant. First, it is possible that the minority group is correct, and LTFCs are much longer than those in Figure 10. Most of the evidence in support of this comes from the post-industrial era, which is problematic on several levels. One of the complicating factors in this debate is the impact of fire control. *Post-industrial* LTFCs over the last 3-4 decades calculated from either/or wildfire and forest inventory age data are indeed extremely long (e.g., Boulanger et al. 2012). While there is less debate over whether fire control activities have been effective (e.g., Chavardes et al. 2018) quantifying its influence is challenging. Reconstructing decades of individual fire behaviour is currently beyond our ability, which means that the impact of fire control (ironically) comes down to expert opinion. A second, related possibility for the wide discrepancy in expert opinions in LTFCs is that this is not a simple case of a difference of opinion based on a shared understanding of baseline science, data, and other evidence (such as fire control impacts), but rather there may be some other unresolved, more fundamental issues in play (e.g., lack of agreement on definitions, personal bias, knowledge momentum, etc.).

The point is, the reasons for this second level of disagreement are likely *fundamentally* different than those responsible for the first level of disagreement. If or how this second level of disagreement should be captured in terms of confidence levels in V4.0 of the LTFC map is unclear (but see ahead to the Discussion).

Capturing the first level of disagreement - among the majority of the experts on the LTFC map - is not nearly as challenging. Overall, it is unlikely that Figure 10 *exactly* captures the long-term, pre-industrial fire cycle averages for each and every part of the study area. However, the chances of Version 4.0 of the LTFC map being *tragically* wrong (i.e., by more than 30% in either direction) are relatively low – notwithstanding the second, more significant level of expert disagreement discussed above. Having said that, confidence levels in the LTFC numbers varies across the study area.

The area with the lowest confidence of LTFCs was the northwestern part of the study area, including much of BC, the northwestern corner of Alberta, and the southwestern corner of NWT. Note that in the final version of the LTFC map, much of this area is represented by a standard 100 year fire cycle, largely defined by the opinions of the BC and NWT fire regime experts, and available studies and data. The challenge with this area is that it functions largely as a wide transition zone between Cordillera and Continental. The sharp, more predictable patterns of fire activity noted in the central and southern foothills of the Cordillera no longer apply, but nor does this area have a true Continental climate. So it is likely that the fire regime of this area is more complex than assumed. The nature of possible LTFC errors in this area could be captured in one or both of two ways. First, the LTFC averages on the map may simply be wrong by some significant degree. (e.g.., by more than 25 years either way). A second possibility is that historical LTFCs are more accurately captured by a finer-scale zonation system. For example, LTFCs may range between (say) 80-120 years by area (much like the Foothills), In this case, perhaps the existing zonation was unable to represent important and more subtle LTFC changes.

A second area of concern as regards confidence levels in the LTFC estimates is the eastern side of the study area, including parts of Manitoba and the eastern edge of Saskatchewan. The combined influence of large water bodies, variable terrain, and the presence of the grassland-forest ecotone suggest that this is another area that likely has a complex fire history. It is fortunate that this area is well represented by direct evidence of historical fire activity. However, most of this evidence is local in nature, which is difficult to extrapolate to adjacent, larger areas with complex elements in play.

A third, but more general-level concern in terms of confidence levels of the output of this project is the degree to which LTFCs do/should capture lower severity fires. Although most, if not all of the study area is thought to have a "stand-replacing" fire regime (Johnson 1992), recent evidence suggests that periodic low and moderate intensity fires occurred across the entire study area (e.g.,Rogeau et al. 2016). This concern may not necessarily directly influence LTFCs, but could indirectly influence how LTFCs are defined and interpreted. For example, should we consider fires of all severity levels as equals? This remains a key knowledge gap – for both scientists and managers.

5.0 Discussion

This was a unique and unprecedented project on several levels. First, it developed a spatial pre-industrial fire regime zonation for western Canadian boreal. Although geographic fire regime frameworks have been previously suggested for the boreal at this scale (e.g. Boulanger et al. 2012), none reflected pre-industrial conditions.

This project then populated the entire 125 million ha fire regime zonation map with pre-industrial long-term-fire-cycles (LTFCs). This is the first such map of its kind. These data can be used as a) best available / defendable scientific reference material or spatial stratum for related (fine or coarse filter) research, management, and policy development activities, or b) a 'straw-man' first approximation of a pre-industrial fire regime framework upon which future fire research projects can be built. For example, future fire research activities can and should focus on the areas with lower LTFC confidence, and developing estimates for other fire regime attributes (e.g., fire size and severity), or even expanding the size of the study area into other parts of Canada.

