TOWARDS A PEACE-LIARD PRESCRIBED FIRE PROGRAM: PART A – RATIONALE

MAY 31, 2019

PREPARED FOR THE BC MINISTRY OF FORESTS, LANDS, NATURAL RESOURCE OPERATIONS AND R.D.
IN PARTIAL FULLFILLMENT OF CONTRACT # GS18FSJ0006
SHIFTING MOSAICS CONSULTING
FORT NELSON BRITISH COLUMBIA CANADA

Statement from BC Government: This report provides recommendations to government for a strategic approach to implementing prescribed fire in northeast British Columbia. It does not represent a position or program of government, and is intended to support discussions with Indigenous peoples and stakeholders.

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EXECUTIVE SUMMARY

The Peace-Liard Prescribed Fire Program (P-LPFP) is a critical part of the landscape of northeast British Columbia. For decades, prescribed fire has been applied to the land to support wildlife and its habitat, to improve quantity, quality and access to forage for livestock, to reduce fuel load resulting from forestry activities, and in some cases to support cultural and traditional values. In 2017, the Fish and Wildlife Section of the BC Ministry of Forests, Lands, and Natural Resource Operations secured funding to critically review and reposition the prescribed fire program into a more contemporary version to reflect current scientific knowledge, incorporate Indigenous communities, stakeholders, industry and parties with a vested interest. A series of engagement sessions were held across the Region in the Fall of 2017. An extensive literature review was also conducted of all of the relevant scientific literature, primarily peer-reviewed and published but also including historical materials. The result of this collaborative, pro-active, interdisciplinary, and engaging process has been a paradigm shift for the Program which has been written into two primary documents: Part A – Rationale and Part B – The Technical and Operational Plan. In developing these documents simultaneously, collaborating to mobilize all knowledge into a Program which meets multiple values and goals, the product is an evolved version of the foundational program which has been implementing prescribed fire since the middle of the past century, with a concentrated effort commencing in the late 1970's by Dr. J. Elliott and staff of the Fish and Wildlife Branch in support by the Northern Guides Association and Northeast BC Wildlife Fund.

The P-LPFP is the most important program for wildlife and its habitat in northern BC. In this Rationale, the concept of the Peace-Liard Fire Matrix (P-LFM) is introduced describing how fire can be strategically distributed through space and time across a broad landscape to meet multiple values and to be tracked and monitored to measure success. Refinement and implementation of the P-LFM requires discussion and recommendations by a variety of stakeholders including Indigenous communities, trappers and guides, Governments, and other interested parties as to the desired stocking rate, grazing capacity, and allocated animal units. These are the most critical considerations for determining the spatio-temporal distribution of fire across the landscape. Not included in this rationale are: education strategy, certification strategy, communication strategy, smoke management strategy, or approval to conduct prescribed fires.

Acknowledgements

The P-LPFP has been developed through a collaborative approach blending western science with traditional and historical knowledge in collaboration with the Fish and Wildlife Section of the BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development and Shifting Mosaics Consulting. This project was financially supported by the Habitat Conservation Trust Foundation. The authors are thankful for the extensive participation, guidance, and knowledge shared during this process with particular acknowledgement to the following sections of the BC Government including but not limited to: Range, Parks, Stewardship, Fish and Wildlife, Ecosystems, Caribou, and the BC Wildfire Service. The authors are grateful for the open and enthusiastic participation from resident hunters, stakeholders, and Indigenous community members. The authors are grateful to the international fire science community for their support so generously offered to our team. GIS lead by: Roberto Concepcion, Shifting Mosaics Consulting/iMap Solutions, with data support from: T. Button, D. Layden, and others. Standing on the shoulders of giants, we acknowledge all those who have contributed time and effort to the foundations of the Peace-Liard Prescribed Fire Program over the past century.

Citation: *Leverkus, S.E.R., Scasta, J.D., Concepcion, R.L., Lavallée, M., and K. White. 2018. Peace-Liard Prescribed Fire Program: Part A – Rationale. Shifting Mosaics Consulting, Fort Nelson, British Columbia, Canada in partial fulfillment of contract # GS18FSJ0006 for the BC Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, Fort St. John, British Columbia, Canada.*

"In order to achieve a better understanding of fire, it must be understood as an integral Earth system process that links and influences regional and global biogeochemical cycles, human activity, and vegetation patterns. Failure to develop a coordinated and holistic fire science will slow efforts to adapt to changing fire regimes and manage fire" (Bowman et al. 2009).

INTRODUCTION

Management of natural resources needs to be based on modern scientific perspectives which promote ecological processes and natural variation of ecosystems using methods and techniques that are ecologically and culturally appropriate (Parr *et al*. 2009; van Wilgen *et al.* 2007; Twidwell *et al.* 2013). A limitation to traditional management at the landscape scale is having few tools to enable management that maintains landscape level heterogeneity to ensure a gradient of habitat types are maintained and/or structured (Fuhlendorf *et al.* 2012; van Wilgen 2013). A plan is needed that has public support, is effective and efficient with limited resources, has flexible fire management approaches, is based on natural disturbance regimes, and is holistic in the agreed upon objectives by all stakeholders and interested parties (Schmiegelow *et al.* 2006; van Wilgen *et al*. 2011).

Moreover, a new paradigm is needed for landscape management and models conserving patterns and processes based on natural disturbance to achieve a greater diversity of management and biological objectives through space and time (Schmiegelow *et al.* 2006; Fuhlendorf *et al.* 2012). Such models should be based on a framework that is adaptable so that they can be altered and adjusted for implementation across many ecosystem types, depending on differing spatio-temporal scales and management objectives, including the preservation of endangered species, conservation of ecological processes, and sequestration of carbon, amongst other critical ecological and cultural objectives (Cissel *et al.* 1999; Brockett *et al.* 2001; McKenzie *et al.* 2011). In order to develop such a plan for prescribed fire in northeast British Columbia, we conducted an extensive review of appropriate literature to form a foundation which we blended with a reinvigoration of past plans to produce the Strategic Plan and the Technical/Operation Plan for the Peace-Liard Prescribed Fire Program.

Disturbance Processes

Disturbance processes are critical to ecosystem function and resilience and from an ecological-perspceictive should be integrated into management (Agee and Huff 1987; Turner *et al.* 1993). Disturbance is defined as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (White and Pickett 1985). Anthropogenic influences and natural disturbance processes result in heterogeneity (differences in vertical structure, distribution, and composition of species) across many landscape scales (from fine to coarse) and many have described heterogeneity as the foundation for contemporary biological diversity (Christensen 1997; Wiens 1997; Fuhlendorf and Engle 2001; Fuhlendorf *et al.* 2006; Fuhlendorf *et al.* 2009). Heterogeneity is important to hydrology (Ludwig *et al.* 2000; Belnap *et al.* 2005), fire behaviour (Archibald *et al.* 2005; Kerby *et al.* 2007; Fuhlendorf *et al.* 2009), grazing patterns (Senft *et al.* 1987; Fuhlendorf and Engle 2004; Fryxell *et al.* 2005), soil aggregate stability and nutrient cycling (Bird *et al.* 2002; Augustine *et al.* 2003; Anderson *et al.* 2006), ecosystem stability (Holling and Meffe 1996; van de Koppel and Rietkerk 2004), species invasion (Deutschewitz *et al.* 2003; Cummings *et al.* 2007), and wildlife conservation including amphibian thermal and disease ecology (specifically boreal toads; Hossack *et al*. 2009 and 2013), raptor and grassland bird conservation (Hovick *et al*. 2015 and 2017), and large ungulate conservation (Boyce *et al*. 2003; Allred *et al*. 2011).

Fire as a disturbance plays an integral role globally and locally as a driver of ecosystem function and processes (Goldammer and Furyaev 1996). Functionally, fires vary in space and time across the landscape, which results in a shifting mosaic of patches with different fire return intervals, promoting habitat heterogeneity and biodiversity (Fuhlendorf and Engle 2001; Fuhlendorf *et al.* 2006; Hossack *et al*. 2009, Leverkus 2015; Leverkus *et al.* 2017). Some areas and some species using the landscape may require high frequency and intensity disturbances while others may require low disturbance frequency and intensity (Knopf 1996; Fuhlendorf *et al*. 2012; Leverkus 2015; Leverkus *et al.* 2017). The boreal forest is a landscape where boreal flora and fauna have adapted to the combined pressure of a long season of cold temperatures and snow with a short season of growth where natural disturbances, such as fire, are active (Bergeron *et al.* 2004; Burton *et al.* 2006). Here, fire is a critical ecosystem driver across varying spatio-temporal scales in the boreal forest. Fire influences species composition and structure, regulates diseases and insects, structures thermal features of habitat, maintains and promotes the productivity and diversity of habitats, regulates fuel loads, and affects nutrient cycling and energy fluxes (Volney and Hirsch 2005). In the boreal forest of Canada, fire is most prevalent in the western and northern ecozones (Stocks *et al.* 2003).

Understanding the historical and contemporary fire regime (defined as the pattern of fire type, intensity, frequency, and severity) is important for developing appropriate and effective fire projects. Fire regimes become complex when an entire landscape is considered from a broad enough perspective (Wright and Bailey 1982). Managing fire and fire regimes at broad scales has long been a contentious global issue and persistent management challenge (van Wilgen *et al.* 2004). Debates over fire management plans have occurred for National Parks across Canada and America as well as other regions in the world including the Kakadu National Park in Australia, Kruger National Park in South Africa, and forested areas in Sweden (Weir *et al.* 1995; Angelstam 1998; Bowman *et al.* 2004; White *et al*. 2011). Fire management has been practiced in African savannas for decades to centuries; however, there have been many problems associated with it, such as unplanned fires, presence of invasive species and the lack of a social licence for prescribed fire (van Wilgen *et al.* 2004; van Wilgen *et al.* 2011). Brockett *et al.* (2001) produced a management strategy for southern African savannas with the primary goal of creating patch mosaics of fire through time since fire which would result in heterogeneity across the landscape.

The Boreal Forest

The most extensive, intact, terrestrial biome on earth is the circumboreal forest that is estimated to contain more than 100,000 species of flora and fauna (Zasada *et al.* 1997; Schmiegelow *et al.* 2006; Burton *et al.* 2008, Flannigan *et al.* 2009). Fire cycles in the boreal forest have changed in the past 200 – 300 years by temporal changes in association with the Little Ice Age and fire suppression policies, suggesting that there is no single “correct” fire regime for any part of the boreal forest and that the system is dynamic, carrying the memory of past fire cycles into the present and future (Bergeron and Archambault 1993; Johnson *et al.* 1998). The fire return interval of the boreal ranges from the burning of yards and corridors annually or in consecutive years by First Nations to other locations having upwards of 700 years since fire (Heinselman 1981; Lewis and Ferguson 1988; Kasischke *et al.* 1995; Larsen and MacDonald 1998).

Fire History and Fire Regimes

Historical and Future Predictions of Fire Regimes

Anthropogenic fire, anthropogenic suppression, and fire ignitions from lightning have shaped the boreal forest and contributed to its current patchwork mosaic since the last Ice Age (Rowe and Scotter 1973; Goldammer and Furyaev 1996; Stocks *et al.* 2003). The presence of fire, and features of the fire regime, in the boreal forest has been extrapolated from fire statistics (Johnson 1992), charcoal found in soil profiles (Rowe and Scotter 1973; Larsen and MacDonald 1998), morphological, and reproductive characteristics of boreal plant species (Rowe and Scotter 1973), oral accounts by First Nations and

Aboriginal people (Lewis and Ferguson 1988; Johnson 1992; Suffling and Speller 1998), age structure, and the mosaic character of forest stands (Rowe and Scotter 1973). Prior to European settlement, lightning-driven fire regimes of large-scale crown fires and high-intensity surface fires occurred in Canadian boreal forests and Rocky Mountain subalpine forests at fire return intervals from 50 to 700 years (Heinselman 1981; Stocks *et al.* 2003); however, it is critical to note that indigenous people burned some isolated areas much more frequently and in different conditions than lightning ignited fires (Lewis and Ferguson 1988). Pollen and rice records provide evidence that the rise of the boreal biome over the Holocene due to cooler and wetter weather may be altered due to anthropogenic influences on climate and fire regimes (for example in Sweden boreal (Brown and Giesecke 2014) and in BC Canada (Brown *et al*. 2017)).

Sedimentological and paleoecological analyses from a sediment core recovered from a small subalpine lake in southeastern BC Canada indicate that during the Holocene climate was a strong control of fire frequency with a peak of 8 fires per 1,000 years (or a 125 year fire return interval) around 9,500 to 7,500 years before present. The lowest frequency during the period of record was 3 fires per 1,000 years (or a 333 year fire return interval (Mustaphi and Pisaric 2014)). Similar sediment core analyses of Sasquatch Lake in western Canada suggests that both insect outbreaks and fire had an effect on forest species composition (Mustaphi and Pisaric 2017). Regional fire occurrence was similarly reconstructed for northern Quebec based on sediment cores from 11 lakes and the greatest fire occurrence was 4,000 to 3,000 years ago with a rate of about 6 fires per millennium (Oris *et al*. 2014). Remy *et al*. (2017) combined modeling with known fire records and determined that the largest fires in the boreal of northeastern Canada occurred 3,000 to 1,000 years ago. Senici *et al*. (2015) conducted modeling that suggests forest connectivity has been a major control on fires historically.

Whitman *et al*. (2015) assessed fire activity in the northwestern US and Alberta and BC by using data from the Canadian National Fire Database (CNFD) for fires greater than 385 ha from 1984 to 2011. The authors defined the "climate space" of fire regimes in this region and concluded using multivariate statistics that the first axis was a latitudinal gradient of temperature and summer precipitation and a second axis was a longitudinal gradient of continentality and winter precipitation. In this study, fire frequency increased with increasing temperature and summer dryness. Whitman *et al*. (2015) also concluded that fire frequency and fire size were greatest at the core of the climate space suggesting that fires primarily occur where climate conditions are optimum for fuel production, ignitions, and conditions conducive for burning overlap yet is at the extremes of precipitation and temperature (within this climate space) and that these areas were primarily coniferous montane and subalpine forests such as the BC interior. CNFD data is publicly available and includes agency provided fire locations, agency provided fire perimeters, and coarse-resolution burned areas from 1980 to 2015 (2017 data are not yet available) (Figure 1).

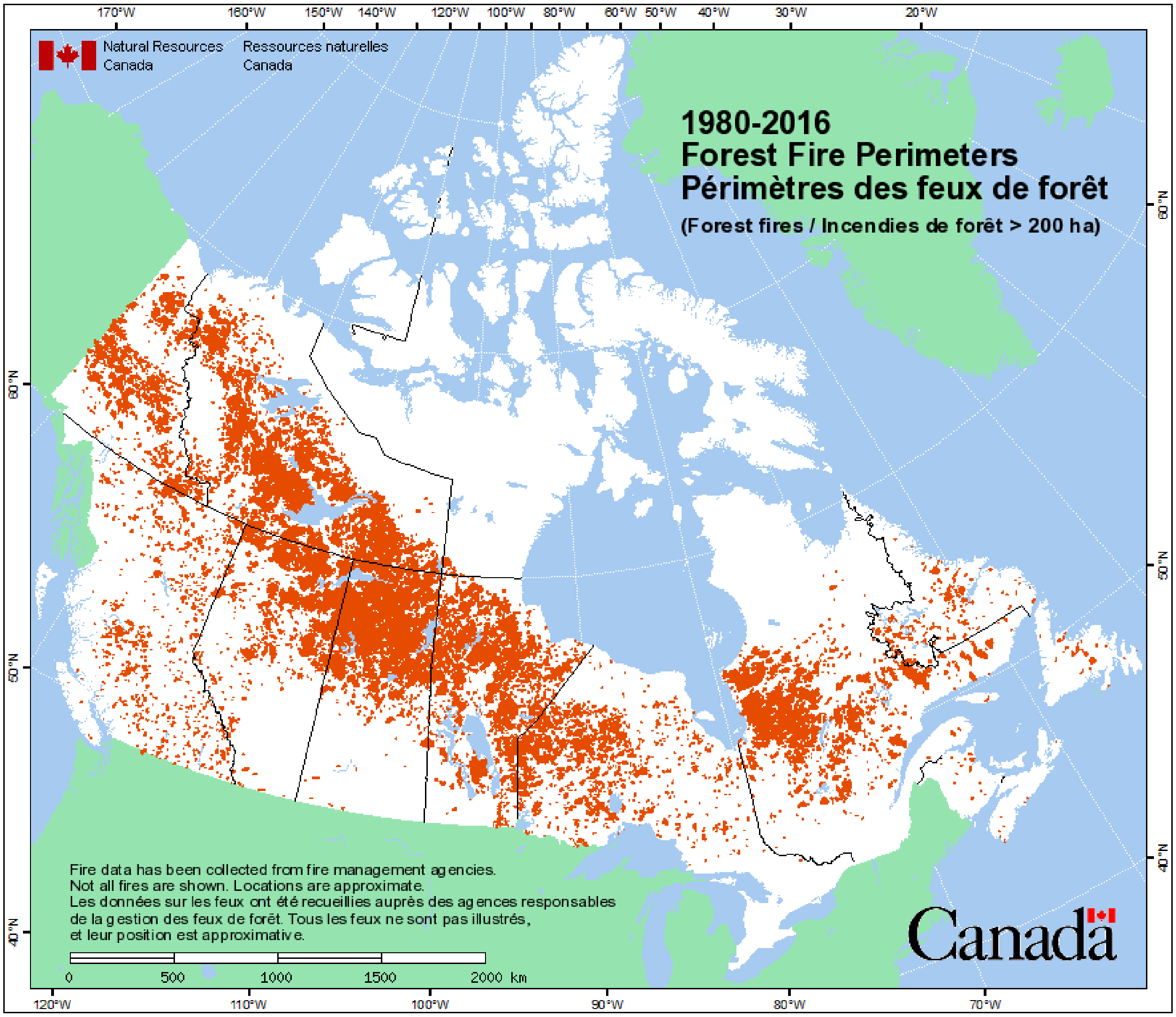

Figure 1 Agency provided fire perimeters from 1980 to 2016 based on the Canadian National Fire Database (http://cwfis.cfs.nrcan.gc.ca/ha/nfdb).

Fosberg *et al.* (1996) suggest three considerations of fire and climate change: changed vegetation (fuels), changed potential for fire occurrence (lightning or human), and change in fire severity resulting from changes in fire weather. Vegetation changes are anticipated as climate changes. Some indications suggest that there will be an increase in broadleaf species and that fire intensity could double in southern sections of the Boreal yet the fire intensity in the northern boreal zone will remain the same (Fosberg *et al.* 1996). Lightning activity is expected to increase 40% from 50 to 70 ^{o}N (cloud to cloud and cloud to ground) while human ignitions are anticipated to increase due to more broad use of and access to the region. In 1993, Wotton and Flannigan predicted that "the length of the fire season will increase by an average of 22% (30 days) across Canada in a world with double CO_2. Thus, considering the number of ignitions and area burned are related to fire season length, and even if any drying effect of increasing temperatures we can expect for forest fuels, Canada's fire regime in forested fuel types can be predicted to become more severe." Moreover, a longer fire season may require more resources for fire management.

Flannigan *et al.* (2005) developed projections of future area burned in Canada based on correlations between historic area burned and fire weather. Wotton *et al.* (2010) used general circulation models (GCMs) to develop future fire occurrence projects across Canada. The results of their scenarios suggest that at the end of the 21st century, there could be an increase in fire occurrence of 75% across Canada. Parisien *et al*. (2014) constructed future fire models for the entire Canadian boreal forest with different temporal resolutions (annual average or finer scale) and found that such models generally converged and showed variation in changing fire regimes across Canada.

There are ten recent studies which provide models with prediction for *future* fire regimes in the boreal forest (Boulanger *et al*. 2014; Buermann *et al*. 2014; Gauthier *et al*. 2014; Gauthier *et al*. 2015a; Gauthier *et al*. 2015b; Stephens *et al*. 2014; Wang *et al*. 2014; Wang *et al*. 2015; Wang *et al*. 2016; Young *et al*. 2016). Gauthier *et al*. (2015a) states that the global boreal forest is a reservoir of carbon that is potentially larger than tropical forests with an estimated 32% of global terrestrial carbon stocks. Gauthier *et al*. (2015a) also points out that boreal tree species have evolved to be resistant and/or resilient to disturbances although the recovery process can be slow and long-term. In the 21st century, the boreal forest biome is anticipated to experience a temperature increase greater than any other forest biome and could shift in climate space to a drier climate space occupied by woodland/shrubland by the end of the century. Similar conclusions are presented by Buermann *et al*. (2014) at the global scale. During this period, fire occurrence, area, and severity are projected to increase in the boreal as are the range for forest pests similar to the recent Canadian mountain pine beetle outbreak (Gauthier *et al*. 2015a). Gauthier concludes that forest management strategies that enhance landscape heterogeneity (among other features such as tree species diversity) might assist in maintaining forest cover, carbon stocks, and biodiversity in general – a direct implication for the application of prescribed fires to accomplish these objectives.

Héon *et al*. (2014) states that the area burned in the North American boreal will increase by 30% to 500% by the end of the 21st century. This increase will have a “cascading effect on ecosystem dynamics and on the boreal carbon balance”. Concurrently, Wang *et al*. (2015) predicts a 35% to 400% increase in fire spread days in Canada by 2050. Héon *et al*. (2014) also reports that the burn rate in their boreal study area almost doubled, going from 1.4% of the land area per year from 1810 to 1909 to 2.4% from 1910 to 2013. Stephens *et al*. (2014) discusses “mega-fires” in the context of the boreal forest and defines these conflagrations as those fires > 10,000 ha in spatial extent and proposes the “mega-fire triangle” to include climate change, fire exclusion, and antecedent disturbance. Such large events typically occur after years of moderate to severe drought, during high wind conditions, and under hot and dry conditions (Stephens *et al*. 2014). Stephens *et al*. (2014) also discuss the mountain pine beetle outbreak in BC as one of the largest in recorded history that affected > 20 million ha in the province. Gauthier *et al*. (2014) suggests that the managed Canadian boreal forest is vulnerable to escalating climate change and that adaptation should include actions that reduce non-climatic stressors and maintain/enhance adaptive capacity in the biophysical and human subsystems of the forest management system. Wang *et al*. (2014) examined potential and realized fire spread and concluded that both are higher in western Canada but that southern fire zones have higher potential for fire spread than northern zones and that drought potential is a major control on Canada fire spread. However, this spread potential differentiation is explained by the authors as northern areas having longer day lengths during peak fire activity, a high proportion of highly flammable fuels, and a “quasi-absence” of fire suppression and thus interpretation of this conclusion is difficult (see Figure 4 in Wang *et al*. 2014). Boulanger *et al*. (2014) forecasts that some of the greatest fire activity increases will occur in northwestern BC, however, Wang *et al*. (2016) predicts increases in fire weather days and fire activity for south-central BC also. Young *et al*. (2016) reports similar trends for the boreal and tundra of Alaska.

Fire Patterns in the Boreal Forest: Spatial and Temporal

At the global scale, Rogers *et al*. (2015) explored why fires in North American boreal forests are of greater intensity crown-type fires while in Eurasia fires are lower-intensity surface-type fires even though fire weather conditions are similar across continents. The authors conclude that the tree species assemblages are driving the differences in fire regimes because dominant tree species in the North American boreal forest have "evolved to spread and be consumed by fires as part of their life cycle" while the dominant tree species in Eurasian boreal forests have "evolved to resist and suppress crown fires" (Rogers *et al*. 2015). Andison and McCleary (2014) conducted modeling of 129 fires across 100 million ha of Canada boreal and suggest that fire patterns vary by major ecological zone and in regards to the relative patchiness and partial burning. Bernier *et al*. (2016) conducted a Canada-wide assessment of fire patterns and determined that fire selected for conifer stands (and against broadleaf tree stands) and selected against young stands (age 0-29 years) and suggests that these model parameters can be used to develop relevant fire risk models (see Figure 5 in this paper for a visual representation of such risk models). Establishing a diverse forage age matrix, rather than a homogeneous and old forest, can be a wildfire spread mitigation strategy because wildfires tend to spread in older stands. Marcoux *et al*. (2015) conducted a study of attributes of fire in southern BC and demonstrated that western larch stumps could be an indicator of mixed-severity fires as they did not occur in high-severity fires but that tree size characteristics were generally indistinguishable between fire severities. Parisien *et al*. (2016) assessed the role of humans on fire activity and found the effect to be highly variable and suggested that human 'footprints' must be included in modeling of fire predictions.

Lehsten *et al*. (2014) suggests that fire sizes over time are best explained by a normal distribution in log space (rather than the power law-based as has prevailed in the literature; see Figure 3 in their paper). Pickell *et al*. (2014) assessed the role of anthropogenic influence on disturbance and found it was detectable in Landsat data a high proportion of the time. Sedano and Randerson (2014) assessed vapor pressure deficit (VPD) over time and found that ignition and spread in boreal ecosystems were largely contingent on this metric.

An additional contributor to the spatial and temporal arrangement of fire across the landscape is derived from insect outbreaks and subsequent fire behavior and regimes specifically for bark beetle and bud worms (Page *et al*. 2014; Perrakis *et al*. 2014; Pureswaran *et al*. 2015). Page *et al*. (2014) provided an overview of mountain pine beetle outbreaks in lodgepole pine stands and the effects on fire behavior and the authors make a plea for more research. Perrakis *et al*. (2014) explicitly examined fire spread and crown fire potential in stands in BC Canada and found that rate of spread and crown fire were on average 2.7 greater in affected stands. Pureswaran *et al*. (2015) takes a broader ecological assessment of potential ecological shifts caused by insect outbreaks with implications specifically for certain tree species. Tabacaru *et al*. (2016) assessed beetle outbreaks in western Canada and found that more burned trees than non-burned trees were attacked but that there was no subsequent population build up.

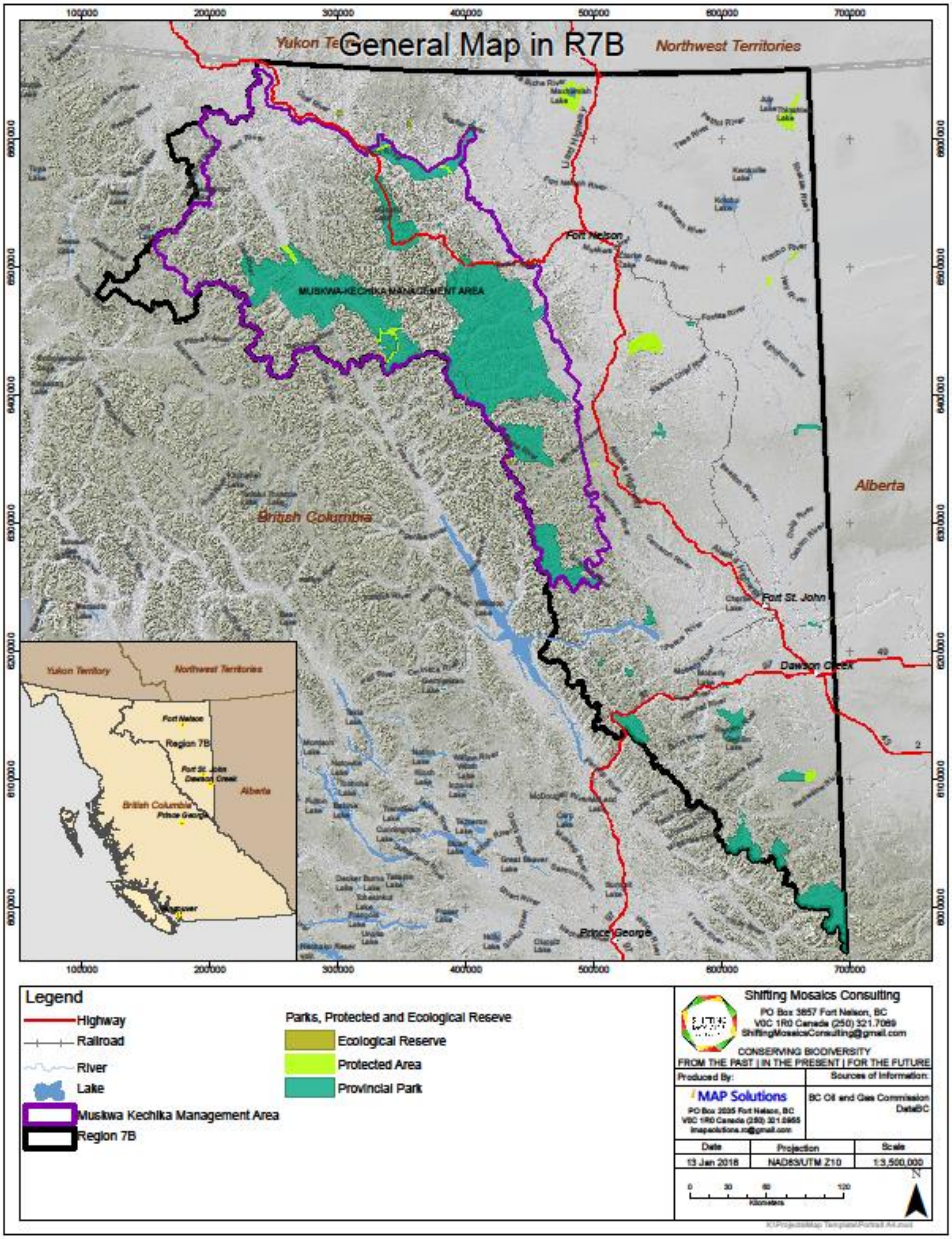

Figure 2 Region 7B is located in northeast British Columbia, Canada.

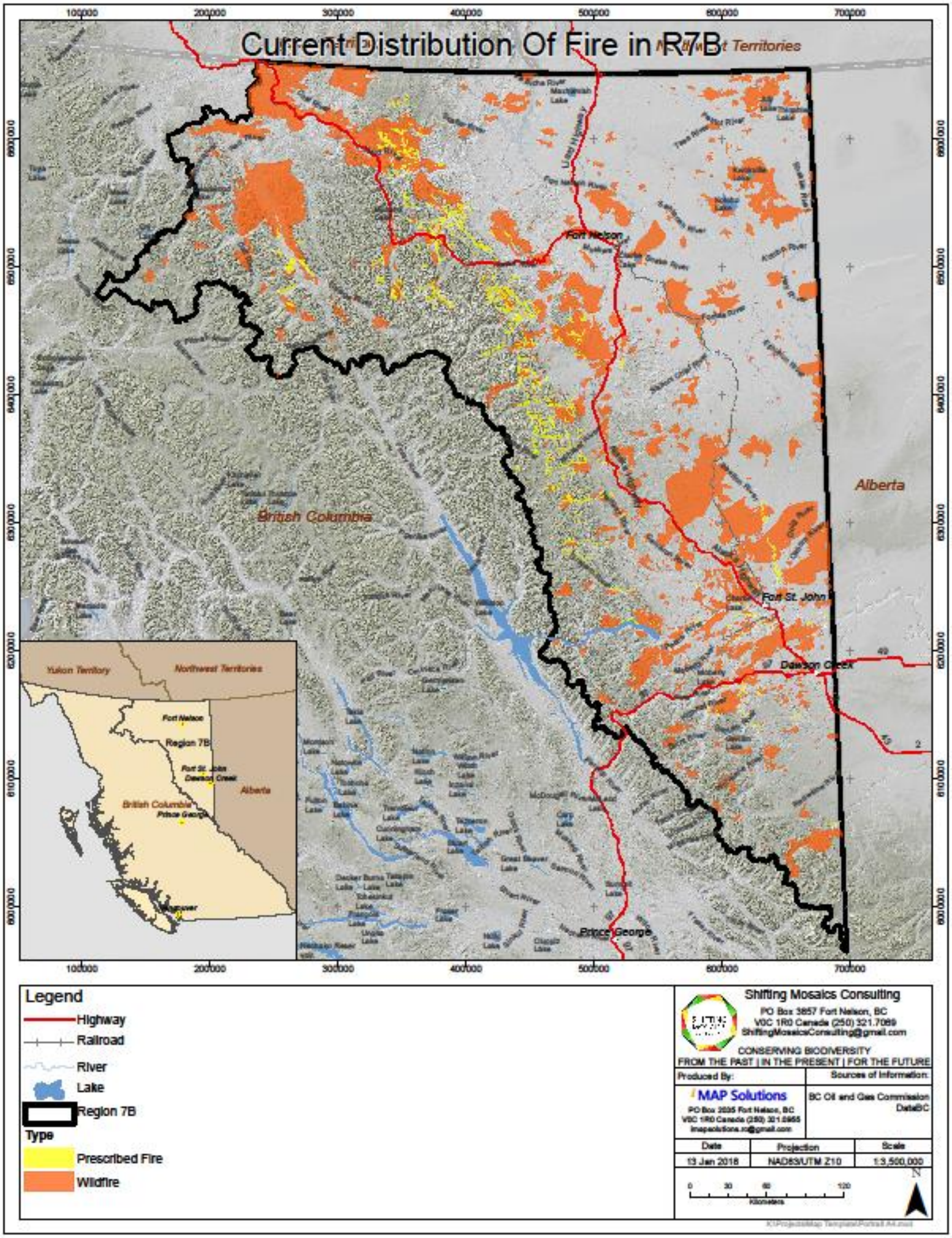

Figure 3a The current distribution of fire across the landscape of Region 7B as analysed by Shifting Mosaics Consulting, 2018 per Leverkus 2015 and Leverkus *et al.* 2017.

Fire in northeastern BC

The boreal forest is a pyrogenic ecosystem driven by human and lightning ignitions resulting in a shifting mosaic of vegetation height, composition and distribution (Rowe and Scotter 1973, Goldammer and Furyaev 1996, Fuhlendorf and Engle 2004). Fire plays such an important role in the boreal forest that the type (surface or crown), intensity (amount of energy released), severity (overall effect of fire on the ecosystem), frequency (number of fires), and time since last fire have significant influence on the distribution and composition of vegetation present on most sites (Parminter 1983). Prehistoric fire return intervals in northeastern British Columbia (BC), also referred to as Region 7B (Figure 2 and 3a), appear to fluctuate and may respond to Holocene global climate cycles (Jull and Geertsema 2006). Climatic conditions have also changed in the last millennium, with noteworthy warming in the Medieval Warm Period, and subsequent cooling during the Little Ice Age (Grove 2001). Much of the low lying portion of the boreal forest in northeastern BC has undergone paludification (i.e., the process of accumulating organic matter as peat and subsequent formation of peatland in the boreal zone) favouring the initiation of muskeg formation some 6,000 years ago (MacDonald and McLeod 1996).

Given the variability of climate and complex synergies between various disturbance agents such as forest fire, geomorphological events, windstorms, insect outbreaks and floods (Delong *et al.* 2013), determining a fire return interval for a particular area proves challenging. Indeed it may be difficult to identify a single fire regime for any part of the boreal forest because it is a dynamic system, carrying the memory of past fire return intervals into the present and future (Bergeron and Archambault 1993, Johnson *et al.* 1998) (Figure 3). The fire return interval of the boreal forest ranges from small frequent burns (such as in the annual burning of yards and corridors by First Nations as documented by Lewis and Ferguson 1988) to much larger wildfire events (up to thousands of hectares) with century-scale return periods (Heinselman 1981, Lewis and Ferguson 1988, Kasischke *et al.* 1995, Larsen and MacDonald 1998). Goldammer (2016) evaluated the use of burning in Eurasia and reports a declining use due to human migration to urban areas and land abandonment.

Human fire ignitions have influenced the spatio-temporal distribution of fire across the boreal (Rowe and Scotter 1973, Lewis 1978, Lewis and Ferguson 1988, Gottesfeld 1994, Pyne 2007) and specifically across northeastern BC (Elliott 1983, Seip and Bunnell 1985, Peck and Peek 1991, Sittler 2013). Fires were historically ignited for a variety of reasons by the Dene and Cree people: hunting and survival, regrowth of vegetation, communication, ceremonial and aesthetic practices (Fort Nelson First Nation and Shifting Mosaics Consulting 2015). The relationship between fire and the Dene and Cree people of Fort Nelson First Nation is culturally complex, and dates back thousands of years (Fort Nelson First Nation and Shifting Mosaics Consulting 2015). The tradition of igniting fires in the spring of each year has since been continued by guide outfitters across the region (Peck and Peek 1991).

The application of repeated prescribed fire in certain areas has had a greater influence on the current state of vegetation cover in northeastern BC than have fire suppression activities. More than 3.5 million hectares have burned by wildfire between 1922 - 2012 and more than 260,000 ha were burned by prescribed fire from 1980 - 2008 (Parminter 1983, Leverkus 2015, Leverkus *et al.* 2017). Historical evidence based on written records, physical evidence (i.e. the mosaic nature of forest stands and their age structure), and the presence of charcoal in the humus layer and soil profile demonstrate the strong influence of fire in the region (Parminter 1983). Wildland fire data specific to BC was analyzed by Leverkus (2015) and Leverkus *et al.* (2017) to determine the spatiotemporal distribution of wildland fire (1922-2015) and prescribed fire (1980-2008) across the Region (Figure 3a and 3b). The largest fires in the recorded history of BC until 2014 have been located in northeastern BC: Kech fire (1958, 244,027 ha), 1950 (117,899 ha and 126,109 ha), Tee fire (1971, 98,899 ha – 110, 419 ha), 1948 (132,495 ha), and the Eg fire of 1982 (166, 698 ha – 182,000 ha) (Parminter 1983, Leverkus 2015, Leverkus *et al.* 2017, BC Wildfire Services).

The BC Government began conducting prescribed fires in the late 1970's. The overall objectives were to: 1) maintain grassland habitat and provide forage for a variety of ungulates and other non-target species through the reduction of woody vegetation encroachment and the promotion of optimal forage plants; 2) maintain ecosystem diversity by promoting grassland habitats across the Region; 3) maintain winter ranges for ungulates to minimize conflict in the agricultural areas; 4) monitor treatment success and feedback into future timing and rotational fire requirements; and 5) digital mapping of prescribed fires (Goddard 2011).

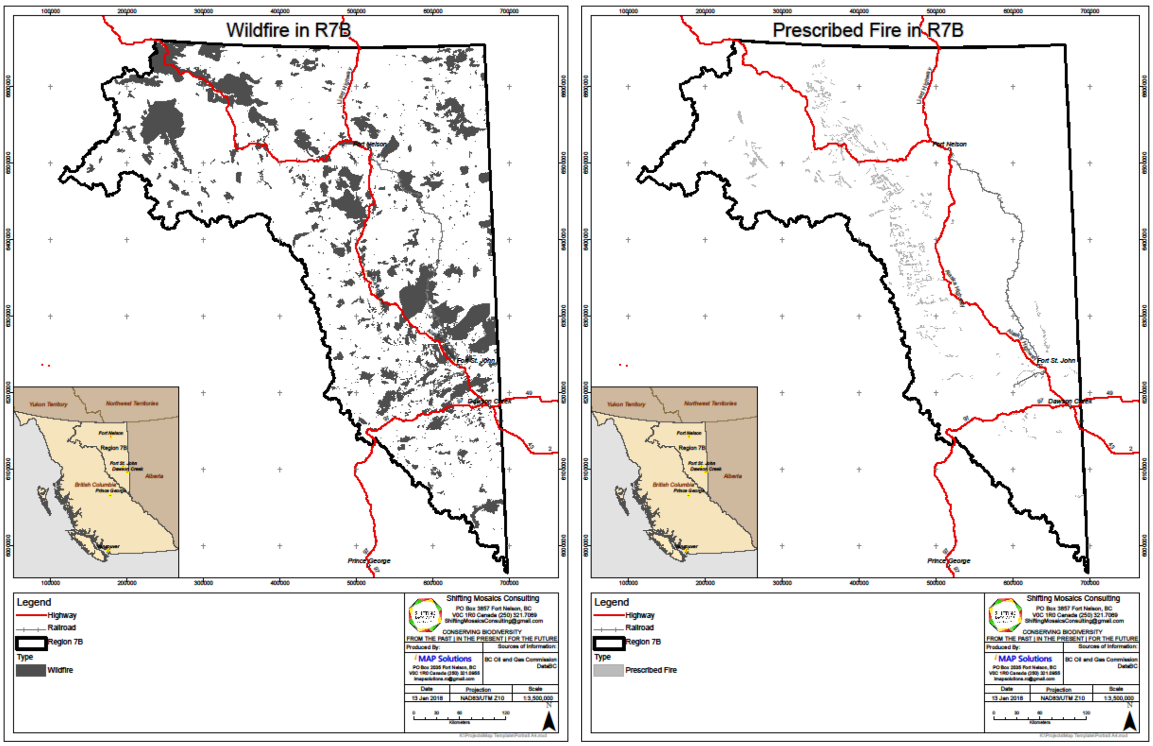

Figure 3b The pyrogenic landscape history of documented wildland fire (1922-2018) in northeastern British Columbia (Region 7B) adapted from Leverkus *et al.* 2015 (L) compared to the spatial fire history of recorded prescribed fires from 1980-2008 as adapted from Leverkus *et al.* 2015 (R).

Anecdotal information from guide outfitters, resident hunters, wildlife conservationists, and long-time residents of the Region have often expressed concern over the decline of prescribed fire in the past decade. Through numerous discussions, it is clear that there is general consensus and continued support for the BC Government to proceed with the Peace-Liard Prescribed Fire Program. Support from these various stakeholders and wildlife associations includes funding for ignitions, lodging, and logistics including volunteer time to assist where appropriate. The centuries of knowledge amongst these groups and interested parties is critical and vital to the success of the program and its longevity. In addition to the concern about the decline and lack of prescribed fire across the Region, there is constant concern about the decline in wildlife and its habitat. The need to look after the wildlife resource and be pro-active in maintaining its habitat to support sufficient numbers was continually brought forward as a paramount concern.

In 2009 Lousier *et al*. conducted a problem analysis and review of the prescribed fire program. This included an extensive literature review of the material available at that time including analyses of the spatial and temporal distribution of fire, gap analysis, and a summary of the long standing issues with the application of fire in the northeast during recent decades. The recommendations included a clarification of these issues and numerous topics and questions to be answered through a research program. Their assessments showed many limitations in the program (Lousier *et al.* 2009 pp.iii). They also suggest that there are no established procedures for: selecting candidate sites for prescribed fire, assessing the impacts of the treatments, or comparative analysis of the success of the treatments on different sites (Lousier *et al.* 2009). The primary recommendation for the operational goal of the wildlife/prescribed fire program is that it should provide a landscape-level mosaic of habitats providing improved late-winter, early-spring foraging opportunities for selected ungulate species (Lousier *et al.* 2009 pp.iiii).

Fire in the Muskwa-Kechika Management Area

The historical fire return interval for the M-KMA is estimated to be between 50 to 400 years as extrapolated from published research by Stocks and Kauffman (1994) and Johnson *et al*. (1998). This range represents variability within fire return intervals given the limited literature available for the specific region. The M-K Wildlife Management Plan states that there are optimal combinations of habitats for each animal species and that in the absence of fire, biodiversity would be reduced in the M-KMA (BC Ministry of Environment 2009). It further states that the availability of early seral grassland components, or sites maintained by recent time since fire, are needed on a continual basis in order to support the numerous species within the M-KMA (BC Ministry of Environment 2009). Areas to have maintenance burning applied are outlined in the Muskwa-Kechika Wildlife Management Plan (BC Ministry of Environment 2009 - pp. 55 and 56). The plan prescribes for 120,000 ha to be in less than 10 years since fire using a split of wildfire and prescribed fire to achieve the total area goal. The implementation of prescribed fire is to occur in burn patches of 50 ha to 1,000 ha over a 10 year rotation with ten percent of the total burned each year. It is stated that the prescribed fire will be split equally inside and outside of provincial parks and will target areas previously burned and those being encroached by brush. These data were provided by the BC Ministry of Environment; however, it is integral to also survey First Nations, resource professionals, stakeholders and other interested parties in the M-KMA in order to establish true management objectives for areas where fire is applied and incorporated.

			Area to have maintenance burning applied (wildfire + prescribed fire)							
Unit	Area of Unit		Outside Parks		Inside Parks		Total over 10 years		Total/year	
	km^2	ha	km^2	ha	km^2	ha	km^2	ha	km^2	ha
Kechika	16,600	1,660,000	150	15,000	25	2,500	175	17,500	18	1,750
Toad	11,100	1,110,000	200	20,000	10	1,000	210	21,000	21	2,100
Gataga	8,800	880,000	15	1,500	25	2,500	40	4,000	4	400
Muskwa	11,300	1,130,000	25	2,500	500	50,000	525	52,500	53	5,250
Finlay	9,500	950,000	10	1,000	5	500	15	1,500	2	150
Sikanni-Halfway	6,600	660,000	225	22,500	10	1,000	235	23,500	24	2,350
Total	63,900	6,390,000	625	62,500	575	57,500	1,200	**120,000**	120	**12,000**

Table 1 The M-KWMP recommended a combined area that would benefit from wildfire and prescribed fire to maintain early seral vegetation communities.

Leverkus (2015) developed fire histories for the M-KMA and the watersheds within the M-KMA following the same methodology as Stocks *et al.* (2003). The historical range and variability of fire for each site was not available; however, the historical and current distribution of time since fire was presented by Leverkus (2015). The area burned by wildfire from 1922 – 2012 in the M-KMA is 19.1% of the total burnable area. The area burned by prescribed fire from 1980 – 2008 in the M-KMA is 4.2% of the total burnable area. The historical fire return interval for the M-KMA is proposed to be 50 to 400 years based on published research by Stocks *et al.* (1994) and Johnson *et al.* (1998). The area burned by wildfire from 1922 – 2012 in each main watershed of the M-KMA ranges from 5.4% to 50.3% whereas area burned by prescribed fire in the same watersheds from 1980 – 2008 ranges from 0% to 14.5% of the total burnable area.

Leverkus (2015) found that the current distribution of time since fire indicates some spatial variation across the landscapes but also some general trends. The least amount of time since fire is found within the 0 to 2 years since fire categories across all scales, ranging from 0 to 0.9% of the total burnable area. This is predictable since it is also the smallest range. The category with the longest time since fire, greater than 90 years, ranges from 44.7% to 90.4% of the total burnable area, which is actually the largest range because there is no upper boundary. The percent of time since fire in each category over the burnable area in the M-KMA also indicates spatial variation. It is clear that the largest spatial distribution of time since fire occurs in greater than 90 years since fire and that the rest of the categories individually occupy less than 10% of the total burnable area each. Leverkus (2015) also found a decline in the number of prescribed fires across the region and the M-KMA over the past 20 years whereas the number of wildfires has fluctuated over the years.

Leverkus (2015) demonstrated that south facing slopes have the highest percentage of prescribed fire on average throughout the region when compared to other aspects. Lousier *et al.* 2009 found similar results. Humans have played a critical role in creating heterogeneity through fire across spatial and temporal patterns on the landscape. In order to maintain heterogeneity and biological diversity as well as to promote resources for selection by wildlife, fire needs to continue being spatially and temporally distributed across the landscape. Leverkus (2015) and Leverkus *et al.* 2017 suggested targeting 0 – 10% of the burnable area in the 0 to 2 years since fire category. This equates to 467,155 ha of treatment in the M-KMA every year if the historical fire return interval is between 50 to 400 years.

Other disturbances: Oil/Gas, Mining, Forestry, Agriculture

The Peace-Liard Region is the primary location of natural resource development in the province. Industrialization of the landscape has been occurring over the past century, most prominently occurring within the recent two decades during the natural gas boom in British Columbia. The surface oil and gas infrastructure present across the landscape is considered as non-burnable, however, there may be opportunities to incorporate prescribed fire in best management practices to protect critical infrastructure. Subsurface infrastructure (pipelines) and seismic lines are considered as burnable whereby pipelines have a minimum 4' depth of cover to provide wildfire protection (and other disturbances). Should prescribed fire be implemented in these areas, there would need to be collaboration with the various oil and gas companies as their riser sites/emergency shut-off devices (ESDs) may have an interaction with fire. The permitting process changed around 2012 as prior to that risers/ESDs were permitted as part of the pipeline right-of-way, however, now the riser/ESD site is non-farmable area (impact to the Agriculture Land Reserve) and need to be permitted separately to properly calculate non-agricultural disturbances within the quarter section. Oil and gas proponents have requested that the proposed prescribed fire units be made available for review so that they can conduct a risk assessment similar to ground disturbance to identify critical infrastructure that needs to be protected.

Mining, forestry, alternative energy (windpower, hydro power), and agriculture are critical industries throughout the Region, all with a footprint on the landscape and needing to be reviewed in proximity to prescribed fire units. During the engagement process and initial collaborative development of this Plan, concern was expressed that there should be minimal to no disturbance to the Timber Harvestable Land Base (THLB) which has been included in the spatial analysis in Part B – Technical and Operational Plan. In addition, values at risk were identified such as infrastructure and Old Growth Management Areas (OGMAs) or old forests in units where they are lacking in distribution which includes the boreal plains in the Dawson Creek and Fort St. John Timber Harvestable Area (THA). It is also necessary to ensure there are clear objectives and experienced personnel when planning and implementing prescribed fires particularly in the industrialized landscapes of the Region and in proximity to values at risk.

Across a broad, changing landscape such as the northeast Region, cumulative effects and impacts offer many variables which must be considered. Fire frequency, industrial development, and climate have changed in the past and continue to change; therefore, it is imperative for land managers to recognize that multiple fire frequencies have existed and will continue to fluctuate (Strauss *et al.* 1989, Johnson *et al.* 1998). Effects of a changing climate on fire management include: primary effects (changes in ecosystem structure and composition and to future fuel load), secondary effects (inter-annual and inter-decadal variability of climate which influences planning for suppression and length of the fire season), and tertiary effects (day-to-day tactical decisions driven by chance exceeding thresholds of fire danger) (Fosberg *et al*. 1996).

"The application of repeated prescribed fire to certain sites and the introduction of a human source of fire starts in other areas has probably had a greater influence on the current state of the vegetative cover than have fire suppression activities." – J. Parminter 1983 pp. 109

LEGAL AND ADMINISTRATIVE FRAMEWORK

British Columbia, in particular the Peace-Liard Region, has a historical interaction with prescribed fire. Planning and implementing prescribed fire needs to align with regulatory and land-use planning documents while accounting for impacts to other values contained within the potential burn locations.

Legislation, Regulations, and Policy

- *BC Wildfire Act* and associated regulations
- *Environmental Management Act*
- *Open Burning Smoke Control Regulations*
- *Muskwa-Kechika Management Area Act*
- *Forest and Range Practices Act* and regulations
- *Park Act*
- *Forest Act*
- *Range Act*
- *Range Planning and Practices Regulations*
- *Wildlife Act*

Risk

As wildfires escalate, the recognition of the need for prescribed fire as a fuels mitigation and wildfire prevention tool become more apparent to the public, a process that may be occurring in Canada (http://www.macleans.ca/news/canada/prescribed-fires-save-money-and-lives-why-dont-we-do-more/). In the US generally, the escalation of wildfires has led to liability reforms as it pertains to prescribed fire in 18 states that have reduced the liability burdens with simple negligence rules and 4 states with gross negligence rules (Sun 2006). It is also critical to understand the applicable provincial and federal government policies that apply stipulations to prescribed burning rangeland and forestland including the *BC Wildfire Act* and the *Open Burning Smoke Control Regulations*.

Risk is generally defined and thought of in terms of the probability that an event will occur and the consequences associated with that event (risk = probability x consequence) (Leverkus *et al.* 2016). For example, the Government of British Columbia (2015) calculates risk in terms of expected loss and requires an estimate of the replacement cost of values at risk impacted by fire. Haight *et al.* (2004) define fire risk as the likelihood that a particular place on the landscape will experience a stand-replacing fire within a discrete period of time.

Miller and Ager (2013) define three components of fire risk: likelihood, intensity and effects. Pyne *et al.* (1996) suggest the "general strategy of prevention is to reduce the probability of a fire by separating ignition (risk) from fuels (hazards)." The Government of British Columbia (2012) identifies hazards as threats that pose danger to infrastructure, risk of fire starting and if a fire were to start, the volatility of the fire's behaviour, the difficulty of controlling the fire, and the potential threat to values at risk. In British Columbia's definition (Government of British Columbia 2012), fuel hazard is the potential fire behaviour based on the physical characteristics of the fuel including arrangement, load, condition of herbaceous vegetation, and the presence of ladder fuels. Vulnerability is the ability to recover from a natural hazard and is shaped by physical, social, economic, and environmental facts, which increase the sensitivity of a community to the impact of hazards (Northwest Territories 2014).

Risk is often measured using a ranking system such as the one that Beever (2015) presents (Figure 4). Hawkes *et al.* (2003) suggests that fire risk assessment should not be static but rather dynamic as ecosystems and disturbances change through space and time. Additionally Miller and Ager (2013) propose a generalized fire risk framework where risk is a combination of the likelihood, intensity, and effects of wildfire (Figure 5).

RISK MATRIX					
CONSEQUENCE / LIKELIHOOD	Insignificant	Minor	Moderate	Major	Extreme
Almost certain (frequent)	Moderate	Moderate	High	Extreme	Extreme
Likely (probable)	Low	Moderate	High	High	Extreme
Possible (occasional)	Low	Moderate	Moderate	High	High
Unlikely (uncommon)	Low	Low	Moderate	Moderate	High
Rare (remote)	Low	Low	Low	Low	Moderate

Figure 4 Beever (2015) suggests a common risk ranking matrix where a team collaborates to identify, analyze and evaluate the "effects of uncertainty on the established objective(s) for developing a comprehensive risk profile." This process links objectives to controls and actions and is therefore suggested as being indispensable (Leverkus *et al.* 2016).

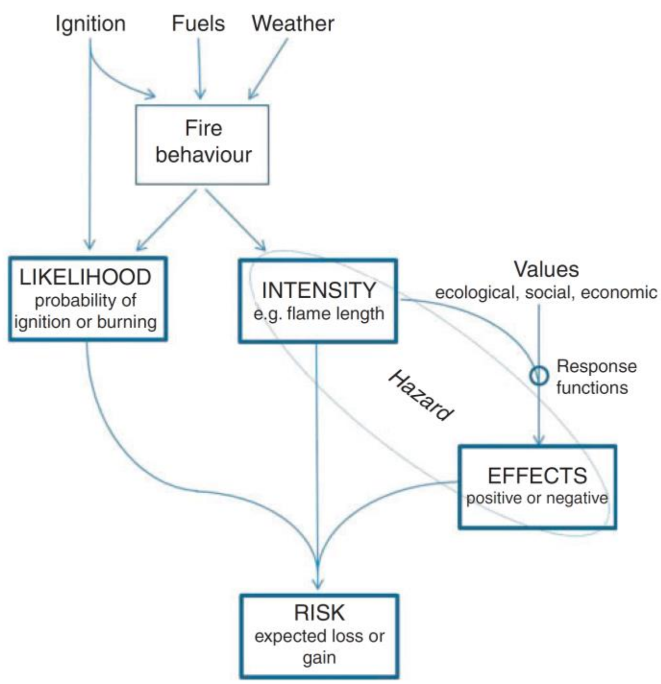

Figure 5 Miller and Ager (2013) propose a generalized fire risk framework where "likelihood is often estimated statistically from ignition data, or simulated with fire behaviour models. Intensity is a major output of fire behaviour models. Effects may be positive or negative and can be estimated using intensity estimates and response functions. Intensity and effects together represent hazards (Miller and Ager 2013)."