This project was also unique in terms of process. While literature reviews, and direct and indirect scientific studies are common tools for researchers, integrating these with expert opinion to create a blended final product represents a methodological first for the Healthy Landscapes Program - and Canadian fire history studies in general. Moreover, the use of experts proved to be both powerful and productive. Consider that the only other – more typical - way of generating a similar output would be via a single individual (expert) solicited to make all of the decisions of filling gaps, extrapolating knowledge, and filtering different lines of evidence. Regardless of the qualifications of that individual, the output would be highly scrutinized and almost certainly require at least one round of feedback from 2-3 independent experts. This project went far beyond that.

In terms of the quality and quantity of project output, the original plan was to capture multiple attributes of fire regimes across the study area, specifically targeting fire frequency, size and severity. While it was unfortunate that the final product did not include all of these parameters, the experts agreed on several things:

a) Fire frequency (expressed as LTFC) was the most important fire regime attribute to capture, and the one with the greatest amount of evidence,
b) There was not enough direct and indirect evidence to fill in gaps with any reasonable degree of confidence for any other fire regime attributes beyond very general and simple rules and relationships, and,
c) Even if the knowledge of other regime attributes existed, the time required to develop these additional layers was beyond the time and resources of a two-day workshop.

In the end, the development of a pre-industrial LTFC map for the western boreal is a considerable and unique accomplishment on its own merits.

This was also a valuable study for better understanding where and to what degree scientific opinion varied on this topic. As discussed above, this project revealed two levels of disagreement. Most of the experts supported the LTFC numbers in Version 4.0 of the map to within plus or minus 5-20 years, which was also consistent with most of the direct evidence. A second level of disagreement suggested that the LTFCs in Version 4.0 of the map were up to three times higher. Disagreements among experts when and where direct scientific evidence is imperfect are not uncommon, and the details of disagreement provide valuable insights (Krueger et al. 2012). In this case, the second (more significant) level of disagreement is the more interesting and informative. The question is: How is it possible for content experts to disagree by such a wide margin?

There are several possible explanations for this phenomenon. First, it may reveal a more subtle level of miscommunication, perhaps as it relates to the minutia of terminology, definitions, scale (both time and space) or output format / expectations. To this last point, I mean that perhaps agreement would have been higher if the workshop group was required to consider LTFC along with fire size and severity as a package. The relationship between frequency, size, and severity is generally understood and accepted (e.g., Parks et al. 2014), a common discussion point among workshop participants, but otherwise poorly documented in terms of specifics.

Another possible reason for the discrepancy between the opinions of the two groups of experts could correspond to a strong bias based on (shared) personal experiences, either for or against a specific method, data type, study, or even an individual. Like everyone else, scientists will tend towards, and are more likely to defend, that which they are most familiar with (Krueger et al. 2012).

The opinion gap could also be due to sheer intellectual momentum. The science of studying fire regimes is not new, but the interest and support for fire regime research has increased significantly over the last 10-20 years, and the rigour of some of the methods has improved substantially. Once we get used to thinking of something as being one way, it can sometimes take a substantial amount of evidence to get us thinking of it as being another way. Note that this explanation could apply to either or both LTFC "camps".

Lastly, it is possible that the minority of experts are right, and pre-industrial LTFCs are 2-3 times higher than those in Figure 10. While this may be the least likely explanation, it is still possible.

Regardless of the reason, the next question is if or how to acknowledge and integrate the confidence level differences. Technically, disagreement is possible to capture using Bayesian statistics (Kuhnert et al. 2010), which allows for a more robust evaluation of risk (of being wrong). A simpler and more common response when agencies are faced with different answers is simply to split the difference. In this case, that would mean increasing the LTFC assumptions in Figure 10 to a more "acceptable" level. The problem with this option is that it means the LTFC numbers are less defensible, since "acceptable" is entirely subjective. Moreover, given the likely reasons for the divergence, such compromises are less likely to be right than either extreme.

A third possibility is to accept and adopt the output from the majority of evidence captured in Figure 10 as the *best available*, but with a) a full acknowledgement of the types and levels of uncertainties, and b) a commitment to address the discrepancies over time through further research, workshops, and/or sensitivity analyses. Sensitivity analyses bracket a centroid estimate of a key parameter (on either side of the centroid) to evaluate its influence on specific behaviour. For example, how do changes in LTFC by plus or minus (say) 50 years influence the amount or patch size of old forest? A sensitivity analysis does not resolve disagreements (i.e., debates about pre-industrial LTFCs are entirely separate), but rather help us better understand the risks of being wrong. It also creates a clean break between science and management, and thus does not compromise the concept of *best available knowledge*.