Strategic Level Planning – Risk Profile (Components, Drivers, Potential Controls)

Objectives: (all risk management starts from well framed and stated objectives)

- To minimise the impact of major bushfires on human life, communities, essential and community infrastructure, industries, the economy and the environment. Human life (including firefighters) will be afforded priority over all other considerations.
- To maintain or improve the resilience of natural ecosystems and their ability to deliver services such as biodiversity, water, carbon cycling and forest products.

Likelihood x	Severity x	Exposure x	Value(s) x	Vulnerability
Risk Assessment • Ignition History -Lightning? -Human? • Seasonality • Topography • Fuel Hazard • Climate	Risk Assessment • Fine Fuel Moisture Content • Rate of Spread • Fuel Consumption • Depth of Burn • Fireline Intensity • Embers / Spotting • Surface / Crown • Perimeter / Area • Flame Depth • Radiant Heat Flux • Fire Cycle / Interval • Smoke • Terrain • Slope • Dangerous trees • Other Firefighter Safety Drivers	Risk Assessment • Proximity -Direction -Distance -Topography • Property Density • Smoke • Severity Duration	Risk Assessment • Public -Health -Safety -Wellbeing • Response Resources -Health -Safety -Wellbeing • Infrastructure • Property • Industry – Economics • Cultural • Environment • Watersheds • Agency Reputation	Risk Assessment • Human Physiology • Property Construction • Property Maintenance • Subdivision Design • Socio – Economics • Resilience • Biodiversity • Fire Ecology • Litigation
Potential Controls • Education • Engineering • *Spark Arresters* • *Power Grid Mgnt* • Enforcement • *Fire Bans* • *Area Closures*	Potential Controls • Fuel Management *-Protection Burning* *-Ecological Burning* *-Mechanical* • Fire Response	Potential Controls • Building Controls • Subdivision Design • Defensible Space • Area Closures • Warnings • Evacuations	Potential Controls • Education • Land Use • Salvage	Potential Controls • Building Controls • Land Use • Training • Experience • Education • Warnings • Advice • Ecological prescribed fire

Figure 6 Beever (2015) suggests a strategic level planning-risk profile which assesses historical likelihood data (past ignitions trends, frequency of climatic and fire behaviour related events and thresholds). The strategic level planning risk profile allows for strategic level forethought and planning as well as risk in the face of an incident occurring on the landscape.

Risk is also present when fire is not appropriately integrated across the landscape. There are risks associated with not burning as well as risks associated with burning. This is a fundamental component of fire in that while not all fire is necessarily desirable, having no fire is also not desirable (Leverkus *et al.* 2016). It is therefore integral to develop a broad-scale strategic fire strategy which includes the acceptance that fire is an ecological process having occurred for centuries across the landscape (Leverkus *et al.* 2016*)*. Spatial and temporal distribution of fuels and vegetation is important in landscape level fire management particularly in a changing climate. Chung (2015) developed a model of variables considered for fuel treatment planning (Figure 7). It is also integral to ensure that such a strategic plan incorporates not only the risks, but the benefits associated with fire across the landscape (Leverkus *et al.* 2016).

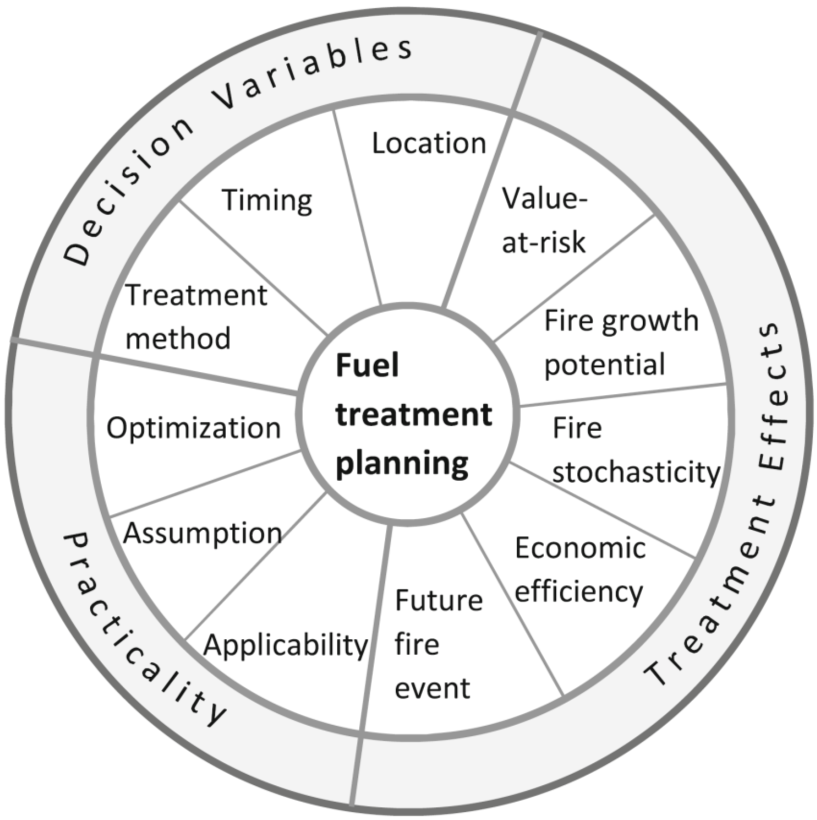

Figure 7 Fuel treatment planning requires the consideration of numerous variables, effects, and practicability (Chung 2015).

Box 4. Firescape risk-to-resilience case study.

Canadian Boreal Forests

Risk. The boreal forests of northern Canada rely on frequent high-intensity, stand-replacing crown fires for ecosystem health and maintenance. Boreal fire occurrence and severity are increasing and are expected to continue increasing because of climate change–induced extreme fire-weather and fire-danger conditions.

Adaptation. Modern but expensive fire-management programs have been effective to date, protecting much of the boreal zone for resource extraction and recreational use. A policy of aggressive fire suppression has been practiced for decades, most recently including resource sharing across Canada and with other countries. However, the recent Canadian Wildland Fire Strategy (CWFS) acknowledged that current fire-management practices have reached a point of diminishing returns, both economically and physically. Currently, 50% of the area burned in Canada occurs in remote northern boreal regions, where fires are monitored but not actively suppressed unless threatening property. An opportunity exists to adopt this policy more widely in heavily protected areas, assessing each fire in terms of potential values at risk, suppressing unwanted fires, and permitting more to burn naturally.

Mitigation. Canadian fire-management agencies are expanding public education and prevention programs and restricting public access to wildland areas during high-risk periods. This can reduce human-caused fire numbers, but lightning fires cannot be prevented and are forecast to increase under a changing climate as a result of greater atmospheric convective activity. The improved detection of lightning and fire occurrence prediction models may help. The further adoption of fuels and hazard mitigation practices to protect communities and high-value resources will be essential.

Resilience. Further public and political education and awareness around emerging fire-management issues and options are urgently required. Inhabitants of areas with forest ecosystems must recognize there will be more fire on the landscape in both the short and longer terms, with significant impacts including air quality, human health, and transportation. Evacuations of communities will increase, particularly in aboriginal communities.

Bottom line

Although natural fire has been deliberately promoted in more remote regions of the Canadian boreal zone, increasing fire activity will dictate a management strategy that monitors but allows more fire on the landscape, including increased fire in areas that were once under intensive protection.

Top: ***Crown fire in the Northwest Territories. Photograph: Dennis Quintilio.*** **Middle:** ***Smoke in Whati, Northwest Territories. Photograph: Dennis Quintilio.*** **Bottom:** ***Fire polygons 1980–2014.***

Figure 8 Smith *et al.* (2016) suggest that boreal fire occurrence and severity are expected to increase due to extreme fire-weather and fire-danger conditions induced by climate change. The future of boreal fire will need to include human acceptance and tolerance of fire on the landscape along with education, awareness, and pre-planning for evacuations and other potential impacts from fire (Smith et al. 2016).

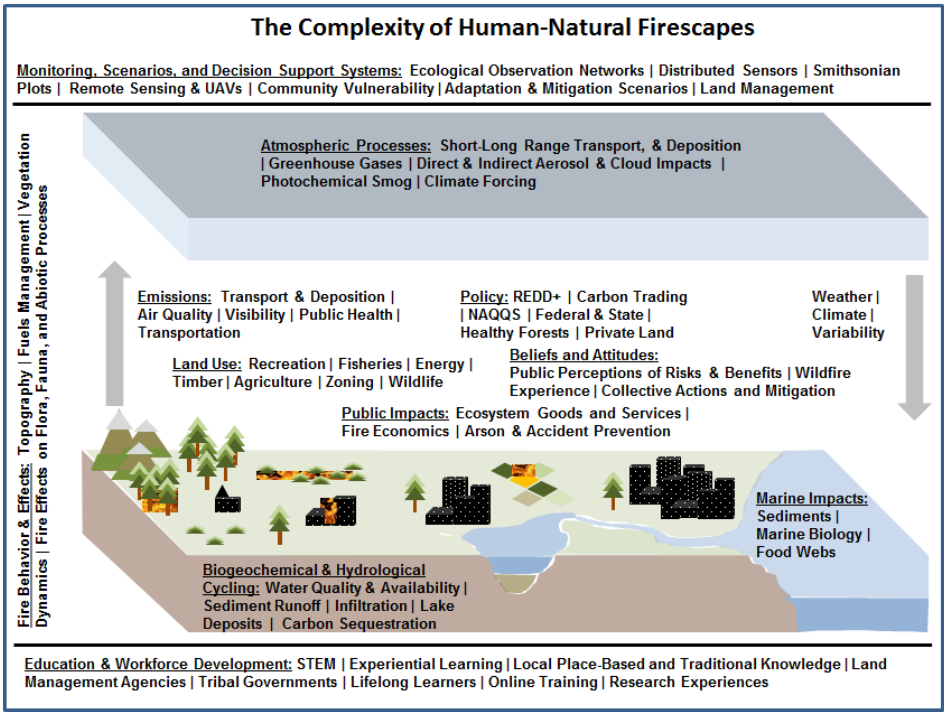

Figure 9 Smith *et al*. (2016) suggest that "research focusing on the design of wildland fire adapted firescape components will have to consider the complex cascading consequences of fires within human-natural firescapes."

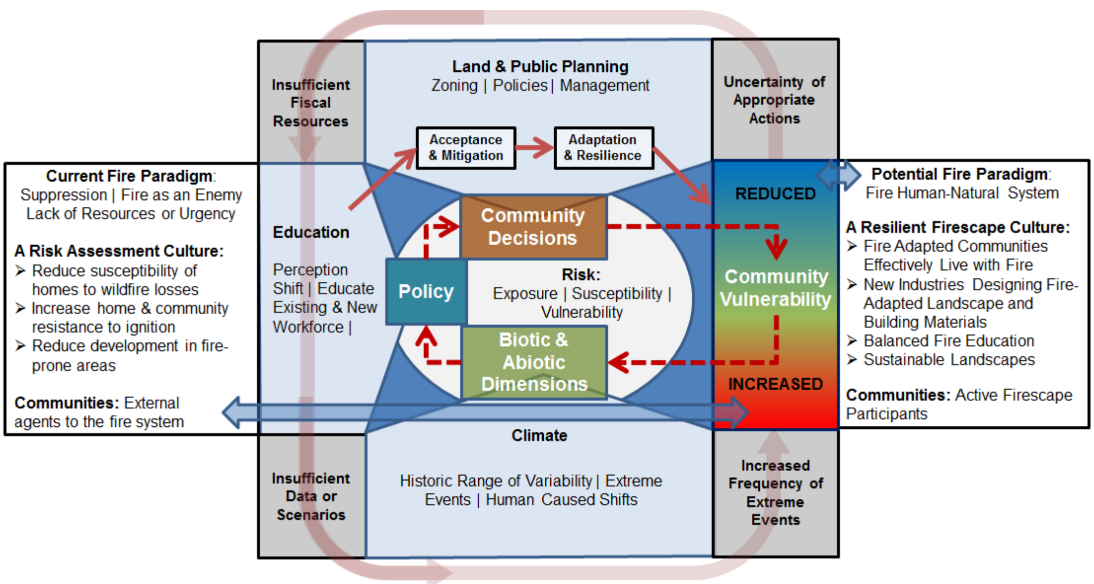

Figure 10 Smith *et al*. (2016) suggest that "a paradigm shift is needed from a system where communities are predominately passively affected by fires to ones where they actively work hand in hand with land management planners, architects, and agencies to coexist with wildland fires. Enhancements in education can lead to improved planning and informed adaptation and mitigation scenarios leading to reduced community vulnerability. A lack of education, resources, or data to make informed decisions can act to increase vulnerability."

High Level Plans and Strategies

BC Wildfire Service Strategy

The BC Wildfire Service is part of and mandated by the Government of British Columbia to deliver effective wildfire management and emergency response support, protect lives and values at risk, and encourage sustainable, healthy, and resilient ecosystems (FLNR 2017). Effective wildfire management is required to protect people, property, and preserve the environment. Assessing a prescribed fire or wildfire against the main values allows BC Wildfire Service to carefully monitor and manage beneficial fires and suppress harmful fires.

The BC Wildfire Management Strategy (2016) provides guidance to restore the "natural" role of wildfire in BC ecosystems while continuing to provide a response plan for harmful fires. The plan intends to support healthier ecosystems, increase community safety, and implement a cost effective fire-suppression program. These objectives will be achieved through the following actions:

1. Reducing fire hazards and risks around communities and high-value areas.
2. Using controlled burning where benefits are clear and risks can be cost-effectively managed.
3. Monitoring and managing, rather than suppressing, fires that pose minimal risk to communities, infrastructure or resources.
4. Implementing land, natural resource and community plans that incorporate wildland fire management at all appropriate scales.
5. Developing a high level of public awareness and support for wildland fire management.

A provincial review occurred in 2003 (Filmon) after wildfires in interior BC destroyed over 334 homes, many businesses, and forced the evacuation of over 45,000 residents. The total cost of the 2003 firestorm is estimated at $700 million; however, the greatest cost was paid by three pilots who died fighting the fires. The report provided several recommendations to manage wildfire hazards and to reduce interface fire risks:

- Develop a fuel management plan with local governments focusing on communities, infrastructure, and watersheds vulnerable to large wildfires.
- Identify and assign fuel management priorities to protect human life, property, and resource values.
- Review and amend Land Use Plans and Land and Resource Management Plans (LRMPs) to incorporate fire management considerations.
- Reduce fuel accumulation in provincial parks.
- Establish strictly controlled conditions for using prescribed fire for fuel management.
- Burn or treat slash onsite to reduce fuel accumulation.

Resource management fire, and specifically prescribed fire, is legislated under Section 23 of the *BC Wildfire Act.* Whereby a prescribed fire burn plan must be submitted to an official and receive the official's approval in writing along with the proponent obtaining a burn registration number (S. 24). Note: Prescribed Fire Complexity Worksheet and Rating Guide in Appendix.

Fire Management Plans and Provincial Strategic Threat Analysis

Fire Management Plans within the 4 zones (Fort Nelson, Fort St. John, Dawson Creek, and Mackenzie) of the Peace-Liard Prescribed Fire Program should be considered when applying fire to the land. The Government of British Columbia performed a wildfire threat analysis which analyzes high-level GIS rasters for provincial assessments resulting in relative threat information across the province. Fire density, headfire intensity, and spotting impact data layers were combined and processed (see

Government of British Columbia 2015). Fire hazard assessments in British Columbia involve analyzing "the ignition potential and predictable fire behaviour based on fuel hazards and site-specific and probable weather conditions. It includes a consideration of the risk of a fire starting, the difficulty of controlling the fire and the potential impact on identified values" (Government of British Columbia 2012). Beck and Simpson (2007) demonstrate a wildfire threat analysis and how to develop a fuel management strategy for BC. Hawkes and Beck (1997) developed a wildfire threat rating system which many have used. Note: additional resources and supporting information can be found in "Maintaining Fire in British Columbia's Ecosystems: an Ecological Perspective" by Erin Hall 2010.

Memorandums of Understanding (MOUs)

1. Agreement between the Ministry of Environment and the Ministry of Forestry – Use of Prescribed Fire for Wildlife Habitat, 1981
2. Protocol Agreement between Ministry of Forests and Ministry of Environment, Lands and Parks – BC Parks, Regarding Administration and Management of *Range Act* Agreements in Provincial Parks and Protected Areas, 1997
3. MOU on Fire Management within BC Protected Lands between the BC Forest Service Protection Program and BC Parks, 2005

Land and Resource Management Plans (LRMPs)

The Peace-Liard Region has four Land and Resource Management Plans (LRMPs) which provide clear direction regarding the importance and use of prescribed fire to maintain or enhance habitats and ecosystems. Each LRMP provides general management direction and objectives supported by prescribed fire.

Page 15 of the *Dawson Creek LRMP* (ILMB 1999) provides the following land-use objectives:

- Conserve the biodiversity of "natural" ecosystems.
- Sustain and manage wildlife habitat for red, blue and yellow-listed species.
- Sustain and manage wildlife and critical wildlife habitat to reduce wildlife-agriculture/range conflicts.

Pages 14 and 15 of the *Fort St. John LRMP* (ILMB 1997b) offers the following objectives, rationales, and encourages the implementation of ecologically appropriate silviculture systems to conserve biodiversity:

- Maintaining the opportunity for the sustainable harvest of fish and wildlife resources by maintaining sufficient habitat of appropriate capability to sustain populations.
- Conserving biodiversity, rare ecosystems, plant communities and habitat types. This will be achieved by identifying and mapping rare ecosystems, plant communities and habitat types and considering them for incorporation into more detailed plans with designations such as sensitive areas or wildlife habitat areas and managing them with ecologically appropriate silvicultural systems. This goal will be further achieved by maintaining larger patches of unfragmented mature and older seral stage forests, where appropriate, and ensuring connectivity between important habitat types by using naturally occurring corridors (e.g. riparian areas).
- *Redfern-Keily Protected Area* (pg. 146) - maintain high capability ungulate winter habitat and maintain functioning and healthy ecosystems in the resource management zone.
- *Goal 2 Approved Protected Areas* (pg. 146) - sites along the Peace River Corridor offer locally important recreational opportunities, as well as, protecting rare grassland ecosystems and mule deer winter range.

Page 28 of the *Fort Nelson LRMP* (ILMB 1997a) has similar objectives:

- Maintain the diversity and abundance of wildlife.
- Maintain the integrity and diversity of existing habitats and ecosystem.
- *Northern Rocky Mountains Protected Area* (pg. 128) - this area provides key winter ranges for wildlife populations. Prescribed fires have been historically used for wildlife habitat enhancement.

The Muskwa-Kechika Management Area and Wildlife Management Plan

The Muskwa-Kechika Management Area (M-KMA) provides an example of a case study in which landscape fire and disturbance related processes are primary ecosystem drivers promoting biological diversity (Parminter 1983). In 1998, the Government of British Columbia created a management model for environmental sustainability and economic stability within the Boreal Cordillera of the boreal forest in Northeast British Columbia, Canada. The diversity of wildlife and viewscapes resulting from varied time since fire in the M-KMA are a source of attraction by eco-tourists, big game trophy hunters and outdoor recreationists. Mountainous aspen rangelands driven by fire are dispersed through conifer-dominated valleys which lie within the expanse of the height of the Northern Rocky Mountains (Raup 1945). The M-KMA was intended to serve as a model which balances the conservation of the environment and wilderness with human activities, primarily resource extraction and tourism, over time.

The Muskwa-Kechika Wildlife Management Plan (M-KWMP) was developed and approved by the Government of British Columbia and outlines priority species and main objectives for maintaining and promoting their habitat. In 2009, a recommendation was made that research was needed to improve the understanding of the long-term fire history of the M-KMA and its role in maintaining ecosystems with the historic and current fire regimes identified, mapped and described so that a “natural” range of variability could be depicted in order to inform management decisions. The M-KWMP also called for the development of a Fire Management Plan specific to the M-KMA which would consolidate portions of existing Forest District and Provincial Park plans, prescribed fire burn plans, listed species occurrences and wildlife habitat information.

Woodland Caribou Recovery

British Columbia is home to three woodland caribou ecotypes – Boreal, Mountain, and Northern – which express distinct behaviours and habitat requirements. Approximately 1,100 South Peace Northern caribou reside in the Peace Region (BC MoE 2013) and are distributed between the Graham, Moberly, Scott, Burnt Pine (extirpated), Kennedy Siding, Quintette, and Narraway herds. Caribou recovery in the South Peace Northern Caribou are directed by the Peace Southern Northern Caribou Plan (BC MoE 2013) and the Quintette Strategic Action Plan (BC FLNR 2017). Low elevation industrial development has altered habitat patterns and structure thus increasing moose and wolf populations that has increased caribou predation risk. South Peace Northern caribou typically spend the majority of their time in high elevation habitat as a refuge from predation. The management objectives outlined in the management plan address habitat protection, reducing industrial footprint, and addressing non-habitat related threats.

The Quintette Strategic Action Plan provides the following management objectives:

- Protect high elevation summer and winter habitats.
- Manage predators within the caribou range in combination with other management efforts.
- Develop and implement a maternal pen project to enhance caribou calf survival.
- Implement functional restoration activities to reduce predator movement along linear corridors.

- Implement ecological restoration activities to support the regeneration of low elevation ecosystems used by caribou.
- Address recreational and snowmobile access into high elevation and high value habitat.
- Develop prey management options to reduce primary prey densities which may reduce wolf densities.
- Implement an effectiveness monitoring program to ensure the management actions are achieving the desired objectives.
- Support compliance and enforcement activities.

The targeted use of prescribed fires may be a management tool that creates early seral habitat favored by moose and elk in low elevations. This ecological approach could facilitate the spatial separation of moose, elk, wolves, and caribou while also supporting the habitat and population objectives outlined in both plans.

The *Implementation Plan for the Ongoing Management of Boreal Caribou (Rangifer tarandus caribou pop. 14) in British Columbia* (MoE 2011) describes similar habitat changes due to industrial developments and the resulting decline of the caribou herds. The plan proposes similar objectives intended to stabilize and recover the six Boreal caribou herds. The significant difference is a recommendation to reduce predators and manage habitat conditions through fire suppression. Within the Boreal Caribou range; prescribed fire is unlikely to be used as a habitat modification tool unless required to reduce fuel loads and minimize the risk of catastrophic wildfires.

In November 1990 A. Brulisauer and Dr. Michael Pitt proposed a study titled "impact of fire on critical caribou habitat in the Spatsizi Wilderness Park Area." The project involved radio collars and telemetry, understanding the dynamic between fire*vegetation response*caribou habitat requirements. This is the only known study in BC to have been conducted to investigate this interaction.

Peace-Liard Moose Management Plan

Moose (*Alces alces*) are a priority species in the Peace Region. First Nations people highly value moose for food, social and ceremonial purposes, and First Nations hold constitutionally protected Treaty and/or Aboriginal rights to harvest moose year-round. Moose are also highly valued by other British Columbians for hunting and their intrinsic values as an iconic Canadian species and an important component of the environment. The Peace Region is estimated to contain 50,000 to 80,000 moose, approximately 40% of the provincial moose population. However, First Nations, stakeholders, and provincial wildlife biologists have observed declines in moose numbers in some areas of the Northeast Region, and are concerned with the on-going pressures on moose from development.

In response to those concerns, the Ministry of Forest, Lands, Natural Resource Operations and Rural Development in the Northeast Region initiated the development of moose management planning documents, including *the Peace Liard Moose Management Plan* (BC FLNR nd.) and the upcoming *Northeast Moose Action or Implementation Plan*. *The Peace Liard Moose Management Plan* or PLMMP is a strategic document that sets out the goals and objectives for moose management in the region. The PLMMP defines the key management levers for moose management as compliance and enforcement, hunting regulations, health & monitoring, habitat management and population management, which align with the broader Provincial Framework for Moose Management in British Columbia (2015). The proposed *Northeast Moose Action/Implementation Plan* will set out the specific actions under each of the management levers and the recent and upcoming application of those actions at a more localized spatial scale.

Ecosystem Restoration Activities in the South Peace

The Peace District Stewardship staff initiated an ecosystem restoration plan for the South Peace area (LM Forest Resource Solutions 2016). The plan explored the types of ecosystems, need for restoration activities, and stakeholder interest. The provincial ecosystem restoration program emphasized maintaining open forest and grasslands to increase forage for wildlife and livestock, improve ecosystem resiliency, reduce fuel loads, improve long-term timber values, and provide a biofuel fibre source by thinning dense stands. Range objectives were developed for the South Peace:

- Maintain healthy and functioning riparian and upland ecosystems
- Restore and maintain desired plant communities
- No net loss of native species
- Appropriate levels of use

The plan identified the following priorities for ecosystem restoration activities:

- Ecosystem restoration effectiveness monitoring, data collection, and management
- Native grasslands and rangeland ecosystems
- Old forest attributes and tree species with high functional importance
- Water quality, fish habitat, and riparian ecosystems
- Wild ungulate habitat and ecosystems
- Landscape connectivity

The plan recommends prescribed fire as a possible method to restore native grasslands, ungulate winter range, and open rangelands.

Ecosystem Restoration Plan for the Fort Nelson Forest District: A Guiding Document

The Fort Nelson Forest District commissioned development of a similar ecosystem restoration strategy to provide guidance when and where prescribed fire should be applied on the landscape. Ecosystem restoration focuses on assisting the recovery of degraded, damaged, or destroyed ecosystems through the reestablishment of structure, species composition, and ecological processes. The main objectives addressed in the report include:

- Support decision makers when reviewing prescribed fire burn plans to determine if fire is the correct method to achieve landscape objectives
  - Outline burning frequencies and intensities in association with benefits and detriments
  - Identify areas and conditions where prescribed fire could support restoration
  - Identify areas and conditions where prescribed fire may be inappropriate
- First Nations have use prescribed fire to modify the landscape and may desire to use prescribed fire in the future
- Guide wildfire suppression activities
- Solicit ecosystem restoration activities in the district.

In 2010, the Fort Nelson Forest District landscape units (LU) were established by Ministerial Order (MAL 2010). The objectives established by the Order apply to all Crown land except for land covered by woodlot licences, research forests, or community forest licences smaller than 600 hectares. Additional assessments estimated the natural range of variability for each landscape unit and proposed maximum prescribed fire rates to avoid significant alterations to the ecosystem's successional pathway. A natural baseline of fire disturbance cycles was estimated using forest age classes 3 and 4 due to the reduced wildfire impact and lack of forest harvest when compared to older age classes (DeLong 1998). Table 2 summarizes the values and objectives for landscape unit groups.

Table 2: Values and Objectives for landscape unit groups in the Fort Nelson Forest District

Landscape Unit Group	Landscape Unit Name	High Values	Moderate Values	Objectives
A	Alluvial West Boreal Churchill Kechika Major Hart Netson Rabbit Sharktooth	Biodiversity, caribou, Stone Sheep	Elk	Maintain natural processes
B	Gatho Prophet Sulpher/8 Mile Tuchodi	Biodiversity, Stone Sheep, elk, caribou, traditional use	Timber, oil and gas	Limit prescribed fire to balance age class distribution; limit resource extraction, maintain natural processes
C	Beaver Holden Hyland Irene Kiwigana Kledo Klowee Klua Sandy	Timber, oil and gas, traditional use	Biodiversity, oil and gas, traditional use, recreation	Maintain natural processes as much as possible while conducting resource extraction; protect infrastructure with full fire control response
D	Kotcho Petitot Shekilie	Biodiversity, caribou, oil and gas, traditional	Recreation	Limit disruption of natural processes, particularly hydrological patterns, while conducting oil and gas activities; protect infrastructure with full fire control response
E	Alluvial MK Alluvial FN	Biodiversity, timber, traditional use	Recreation	Maintain a high amount (>50%) of natural forest (unmanaged forest of any age including old forest) where natural processes can occur
	Cridland Clarke	Caribou		No restoration activity is recommended

Group B landscape units occur primarily in the Muskwa-Kechika Management Area, are mostly Class A park and have limited timber or oil and gas value. Extensive prescribed burning by guide-outfitters may have created unbalance forest age distribution with a lack of young forest to recruit into old forest. Table 2 recommends maximum areas impacted by fire to balance forest age classes.

Table 3: Suggested average fire disturbance within the SWB over the next 50 years to recover the Landscape Unit age class distribution

Landscape Unit	Historical Burn Area (ha)	Total Landscape Unit Area (ha)	Suggested annual fire average (ha)	Suggested 5-year fire average (ha)
Sulpher/8 Mile	22, 999	236, 107	602	3,010
Tuchodi	25, 510	200, 042	390	1,950
Gatho	13, 120	164, 152	476	2,380
Prophet	12, 638	116, 272	270	1,350

Peace Region Natural Disturbance Units and Benchmarks
DeLong (MoF 2010) completed a land unit and benchmark process for natural-disturbance based forest management in Northeastern British Columbia. The document indicates fire is the key-stand replacement disturbance agent within the boreal forest (BWBS) with a 1 in 100 year fire return interval.

Table 4 summarizes his findings of the disturbance history of the boreal forest in Northeast British Columbia. It is possible that a combination of this information could be combined to guide the frequency, size, and location of prescribed fires and stand replacement activities. The data indicates that approximately 30% of the fires within the Boreal Foothills created patches between 101 – 1000ha and 40% created patches >1000ha with a stand replacement cycle occurring every 120 to 150 years. The Boreal Plains – Alluvial and Northern Boreal Mountains have experienced significant prescribed fire altering the natural disturbance regime and patch size distribution according to DeLong's assessment.

Table 4: Estimates of stand disturbances within the boreal natural disturbance units.

Natural Disturbance Unit	Stand replacement disturbance cycle	Time since disturbance distribution (% of total forest area)				Patch size (ha) (% of total disturbance area)				Disturbance Type (% of disturbance area)	
		>250 yr	>140 yr	>100 yr	<40yr	>1000	101-1000	51-100	<50	Stand Replacement	Gap Replacement
Boreal Foothills – Mountain	150	15-25	33-49	43-62	19-36	40	30	10	20	80	20
Boreal Foothills – Valley	120	8-17	23-40	33-55	19-45	40	30	10	20	90	10
Boreal Plains – Alluvial	200	23-37	41-61	52-72	12-33	0	0	40	60	80	20
Boreal Plains - Upland	100	6-12	17-33	28-49	25-50	70	20	5	5	98	2
Northern Boreal Mountains	180	20-35	37-60	48-70	12-34	60	30	5	5	70	30

DeLong (2007, 2014) conducted additional analysis and determined the range of natural variability at a landscape unit or natural disturbance unit level. These units delineate the landscape based on topography and ecosystem characteristics; the natural range of variability provides the minimum and maximum disturbance thresholds that would allow the ecosystems to maintain all age and structural classes for long-term ecosystem resiliency.

Forest Carbon Strategy
The provincial forest carbon strategy outlines current and planned initiatives to manage forest carbon and improve the sustainability of forests, communities and industry while mitigating the effects of climate change.

Climate Change Strategy
The Ministry of Forests, Lands & Natural Resource Operations' (FLNRO) Climate Change Strategy outlines goals and objectives for effectively responding to and mitigating the impacts of climate change.

Forest Enhancement Society – First Nations Service Delivery Model

First Nation communities are not always effectively engaged in the full range of wildfire protection programs available in British Columbia, most of the Northeast Region's First Nation communities are situated in the Wildland-Urban Interface (WUI). The First Nations Emergency Services Society (FNESS) is developing a program to identify strategic priority areas for First Nations Forest Enhancement Program Initiatives align with regional land, fire, and habitat management plans. Additional support may be provided to First Nation Communities to develop and leverage partnerships to develop tactical and operational plans to treat priority areas within and adjacent to communities.

Throughout 2017, FNESS partnered with the Fort Nelson First Nation, Northern Rockies Regional Municipality, Geoterra IRS Ltd, Shifting Mosaics Consulting, Partners in Protection, FireSmart Canada, and Hummingbird Drones to deliver the FireSmart Home Ignition Zone Wildfire Mitigation and Unmanned Aerial Vehicle Pilot Project to the community of Fort Nelson. While this project occurred across a smaller scale than the entire Region, there are many synergies and collaborations possible as fire management is incorporated through space and time. In addition, FNESS works with many of the Treaty 8 Nations in the development and revisions to their Community Wildfire Protection Plans (CWPP).

BC Parks Management Plans

BC Parks management plans outline the vision and direction for a protected area. These plans provide direction for the types, location, and volume of uses and activities that align with the management objectives. These plans are developed in consultation with First Nations, local governments, and other interest groups.

BC Cumulative Effects Framework

The province of British Columbia is developing a cumulative effects framework to address changes to the landscape associated with past, present, and future human activities and natural processes. The cumulative effects framework is intended to be a set of policies, procedures, and decision-support tools to consistently and transparently manage the natural resource sectors. Prescribed fire is a human activity that may mimic natural processes, the influence of prescribed fires within the cumulative effects framework will vary depending on the framework's value, the size and location of the fire.

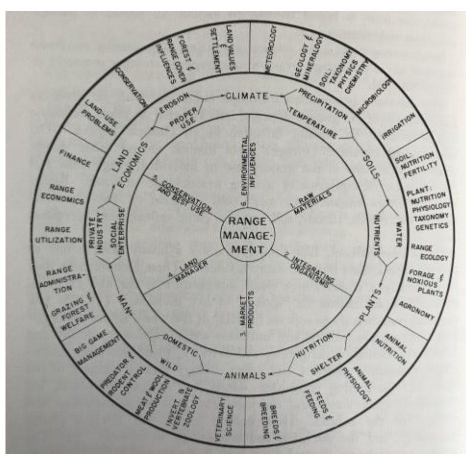

Figure 11 Sampson (1952) presented a diagram of range management and its integrating organisms and disciplines. The spokes and intention of this wheel remain true to the current day in the delivery of an effective strategic approach to prescribed fire with the acknowledgement and incorporation of multiple values and interactions across the broad landscape.

PRESCRIBED FIRE VALUES

Frederic Clements and John Weaver successfully argued that "vegetation is more than the mere grouping of individual plants. It is the result of the interactions of numerous factors. The effects of the plants upon the place in which they live and their influence upon each other are especially significant… A study of vegetation reveals that it is an organic entity and that, like an organism, each part is interdependent upon every other part" (Weaver and Clements 1938). Almost a century later, the concepts proposed by Clements and Weaver have relevance for the Peace-Liard Prescribed Fire Program: vegetation composition, structure, integrity, and distribution as it relates to fire behaviour (as a fuel type), carrying capacity and animal unit months (as forage, browse, and other sources of nutrition), habitat (as structural components and required resources for species survival), anthropogenic economic production (as timber and other features to sell, non-timber forest products), spiritual, cultural and recreational practices (medicinal plants and berries, peaceful enjoyment and sacred places), and carbon storage amongst others. In recognition of these dynamics, thirteen values were identified around prescribed fire which stemmed from an initial discussion in the summer of 2017, with more than 15 government representatives from across the northeast Region who had gathered to synthesize prescribed fire and the values, challenges, and opportunities for refining and evolving the Peace-Liard Prescribed Fire Program as follows:

1. Reducing Fuel Loads and Fuel Continuity

Forest fuels can accumulate to levels that can increase wildfire severity but strategic use of prescribed fire can reduce fuel accumulation leading to reduced fire spread and intensity. Ultimately, prescribed fire effects on fuels can reduce the size, intensity, and damage of wildfires (Fernandes and Botehlo 2003). The duration of efficacy is limited by the relatively rapid re-accumulation of vegetation fuels and for herbaceous fuel loads this is only 2 to 6 years (Fernandes and Botehlo 2003). It has been suggested that optimal effects of prescribed fire applications to reduce fuels and wildfires are most promising in heterogeneous landscapes where extreme weather likelihood is low and that efficacy is a function of the entire fire management process (Boer et al. 2009; Fernandes and Botehlo 2003). Application of prescribed fire at an effective landscape scale is also crucial for both planning and implementation considerations (Agee and Skinner 2005). The reduction of fuel loads and fuel continuity achieved through prescribed fire also interacts with smoke and emissions management.

2. Removing Logging Debris

Prescribed fire may be a tool to remove woody debris after forest harvest (i.e., slash) (Weir 2009). The use of prescribed fire after clearcutting in a black spruce boreal forest had positive benefits for restoring stand productivity (Renard *et al.* 2016). It is important to consider the effects of burning slash in piles and the subsequent effects from such a concentrated heat source (Page-Dumroese *et al*. 2017). Salvage logging after a fire event may not be an accepted practice across the Region due to impacts on the physical structure of forest stands and aquatic systems, key ecosystem processes, and elements of the biota and species assemblages (Lindenmayer and Noss 2006). Salvage logging removes biological legacies, simplifies forest stands, changes connectivity between patches of vegetation, and homogenizes the landscape pattern (Lindemayer and Noss 2006). Hebblewhite *et al*. 2009 report that moose avoided postfire logged stands as measured using telemetry and pellet counts due to higher wolf predation.

3. Silviculture Preparation

Prescribed fire is a tool for silviculture site treatment. The implementation of prescribed fire supports pine regeneration and/or seedbed preparation prior to planting. Fire has been documented to remove litter and vegetation that constrains red and white pine regeneration (Mcrae *et al*. 1994). This value has been articulated for seedbed preparation for loblolly pine (Lotti 1962). The use of prescribed fire for silviculture site preparation as described above has been suggested to be the largest application of prescribed fire in Canada (Weber and Taylor 1992). Lepine *et al.* (2003) conducted an analysis of escaped fires from broadcast burning in the Prince George Forest Region and concluded that prescribed fire, when implemented under appropriate conditions and prescriptions, is an effective silvicultural practice.

4. Reduce Vegetation Competition

Periodic fires strongly dictate vegetation successional patterns and have the possibility to encourage coniferous tree growth. Classic examples of this conifer stimulation and competition reduction from fire is demonstrated for both jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) in Canada (Weber and Stocks 1998). For both of these conifer species, fire opens serotinous cones, establishes a bare soil seedbed, and removes temporarily the vegetation that would compete with new seedlings for light and water resources. When fire (n = 250) was compared to mechanical harvest (n = 131) in central Canada, sites without fire demonstrated a shift from conifer-dominated to deciduous dominated forests, suggesting that it is not only fire as a management tool but also as an ecological process that is important for the boreal (Carleton and Maclellan 1994). It is important that assessments of both short-term and long-term effects of fire on plant succession be considered for fire projects (Wang and Kemball 2005).

5. Control Insects and Disease

Targeted use of prescribed fire may reduce the spread of insects or diseases that impact forest, range, or wildlife health. From an animal health perspective, fires have been shown to decrease external (tick and fly) parasites and internal (gastrointestinal and lung) parasites of both domestic and native ungulates (Scasta *et al*. 2015; Scasta *et al*. 2016). From a specifically wildlife perspective, this includes lungworms in Stone's sheep (Seip and Bunnell 1985) and chytrid disease in boreal toads (Hossack *et al*. 2013). The application of fire to manage forest insects and diseases is less clear because many of the insects in fire-prone forests have developed mechanisms to avoid, tolerate, or colonize burned areas. However, several examples of successful prescribed fire applications are available including (1) to control cone-infesting *Conopthorus resinosae* that overwinters in fallen shoot tips and the related *C. coniperda* in a white pine orchard, (2) reduction of acorn weevils in red oak stands, and (3) control of seed-infesting insects in ponderosa pine stands (McCullough *et al*. 1998). However, some applications have not been successful due to insect adaptations; for example, the use of burning to reduce pandora moths in ponderosa pine was unsuccessful because the moth selects pupation sites in areas with low fuel loads (McCullough *et al*. 1998).

Probably of greater interest is the use of prescribed fire to reduce bark beetles and wood-borers. Some successful examples are available including: (1) prescribed fire in western Canada destroyed overwintering *Dendroctonus rufipennis* in slash and stumps in harvested spruce stands, (2) prescribed fire after harvest controlled populations of *Ips pini* and *Dendroctonus ponderosae* in ponderosa pine stands and lodgepole pine stands, and (3) prescribed fire killed *Monochamus* spp. larvae, a wood-boring insect, in Canada lodgepole pine stands (McCullough *et al*. 1998). While Sudden Aspen Decline (SAD) has not been documented in the Region, it is present in many locations in North America and is the sudden dieback and rapid mortality of aspen. R. Kabzems, Research Silviculturalist, is notably the leading professional on aspen in the Region. D. Bartos, Ecologist with the USDA Forest Service, is highly regarded as an expert on aspen (http://www.western-aspen-alliance.org/index). Finally, the stand alterations from prescribed fire, specifically the age and density, may also create heterogeneity in beetle outbreaks and wildfire risk although beetle outbreaks also have different effects on wildfire behavior ranging from increased risk to decreased risk, indicating the fire-insect interaction is quite complex (McCullough *et al*. 1998).

6. Forage and Browse for Herbivores

Prescribed fire can reduce shrub encroachment and increase forage crude protein, palatability, nutrient density, and biomass production as demonstrated in tallgrass prairie (Allred *et al*. 2011), northern mixed grass prairie (Powell *et al*. 2017), and pine-wiregrass plant communities (Hilmon and Hughes 1965). In all of these scenarios the crude protein is the highest in the forage regrowth that occurs immediately after burning, with a crude protein advantage that persists for 90 to 120 days. The removal of the standing dead biomass, and the tender leaves of the forage regrowth, provides a more palatable forage for grazing animals.

Stocking rate, as it pertains to the needs and requirements for forage and browse, is a foundational consideration in the Peace-Liard Prescribed Fire Program. Stocking rate, as defined by the Society for Range Management (1989), is “the amount of and allocated to each animal unit for the grazable period of the year” … “the number of specific kinds and classes of animals grazing or utilizing a unit of land for a specified time period” (Campbell and Bawtree 1998). As stated by Holechek *et al.* (2004) and commonly acknowledged by all rangeland professionals: “selection of the correct stocking rate is the most important of all grazing management decision from the standpoint of vegetation, livestock, wildlife, and economic return.” An animal unit, typically defined as one mature cow weighing 455 kg either dry or with a calf up to 6 months of age, and consuming 9.1kg of forage per day, 273kg per month, and 3,318kg per year (Holechek *et al.* 2004). An animal unit month (AUM) is the amount of feed or forage (273kg) required by one animal unit for one month (Holechek *et al.* 2004). Carrying capacity, or grazing capacity, refer to “the maximum stocking rate possible year after year without causing damage to vegetation or related resources … grazing capacity is generally considered to be the average number of animals that a particular range will sustain over time” (Holechek *et al.* 2004). The calculation of stocking rate is determined by “dividing the total usable forage per unit area by the total forage demand of the grazing animals for the grazing period” (Holechek *et al.* 2004). In British Columbia, there is a legislated requirement that 25% of available forage and browse on rangelands be allocated to wildlife. Stocking rate, grazing capacity, and desired allocated animal units are critical considerations for determining the spatio-temporal distribution of fire across the landscape.

Animal	Animal Weight (lb)	Animal Weight (kg)	Daily Dry Matter Intake(lb)	Daily Dry Matter Intake(kg)	Animal Unit Equivalents
Cattle (mature)	1000	455	20.00	9.10	1.00
Cattle (yearling)	750	318	15.00	6.80	0.75
Sheep	150	68	3.00	1.40	0.15
Goat	100	45	2.00	0.90	0.10
Horse	1200	545	36.00	10.90	1.80
Donkey	700	318	21.00	6.40	1.05
Bison	1800	818	36.00	16.40	1.80
Elk	700	318	14.00	6.40	0.70
Moose	1200	545	24.00	10.90	1.20
Bighorn sheep	180	82	3.60	1.60	0.18
Mule deer	150	68	3.00	1.40	0.15
White-tailed deer	100	45	2.00	0.90	0.10
Pronghorn antelope	120	55	2.40	1.10	0.12
Caribou	400	182	8.00	3.60	0.40

Figure 12 Animal Unit Equivalents as adapted from Holechek 1988 and Holecheck *et al.* 2004.

Animal	Weight (kg)	AUM Equiv.	No. per AUM	Intake kg/day *	Forage use kg/day *
Cow	450	1	1	10	13
Cow	680	1.4	0.74	14	18
Heifer	320	0.8	1.25	8	10.5
Bull	770	1.5	0.7	15	19
Horse	600	1.2	0.8	12	15.5
Sheep	55	0.2	5	2	2.5
Pronghorn	55	0.2	5	2	2.5
Deer	70	0.25	4	2.5	3
Elk	275	0.7	1.4	7	9
Ground squirrel	0.5	0.006	177	0.06	0.07
Jack rabbit	3	0.024	42	0.2	0.3

*expressed in dry matter

Figure 13 AUM Equivalents as adapted from the Draft, Remedial Measures Primer Pilot Version 1.0.

Fuhlendorf *et al.* (2012) recently proposed 6 new principles of rangeland conservation of pattern and process which serve as foundations to the conceptualization and implementation of the P-LPFP:

1. Maintenance of large continuous tracts of rangelands is critical for conservation of patterns and processes so that disturbance processes can interact with complex landscapes and form multiscaled mosaics.
2. Grazing intensity (i.e. stocking rate) is the primary factor influencing the effect of grazing on rangelands, but no single grazing intensity is “proper.” For ecosystems that evolved with grazing, all evolutionary appropriate grazing intensities are essential to conservation of biodiversity across large, complex landscapes.
3. Obtaining uniform distribution of grazing in time and space across a landscape is neither possible nor desirable. Managing grazing distribution for heterogeneity as a shifting mosaic across the landscape should be the goal.
4. Shifting mosaics are necessary for maintaining ecosystem structure and function and achieving multiple objectives. Managing for a single condition, state, phase, or successional stage might

maximize and sustain livestock production but will not be capable of promoting biodiversity or multiple uses.

5. Conservation of rangelands ultimately should consider all species of animals and plants. Individual species and groups can be used as diagnostic indicators of response to management, but plants and animals should not be considered "sacrifice species" or "management objectives" across an entire landscape.
6. Disturbance regimes, such a fire and grazing, are as vital to ecosystem structure and function as climate and soils. They must be viewed as interactive processes if we are to have any hope of maintaining biodiversity.

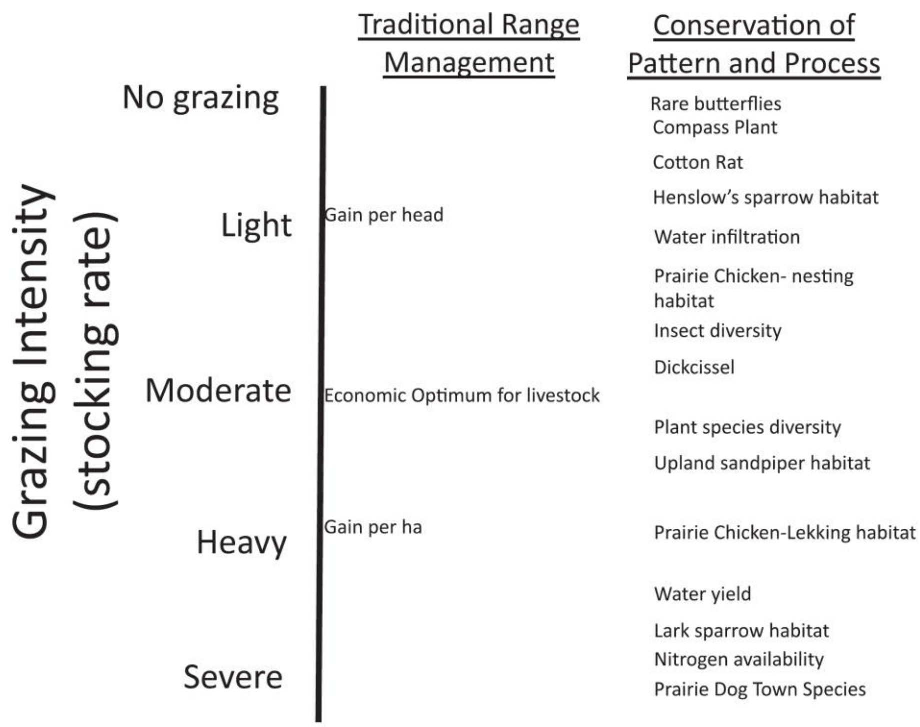

Figure 14 Fuhlendorf *et al.* (2012) compare the objectives achieved through the utilitarian paradigm of "proper" range management with conservation of pattern and process examples.

7. Aesthetic Enhancement

Properly located prescribed fires can maintain recreational and aesthetic values by maintaining open stands, encouraging annual plant growth, or enhancing wildlife species diversity, however, the application of fire for aesthetics is complex. Research on visual management has shown that the immediate effect of prescribed fires is negative, but over time the effect is likely positive, and that the scale of fire severity influences perceptions (Anderson *et al*. 1982; Taylor *et al*. 1984). Thus, implementation for this purpose must be strategic and should include leaving unburned islands, limiting the amount of road frontage burned, and/or burning during periods when visitation is lowest (Gobster 1999). This contrast of short-term negative connotations and the long-term appreciation for the role of fire in regenerating forests as a visually pleasing process has been documented over the decades following the Yellowstone fires (Gobster 1999).

8. Access

Prescribed fire can reduce understory vegetation improving safety and access for forestry crews, wildlife, livestock, or recreational users. Specifically, burning the understory enhances the ability for cruising, marking, and harvesting timber (USDA 1989). The accessibility benefit is similar for hunters and other recreational uses (USDA NRCS 2016). Range tenure holders may be adversely impacted by deciduous tree regrowth post-harvest and prescribed fire may reduce stem density restoring livestock access into previously inaccessible areas of the range. The application of prescribed fire may adversely impact certain species, including caribou, by improving predator movements through natural barriers.

Figure 15 Transportation corridors are important features to protect across the Region. Photo credit: A. Chalabai 2015.

9. Support Fire-Dependent Species

Certain species require fire to propagate and thrive in fire-disturbed environments and certain wildlife species benefit from fire-scars or disturbances resulting from fire. Examples of fire-dependent woody plant species include those with serotinous cones (many pine specie, black spruce, and paper birch). Examples of fire-dependent herbaceous plant species include Bicknell's geranium (*Geranium bicknellii*) that requires the high heat from fires to break dormancy and germinate (USDA 2017), eastern pasqueflower (*Pulsatilla patens*) that needs fire to alter the litter environment (Kalamees *et al*. 2012), and fireweed (*Chamerion angustifolium*) that can rapidly colonize burned areas. Amphibians such as boreal toads may also benefit from the altered thermal environment (Hossack *et al*. 2009). Many other examples of more generalist flora and fauna exist that require fire-disturbed or specific time since fire intervals at specific life stages.

10. Nutrient Cycling

Prescribed or wild fire can accelerate the release of nutrients supporting rapid vegetation growth post-burn. In North American grasslands, the removal of plant biomass led to an increase of plant available nitrogen (N) typically in an early pulse following the fire (Knapp and Seastedt 1986; Blair 1997; Augustine et al. 2010). The interaction between fire and the subsequent focal grazing of large ungulates may enhance the N cycling and availability process (Anderson *et al*. 2006). It is important to consider that the temporary N availability pulse occurs within the context of potential net volatile loss of N and the nitrogen:carbon dynamics.

Carbon

Models developed for the boreal forest suggest an increase of 20% to 50% in annual area burned, due to continued changing climate, which may influence fire return intervals by decreasing them from potential upper levels of 150 years to 100 years in some locations (Kasischke *et al.* 1995). Although there are a high number of annual fires across the boreal, currently, only a small percentage result in large areas burned (Burton *et al.* 2008). It has been reported that there will be impacts on terrestrial carbon in the boreal resulting from an increase in fire severity and occurrence due to climate change and increased fire seasons and lightning activity (Amiro *et al.* 2001, Stocks *et al.* 2003, Flannigan *et al.* 2009, Wotton *et al.* 2010). A higher percentage of deciduous trees is anticipated to result from this shift in fire regime and is anticipated to increase carbon storage (Kasischke *et al.* 1995). This pattern of fire and varied vegetation structure across the landscape is critical for many species and communities (Rowe and Scotter 1973, Burton 2008) as well as potential opportunities for carbon storage budgeting.

It is argued that fire can have a positive or a negative feedback on global warming (Bowman *et al.* 2011). In the boreal where fire is a natural disturbance, anthropogenic climate change could increasingly influence the extent, frequency and intensity of fires resulting in the release of greenhouse gases and particulates with a mobilization of carbon that is currently stored in permafrost which could provide a positive feedback to global warming (Bowman *et al.* 2011). Conversely, fire could slow regional warming trends by changing the albedo when tree cover is reduced and more snow is exposed which increases reflectance (Bowman *et al.* 2011). Twenty-five percent of the global vegetation carbon pool is stored by boreal forests (88 petagrams of carbon) (Dixon *et al.* 1994). Natural disturbances along with vegetation age class structure, disturbance history and woody debris influence carbon dynamics, acting as either sources or sinks (Kruz and Apps 1999). When there is an increase in forest age, there is a decrease in the ability to sequester carbon therefore having a shifting mosaic across the landscape, of differences in vertical structure and age class, may positively influence the carbon budget through increased sequestration (Kurz and Apps 1999, Burton *et al.* 2008).

11. Enhance and Maintain Wildlife Habitat

Fire can establish a mosaic of plant successional states relative to time since fire that can be important for a suite of wildlife species at different seasonal of life stages. This ecological process of fire structuring shifting mosaics of habitat has been suggested to be the basis for conservation (Fuhlendorf *et al*. 2006). The importance of this fire-driven habitat heterogeneity spans trophic levels as it can be important for broad guilds of invertebrates, birds, reptiles, amphibians, small mammals, large mammals, and apex predators (Scasta *et al*. 2016). Also important is spatial segregation as it extends to the predator-prey dynamic. Extensive wildlife species with specific examples of how prescribed fire can benefit species is found in the Appendix and in Lousier *et al.* 2009.

Figure 16 Wildlife have different resource requirements for varying time since fire across the Boreal to meet their habitat needs. Left to right: Wood bison (S. Leverkus), grouse (S. Leverkus), fisher (C.M. Gitscheff), caribou (S. Leverkus).

12. Species and Ecosystems at Risk

Varying time since fire across the landscape is a lens which can be used to view the needs and requirements of time since disturbance for species and ecosystems at risk. Lousier *et al.* 2009 provides an excellent resource for rare occurrences of species in the Peace Region (pp.26-28 and 66-69). Several examples of species at risk follow with literature regarding their required resources and interactions with fire where applicable.

Woodland caribou (*Rangifer tarandus caribou*) require large, continuous forest stands with connectivity to alpine areas (BC Ministry of Environment 2009). Caribou select for alpine, subalpine, lowland conifer forests and muskeg. They exhibit resource selection for northern exposures in the winter and select closed forests when the snow depth is more extreme (BC Ministry of Environment 2009). Caribou forage on lichen, grasses, sedges and horsetails. In the M-KMA, the M-KWMP management direction is for large patches of suitable habitat with minimized habitat fragmentation and maintained landscape connectivity. This includes maintaining lichen winter ranges and suitable mature coniferous forests. In particular, two outcomes of the direction are to have minimized disturbance in natality sites and winter range.