The final option is to avoid the use of LTFC information in policies and practices until there is either 100% agreement from the scientific community, and/or incontrovertible direct evidence of LTFCs for the entire study area. Given the desire and commitment to use NRV to help guide forest land management, and the associated costs, this is not a very practical option. The fact is that a large portion of the study area is currently being actively managed, and the entire study area is of interest from a range of values including carbon, caribou, fire, MPB, water, and biodiversity. The decision to avoid or reject imperfect evidence in favour of waiting for something better is unlikely to be optimal for either the health of the ecosystem, or for any of the associated social and economic values.

6.0 Conclusion

The original objective of this project was – ***to develop a first approximation summary of the pre-industrial (NRV) fire regime attributes of the western boreal forest of Canada based on the best available knowledge***. In a perfect world, this would require tens of millions of dollars, and several decades of direct, focused, and well-published research. The problem is that policies and practices that rely on this knowledge cannot wait for answers. This project addressed that need by broadening the definition of "evidence" to include alternative and previously poorly acknowledged/documented knowledge sources. This project recognized and included knowledge from direct, published scientific evidence, indirect (i.e., unpublished) scientific evidence, historical unpublished data, stories and photos, and the opinion of experts.

This unique journey ended with the creation of a pre-industrial fire regime map for the western boreal, populated with long-term-fire-cycles (LTFCs). Included in the output is an objective evaluation of the risks of some or all parts of the LTFC map being in error and an open discussion of where and how expert opinion differed.

The effort required to coordinate and compile the various elements of this project was substantial. Moreover, the quality of each element stands on its own merits. Although it is unfortunate that the only fire regime attribute captured in map form was LTFCs, the project process clearly demonstrated how and why including other attributes was an unrealistic goal. Moreover, the zonation map, and the LTFCs that populate it represent critical, unprecedented new baselines / benchmarks for others to use and build on.

In the end, V4.0 of the LTFC map clearly represents *best available knowledge*. It is hoped that this first version of such a map will not only provide a solid foundation for policy and management, but inspire other researchers, managers, and policy-makers to continue to question, explore, and improve the map and the associated fire regime attribute matrix.

This project also pushed the boundaries of traditional definitions of "evidence", and at least began a discussion of the necessity, and the challenges of dealing with imperfect knowledge. These are new perspectives and skills that are likely going to be useful moving forward, and entirely consistent with the principles of EBM.

7.0 Recommendations

To be clear, and as a reminder, the sentiments expressed in this section represent those of the author, and do not necessarily reflect those of either fRI Research, or any members of the HLP team:

1) Accept Version 4.0 of the LTFC map as the *best available knowledge* of pre-industrial fire regimes for both managers and regulators. This product far exceeds anything previously developed as regards both quality and quantity. Avoiding integrating this information into policy

and practice in the near term is not recommended. Best available knowledge is by definition a moving target, so waiting for something better is illogical. Moreover, the option of choosing to not act based on new information may seem to be consistent the *precautionary principle*, but in this case is may be the most damaging option to the ecosystem over the both the short and long term.

2) Change the narrative when talking about "knowledge". As a group, forest land managers and regulators have been guilty in the past presenting incomplete or partial knowledge as fact. Over time, this can and has led to an erosion of trust. Rather, introduce the term *best available knowledge,* which is both appropriate and accurate.

3) Use this report and the final map to develop some next steps in terms of knowledge gaps and risks. The details of the results in this report clearly define areas of lower confidence and disagreement among experts. In other words, this report is essentially a roadmap for future fire research activities. A coordinated regional approach would be most efficient, but there may be cases where local knowledge is a priority.

4) Integrate expert opinion more often, but only with the appropriate design rigour and expertise. If nothing else, this project demonstrated the tremendous amount of knowledge fire experts hold – beyond papers, reports and presentations that is. The workshop and feedback process used in this study were the first of their kind in fire research in Canada. However, without the integration of experts, a defensible final product would not have been possible. In hindsight, our own processes could have been more effective and rigorous, and we will learn from that experience for next time. However, all of natural resources management could be learning from this project by looking for more opportunities where experts can be used to help build new knowledge.

5) Anticipate and welcome disagreement among experts. Right now, disagreement, particularly among scientists, often happens in the shadows as hearsay or dismissal, which too often forces managers and others to take sides. We need to confront, address, and document disagreement as potentially valuable information.

6) Depending on the amount and type of feedback to this final report, the Healthy Landscapes Program and/or other research groups may want to consider *at least* having a discussion of if or how to manage updates and changes to V4.0 of the fire regime map. If nothing else, this project revealed that a) almost everyone has an opinion about historical fire regimes, and b) relevant new research comes online regularly. The question is: *Is there a shared desire, or a need across the study area – or beyond = for a plan to coordinate map updates*? The form of updates could range from changing LTFC numbers or regime zones, to adding digital annotations, to expanding the depth or breadth of the map.

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