Recent caribou papers include Anderson and Johnson 2014; Beguin *et al*. 2015; Bichet *et al*. 2016; Gustine *et al*. 2014; Mallon *et al*. 2016; Polfus *et al*. 2014; Rickbeil *et al*. 2016; Whitman *et al*. 2017. Anderson and Johnson (2014) report on barren-ground caribou response to fire from the Northwest Territories of Canada. Generally, while barren-ground caribou avoided areas with a high density of burns, they did use early-seral habitat considerably and areas adjacent to burn area boundaries. The authors concluded that at some spatial and temporal scales, some individual barren-ground caribou may be less averse to fire than previously thought (Anderson and Johnson 2014). Beguin *et al*. (2015) assessed the effects of logging and fire on caribou in eastern Canada and found that salvage logging was a feasible strategy to minimize the effects on habitat and suggest that cumulative effects must be considered. Bichet *et al*. (2016) reports that maintaining animal assemblages as monitored relative to the single-species management for boreal caribou is a good indicator of trends. Gustine *et al*. (2014) assessed the Porcupine caribou herd and suggests that fire-induced lichen reductions may lead to caribou population reductions. Mallon *et al*. (2016) put caribou resource availability in the context of soil drainage and found "found no difference in total understory vegetation percent cover, productivity or foliar C/N between burned and harvested stands" and that soil drainage class was a large determinant of such features. Polfus *et al*. (2014) evaluated how traditional ecological knowledge (TEK) could be incorporated into caribou management. Rickbeil *et al*. (2016) assessed caribou in the Northwest Territories and their response to fire and concluded that the effect of fire on caribou distribution is more of a function of forest stand structure than lichen availability. For further discussion regarding the interaction between caribou and fire, we suggest a review of McLoughlin *et al.* 2016 (pp 12-13, 37 – 39) and Saperstein and Joly 2004.

Wood bison (*Bison bison athabascae*) and plains bison (*Bison bison bison)* select for early-seral grassland or limited time since fire (BC Ministry of Environment 2009, Leverkus 2015). Higher level management direction for habitat of wood bison and plains bison is to apply prescribed fire for key habitats including the supply of early seral areas, or recent time since fire (BC Ministry of Environment 2009). Due to the high incidents and bison mortality associated with vehicle collisions, higher level plans such as the M-KWMP prescribes improving the grasslands east of the Alaska Highway within the Nordquist Wood bison herd region.

The M-KWMP lists the identification and protection of important Northern myotis (*Myotis septentrionalis*) and sandhill crane (*Grus canadensis canadensis*) habitat as a primary management outcome. Habitat for the Northern myotis includes cliff bands, open mature cottonwood forests and wetland areas. Bats roost in trees with loose bark and cavities and avoid foraging in high density stands (Fisher and Wilkinson 2005). The M-KMA is along the migratory route of Sandhill cranes and other migratory birds such as the snowy owl. Breeding and migration staging areas in the M-KMA are important for Sandhill cranes. The plan acknowledges the need for improved knowledge of the breeding range of Peregrine falcon (*Falco peregrinus anatum)* and Short-eared owl (*Asio flammeus*). Important habitat considerations for Peregrine falcons are nesting sites which are isolated and protected with quality hunting grounds nearby. Nesting locations in open areas and hunting grounds on open rangelands are important habitat components for Short-eared owl (BC Ministry of Environment 2009). Maintaining suitable breeding habitat for Cape May warbler (*Dendroica tigrina*) and Black-throated green warbler (*Dendroica virens*) is attainable through the maintenance of large patches of unfragmented mature and old forest. Connectivity between stands is listed as an outcome of the management direction for the two warbler species. Hovick *et al.* (2017) bring forward the concept of pyric carnivory in the raptor use of prescribed fires.

The M-KWMP lists the application of prescribed fire for key habitats such as low-intensity burns in mid-age to old aspen forest for the Connecticut warbler (*Oporornis agilis*) as well as maintaining forest stand structure and connectivity with minimal habitat fragmentation. For the Connecticut warbler and all ungulates, the M-KWMP recommends as an outcome that their management be included in the M-KMA Fire Management Plan which is non-existent to date of 2013. Connecticut warblers have been documented to nest and forage in forest stands between 14 and 28 years since fire and they may select for shrub layers found in more recently burned areas (Hobson and Schieck 1999, Schieck and Hobson 2000). Additional provincially red-listed bird species which may be present include: Upland sandpiper (*Bartramia longicauda*) and Nelson's sharp-tailed sparrow (*Ammodramus nelson*) (BC Ministry of Environment 2009). Sandercock *et al.* (2015) and Hovick *et al.* (2017b) have recently published research documenting the interaction between prescribed fire on resource selection and habitat for sandpipers and shorebirds, respectively. Recent time since fire is important to a broad range of birds inhabiting the boreal (Nappi *et al*. 2004).

13. Cultural Values

Understanding the important interaction between humans and fire resulting in the current cultural landscape across the Region is an important component of the Peace-Liard Prescribed Fire Program (Barrett 1982, Fry and Baum 1969, Lewis 1978, Turner and Peacock 1997, Yibarbuk *et al.* 2001). Oral history is important to consider when identifying the role of indigenous people in shaping a landscape (Baum and Fry 1974, Nolan and Turner 2011). Indigenous practices of lighting fire in the boreal and northern Canada have been documented (Rowe and Scotter 1973, Lewis 1978, Lewis and Ferguson 1988, Gottesfeld 1994, Yibarbuk *et al.* 2001, Pyne 2007). While there are references to Indigenous fires across northeastern BC (Elliott 1983, Seip and Bunnell 1985, Peck and Peek 1991, Sittler 2013), there is only one piece of literature specifically citing the interaction between fire and the Dene and Cree of Northeast BC (Fort Nelson First Nation (FNFN) and Shifting Mosaics Consulting (SMC) 2015).

"The Southern Tutchone of the southeastern Yukon are known to have burned to enhance wildlife habitat and enable the harvest of *Hedysarum alpinum* roots by thawing the ground early in the spring (Hawkes 1983). If prescribed fire was used by the natives of northern Alberta and the southern Yukon it seems safe to assume that it was also used in northern BC" John Parminter 1995 pp.3). Regional ethnographic information about the traditional use of fires was documented by interviewing Dene and Cree elders and community members from Fort Nelson First Nation (Fort Nelson First Nation and Shifting Mosaics Consulting 2015). FNFN and SMC (2015) found that fire was an important tool for FNFN and that "fire brings people together with the landscape they have been part of for centuries." Historic and contemporary uses of fire include: grass burning and clearing, vegetation regrowth, aesthetics, spiritual and ceremonial, hunting ("*burning along the rivers would produce new growth that would entice the moose and deer and would provide sightlines for making hunting easier*"), protection from animals and insects, warmth and cooking, communication, and light. Traditionally, FNFN people burned hillsides and hay meadows, and around cabins and campsites. This is very similar to the practices in northern Alberta as documented by Lewis and Ferguson in the late 1970-1980's. From the publication by FNFN and SMC (2015), there are several quotes from FNFN community members, amongst many others, which are important to consider in the historical interaction of fire across the Region and the cultural landscape that has since been developed (pp 13-17):

"I was born and raised at Kahntah, and my earliest memory of burning was when I was ten or twelve years old…. They burned in the evening in the early spring for horses, and in August they would cut down the new growth. Deer would eat the new growth too."

"I spent most of my childhood in Nelson Forks, and I remember burning every year in the south. We burned to control grass and brush, and it was done mostly for animals, and to make travel much easier within the area. Overgrown brush is a hazard – with build up of brush you could have a big fire and it could burn the cabin. Fire brought in moose and rabbits, and it's been done for centuries. My family has been burning for many generations"

"I help burn every year, since I was 5 or 6 years old, and learned it from my grandparents and other elders. Everyone in the family burned because it was the only way to keep the land clear."

"My earliest memory is from 1942. They had big fires, forest fires, not just meadows like people are interested in. Fires in the Territories, AB and BC, nearly wiped out all the rabbits, and other animals suffered without food. In 1955 people started fighting fire. Tuchodi Lake/Muskwa would burn every year, and it was good for hunting. Today, if you make a small fire for tea, the ranger will charge you a fine. No tea for you."

"I burn every year in early Spring. Everyone would burn along creeks and rivers, and around beaver ponds, and around cabins when there was still some snow ion the ground. When the willows grow – let them grow and burn the spruce. The usual reasons for burning were for graze for animals. The dead grass that dies off and builds up is the worse to catch fire which is very dangerous. Women would be swatting with their brooms, children would have buckets of water while the men burned. Wet gunny sacks and a rake were used to smother the fire. Everyone got involved."

"… Lots of rabbits, moose, and bears came to eat the new shoots after burning."

"We usually burned to maintain river/mountain corridor … to maintain land for horses, and for safety – to open visual corridors so you're not in a hole peeking through the bush."

"I think there should be more fires. There's too much brush and it makes it hard to walk through important areas. The windfall is really bad for animals in the winter. They get in trouble and it's easier for the wolves to get them."

"The forestry service should let First Nations people burn in their areas. There are a lot of limitations to burning now, and all the paperwork and permits makes it hard. You can't light a fire in your own yard without being called an arsonist."

The tradition of igniting fires in the spring of each year has been continued by guide outfitters across the region (Peck and Peek 1991). Additional anecdotal information important to consider and integrate may be accessed from other traditional and historical land users such as the Guide Outfitters, Transporters, Trappers and long-time residents of Northeast British Columbia. Also related to ignitions and interactions with fire, numerous Indigenous community members served on wildfire fighting crews across the north. There is a rich history of knowledge amongst these former firefighters, along with the generations of fire lighters, which needs to be documented and incorporated into natural resource planning and management.

"I started firefighting when I was 16 years old, got $1.25 per hour and worked long days. Clarke, Scatter, Snake, and Liard River are some of the biggest forest fires I remember. The Kotcho fire was big too – in 1976-1977 it burned the whole summer" – as noted by an FNFN community member (FNFN and SMC 2015).

Figure 17 Firefighters, 1966, Fort Nelson courtesy of Roger Needlay - former firefighter and FNFN community member.

INTERACTIONS WITH FIRE

Vegetation Interaction with Fire

The boreal forest provides an example of a landscape where flora and fauna have adapted to the combined pressure of a long season of cold temperatures and snow cover and a short, but intense growing season where natural disturbances, including fire, are active (Bergeron *et al.* 2004, Burton *et al.* 2006). Fire-adaptations of species in the boreal include the ability to resprout after fire such as suckering of aspen (*Populus tremuloides* Michx) (Schier and Campbell 1978), seed-banking species such as Bicknell's geranium (*Geranium bicknellii*) and Corydalis species (*Corydalis sempervirens* (L.) Pers., *C. aurea* Willd.) (MacKinnon *et al.* 1999, Catling *et al.* 2001), and serotinous cones such as lodgepole pine (*Pinus contorta* var. *latifolia* Douglas ex Louden) (MacKinnon *et al.* 1999). Fire is a critical ecosystem driver across varying spatio-temporal scales in the boreal forest. Specifically, fire influences plant species composition and structure, regulates diseases and insects, maintains and promotes the productivity and diversity of vegetation types, and affects nutrient cycling and energy fluxes (Rowe and Scotter 1973, Volney and Hirsch 1996).

Boreal mixed wood stand dynamics were assessed by Bergeron *et al*. (2014). Note Figure 4 in this paper that has a nice demonstration of forest stand features relative to time since fire. Lodgepole pine was assessed by Edwards *et al*. (2015) and it was determined that lodgepole pine seedlings were non-existent in unburned areas, present in burned areas, and increased in density relative to burn severity and that these stands were resilient to the combined fire+beetle disturbance pattern. Forest recovery, general forest stand structure, biodiversity, and ecosystem services are assessed by (Bolton *et al*. 2015; Hekkala *et al*. 2014; Héon *et al*. 2014; Hume *et al*. 2016; Ireland and Petropoulos 2015; Thom and Seidl 2015; Wu *et al*. 2014). Héon *et al*. (2014) report that fire overlap is likely constrained by heterogeneity of forest age structure across the landscape as abundant forest stands provide resistance against increasing fire size and decreasing fire intensity (as indicated by the 3rd largest fire in Canada since 1980) and that fire overlap occurred about half as much as would be expected by chance (see Figure 5 in Héon *et al*. 2014).

Three studies quantified boreal hydrology, permafrost and tree cover as it relates to a changing climatic and disturbance regime (Helbig *et al*. 2016; Ireson *et al*. 2015; Kettridge *et al*. 2015). As water table position drops for northern peatlands and subsequently interacts with wildfire, it is predicted that the plant community will shift to a shrub-grass ecosystem that is non-carbon accumulating (Kettridge *et al*. 2015). Similarly, the Taiga Plains of Canada are predicted to undergo changes in percent tree cover due to the concomitant interaction of permafrost thaw, wildfire disturbance, and postfire regrowth (Helbig *et al*. 2016). These drastic changes have rendered the Boreal Plains Ecozone of western Canada as an area of "maximum ecological sensitivity" due to the escalating disturbance regime, vegetation shifts, and altered water cycle (Ireson *et al*. 2015). Four studies assessed lichens, fungal, and soil communities (Lafleur *et al*. 2016; Sun *et al*. 2015; Xiang *et al*. 2014; Zouaoui *et al*. 2014). Lafleur *et al*. (2016) specifically assessed *Cladonia* response to fire and logging and suggested that it is resilient to logging and that there was no difference between logged and burned sites. Sun *et al*. (2015) assessed a 152 year fire chronosequence and found that soil fungal communities were most diverse after a fire and that diversity declined as time since fire elapsed. In a Chinese boreal forest, fire altered the soil bacteria community significantly, and recovery to pre-fire conditions took about 11 years. Zouaoui *et al*. (2014) similarly showed that time since fire is the factor determining lichen community attributes.

Species Requirements for Varying Time Since Fire

Time since fire and interacting ecological processes such as pyric herbivory and geomorphological movements drive the vegetation structure in parts of the alpine and sub-alpine and most parts of the open range and open forest within the Region (Geertsema and Pojar 2007, Burton *et al.* 2008, Fuhlendorf *et al.* 2009). Often, there is a lack of recognition and incorporation of the critical ecological process of fire and the resulting interactions with it such as pyric herbivory, the fire-grazing interaction, (Fuhlendorf *et al.* 2009) across the Region. Open range and open forest are reliant on fire in the Region making the diverse priority species require varying time since fire for their resource selection of habitat preference (Figure 18) (Natcher 2004). Lousier *et al.* (2009) also bring forward similar commentary. Different resources and land cover are required during different phases of a lifecycle from birth, lambing, calving and hatching to foraging, roosting, escaping, rutting and all other components of a species' lifecycle. Proximity to escape terrain may be critical for a species' survival whereas another species may require considerable cover for thermal regulation (Blood and Backhouse 1998, Walker *et al.* 2006).

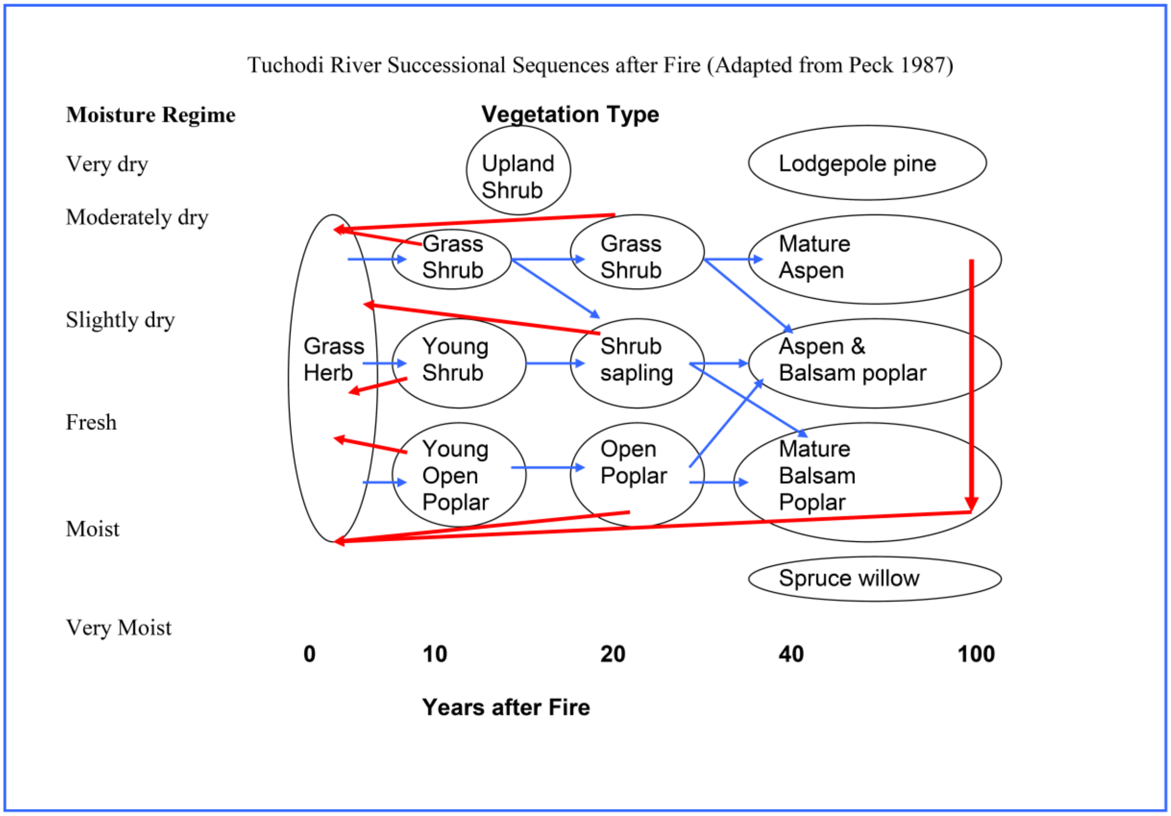

Figure 18 R. Kabzems interpreted the work of R. Peck's M.Sc. thesis of 1987 to identify the general response patterns to fire in the pyrogenic ecosystem of the Tuchodi River area.

Leverkus *et al*. 2017 generalized the habitat requirements of the 24 priority species and 3 additional regionally important species within the M-KMA with a focus on how fire is thought to influence land cover, resource selection and habitat maintenance (Figure 19) (adapted from Lamprey 1963, Heady 1966, Fuhlendorf *et al.* 2012, Leverkus *et al.* 2017). Of the 27 species including the priority wildlife species of the M-KWMP, six are red-listed (Wood bison, Plains bison, Peregrine falcon, Bay-breasted warbler, Cape may warbler and Connecticut warbler), seven are blue-listed (Grizzly bear, wolverine, fisher, Northern myotis, Short-eared owl, Black-throated green warbler and Bull trout) and eleven are yellow-listed (moose, elk, Mountain goat, Thinhorn stone's sheep, Gray wolf, Lesser sandhill crane, Lake trout, Arctic grayling, Rainbow trout, Northern pike and Western toad). Caribou are red and blue-listed in the M-KWMP. The Provincial listings are Red, Blue or Yellow in reference to the species' Provincial Conservation Status Rank (BC Ministry of Environment, 2009). Red-listed includes any ecological community, and indigenous species and subspecies that is extirpated, endangered, or threatened in British Columbia whereas blue-listed includes any ecological community, and indigenous species and subspecies considered to be of special concern (formerly vulnerable) in British Columbia (Province of British Columbia 2013d). Yellow-listed species and communities are not currently at risk in British Columbia. Additional species listed in the M-KWMP which are not considered to be priority species include: Mule deer, White-tailed deer, cougar, lynx, marten, River otter and beaver. Humans and horses are part of the landscape of the M-KMA and are included as priority species.

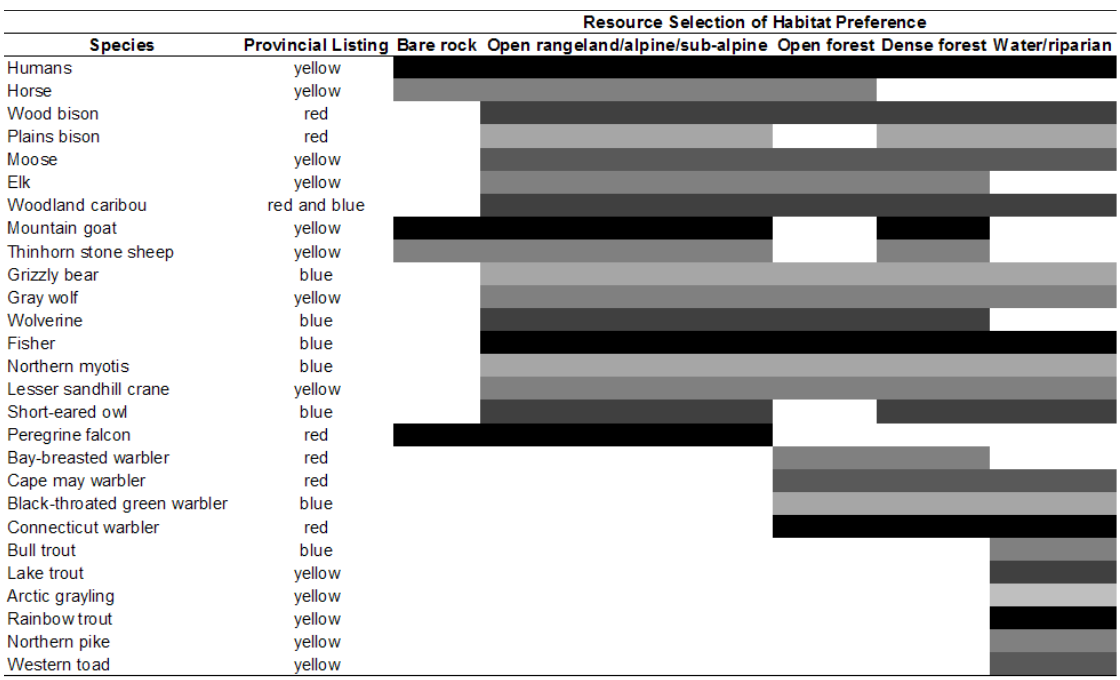

Figure 19 Priority wildlife species of the M-KMA and their resource selection of habitat preference, adapted from Lamprey 1963, Heady 1966, Leverkus et al. 2017.

Varied time since fire influences species distribution and resource selection including:

- access to and abundance of browse, forage, insect, fruit and berries (Seip and Bunnell 1984, Seip and Bunnell and 1985, Munro *et al.* 2006, Ciarniello *et al.* 2007, Stevens *et al.* 2007)
- availability and abundance of prey species and their habitat requirements (Boutin *et al.* 2003, Sullivan *et al.* 2006, Hatler and Beal 2010)
- hunting areas and riparian areas (Krebs *et al.* 1995, Hatler and Beal 2010)

- host plants and vegetation important for invertebrate lifecycles (Baum and Sharber 2012)
- vertical structure such as coarse woody debris, snags, rotting trees and layered overhead vegetation for shelter, denning, protection, roosting, cover, escape, breeding, lambing, calving, naissance and migrating staging areas (Seip and Bunnell 1984, Hobson and Schieck 1999, Schieck and Hobson 2000, Fisher and Wilkinson 2005, Hatler and Beal 2010)
- seasonal movements influenced by snow depth, exposure to sun and wind, travel corridors (Hatler and Beal 2010)
- habitat connectivity and suitability (BC Ministry of Environment 2009, Holsinger and Keane 2011)
- ecological processes (Dublin 1990) and refugia (Elliott 1983)

Species in the M-KMA may be limited by climate, vegetation cover and predation (BC Ministry of Environment 2009). Predator movements and resource selection may be influenced by prey movements and resource selection (Walker *et al.* 2006). Therefore, although the resource selection of habitat preference shows general habitat requirements, these may shift in specific areas depending on biotic and abiotic interactions. In addition to time since fire influencing vegetation structure and prey dynamics, the distribution of grizzly bears, and all other priority species considered in the M-KMA, depends on many factors including weather, precipitation events, population size, abundance of resources and human interactions.

Whether a species is a specialist or a generalist and what limitations are imposed by the environment should be a central consideration in landscape level management along with the varying reproductive cycles and requirements of each species (Hatler and Beal 2010). Depending on the season and the climatic variations, there may be stronger selection for areas with minimal time since fire especially by ungulates including Stone's sheep, elk and moose. Resource selection for minimal time since fire can be seen in northern ungulates particularly during the winter months when forage is limited (Seip and Bunnell 1984, Seip and Bunnell 1985, Peck 1992). The limiting factor for species such as Stone's sheep (*Ovis dalli stonei*) is winter access to forage. Access and availability of winter forage may result from minimal time since fire (Seip and Bunnell 1984). Open rangeland is essential for snow removal which is essential for winter utilization by wildlife (Elliott 1983). Conversely in the summer months, adequate nutrition is required in order to prevent reduction in pregnancy rates, conception and calving and to maintain proper nutrition for lactation (Couturier *et al.* 2009). Varied time since fire across the landscape is able to provide the nutritional requirements of ungulates (Elliott 1983, Allred *et al.* 2011).

Canada's economic history was built on the fur trade (Hatler and Beal 2010). Since the 16th century, fur has been trapped, auctioned and sold across Canada. Furbearing animals require varying vegetation structure across their home ranges. Natcher (2004) reports that fires created browse that was important for increasing prey species of furbearing predators, such as rabbits and voles. Linear disturbances and the unnatural footprint created from natural resource development influence furbearer distribution across the landscape (Webb and Boyce 2009). If habitat needs are lacking, furbearer populations are unable to perform and grow to their fullest capacity (Hatler and Beal 2010). The main furbearing species in Northeast British Columbia include: beaver (*Castor canadensis)*, black bear (*Ursus americanus*), coyote (*Canis latrans*), fisher (*Pekania pennanti*), lynx (*Lynx canadensis*), marten (*Martes americana*), mink (*Mustela vison*), muskrat (*Ondatra zibethicus*), river otter (*Lontra canadensis*), red fox (*Vulpes vulpes*), red squirrel (*Tamiasciurus hudsonicus*), least weasel (*Mustela nivalis*), grey wolf (*Canis* lupus), and wolverine (*Gulo gulo*).

It is important to recognize the habitat requirements not only of furbearing species across the landscape, but also the prey that they feed on and what their habitat requirements consist of (Hatler and Beal 2010). For example when analysing the resource features that fisher and lynx need, it is important to consider the requirements of snowshoe hares (*Lepus americanus*) which are a primary food source for both species and which is considered to be a keystone species in the boreal forest (Boutin *et al.* 2003, Sullivan *et al.* 2006, Hatler and Beal 2010). Areas with time since fire of 15 to 40 years are high suitability and capability habitat for hares and hunting areas for fisher and lynx (Hatler and Beal 2010). Food and predation are known to be critical interactions in the life cycle of hares which in turn influence the distribution of fisher and lynx (Krebs *et al.* 1995). Lynx typically forage in younger aged forests, however they also select older forests where there are thickly branched trees and tangles of coarse woody debris from deadfall for shelter, denning and protection (Hatler and Beal 2010). Although not considered as a priority species, beaver (*Castor canadensis*) may contribute to habitat heterogeneity through their influence on vegetation structure across the region (Stevens *et al.* 2007).

As a disturbance on the landscape, fire is able to change vegetation states from closed forest to open rangeland. In the M-KMA, it has been anecdotally observed that elk (*Cervus elaphus*) browse on resprouting aspen post-fire. Much like elephants (*Loxodonta africana*) are able to hold grassland states in Africa after fire changed the vegetation state, it may be possible that a similar pyric herbivory action by elk and other ungulates is able to hold certain areas in an open rangeland state (Dublin 1990). The M-KWMP Technical Manual (2009) also suggests that ungulates are able to transform local vegetation communities.

The M-KWMP acknowledges that the M-KMA does not contain sufficient habitat for all species, primarily for species such as Peregrine falcon and Wood bison which are species requiring open areas resulting from minimum time since fire. In order to ensure that these species are maintained at viable population levels, active management is required to define and improve their status. For species that had secure populations as of 2009 and are of high public interest and use, such as elk and moose, management is directed to maintain functionally significant populations (BC Ministry of Environment 2009). There is specific direction in the M-KWMP that prescribed fire should be applied in order to maintain adequate vegetation and cover classes. For decades, prescribed fire has been recommended for habitat maintenance and promotion of wildlife in the M-KMA; however, there is a declining trend in fire across the landscape of the M-KMA (Elliott 1983, Haber 1988, Peck and Peek 1991).

The M-KWMP also lists the desire for reduction of negative interactions between bears and humans. It is possible that with varied time since fire shifting across the landscape, predator and prey movement and resource selection across the landscape could be both dispersed and altered which could reduce hunting pressure (Peck and Peek 1991). The strategic use of prescribed fire in the Northeast may spatially distribute resources for ungulates resulting in distributed hunting pressures. Throughout the year and in different seasons, priorities in resource selection may change. Resources selected for during birthing times may be different from those selected for foraging or during the mating season. Fire, forestry practices, and range management can be used to expand ranges of wildlife and provide appropriate resources for access to escape terrain and thermal cover (Peck and Currie 1992).

Predator Management Considerations and Interactions with Prescribed Fire

The restoration of the ecological process of frequent fire, coupled with the anticipated response of increasing herbivore (for both small and large mammals) forage resources and population densities in burned areas, may suggest that additional predator management be considered. For example, Florida panthers were documented to preferentially use recently burned areas in a radio-collar and time-since-fire experiment using data from 1989 to 1998 (Dees et al. 2001). The researchers hypothesized that panthers were attracted to areas burned < 1 year prior due to an increase of deer and other prey species (Dees et al. 2001). Although Florida panthers are one of the most endangered predators globally, this predator*fire interaction may hold in areas with more abundant predators (Bond 2015). For example, avian predators have also been shown to preferentially use burned areas (Jones et al. 2002), with a recent study documenting certain raptors being attracted to active fires (Hovick et al. 2017). However, information for large carnivore use of prescribed fires is lacking. While wolves and bears are known to use recently burned areas, what is unknown is the abundance and relative use in burned areas compared to unburned areas (Fisher and Wilkinson 2005). Lynx have been documented to use burns preferentially due to the increase in hare abundance in recent burns (Fisher and Wilkinson 2005). Thus, what is clear is that fire can likely alter the predator*prey dynamics at local and regional scales and attention should be paid to predator populations, especially if prey species of concern may be at risk.

From 1984-1987 the Fish and Wildlife Branch assessed population responses of caribou, moose, and Thinhorn Stone's sheep to reduced levels of wolf predation (Elliott 1984, 1984b). "The ungulate herds of northeastern British Columbia have undergone devastating declines. Of the three species that were most abundant in the early seventies, caribou have crashed by some 75% or 7,500 animals (Berferud 1978), moose by 80% or 90,000 animals (Elliott 1986a), and mountain sheep by 50% or 7,000 animals (Elliott 1985a). These declines have been a direct consequence of the low survival of juveniles due to high predation, especially by wolves" (Elliott 1986).

"Fire plays such an important role in the boreal forest that the type (e.g. surface or crown), intensity (amount of energy released), severity (overall effect of fire on the ecosystem), frequency (number of fires per unit time on a particular site), and time since the last fire have a significant bearing on the vegetational composition of most sites… Fire has been an important factor in determining the vegetative composition of the landscape and thus the type, quantity, and distribution of wildlife habitat … The repeated application of fire in these areas has resulted in overlapping fire boundaries such that it is virtually impossible to determine the actual areal extent of any one particular fire."
– J. Parminter 1983 pp. 10 and 13

STRATEGIC PLAN

Vision

To safely implement a strategic prescribed fire program based on an evolution of the foundational work conducted in the past by the BC Fish and Wildlife Section, Guide Outfitters, Ranchers, and Indigenous people in Northeast BC, which will support the identified prescribed fire values and will protect the right to professionally conduct prescribed fires in Region 7B.

Mission

The mission of the program is to 1) foster cooperation among all parties in Northeast BC with an interest or stake in prescribed fire; 2) strategically and safely implement prescriptions across the landscape and 3) maintain and promote fire-absorbent and resilient landscapes.

Goals

Goal 1: Establish and sustain a high priority for prescribed fire throughout the Region

Goal 2: Establish and enhance partnerships and acquire sufficient resources to promote and implement increased prescribed fire operations

Goal 3: Develop public communication and education to garner support, acceptance, and recognition of the value of prescribed fire

Goal 4: Enhance the credibility and professionalism of Prescribed Fire Practitioners across the Region

Goal 5: Develop a Prescribed Fire Council or Prescribed Fire Association in conjunction with the US

Goal 6: Mitigate smoke impacts on air quality and traffic by smoke management

Goal 7: Continue to document oral history of prescribed fire locations and values across the Region

Goal 8: Take a strategic and proactive role in policies that positively impact prescribed fire in NEBC

Goal 9: Increase research in the science and application of prescribed fire that will benefit land managers and landowners

Goal 10: Maintain, update, and manage prescribed fire and related databases and tracking resources to meet desired goals of varying time since fire across the Region

Decision Considerations for Prescribed Fire in Region 7B

- Time of year
- Site values
- Fuel types
- Smoke management
- Boundaries and surrounding area
- Slope characteristics
- Site shape, size and visibility
- Land ownership
- Population density

Wildland-Urban Interface and Wildland-Industrial Interface

The WUI is where houses and fairly dense vegetation are both present. The WUI is often the focus of fire prevention and preparedness projects including fuel reduction in forests, fuel removal in the immediate vicinity of homes, and emergency evacuation planning. The WUI is considered as any area where combustible vegetation is found adjacent to homes, farm structures, or other buildings and is within two kilometers of a community with a density of 6 to 250 structures per square kilometer (Government of BC 2015). Recently introduced by Johnston (2016) and Johnston and Flannigan (2018), the wildland-industrial interface (WUI-Ind) and the wildland-infrastructure interface (WUI-Int) have been added to the traditional WUI. Johnston (2016) and Johnston and Flannigan (2018) developed Wildland Urban Interface (WUI), Wildland Industrial Interface (WII), and Infrastructure Interface (II) maps which provide additional strategic planning support.

Monitoring and Data

The BC Range Program has conducted rangeland monitoring and reviews over the past several decades. There are many monitoring opportunities and protocols associated with the BC Range Program including the Range Reference Areas (RRAs) of BC (https://www.for.gov.bc.ca/hra/Ecology/RRA.html). RRAs are permanent installations which monitor the impact of livestock, wildlife, and other disturbances on rangelands within BC. There are more than 10 RRAs in the Region, all with longstanding datasets.

R. Kabzems and C. DeLong have produced works which should be considered in vegetation responses and monitoring programs regarding prescribed fire. Additional literature important to review includes: Haeussler *et al.* 2004; Haeussler 2007; DeLong 2010; and Parminter 2014. There are numerous additional monitoring projects and case studies regarding fire, rangelands, and herbivores across the Region including but not limited to:

- Report on a Soils Field Reconnaissance of the Kechika Valley, Stikine-Spatsizi Valley and the Telegraph Creek Area – D.J. Wilford, Research Pedologist, BC Forest Service 1977
- The Northern Fire Ecology Project – J. Parminter and B. Hawkes
- Range burning, Stone's sheep, and the leaky bucket; Species composition and herbage production of mountain rangelands in northern British Columbia; and Nutrition of Stone's sheep on burned and unburned ranges - D. Seip 1984 – 1985
- Elk, *Cervus elaphus*, habitat use related to prescribed fire, Tuchodi River, British Columbia and Northeast elk enhancement project: Final report - R. Peck - 1992

- Fort Nelson East Slope Wildlife and Forest Capability Mapping – C. Clements, Shearwater Mapping Ltd., Victoria 1992
- North East Burn Evaluation – Bison Habitat Monitoring – R. Maxwell, D. Clark, A. Stewart, and B. Harper of the Habitat Inventory Section, Wildlife Branch, Victoria 1992-1993
- Range Monitoring Project: Fort Nelson Forest District – S.J. Michalsky, EnviResearch Consulting Ltd. 1994
- Sikanni-Halfway Bison Assessment – Eastern Slopes Rangeland Consultants - 1994
- B.C. Forest Land Use Coordination Office Range Inspections July 12-18 1999 – Mancroft-EBA Consultants, 2000
- An Evaluation of the Range within the Northern Rocky Mountains Provincial Park and Kwadacha Provincial Park – D. Fraser, Range Practices Specialist, Forest Practices Branch 2003
- Muskwa-Kechika Trust Fund Project #MK-2003-2004-16 Range and Campsite Assessments
- An Evaluation of Range in the NE Sector of the Muskwa-Kechika Management Area – D. Fraser, Range Practices Specialist, Forest Practices Branch 2004
- Northern Rocky Mountain RRAs: 1997-2008 including Hammett, Mt. Withrow, Mt. Bertha – L.J. Blonski, Range Branch, Ministry of Forests and Range 2009
- Influence of prescribed fire on Stone's sheep and Rocky Mountain elk: forage characteristics and resource separation – K. Sittler, Natural Resources and Environmental Studies, University of Northern British Columbia, BC 2013
- Conservation of biodiversity in northern Canada through ecological processes and cultural landscapes – S. Leverkus, Oklahoma State University/Shifting Mosaics Consulting, Fort Nelson, BC 2015
- Relevant wildlife and endangered species management plans such as The Wood Bison Management Plan
- Several researchers also have permanent or semi-permanent monitoring stations which could provide additional data and monitoring opportunities for inclusion in the Peace-Liard Prescribed Fire Program: Richard Kabzems – Research Silviculturalist; Krista Sittler – Biologist who completed her Masters Degree under Dr. Kathy Parker at UNBC; Dr. Marten Geertsema, Alexandre Bevington, and Vanessa Foord of the BC FLNRO with research locations throughout the Region, and Dr. Sonja Leverkus – Biologist/Agrologist/Ecologist who completed her PhD under Dr. Samuel Fuhlendorf at Oklahoma State University.

The BC Range Program developed a series of guidelines and protocols for monitoring rangelands and could be incorporated in the Peace-Liard Prescribed Fire Program monitoring moving forward. Of special note are the following associated publications: 'Assessing upland and riparian areas", 'Understanding ecosystem processes', 'Considering tools for remediation', and 'Determining available forage.' These are found on the Range website: https://www.for.gov.bc.ca/hra/Publications/index.htm. Additional resources may also be found on the Ecosystem Restoration website: https://www.for.gov.bc.ca/hra/Restoration/index.htm. The Rangeland Handbook for BC written by C.W. Campbell and A.H. Bawtree (1998), Range Management Principles and Practices by J.L. Holechek, R.D. Peiper, and C.H. Herbel (2004), and A Guide to Integrated Brush Management on the Western Canadian Plains (2008) by the Manitoba Forage Council are excellent resources.

One of the deliverables for the Peace-Liard Prescribed Fire Program evolution and strategic development included upgrading the monitoring protocol. A draft document has been developed including datasheets. Over the recent past, the Fish and Wildlife Section has conducted burn monitoring as explained in Goddard (2011). The data system that has been employed until present is heavily focussed on vegetation but could be expanded to include wildlife and soils (K. Peck, *pers. comms.* 2017*)*.

K. Peck has recommended working from the current database and monitoring program to create better monitoring information long-term and to allow comparisons back to older monitoring data. The current database is housed in the Fish and Wildlife Section office in Fort St. John. The provincial standard for Environmental Monitoring in Rang and Wildlife Habitat Management is found at https://www.for.gov.bc.ca/hts/risc/pubs/teecolo/habitat/index.html. Additionally, the Forest and Range Evaluation Program (FREP) collects and communicates natural resource monitoring information to inform decision making, improve resource management outcomes, and provide evidence of government's commitment to environmental sustainability. The FREP program could support monitoring initiatives associated with the Peace-Liard Prescribed Fire Program. For more information: https://www2.gov.bc.ca/gov/content/industry/forestry/managing-our-forest-resources/integrated-resource-monitoring/forest-range-evaluation-program/frep-monitoring-protocols

Another consideration in monitoring prescribed fire efficacy and success is to directly monitor the response of livestock and wildlife in the area. This can be achieved through the deployment of GPS collars (i.e. Sittler 2013, Leverkus 2015), through pellet counts (Peck and Peek 1991), and through the body scoring and condition of the animals themselves (Elliott 1984 – survival of young sheep, increased horn growth as reflected in horn annuli rings; body condition scoring system for horses by T.J. Pittman 1993).

Funding

Lousier *et al.* (2009) reports that the P-LPFP (formerly known as the MOE burn program) was partially funded by local wildlife associations and received funding in excess of $100,000 per year from sources including the Habitat Conservation Trust Foundation (HCTF), North Peace Rod and Gun Club, Northeast BC Wildlife Fund, and the Northern Guides Association.

"Prescribed fire can readily be used to create and maintain elk range. Burning in the study area in the past has been restricted to dry, upland south and southwest facing slopes that have been relatively easy to burn. Extremely high elk concentrations on these sites were recorded. In an attempt to disperse elk densities, future burning prescriptions should be expanded beyond these upland sites. This will involved burning wetter sites, with more difficult prescriptions, and necessitate longer burning seasons. Since elk use of open habitat can be limited by excessive snowfall accumulations, enhancement plans should incorporate alternative habitat as well as microclimatic considerations." V.R. Peck and J.M. Peek 1991

The Peace-Liard Fire Matrix (P-LFM)

Across a large landscape, there may be specific sites with certain features, slopes and topography that render them critical to the function and structure of the landscape as a whole. Natural disturbance processes and the range of natural variability (the range of variation that a set of ecological patterns or processes may naturally exhibit over a given historical period) across such a landscape need to be included in land management decisions and objectives in order to maintain ecological resilience in a changing climate (Johnson *et al.* 1998, Turetsky *et al* 2002, Kareiva and Marvier 2003, Schmiegelow *et al.* 2006, DeLong 2010, DeLong 2013, Burton *et al.* 2008, Moritz *et al.* 2013). The role of landscape disturbances, such as fires and geomorphological events, is important to consider in biophysical diversity and management planning (Geertsema and Pojar 2007).

The P-LFM has been developed with the objective of maintaining an appropriate amount of fire distributed spatially and temporally creating processes across the landscape which may result in resilient populations of the priority species and their critical habitat. The P-LFM developed in Part B has been modelled across three scales: Region 7B, Natural Disturbance Units, and Land Units. Additional spatial division across the landscape is currently being conceptualized integrating the recent publication of Johnston and Flannigan (2018) which introduces the WUI-Ind and WUI-Inf.

The Peace-Liard Prescribed Fire Program Part B – Technical and Operational Plan further describes the implementation and analytical components of the P-LFM. The matrices that have been developed through this process also provide a mechanism for tracking fire throughout the Region to ensure that desired spatial and temporal distribution targets of fire are being met. The P-LFDM is able to be modified so that the desired pattern across the landscape and heterogeneity objectives can be achieved. The matrix can be altered in years when there is more wildfire or early-seral creating disturbances than anticipated or it can be altered to increase prescribed fire when there is a lack of disturbance.

A result of establishing and maintaining the P-LFM incorporating time since fire across multiple scales could be the decrease in susceptibility to insect outbreaks such as the mountain pine beetle (Amoroso *et al.* 2011). As the disturbance resulting from mountain pine beetle infestations begins to surface across the Northeast Region, coupled with the reduced timber harvest and lack of recent time since fire, it is possible that the additional increase in fuel loading combined with the regional increase in lightning strikes and mean annual temperature will result in unplanned, catastrophic wildfires. By coordinating timber harvest schedules and by applying prescribed fire in key locations across this landscape, there will be an increase in fuel breaks and a potential change in fire dynamics and characteristics. In this scenario, it is possible that the fragmented mosaic of lower-flammability vegetation could move fire from the canopy to the ground while promoting increased aesthetically pleasing landscapes and higher potential for carbon sequestration and heterogeneity (Kelly *et al.* 2013). Using the P-LFM as a model for landscape management and planning could avoid, mitigate and/or prepare an ecosystem for impacts from disease outbreaks, natural disturbances and other influences which could decimate a landscape of uniform structure, age and quality.

CONCLUSION

Around the world managers are slowly moving their focus from single species and large game promotion to focus on broader biological diversity conservation (van Wilgen *et al.* 2007). Longer temporal scales should be analysed in order to gain an accurate representation of the ecological patterns and processes occurring in a specific area (Dublin 1990). Fire is a fundamental aspect of human culture where it is noted in the literature that early humans influenced fire regimes through changing the timing and increasing the number of ignitions (Pyne 1997, Bowman *et al.* 2011, Trauernicht *et al.* 2013). Thus, in order to successfully develop and implement the P-LFM, anthropogenic influences and cultural integrity must be considered (Bowman *et al*. 2011, Trauernicht *et al*. 2013). Integrating historical data and knowledge about patterns and processes into current and future management will result in an ecologically and culturally appropriate approach to managing natural resources (Swetnam *et al*. 1999).

There is a need for a comprehensive understanding of the new principles for the conservation of patterns and processes critical for rangeland ecosystems (Fuhlendorf *et al.* 2012). Furthermore, one of the largest questions that land managers in British Columbia are attempting to answer is around the increase in fire due to a changing climate and what the threshold of fire is before it becomes detrimental. There is scientific consensus indicating that the carbon-rich boreal zone will have the most significant impacts from climate change and will have extended fire seasons of increased fire occurrence and severity with resulting influences on terrestrial carbon cycling and storage (Weber and Flannigan 1997, Amiro *et al*. 2001, Stocks *et al.* 2003). Leroux and Schmiegelow (2007) suggest that the boreal may be the only region of the world that has the last opportunities for conservation planning and maintaining intact species assemblages and ecological processes. Recognizing that the interaction of fire with other disturbances is a pattern-driving process which contributes to heterogeneity is of global significance for conserving biodiversity and cultures (Fuhlendorf *et al.* 2012).

There is no single fire regime or industrial development process that is suitable for an entire landscape across a broad scale. There are requirements by species and areas for varying frequencies and disturbance intensities. To conserve biodiversity, heterogeneity must be maintained and shifting mosaics need to be created, maintained and supported. Not only will this allow time since disturbance to spread out across the landscape, it will allow land managers to view fire as an ecological process that drives ecosystems that can be implemented as a tool in certain locations or suppressed in others due to values impacted by fire.

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APPENDIX

Glossary

Glossary of fire terms as per Leverkus *et al.* 2016.

Note the 2003 glossary of forest fire management terms produced by CIFFC located at:
http://bcwildfire.ca/MediaRoom/Backgrounders/2003_Fire_Glossary.pdf

Fire

Fire (CIFFC 2003) is the simultaneous release of heat, light, and flame, generated by the combustion of flammable material. In a wider sense, any outbreak of fire. The Merriam-Webster dictionary defines fire as the phenomenon of combustion manifested in light, flame and heat. Pyne *et al.* (1996) define fire as a manifestation of a chemical reaction where flame, a gas phases phenomenon, is only part of the whole process. For this report, fire is presented and discussed in the context of wildland fire (i.e. wildfire or prescribed fire). In the Yukon, the Wildland Fire Management Branch (WFM) is comprised of wildland fire managers.

Note the difference between forest fire and wildfire as follows:

Forest fire (CIFFC 2003) is any wildfire or prescribed fire that is burning in forested areas, grass, or alpine/tundra vegetation. Variously defined for legal purposes (e.g., the State of California Public Resources Code: uncontrolled fire on lands covered wholly or in part by timber, brush, grass, grain, or other flammable vegetation). Types of fires are ground, surface, and crown (NFCG 2008).

Wildfire is an unplanned or unwanted wildland fire including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out (NFCG 2008). Contrasted with prescribed fire (CIFFC 2003).

Wildland fire is any non-structure fire that occurs in the wildland. Three distinct types of wildland fire have been defined and include wildfire, wildland fire use, and prescribed fire (NFCG 2008).

Firebreaks, fireguards, firelines (Weir 2009)

Firebreaks, fireguards, and firelines delineate the boundary of a fire and serve to contain a prescribed fire and to change the characteristics of fuel in, around, and/or ahead of a wildfire. This can be achieved through wetlining, blading with heavy machinery to expose soil, mowing, and back-burning or black-lining.

Fire history (Joint Fire Science Program, Johnson 1992)

Fire history provides the evidence of the past interaction between fire and climate. This includes the spatial and temporal extent of past fires.

Fire intensity and severity (Joint Fire Science Program, Morgan *et al.* 2001)

Fire intensity is a physical description about the behaviour of an individual fire and is correlated with flame length. Fire severity includes a combination of: degree of tree mortality, heat penetration into the soil and resulting effects on soil, degree of organic biomass consumption on and within the soil, change in ash and soil colour.

Fire management (BC Wildfire Service/ CIFFC 2003 and Martell 2015)

The activities concerned with the protection of people, property, and forest areas from wildfire and the use of prescribed burning for the attainment of forest management and other land use objectives, all conducted in a manner that considers environmental, social, and economic criteria. Note: Fire management represents both a land management philosophy and a land management activity. Fire management involves the strategic integration of such factors as knowledge of fire regimes, probable fire effects, values-at-risk, level of forest protection required, cost of fire-related activities, and prescribed fire technology. These factors are then incorporated into multiple-use planning, decision-making, and day-to-day activities to accomplish stated resource management objectives. Successful fire management depends on effective fire prevention, detection, and pre-suppression, having an adequate fire suppression capability, and consideration of fire ecology relationships. Fire management can be defined as "delivering the right amount of the right fire to the right place at the right time at the right cost" (Martell 2015).

Fire regime (Joint Fire Science Program, Morgan *et al.* 2001)

Fire regimes characterize the spatial and temporal patterns, including ecosystem impacts, of fire on the landscape. Fire regimes "reflect the fire environment, and influence the type and abundance of fuel, thereby affecting fire behaviour and fire effects through time" (Morgan *et al.* 2001). Important factors in describing and determining fire regimes include: frequency, severity, intensity, predictability, size, seasonality, spatial patterns, vegetation type and weather/climate patterns. Fire regimes are affected by terrain, slope, landscape pattern, ignition loads and management regimes.

Fire rotation period and fire cycle (Morgan *et al.* 2001)

Fire rotation period and fire cycle incorporate fire perimeters and are defined as the length of time necessary to burn an area equivalent to a specific study area. Fire cycle is calculated based on the distribution of ages in a time-since-fire model.

Fuel (Joint Fire Science Program, Pyne *et al.* 1996, Weir 2009)

Fuel is the vegetative material that burns in a fire. There are many characteristics to consider with fuel such as fuel quantity, continuity, size and shape, compactness, arrangement and moisture amongst others. Fuel is dynamic and it changes through time (daily, weekly, monthly, seasonally, annually, etc). Fuel type is a description of fuel itself, whereas fuel state is dependent on changing environmental conditions. There are three types of fuels:

<u>Ground fuel</u>: all combustible materials below the surface litter layer (i.e. duff, peat layers or living plant materials such as roots). Ground fires burn the subsurface organic fuels and typically result in a lot of smoldering combustion and less active flaming. Roots of overstory species may be killed because of prolonged high temperatures in the rooting zone.

<u>Surface fuel</u>: fuels on the ground (herbaceous plants, grass, shrubs, leaf and needle litter, moss, lichen, upper layer of duff and dead branch debris). Surface fires spread by combustion of surface fuels and only burn the lowest vegetation layer giving them low to moderate severity without extensive overstory vegetation mortality.

<u>Aerial or crown fuel</u>: crowns or canopy of trees and shrubs. Crown fires burn through the tree crowns but in most cases, the understory vegetation is also burned.

Fuel load (Weir 2009)

Fuel load is a measure of the potential energy that could be released by a fire. It is the total amount of flammable fuel for the surface area of the burn unit and is normally measured on a dry weight basis (kg/ha). It is not the total amount of vegetation in the burn unit but what is available to actually burn within the unit.

Fuel management (BC Wildfire Service and Martell 2015)

The process of modifying forest and range fuels to reduce the fuels available to burn in a wildfire event. This modification of flammable fuel complexes can involve thinning out of trees, pruning branches, prescribed fire use and other best practices. The primary objective is to manage hazardous wildland fuels in and around communities and out to the landscape level, in order to reduce the potential for loss of life, property, and infrastructure.

Initial attack (CIFFC 2003/Martell 2015)

The action taken to halt the spread or potential spread of a fire by the first fire fighting force to arrive at the fire (CIFFC 2003). The early stages of suppression and the resources that are allocated to the fire.

Prescribed fire (CIFFC 2003/Bureau of Land Management)

Any fire utilized for prescribed burning; usually ignited according to agency policy and management objectives. A prescribed fire may be defined as any fire ignited by management actions under certain pre-determined conditions to meet specific objectives related to hazardous fuels reduction or habitat improvement. Proper planning elements are identified and explained in the technically reviewed and approved prescribed fire plan.

Prescribed burning (CIFFC 2003) and *Prescribed fire* (CIFFC 2003)

The knowledgeable application of fire to a specific land area to accomplish predetermined forest management or other land use objectives. (Synonym: Fire use). Prescribed fire is any fire utilized for prescribed burning; usually ignited according to agency policy and management objectives.

Values at risk (BC Wildfire Service/CIFFC 2003)

The specific or collective set of natural resources and anthropogenic improvements/developments that have measurable or intrinsic worth and that could or may be destroyed or otherwise altered by fire in any given area.

Wildland-Urban interface (WUI) (Haight *et al.* 2004, Evans *et al.* 2015, Government of BC 2015)

The WUI is where houses and fairly dense vegetation are both present. The WUI is often the focus of fire prevention and preparedness projects including fuel reduction in forests, fuel removal in the immediate vicinity of homes, and emergency evacuation planning. In the US, there are two types of WUI: interface (3 or more structures per acre with shared municipal services) and intermix (as sparse as one structure per 40 acres) (Evans *et al.* 2015). The WUI is also considered as any area where combustible vegetation is found adjacent to homes, farm structures, or other buildings and is within two kilometers of a community with a density of 6 to 250 structures per square kilometer (Government of BC 2015). Recently introduced, the wildland industrial interface (WII) and an infrastructure interface are being considered in addition to the traditional WUI. Note: Johnston 2016.

Literature Review Methodology

We conducted an extensive review of scientific literature and relevant government documents using academic literature search engines (specifically, Thomson Reuters Web of Science and Google Scholar), specifically for boreal fire search terms including northern Canada fire, northeast BC fire regime, boreal fire regime, historical fire regimes of the boreal, prescribed fire in Canada, prescribed fire in BC and the boreal, wildlife search terms, and author search terms (i.e. Flannigan, Wotton, Parminter, Hawkes, Turetsky, Amiro, Stocks, Martell, Beck, Bergeron, Van Wagner, Alexander, Johnson, DeLong). All literature current to November 2015 was reviewed (Leverkus 2015) with additional review from 2014 to present where the first 100 search results were screened for relevance and inclusion in this literature review. After 2014, we found a total of 69 scientific reports of which 67 were peer-reviewed journal articles, 1 was a thesis, and 1 was an Extension report. It was common to find papers by specific authors although the author of interest was frequently not the first author (for example – for Mike Flannigan is a co-author on Parisien *et al*. 2014 and Wang *et al*. 2015).

Supporting references for "Enhance and Maintain Wildlife Habitat" Prescribed Fire Value

As per Leverkus *et al.* 2017:

Species	Habitat/Vegetation Type Resource Selection	Citation
Humans, *Homo sapiens*	rock: viewscapes, recreational activities, hunting	Fort Nelson Land and Resource Management Plan 2009
	alpine: hiking, viewscapes, hunting, wildlife viewing	Meidinger and Lewis 1983, Fort Nelson Land and Resource Management Plan 2009
	sub-alpine: hunting, hiking, viewscapes	Meidinger and Lewis 1983, Fort Nelson Land and Resource Management Plan 2009
	open rangeland: hunting, hiking, viewscapes, trapping	Meidinger and Lewis 1983, Fort Nelson Land and Resource Management Plan 2009, Hatler and Beal 2010
	open forest: trapping, hunting, recreational activities	Meidinger and Lewis 1983, Fort Nelson Land and Resource Management Plan 2009, Hatler and Beal 2010
	dense forest: trapping, hunting	Fort Nelson Land and Resource Management Plan 2009, Hatler and Beal 2010
	muskeg/riparian areas/rivers/lakes: trapping, transportation, fishing, hunting	Fort Nelson Land and Resource Management Plan 2009, Hatler and Beal 2010
Horse, *Equus caballus*	open rangeland: foraging	Haber 1988, Burns 2001, Beever *et al.* 2008, Edwards 2008, Vince 2011, Girard *et al.* 2013
	open forest: foraging, cover	Edwards 2008, Beever *et al.* 2008, Vince 2011, Girard *et al.* 2013
Wood bison, *Bison bison athabascae*	open rangeland/sedge meadows: foraging and wallowing	Soper 1941, Larter and Gates 1991, Harper and Gates 1999, Harper *et al.* 2000, Fortin *et al.* 2002, BC Ministry of Environment 2009, Goddard 2011
	open forest: rutting, rubbing and foraging	Soper 1941, Larter and Gates 1991, Harper *et al.* 2000, Fortin *et al.* 2002
	dense forest: cover, rubbing and forage	Soper 1941, Larter and Gates 1991, BC Ministry of Environment 2009a
	muskeg/riparian areas: foraging and wallowing	Soper 1941, DeLong *et al.* 1991, Larter and Gates 1991, Harper *et al.* 2000, Fortin *et al.* 2002
Plains bison, *Bison bison bison*	open rangeland/sedge meadows: forage	Pojar and Stewart 1991a, Fuhlendorf *et al.* 2010, BC Ministry of Environment 2009a, Goddard 2011
	dense forest: cover and forage	BC Ministry of Environment 2009a
	muskeg/riparian areas: forage	Pojar and Stewart 1991a, Fuhlendorf *et al.* 2010
Moose, *Alces alces andersoni*	alpine	Meidinger and Lewis 1983, Gustine and Parker 2008, BC Ministry of Environment 2009a
	subalpine: winter use	BC Ministry of Environment 2009a
	open rangeland: forage	DeLong *et al.* 1991, Pojar and Stewart 1991a, Nappi *et al.* 2004, Fisher and Wilkinson 2005, Gustine *et al.* 2006b, BC Ministry of Environment 2009a, Goddard 2011
	open forest	DeByle 1984, DeLong *et al.* 1991, Pojar and Stewart 1991a and 1991b, Fisher and Wilkinson 2005, BC Ministry of Environment 2009a
	dense forest: forage and thermal cover	DeLong *et al.* 1991, BC Ministry of Environment 2009a
	muskeg/riparian: forage	DeLong *et al.* 1991, Pojar and Stewart 1991a, BC Ministry of Environment 2009a
Elk, *Cervus elaphus*	alpine	Pojar and Stewart 1991b
	subalpine: winter use	Seip and Bunnell 1985, Gustine and Parker 2008, BC Ministry of Environment 2009a
	open rangeland: foraging	Kufeld 1973, DeByle 1984, DeLong *et al.* 1991, Peck and Peek 1991, Peck and Currie 1992, Gustine *et al.* 2006b, Christianson and Creel 2007, Sawyer *et al.* 2007, Van Dyke and Darragh 2007, Keigley and Frisina 2008, Long *et al.* 2008, Yukon Elk Management Planning Team 2008, BC Ministry of Environment 2009a, Long *et al.* 2009, Goddard 2011
	open forest: cover, foraging and browse (winter), rubbing	DeByle 1984, Seip and Bunnell 1984, DeLong *et al*. 1991, Peck and Peek 1991, Pojar and Stewart 1991a, White *et al.* 1998, White *et al.* 2003, Sachro *et al.* 2005, Christianson and Creel 2007, Keigley and Frisina 2008, Long *et al*. 2008, Yukon Elk Management Planning Team 2008
	dense forest: thermal cover, hiding and browse (winter), rubbing	DeByle 1984, Seip and Bunnell 1984, Peck and Peek 1991, Keigley and Frisina 2008

Woodland caribou, *Rangifer tarandus caribou*	alpine: summer use and winter use	Seip and Bunnell 1985, Pojar and Stewart 1991b, Gustine *et al.* 2006a, Gustine and Parker 2008, BC Ministry of Environment 2009a
	subalpine	BC Ministry of Environment 2009a
	open rangeland	Pojar and Stewart 1991b
	open forest	DeLong *et al.* 1991, Pojar and Stewart 1991a, Fisher and Wilkinson 2005, Dalerum *et al.* 2007, BC Ministry of Environment 2009a
	dense forest: winter use	DeLong *et al.* 1991, Fisher and Wilkinson 2005, Gustine *et al.* 2006a, Dalerum *et al.* 2007, Gustine and Parker 2008, BC Ministry of Environment 2009a
	muskeg/riparian	Pojar and Stewart 1991a, BC Ministry of Environment 2009a
Mountain goat, *Oreanmnos americanus*	rock: escape terrain	Pojar and Stewart 1991b, Hamel and Côté 2007, BC Ministry of Environment 2009a
	alpine	Meidinger and Lewis 1983, Pojar and Stewart 1991b, Hamel and Côté 2007, BC Ministry of Environment 2009a
	open rangeland	DeLong *et al.* 1991, Pojar and Stewart 1991b, Peck and Currie 1992, Goddard 2011
Stone's sheep, *Ovis dalli stonei*	rock: escape terrain and mineral licks	Pojar and Stewart 1991a, Walker *et al.* 2006, BC Ministry of Environment 2009a, Sittler 2013
	alpine: winter range, yearly	Meidinger and Lewis 1983, Seip and Bunnell 1984, Seip and Bunnell 1985, Pojar and Stewart 1991b, Walker *et al.* 2006, BC Ministry of Environment 2009a
	open rangeland/ burned sub-alpine: foraging	Meidinger and Lewis 1983, Seip and Bunnell 1984, Seip and Bunnell 1985, DeLong *et al.* 1991, Pojar and Stewart 1991a, Pojar and Stewart 1991b, Gustine *et al.* 2006b, Walker *et al*. 2007, BC Ministry of Environment 2009a, Goddard 2011, Vince 2011
	dense forest: escape terrain	BC Ministry of Environment 2009a
Grizzly bear, *Ursus arctos*	alpine: root digging	Meidinger and Lewis 1983, Pojar and Stewart 1991b, Munro et al. 2006, BC Ministry of Environment 2009a
	subalpine	BC Ministry of Environment 2009a
	open rangeland: root digging	DeLong *et al.* 1991, Pojar and Stewart 1991a, Pojar and Stewart 1991b, Gustine *et al.* 2006b, Munro *et al.* 2006, BC Ministry of Environment 2009a
	open forest: insect feeding and frugivory	Munro *et al.* 2006, BC Ministry of Environment 2009a
	dense forest: selection for spruce forests	Ciarniello *et al.* 2007, BC Ministry of Environment 2009a
	muskeg/riparian area	DeLong *et al.* 1991, Pojar and Stewart 1991a, BC Ministry of Environment 2009a
Gray wolf, *Canis lupus*	alpine	BC Ministry of Environment 2009a
	subalpine	BC Ministry of Environment 2009a
	open rangeland	DeLong *et al.* 1991, Pojar and Stewart 1991a, Fisher and Wilkinson 2005, Gustine *et al.* 2006b, BC Ministry of Environment 2009a
	open forest	DeLong *et al.* 1991, Pojar and Stewart 1991a, BC Ministry of Environment 2009a
	dense forest	DeLong *et al.* 1991, BC Ministry of Environment 2009a
	muskeg/riparian area	DeLong *et al.* 1991, Pojar and Stewart 1991a, BC Ministry of Environment 2009a
Wolverine, *Gulo gulo*	alpine: denning and rearing kits	Lofroth and Krebs 2007
	subalpine: summer use	Krebs *et al.* 2007
	open rangeland: dispersal corridors	Pojar and Stewart 1991a, Dalerum *et al.* 2008
	open forest: dispersal corridors, winter use	Pojar and Stewart 1991a, Krebs *et al.* 2007, Dalerum *et al.* 2008
	dense forest	DeLong *et al.* 1991
	resource selection linked to availability and distribution of food resources	Hatler and Beal 2010
Fisher, *Martes pennanti*	open rangeland: foraging	Fisher and Wilkinson 2005, Hatler and Beal 2010
	open forest: hunting	Boutin *et al.* 2003, Sullivan *et al*. 2006
	dense forest: foraging, winter use	Boutin *et al.* 2003, Fisher and Wilkinson 2005, Sullivan *et al.* 2006, Hatler and Beal 2010
	muskeg/riparian area: foraging	Hatler and Beal 2010

Northern myotis, *Myotis septentrionalis*	open rangeland: foraging (insectivore)	Wilsmann *et al.* 1996, Fisher and Wilkinson 2005
	open forest: roosting, foraging (insectivore)	DeLong *et al.* 1991, Wilsmann *et al.* 1996, Ciechanowski *et al.* 2007, BC Ministry of Environment 2009a
	dense forest : roosting/hibernacula and foraging (insectivore)	Wilsmann *et al.* 1996, Fisher and Wilkinson 2005, Ciechanowaski et al. 2007
	riparian area/water: foraging (insectivore)	Wilsmann *et al.* 1996, BC Ministry of Environment 2009a
Lesser sandhill crane, *Grus canadensis canadensis*	open rangeland/sedge meadows: stopover sites, breeding, nesting	Cooper 1996, Blood and Backhouse 1999, International Crane Foundation
	open forest: escape cover	Blood and Backhouse 1999, International Crane Foundation
	dense forest: escape cover, resting, feeding	Campbell *et al.* 1990, Cooper 1996
	riparian area/wetland: nesting, loafing, roosting	Cooper 1996, Blood and Backhouse 1999, International Crane Foundation
Short-eared owl, *Asio flammeus*	alpine/tundra: nesting	Dement'ev 1951, Mikkola and Sulkava 1969, Clark 1975, BC Ministry of Environment 2009a
	open rangeland: nesting	Dement'ev 1951, Mikkola and Sulkava 1969, Clark 1975, BC Ministry of Environment 2009a
	dense forest: nesting	Dement'ev 1951, Mikkola and Sulkava 1969, Clark 1975, BC Ministry of Environment 2009a
	riparian area/water: hunting	Dement'ev 1951, Mikkola and Sulkava 1969, Clark 1975, BC Ministry of Environment 2009a
Peregrine falcon, *Falco peregrinus anatum*	rock/cliff: nesting	BC Ministry of Environment 2009a
	alpine/tundra: nesting	BC Ministry of Environment 2009a
	open rangeland: hunting	BC Ministry of Environment 2009a
Bay-breasted warbler, *Dendroica castanea*	open forest: foraging in upper canopy, nesting (300 - 400ha continuous tracts of forest minimum required), mature white spruce (pure stands or mixed with aspen, birch, balsam poplar)	Cooper *et al.* 1997, Blood and Backhouse 1998
	dense forest: foraging in upper canopy, nesting (300 - 400ha continuous tracts of forest minimum required), mature white spruce (pure stands or mixed with aspen, birch, balsam poplar)	Cooper *et al.* 1997, Blood and Backhouse 1998
Cape may warbler, *Dendroica tigrina*	open forest (300 - 400ha continuous tracts of forest minimum required)	BC Ministry of Environment 2009a
	dense forest: breeding, foraging in upper canopy, nesting (300 - 400ha continuous tracts of forest minimum required)	Blood and Backhouse 1998, BC Ministry of Environment 2009a
	riparian area	BC Ministry of Environment 2009a
Black-throated green warbler, *Dendroica virens*	open forest: forest edge (300 - 400ha continuous tracts of forest minimum required)	DeLong *et al.* 1991, Blood and Backhouse 1998, BC Ministry of Environment 2009a
	dense forest: foraging in mid-to upper canopy, nesting, forest edge (300 - 400ha continuous tracts of forest minimum required)	Blood and Backhouse 1998, Schieck and Hobson 2000, BC Ministry of Environment 2009a
	muskeg/riparian area	DeLong *et al.* 1991, BC Ministry of Environment 2009a
Connecticut warbler, *Oporornis agilis*	open forest: ground nesting and foraging (300 - 400ha continuous tracts of forest minimum required)	Blood and Backhouse 1998, Hobson and Schieck 2009, BC Ministry of Environment 2009a
	dense forest (300 - 400ha continuous tracts of forest minimum required)	BC Ministry of Environment 2009a
	muskeg/riparian area	DeLong et *al.* 1991
Bull trout, *Salvelinus confluentus*	given adeqaute connectivity to robust population segments, bull trout are resilient to fire's effects	Dunham *et al.* 2003, Holsinger and Keane 2011
Lake trout, *Salvelinus namaycush*	riparian area	Dunham *et al.* 2003
Arctic grayling, *Thymallus arcticus*	riparian area	Dunham *et al.* 2003
Rainbow trout, *Oncorhynchus mykiss*	riparian area	Dunham *et al.* 2003
Northern pike, *Esox lucius*	riparian area	Dunham *et al.* 2003
Western toad, *Bufo boreas*	riparian area	Pojar and Stewart 1991a

Fire can establish a mosaic of plant successional states relative to time since fire that can be important for a suite of wildlife species at different seasonal of life stages. This ecological process of fire structuring shifting mosaics of habitat has been suggested to be the basis for conservation (Fuhlendorf et al. 2006). The importance of this fire-driven habitat heterogeneity spans trophic levels as it can be important for broad guilds of invertebrates, birds, reptiles, amphibians, small mammals, large mammals, and apex predators (Scasta et al. 2016). Following are wildlife species specific examples of how prescribed fire can benefit species (also note Lousier *et al.*2009 for complementary citations):

During the Wisconsin glaciation and the mini-glaciation of the late 1800s there were portions of northeast BC that provided refugia to elk (Elliott 1983). Elk select burned subalpine slopes for the majority of the year and they require large contiguous areas of open rangeland where they forage on ferns, grasses, sedges, willows, rose and shrubs (Seip and Bunnell 1984, BC Ministry of Environment 2009). In addition, they require forested areas for cover and browse during the winter (Seip and Bunnell 1984). The primary habitat objective for elk is to maintain large early-seral grassland areas through the application of prescribed fires and opportunistic use of wildfires. This can be achieved through the maintenance of varied time since fire across the landscape. The North Eastern British Columbia Elk

Enhancement Program, initiated in 1982 by the BC Fish and Wildlife Branch, had the primary goal of sustaining elk populations of up to 4,000 head year-round through the integration of prescribed fire and other habitat enhancement tools (Elliott 1983). Elliott (1983) found that elk responded to prescribed fires and remained within the prescribed fire units year-round.

Stone's sheep (*Ovis dalli stonei)* are the only subspecies of thinhorn sheep which occur in the Region. (BC Ministry of Environment 2009). 100% of the world population of Stone's sheep inhabit Northern British Columbia. The limiting factors to their distribution and abundance are predation and restricted escape terrain (BC Ministry of Environment 2009). During different seasons, Stone's sheep use burned subalpine ranges (Seip and Bunnell 1984, Seip and Bunnell 1985, Sittler 2013).

Moose (*Alces alces*) browse on shrubs and young deciduous trees found in recently burned areas, forest cutblocks, and locations where there has been limited time since disturbance (BC Ministry of Environment 2009). They are dispersed throughout the Peace-Liard Region and occur from the alpine to valley bottoms. The M-KWMP and Peace-Liard Moose Management Plan (BC FLNR nd) direction for habitat of moose is to apply prescribed fire and moose-friendly silviculture practices in key habitats to ensure sufficient early seral shrubland to support moose populations. Fires in the boreal provide moose with important nutrients they require (Geist 1999) and the increased available browse may last from 20 to 40 years depending on pre-fire vegetation and fire severity (Rowe and Scotter 1973, Viereck and Schandelmeier 1980, Weixelman *et al.* 1998, Fisher and Wilkinson 2005, Maier *et al.* 2005). Minerals stored in woody tissues of trees are released in forest fires and are absorbed by shrubs and herbaceous species regrowing after the fire, providing a source of minerals for moose (Geist 1999). Escape terrain is important for moose and it includes frozen, snow-covered lakes, old burns, and places with obstacles to hide behind (Geist 1999). Amount of browse, cover, presence of moose in adjacent areas, and prior use of the area also influence moose utilization and selection of burned areas (Viereck and Schandelmeier 1980). Old-growth forests are critical to the winter survival of moose in areas of deep snow (Fenger and Harcombe 1990).

Joly *et al*. (2017) assessed moose in Alaska and found that during winter females selected burned areas and areas that received higher amounts of solar radiation. Kielland (2015) concluded that high severity fire created habitat that moose used in the summer presumably for the high deciduous component. Michaud *et al*. (2014) assessed moose distribution in southern and central Ontario based on remotely sensed environmental indicators (including fire). Street *et al*. 2015a and 2015b assessed Ontario moose distribution Resource Selection Functions (RSFs) and demographics and found deciduous cover and NDVI were strong predictors of moose selection. Scotter (1964 and 1971) found that moose select for 1 to 50 years since fire.

Moose consume five to six metric tons of food a year (Pastor *et al.* 1988). Young willow leaves are the most nutritious food source for moose whereby young willow have high concentrations of protein, calcium, and phosphate which are important components of the apatite crystals that form bones (Geist 1999). As a concentrate feeder, feeding on plants low in fiber and high in nutrients, moose select plants that are easier to digest (Geist 1999). In the summer, browsing and foraging are concentrated on leaves of new willow shoots, aquatic plants, vegetation from old burns and alpine areas including twigs and tall annual plants, grasses and sedges (Geist 1999). Winter nutrient selection includes woody browse (young willows- *Salix sp.*, red osier dogwood – *Cornus stolonifera*, high-bush cranberry – *Viburnum edule*), douglas and alpine firs (Geist 1999). Preferred deciduous species include birch (*Betula sp.*), aspen (*Populus tremuloides*), balsam fir (*Abies sp.)* (Turner *et al.* 2001). Moose browse on shrubs and young deciduous trees found in recently burned areas and locations where there has been limited time since disturbance (Maier *et al.* 2005, BC Ministry of Environment 2009). Rowe and Scotter (1973) report that there is evidence that the availability of browse species on recently burned areas is generally superior in both quality and quantity.

There is literature available supporting a positive interaction between moose and forest harvesting depending on the age and sex of the moose, seasonality, and distribution of forest harvesting across the landscape. However, the quality and quantity of moose habitat and the surrounding matrix must be taken into serious consideration. Patch quality (the quality of the vegetation, soil, water, etc. within a patch of land), boundary effects (such as fragmentation or increased movement), patch context (how that area of vegetation compares to the rest of the landscape) and connectivity in landscapes are profound (Leverkus 2014).

Mountain goat (*Oreamnos americanus*) select steep, rocky, forested outcroppings and are known to move in response to snow depth. The majority of their diet consists of lichens, ferns, forbs, grasses, shrubs and woody browse and they often travel long distances to gain access to mineral licks (BC Ministry of Environment 2009). Higher level planning for mountain goat lists the major management direction for their habitat as maintaining connectivity (BC Ministry of Environment 2009) which can be achieved through prescribed fire.

Ungulates in general and their response to fire were addressed in the Extension article by Sittler *et al*. (2014) titled "Burning for northern mountain ungulates: effects of prescribed fire". In addition to the previously mentioned ungulate species, there is also mention of other ungulates including mule deer (*Odocoileus hemionus)* and white-tailed deer (*Odocoileus virginianus)*. Deer require a varied time since fire mosaic to fulfill their habitat needs which include access to mature forests and open rangeland slopes with minimal snow accumulation.

There are no specific objectives related to habitat in regards to reptiles and amphibians; however, the Western toad (*Bufo boreas*) is listed as a species of concern in the Region whereby improved knowledge of populations and migrations corridors are addressed. Additional reptiles and amphibians that may occur in the Region include: boreal chorus frog (*Pseudacris triseriata*), Columbia spotted frog (*Rana luteiventris*), wood frog (*Rana sylvatica*), long-toed salamander (*Ambystoma macrodactylum*), red-sided garter snake (*Thamnophis sirtalis*) and Western terrestrial garter snake (*Thamnophis elegans*) (BC Ministry of Environment 2009). The priority groups of invertebrates in the M-KMA include: lepidopterans, odonates and molluscs. Provincially red-listed invertebrate species which may be present in the M-KMA include: Alberta arctic (*Oeneis alberta*), Philip's arctic (*Oeneis philipi*), Old world swallowtail (*Papilio machaon hudsonianus*), Striped hairstreak (*Satyrium liparops*), Coral hairstreak (*Satyrium titus titus*), Great spangled fritillary (*speyeria Cybele pseudocarpenteri*), Ms. McKinley alpine (*Erebia mackinleyensis*), Magdalena alpine (*Erebia magdalena*), Plains forktail (*Ischnura damula*), and Kennedy's emerald (*Somatochlora kennedyi*). The primary management objective for invertebrates as listed is to maintain the habitat matrix and habitat suitability (BC Ministry of Environment 2009). It may be possible that the host plants and the environment required in different parts of the life cycles of invertebrates require a specific time since fire. Studies have shown that there is a positive interaction between the heterogeneous application of fire across a landscape and different butterfly species (Baum and Sharber 2012).

Fish habitat and water quality is influenced by disturbances in the surrounding watershed and therefore forms an important consideration when planning prescribed fire activities and managing wildfire activity. There are native fish species which have adapted with fire and are resilient to fire's effects such as Bull trout (*Salvelinus confluentus*) a blue-listed species (BC Ministry of Environment 2009, Holsinger and Keane 2011). Holsinger and Keane (2011) developed a model that may provide a better understanding for the persistence of Bull trout in varying changing climate regimes.

Although fisher (*Pekania pennanti*) are a forest-dwelling species selecting for coniferous and mixed forest habitats, they also utilize the forest edge and riparian areas including conifer and shrub patches that occur over varying time since fire. Heterogeneity is more important to fisher resource selection as the structural make-up of the forest has a greater influence than the species composition or age (Hatler and Beal 2010). Structural features that are important requirements for fisher include: coarse woody debris, snags and layered overhead vegetation (Hatler and Beal 2010). Fishers select to den in trees that are typically greater than 50cm diameter at breast height and that have a fire scar or wound where they can create a den in the rotting interior of the tree. Fisher are not well adapted to walk through snow therefore their winter resource selection includes thick canopied forests with shallow snow depth on the floor or low elevation mountainous areas with slopes that are exposed to the sun and wind (Hatler and Beal 2010). Fishers hunt for prey in habitats with less vertical structure that are more open; however, they rest and den in areas with high structural diversity ranging from cavities and platforms high off the ground in the summer to underneath coarse woody debris covered in snow in the winter (Hatler and Beal 2010).

Marten (*Martes americana*) studied in Alaska by Baltensperger *et al*. (2017) documented a "Change-detection analyses revealed an ongoing westward expansion of likely marten distribution on the Kenai Peninsula since at least 1988, and historic records indicated longer-term growth. Top predictors in the models included "soil ecotype, landcover, distance to trails, and distance to recreation sites". One new mink paper was found by Hodder (2016) based on research in BC, Canada. The primary driver for habitat resource selection of the 7 collared mink in this study was based on riparian features.

Wolverine (*Gulo gulo*) typically select for high elevation forests and alpine tundra. They also utilize a variety of lower-elevation areas particularly in the winter (Hatler and Beal 2010). Their resource selection is closely linked with the availability and distribution of their food resources. Wolverine feed on rodents, ungulates, birds, berries, and carrion (Hatler and Beal 2010), all of which could be stimulated by fire.

The gray wolf (*Canis lupus*) is a highly adaptable predator and one of the dominant carnivores of the boreal. Distribution is affected by snow depth in the winter and selects areas where ungulates such as moose, caribou, elk, Stone's sheep, mountain goat and deer concentrate (Hatler and Beal 2010). Wolves travel and hunt along frozen watercourses as well as on previously disturbed linear features such as seismic lines and trails. They utilize closed canopy forests and open slopes that are exposed to sun and wind (Hatler and Beal 2010).

Grizzly bears (*Ursus arctos*) are omnivores that select for resources across the landscape including berry and fruit producing shrubs and forbs, insects, roots and ungulates depending on the season (Munro *et al.* 2006). It is hard to specify exact grizzly bear habitat because there is no single habitat that they select for (Munro *et al.* 2006). Ciarniello *et al.* (2007) found that grizzly bear habitat selection is scale dependent and that their resource selection depends on the vegetation availability in each particular landscape. Therefore this complex spatial and temporal use of resources for habitat, food and activities of grizzly bears lends itself as a prime example of the need for a landscape management plan that incorporates time since fire and heterogeneity as primary objectives. A mosaic of vegetation and vertical structure across the landscape that could be driven by time since fire may be the ideal habitat for grizzly bear populations (Munro *et al.* 2006).

Management direction for grizzly bear and wolverine in the Muskwa-Kechika Management Area (M-KMA) is to maintain connectivity between important habitats. At the landscape and stand level, management for important fisher habitat is required which result in the retention of large, windfirm stands of suitable fisher habitat. In addition to the previously mentioned priority species identified in the M-KWMP, there is also direction for other furbearing animals including marten, river otter, beaver, lynx, black bear, coyote and cougar (*Puma concolor*). Retention of suitable levels of coarse woody debris is a management direction outcome for marten, while suitable riparian habitat and abundance of prey are outcomes for the management direction associated with river otter. Black bears (*Ursus americanus*) have also been noted in the M-KMA at all elevations, and they select for burned areas and other openings on the landscape (Fisher and Wilkinson 2005, BC Ministry of Environment 2009).

Supporting documentation

The Management of Prescribed Fire in North East British Columbia

- Sonja Leverkus, P.Ag. - September 4 2008

There is a long history of fire in the North East of British Columbia. Fire has been historically used as a treatment method in maintaining open rangeland and open forest. The Fort Nelson Forest District encompasses this incredible landscape and wilderness including First Nation traditional territories, the Muskwa-Kechika Management Area, Provincial Parks and Protected Areas, guide outfitting and transporting areas, ranches and farms, and Oil/Gas and forestry activity. In such a unique landscape with multiple interests, claims and stakeholders, it is highly important to manage the land to the best of our abilities. In the past 2 years there has been a significant movement to integrate all the land managers involved with prescribed fire on the land base. The main goal of this is to build off of past work in this field which results in formalized processes and collaboration, ensuring the efficient, effective and appropriate application of best management practices for prescribed fire and burning in the North East.

In Fall 2007, the Burn Plan Team was established in order to assist applicants with the application and design of their Prescribed Fire Burn Plans and the Level 1 Impact Assessments required by Parks and Protected Areas. This team of resource professionals assists in developing burn plans and provides extension work when needed. The Burn Plan Team consists of the following members:

Sonja Leverkus, Range Agrologist/Tenures Forester – Ministry of Forests and Range;

Ralph Kermer, Protection Officer – Ministry of Forests and Range;

Harry Offizier, Protection Officer – Ministry of Forests and Range;

Al Hansen, Liard Area Supervisor, Parks and Protected Areas - Ministry of Environment and;

Rob Honeyman, North Peace Area Supervisor, Parks and Protected Areas – Ministry of Environment.

In the Spring of 2008, the North East Prescribed Fire Council (NEPFiC) held its initial meeting in Fort Nelson. With many different issues concerning prescribed fire, it was deemed incredibly vital to pull together and co-ordinate the many decision makers and managers who are involved with fire. By integrating decision makers with the technical support that is required when dealing with treatment processes such as prescribed fire, a community of practice is created with a focus on the need to balance and recognize resource values. The Council consists of a main core of members who actively work on the ground and who also are involved in the prescriptions of fire on the land base. This core, which includes the Burn Plan Team and biologists from the Ministry of Environment, is supported by professionals from rangeland ecology to fire management to geomorphology to ecosystem restoration and wildlife management, including the guide outfitting industry. In the near future, we look forward to welcoming first nation partners to the Council.

Rob Woods, Wildlife Biologist from the Ministry of Environment, continues to work on the 10 year burn plan for the North East. In previous years, it was he and John Elliot who were responsible for running the Prescribed Fire Burn Program for ungulate forage enhancement. This program began in late 1970 and is now being continued by Rob Woods and Conrad Thiessen, also a Wildlife Biologist with the Ministry of Environment.

Vital to the success of the management and implementation of prescribed fire, is the continuum of an environment with open communication, clarity and transparent processes around burning, the use of fire as a treatment method and the mop-up associated with the prescription. Working in collaboration with the wildlife biologists from the Ministry of Environment (Rob Woods and Conrad Thiessen), the Parks Area Supervisors (Rob Honeyman and Al Hansen), the Protection Officers (Ralph Kermer, Harry Offizier and Rick Grayston) and the many Range Tenure holders, the results of this multi-agency and multi-disciplinary group can be seen by the success it has achieved in the past year. It is important to mention that we are very fortunate to work with the guide outfitting and transporter industries, as well as the livestock industry, and we all truly appreciate their support, participation and dedication to this work.

PRESCRIBED BURNING AND FORAGE IN BRITISH COLUMBIA'S NORTHEAST

--draft--

INTRODUCTION

Big game guiding is a major source of economic activity in northeastern British Columbia. Guides and hunters alike rely on early seral forage and browse areas for both game animals and for packhorses, and prescribed burning has been a traditional way of creating and maintaining forage along river valleys, game movement corridors, and adjacent to guide base and spike camps.

A number of unanswered practical and ecological questions are associated with this activity. I had the privilege of accompanying Sonja Leverkus, MOFR Range Agrologist, and Rob Woods, MOE Wildlife Biologist, as we visited several camps and drainages in the area at the end of July, 2008. These are some preliminary notes on my observations. They are by no means definitive, but will perhaps serve to further the analysis and resolution of these complex and largely unresearched issues.

THE QUESTIONS

These are the outstanding questions , as I see them:

- What were the historical (pre-European contact) fire dynamics (frequency, intensity, size) in the Boreal White and Black Spruce (BWBS) subzone of northeastern BC?
- Were there pockets of more intense First Nations fire activity in this area, in pre-contact times?
- Are current and planned prescribed burns within the historical norms for frequency, intensity and size?
- If current and planned prescribed burning is "outside" of historical norms, can permanent ecological damage result?
- We are assuming that fire is the dominant disturbance process in the BWBS, and fire creates various seral stages over time and space. What are the BWBS seral stages? What was the pre-contact seral stage distribution at the landscape level, and how different is the current seral stage distribution?
- Quaking aspen appears to be the primary early seral species emerging after a fire, and it quickly reaches closed canopy status, reducing forage and browse values to near zero. What is the most effective burn season and sequence, that will delay aspen suckering and growth, in order to lengthen the period of time when herbaceous forbs, grasses and shrubs are dominant?
- Can grazing and browsing, by both wild and domestic ungulates, be managed along with prescribed fire in such a way that they assist in the lengthening of the herbaceous seral stage?
- Prescribed burning can cause negative "second order" effects, one obvious one being that burning leads to increased forage, leading to increased elk populations, leading to increased predator populations, and a subsequent decline in wild sheep populations. Can a prescribed burning threshold (for fire frequency and size) be defined, below which those second order effects are minimized?
- What are the techniques for monitoring pre- and post-burn tree canopy closure, burn intensity, herbaceous forage and browse production, and landscape level seral stage distribution, that are appropriate to the limited available manpower and large size of the region?

QUESTION BACKGROUND MATERIAL AND OBSERVATIONS (NOT ANSWERS)

What were the historical (pre-European contact) fire dynamics (frequency, intensity, size) in the Boreal White and Black Spruce (BWBS) subzone of northeastern BC?

DeLong, MacKinnon and Jang (1990) suggest that fire has had a major influence on BWBS plant communities, and that true climax forests in the subzone are practically nonexistent. According to John Parminter of MOFR, the pre-contact fire frequency in the BWBS was every 200 to 350 years. His assessment is that beginning in the 1940's, fire frequency shortened dramatically with the advent of guide-outfitter burn activity. No other fire frequency estimates were found in the literature. Neither white or black spruce are likely to record fires in the form of fire scars. During the tour, a few lodgepole and aspen were observed to have fire scars, but as these are both fairly short-lived species, the scars were likely of recent origin. Further investigation of fire history by a trained dendrochronologist could shed light on the pre-contact fire regime.

Were there pockets of more intense First Nations fire activity in this area, in pre-contact times?

Given the remoteness of the area and the long winters, First Nations fire activity was likely less here than in the BC southern Interior. Parminter suggests there would have been burning for blueberry production in certain areas. No doubt specific low elevation south and southwest slopes along river valleys and travel corridors would have been subject to some anthropogenic fire activity. Again, no published data was found on this topic.

Are current and planned prescribed burns within the historical norms for frequency, intensity and size?

Both Parminter and Dale Seip, MOFR, feel that recent burning is indeed outside historical norms for frequency. My assumption is that recent burning is less than historical norms in terms of fire size and fire intensity. Until the first question is answered however, this is all speculative.

If current and planned prescribed burning is "outside" of historical norms, can permanent ecological damage result?

Possible permanent ecological damage could be in the form of loss of soil organic matter, soil erosion or soil chemical changes that result in a loss of site productivity. Another source of ecological damage is the potential permanent loss of species (either directly or through loss of habitat). There is no specific documentation on this. There is an interesting analogue in the wet forests of southwestern Washington, USA, where repeated First Nations burning activity created and maintained small "prairies" along travel corridors, in what would otherwise be dense coniferous forest. Generally, increasing the amount of "edge" (as in a forest/grassland edge) increases the overall biodiversity in an area. Part of the answer to this question will lie in the physical scale of the burning activity.

Anderson and Bailey (1980) examined aspen parkland areas of east central Alberta which had been spring-burned annually for more than two decades, and compared them with adjacent unburned areas. In the burned areas, the cover of herbaceous species increased at the expense of shrubs, but aspen suckers increased compared to controls. Cover of late seral rough fescue decreased. Annual herbage production decreased in the burned areas. Soils in the burned areas experienced an increase in organic matter and phosphorus content in the Ah horizon, and nitrogen status remained unchanged.

We are assuming that fire is the dominant disturbance process in the BWBS, and fire creates various seral stages over time and space. What are the BWBS seral stages? What was the pre-contact seral stage distribution at the landscape level, and how different is the current seral stage distribution?

Current and potential burn areas should be identified as to BEC variant and site series, as a start, using DeLong, MacKinnon and Jang (1990). These same authors describe both low-elevation stands with aspen or balsam poplar dominant as seral or non-climax. Lodgepole dominant stands at mid-elevation or on coarse-textured soils are also described as seral. A hypothetical climax forest is described as dominated by white and/or black spruce or perhaps subalpine fir. Based on my observations, an immediate post-fire seral stage could also be defined, consisting of various shrubs, herbs and grasses. This primary seral stage may differ between low elevation and mid-elevation or coarse textured soil sites.

Peck and Peek (1991) defined nine different "community types" in a large BWBS study area along the Tuchodi River. They were grass-herb, grass-shrub, young shrub, shrub-sapling, open poplar, mature popla, spruce-willow, white spruce and black spruce. A "years since last fire" and dominant vegetation type were described for each. This paper would be a useful starting point for developing management-oriented seral stage descriptions.

Current and historical landscape level seral stage distribution (ie, the proportion of the landscape in each defined seral stage) is an important parameter for management. The underlying assumption is that species have adapted to a particular range of seral stage distributions over time, and that ecosystem resilience, biodiversity and productivity are greatest when landscapes are managed within that range of historical seral stage distributions. None of this information appears to be available for the BWBS. Some extrapolations could be made comparing the earliest available airphotos (available through BC Maps in Victoria) to contemporary airphotos. Other archival photos, possibly from the Alaska Highway construction or other sources, may be of use. I left a phone message with Roger Wheate of UNBC about access to airphotos, but have not yet received a reply.

Quaking aspen appears to be the primary early seral species emerging after a fire, and it quickly reaches closed canopy status, reducing forage and browse values to near zero. What is the most effective burn season and sequence, that will delay aspen suckering and growth, in order to lengthen the period of time when herbaceous forbs, grasses and shrubs are dominant?

Dr. Brad Hawkes of CFS-Victoria suggested the most effective time to burn aspen is just as it is leafing out. John Parminter referred to Ross Peck's recommendation of a 20-year burn cycle to maintain habitat for elk.

An interesting perspective on aspen suckering was provided to me by Dr. Charles Kay, a big game biologist from the University of Utah who has substantial research experience with aspen, wild ungulates, and First Nations burning practices. He suggested that aspen extensive aspen suckering after a stand-replacement fire indicates that the site had previously been in an aspen-dominant stage in the recent past. This would in turn indicate a previous fire or fires. The site at Buffalo Creek comes to mind.

Can grazing and browsing, by both wild and domestic ungulates, be managed along with prescribed fire in such a way that they assist in the lengthening of the herbaceous seral stage?

The Gathto site should not be used as a model for anything, but it does provide abundant evidence that grazing/browsing can suppress woody (in this case aspen) vegetation.

Hypothetically, elk and moose browsing could serve to lengthen the post-burn herbaceous-dominated seral stage by suppressing aspen suckering. However, many other factors come into play here, and managing wild ungulate numbers is always challenging. Given the large areas and lack of management manpower, post-fire grazing/browsing is more an uncontrolled variable than a management tool.

Prescribed burning can cause negative "second order" effects, one obvious one being that burning leads to increased forage, leading to increased elk populations, leading to increased predator populations, and a subsequent decline in wild sheep populations. Can a prescribed burning threshold (for fire frequency and size) be defined, below which those second order effects are minimized?

Good question. I have no idea what the answer is, but I do know it will be a mixture of ecology, politics and economics, and will only be successfully arrived at with all relevant parties at the table.

What are the techniques for monitoring pre- and post-burn tree canopy closure, burn intensity, herbaceous forage and browse production, and landscape level seral stage distribution, that are appropriate to the limited available manpower and large size of the region?

The standard circular plots explained in Describing Ecosystems in the Field are probably appropriate for burn monitoring. A key component in any burn monitoring is to establish pre-treatment plot(s) prior to burning. This is challenging, since burns are often delayed, or don't burn at the location or intensity that they are supposed to. The alternative is to sample unburned areas after the burn ("substituting space for time") and use those as the control. This is commonly done, but is scientifically suspect.

Since the primary burn objective is the creation of more usable forage and browse biomass, it is logical to include some monitoring in this regard. A typical forage biomass sampling method involves clipping a series of 1 meter squared plots down to a level of 2.5 cm above ground level, placing the forage into paper bags, drying them down to "air-dry dry weight" by placing them at room temperature in a well-ventilated location for two weeks, and then weighing them. Grams per meter squared translates directly into kilograms per hectare. Depending on the kind of forage/browse data required, the bags may be fractionated into shrubs, herbs and graminoids, and subtotal data collected. The shrub (and juvenile aspen) component may be challenging, since only a fraction of its total weight represents usable biomass. This can be corrected for by arbitrarily eliminating all woody material over a certain diameter, or (again arbitrarily) selecting a non-palatable biomass correction factor and subtracting it from the shrub/tree component. This work may be further simplified by leaving woody material over a certain diameter onsite. Forage biomass is generally considered to be current year growth; dead stems and aftermath from the previous year is not counted.

Site photographs are a useful adjunct to data, but on their own do not provide much management information.

Burn effects on herbaceous vegetation typically span over several years. A suggested monitoring scenario would be: 1 year prior to burning; 1 year after burning; 3 years after burning and 5 years after burning. Both vegetation and biomass monitoring can potentially be done at the same time, in separate but adjacent plots.

Some simple soil erosion monitoring may be an appropriate add-on in certain heavily used areas.

CONCLUSIONS

The prescribed burning issue in the Northeast is a profoundly complex management scenario, with competing values, a lack of data and minimal staff. I believe the best approach to this issue is to build a voluntary team representing the key sectors, fully recognize those challenges and shortcomings, agree on operational trials, research and/or inventory to begin collect the missing data and proceed, in an adaptive management fashion, adjusting management based on the incoming flow of trial, research, inventory and observational data.

Much of the concern about burning in the Northeast has been due to the scale and size of fires. Based on my preliminary observations, it seems that switching from broadscale prescribed burning to small, precisely targeted burns in appropriate site series, slopes and aspects, with commitments to follow up and re-burn on ecologically appropriate schedules, seems to be a viable alternative. If the burn schedules for these specific sites turn out to be in fact outside the historic natural fire interval, then at least the departure is done as a conscious management strategy, with monitoring for signs of permanent ecological (soil) damage in place.

Don Gayton, M.Sc, P.Ag.

September, 2008

In 2007, Richard Kabzems, Research Silviculturalist of the BC Ministry of Forests, Lands, and Natural Resource Operations, conducted a literature review at the request of the Range Officer in Fort Nelson (S. Leverkus) as follows in the "Effects of Prescribed Fire on Plant Succession in the Northern Rockies of British Columbia"

Effects of Prescribed Fire on Plant Succession in the Northern Rockies of British Columbia

Second draft, March 2007 – R. Kabzems

The purpose of this brief review is to provide a summary of literature describing post fire plant community succession in the Northern Rockies and foothills of northern British Columbia. The area is west of the town of Fort Nelson and south of the Yukon border and includes portions of three zones of the biogeoclimatic ecosystem classification system, Alpine Tundra (Pojar and Stewart 1991a), Spruce Willow Birch (Pojar and Stewart 1991b) and Boreal Black and White Spruce (DeLong et al. 1991).

Introduction

The Boreal Black and White Spruce (BWBS) zone is found at lower elevations (900 to 1000 m) and in valleys of the Northern Rockies. It has a northern continental climate with mean annual temperatures of -2.9 to 2o C (DeLong et al. 1991). Annual precipitation ranges between 330 and 570 mm with 35-55% of this falling as snow. The Spruce Willow Birch (SWB) zone is found at higher elevations than the BWBS zone, ranging from 1000 m to 1200 m (DeLong 2004). The climate of the SWB is an interior subalpine type (Pojar and Stewart 1991b). Mean annual temperature is -0.7 to -3o C. Mean annual precipitation is 460 to 700 mm, with 35-60% occurring as snowfall. Moist Pacific air from the west frequently causes sudden local storms during summer. Cold spells in winter can be broken by Chinook winds which also contribute to reduced snow cover on south aspect slopes. The Alpine Tundra zone is the highest elevation zone with the shortest, coldest growing season.

A general vegetation pattern is of intermittent to closed forest cover of white spruce plus variable amounts of lodgepole pine and aspen in the valley bottoms and on lower slopes (Pojar and Stewart 1991b). Prescribed burning in many valleys has resulted in extensive seral trembling aspen forests, particularly on warm, southern aspect slopes (DeLong 2004). Black spruce is common on upland sites, often with lodgepole pine on slopes with cooler aspects and in wetlands. Black cottonwood occurs along streams and rivers and is often associated with white spruce. Subalpine fir is found higher on the slopes, particularly on northern and eastern exposures. Upper elevations below treeline are often dominated by 1 – 4 m tall birch (Betula glandulosa) and willow species (Pojar and Stewart 1991). Some of the high wide valleys are subject to massive cold air ponding and have a non-forested mosaic of shrubfields, fens and dry to moist grassland on the valley floor and lower slopes.

Two general types of grassland are frequently found in this area (Pojar and Stewart 1991b). One is a dry grassland developed on steep south aspect slopes with shallow, coarse textured soils on calcareous parent materials. Typical species include glaucous bluegrass (Poa glauca), purple reedgrass (Calamagrostis purpurascens) Altai fescue (Festuca altaica), fuzzy-spiked wildrye (Elymus innovatus), slender wheatgrass (Agropyron trachycaulum), three-toothed saxifrage (Saxifraga tricuspidata) prairie cinquefoil (Potentilla pensylvanica), pasture sage (Artemesia frigida) and northern wormwood (Artemesia campestris ssp. borealis).

The second type of grassland described by Pojar and Stewart (1991b) is a dry to fresh Altai fescue grassland on flat to gently rolling outwash or morainal landforms with species such as mountain monkshood (Aconitum delphinifolium), mountain sagewort (Artemisia norvegica ssp. saxatilis), tall Jacobs-ladder (Polemonium caeruleum) and numerous other forbs and grasses.

Aspen fire ecology

Fire history has increased the amount of aspen stands in the Northern Rockies, and aspen dominated stands are often the most likely candidates for prescribed fires. Some of the features of aspen fire ecology are summarized below.

Even a low severity fire can kill aspen (Bradley et al 1992). Burning is a stimulus to aspen regeneration for several reasons (Peterson and Peterson 1992): a) the hormonal inhibition of sucker production is removed when the overstory stems are killed, b) increased soil temperatures after the fire stimulates sucker production and c) increased light available after removal of aboveground vegetation encourages growth of suckers. Low severity fires may not kill enough stems in the parent stand, and high severity fires may kill shallow aspen roots (Brown and DeByle 1987).

Aspen resprouting usually begins within the first growing season following fire, although suckering after a severe burn may be delayed because the new suckers must come from a greater depth in the soil (Brown and DeByle 1987). Repeated fires at this stage can reduce abundance and vigor of aspen suckers (Peterson and Peterson 1992).

Fire severity, the depth of burn, degree of removal of organic material and extent of soil heating during a fire, can have both immediate and lingering impacts on regeneration of forest vegetation (Hood et al. 2007). Growth of aspen suckers in the first year following a fire is negatively correlated with fire severity, but that effect does not persist in the second and third years following a burn (Wang 2003). Less fire tolerant species are likely to be replaced by species which are better adapted to fire. Severe fires, which remove all the surface organic material are more likely to cause changes in plant community composition and variation in re-growth of vegetation.

A low severity fire in an immature or mature stand would open the stand by causing partial mortality of the existing stems (Bradley et al 1992). Environmental conditions in this open stand may stimulate some suckering (Peck 1987, Bradley et al. 1992) creating a multi-aged, variable height aspen stand.

Interactions with fire and ungulates

The use of prescribed fire on landscapes containing high elk (Cervus elaphus) densities has been found to hinder aspen regeneration (White et al. 1998, 2003). Browsing by elk impeded the rejuvenation of aspen stems following prescribed fire. Herbivory by ungulates can significantly suppress or reduce aspen sucker production (e.g. White et al. 2003). Combined with fire, high levels of ungulate herbivory can dramatically reduce regeneration of woody species (e.g. Bailey et al 1990). Bailey and Whitham (2002) found that aspen stands exposed to high severity burns but no elk had 10 times greater aboveground biomass than stands exposed to intermediate burns. The combination of elk and high-severity burns, however, reduced above-ground biomass 90-fold.

Fire behaviour and fuel consumption patterns

In general, low intensity surface fires are characteristic of aspen stands (Peterson and Peterson 1992). The downed stems left by one low severity fire may contribute to a high severity fire with the next disturbance by contributing large dry fuel. Aids to flammability in aspen stands include the presence of large downed woody fuel, small conifers and an open canopy (Bradley et al. 1992). Curing of herbaceous vegetation increases the flammability of the fine fuels found in aspen understories.

Successional relationships for prescribed fire areas

The pre-burn vegetation type is one the key factors determining the plant community which will develop after a prescribed fire. For a particular site, the successional pattern can be determined by pre-burn vegetation type and age, moisture regime, fire severity and season of burn (Viereck and Schandelmeier 1980 cited by Peck 1987). In the northern Rockies, a combination of large wildfires (1930's to 1950's) and prescribed burns to enhance big game habitat (1970's and 1980's) has increased the area in grass or shrub cover, or in younger aspen forests (Peck 1987). Thus, the vegetation types and seral stages on a particular site may reflect a complex fire history.

Successional relationships for plant communities in the Tuchodi River valley were described by Peck (1987). Initial vegetation development following fire on upland slopes was typically the grass herb type. The combination of site moisture availability in combination with fire severity influenced the particular successional sequence (Peck 1987). Hotter burns on drier sites lead to a grass shrub type. Moderate burns and/or site conditions with greater available moisture lead to development of a young shrub type, while cooler burns resulted in the development of a low density, open stand of young aspen or balsam poplar (Peck 1987).

The grass shrub type may persist on upland, drier slopes, especially if shrub regeneration was suppressed by browsing. On average moisture sites the most common successional sequence was to a shrub sapling type (Peck 1987). The lodgepole pine type present on well drained northerly slopes represented a variety of fire ages (Peck 1987). Moisture availability determines the amount of aspen and balsam poplar on the mature forest sites, with predominately aspen on drier sites, grading to a mixed aspen and balsam poplar type, and mature balsam poplar type as moisture increases (Peck 1987). Without disturbance, over time any of these types could develop into a white spruce type. Fire at any stage in the successional sequence usually results in the initial grass herb type (Peck 1987).

Many older conifer stands in the SWB zone are open in nature and large meadows are not uncommon (Parminter 1983). Discontinuities in vegetation, topographic variation and fuel breaks in the form of stream channels increase the probability that trees survive fires, singly or in groups (Parminter 1983). Conifer stands can be all aged in nature due to this variability in fire conditions, disturbance history and presence of seed sources (Parminter 1983).

Post burn forage production

There is a general pattern of decreased forage production in the year of spring burning or the year following a fall burn (Bartos and Mueggler 1981). Forage production is stimulated above pre-burn levels 2 or 3 years post burn (Brown and Debyle 1989, Bartos and Mueggler 1981). The duration of the stimulated forage production is generally less than fire years (Brown and Debyle 1989) and is highly dependent on the amount of shrub and tree regeneration which occurs on the burn site. Forb production often increases more than grass production (Anderson and Bailey 1980, Bartos and Mueggler 1981). Biomass of shrub species should return to pre-burn levels within 5 to 10 years after the fire (Brown and Debyle 1989).

The preburn fire community is the key factor to determine post-fire plant composition. It can have a greater effect on understory vegetation response than fire intensity (Brown and DeByle 1989).

Brown and DeByle (1989) note that variable vegetation responses should be expected for fire, even when all other factors are similar.

Frequency of burning

In the aspen parkland of Alberta, annual burning (Anderson and Bailey 1980) did result in an increase in the number of grass, sedge and forage species. While grassland cover increased and forest cover decreased, the density of fire adapted shrubs (including aspen and Saskatoon) increased. Annual burning resulted in a shift from a relatively few large plants to many small plants.

A relatively small portion of the available habitats in the SWB have been targeted for ungulate habitat enhancement (Peck 1987). Repeated short interval (5-10 years) prescribed fires were commonly applied to drier southerly aspect slopes dominated by aspen communities in different seral stages (Peck 1987). The initial post fire vegetation is commonly dominated by fireweed, a variety of legumes, wild rye and brome grasses (Elliot and Webster 1983 as cited by Peck 1987). Intense animal browsing may restrict development of aspen and shrub species, maintaining open grass-herb communities for some time (Harcombe 1978 and Lea 1985, as cited by Peck 1987). On sites with greater moisture availability, and less browsing pressure, aspen and willow regeneration will come to dominate these stands (Peck 1987).

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Prescribed Fire Complexity Worksheet & Rating Guide

Complexity Element	**Weighting Factor**	**Complexity Factor**	**Total Value**
Safety	5		
Threats to Boundaries	5		
Fire Behaviour	5		
Objectives	4		
Size of Burn Organization	4		
Improvements within Burn Area or Adjacent to Burn Area	3		
Environmental/Timber/Cultural or Social Values	3		
Air Quality Values/Issues	3		
Logistic Considerations	3		
Political Considerations	2		
Tactical Operations	2		
Multiagency Involvement	1		
	Project Total		

Type III Burn Boss Required for Projects with Rating of 40 - 51
Type II Burn Boss Required for Projects with Rating of 52 - 84
Type I Burn Boss Required for Projects with Rating of >84

The Prescribed Fire Complexity Analysis provides a method to assess the complexity of the planned prescribed fire project. The analysis incorporates an assigned numeric rating complexity value for specific complexity elements that are weighted in their contribution to overall complexity.

The weighted value is multiplied by the numeric rating value to provide a total value for that element. All elements are then "added to generate the total project complexity value. Breakpoint values are provided for low & moderate and high complexity elements." This complexity worksheet is accompanied (on the following pages) by a guide to numeric values for each complexity element shown.

Guide to Numeric Rating

Complexity Element	1	2	3
Safety Weighting Factor 5	Safety issues are easily identified and mitigated.	Number of significant safety issues have been identified. All safety hazards have been identified on the LCES worksheet and mitigated.	Complex safety issues exist No vehicle access or remote access only.
Threats to Boundaries Weighting Factor 5	FFMC of 80 - 85 Low threat to boundaries. Low risk of spotting. Boundaries naturally defensible.	FFMC of 86 - 90 Moderate threat to boundaries. Moderate risk of spotting. Boundaries need modification to strengthen fuel breaks, lines etc.	FFMC of > 90 High threat to boundaries. High risk of spotting. Boundary modification necessary to compensate for continuous fuels.
Fire Behaviour,Wx,Fuel & Topog. Weighting Factor 5	Low variability in slope or aspect. Wx uniform & predictable. Surface fuels only (grass,needles) Uniform fuel type/load. No drought conditions present.	Moderate variability in slope or aspect. Wx variable but predictable. Ladder fuels present. Moderate variability in fuel type or loading. BUI indicates normal to moderate drought conditions exist.	High variability in slope or aspect. Wx variable & difficult to predict. Highly variable fuel types or loading. BUI indicates severe drought conditions exist. Altered fire regime, hazardous fuel or stand density conditions exist. Extreme fire behaviour potential.
Objectives Weighting Factor 4	Maintenance objectives Easily achieved objectives. Broad prescription.	Restoration objectives Reduction in both live & dead fuels Objectives judged to be moderately hard to achieve. Objectives may require moderately intense fire behaviour.	Restoration objectives in altered fuel situations. Precise treatment of fuels & multiple ecological objectives. Conflicts between objectives & constraints. Requires high intensity fire or a combination of fire intensities that are difficult to achieve.

Size of Project Organization Weighting Factor 4	Single resource project < 12 people on site.	Multiple resource project 13 - 24 people on site. Short term need for specialized resources.	Multiple branches, divisions or groups. > 24 people on site. Specialized resources required to accomplish objectives.
Improvements Weighting Factor 3	Very little risk to people or property or improvements within or adjacent to project.	Several values to be protected Mitigation through planning and/or preparations is adequate. May require some commitment of specialized resources.	Numerous values and/or numerous values to be protected. Severe damage likely without commitment of specialized resources with appropriate skill levels.
Timber/Natural/Cultural & Social Values Weighting Factor 3	Very little risk to values within or adjacent to project.	Several values to be protected Mitigation through planning and/or preparations is adequate. May require some commitment of specialized resources.	Numerous values and/or numerous values to be protected. Severe damage likely without commitment of specialized resources with appropriate skill levels.
Air Quality Weighting Factor 3	Few smoke sensitive areas near project. 95% Smoke is produced for less than 1 burning period. No potential for scheduling conflicts with other agencies.	Multiple smoke sensitive areas, but smoke impact mitigated in plan. 95% Smoke produced for 2 - 4 burning periods. Low potential for scheduling conflict	Multiple smoke sensitive areas with complex mitigation actions required. 95% Smoke produced longer than 4 days. Class 1 smoke sensitive areas. High potential for scheduling conflict
Logistics Weighting Factor 3	Easy Access Less than 4 day project, not including patrol status.	Difficult Access Support required for 4 - 10 days. Logistics Officer required. Anticipated difficulty in obtaining resources.	No vehicle or remote access only. Duration of project is greater than 10 days. Large logistics section required. Remote camps.
Political Considerations Weighting Factor 2	Minimal impact on neighbours or visitors. Minimal controversy. Minimal media interest.	Some impact on neighbours or visitors. Some controversy but mitigated. Press release or communications plan required	High impact on neighbours or visitors. High internal or external concerns Media present during operations, media contact on site.

Tactical Operations Weighting Factor 2	Simple ignition pattern. Single ignition method. Holding requirements minimal.	Multiple ignition methods or sequences. Use of specialized ignition methods. Holding actions required to check, direct, or delay fire spread. Simultaneous use of hand and aerial ignition methods.	Complex ignition patterns. Simultaneous use of multiple ignition patterns or methods. Success of actions critical to accomplishment of objectives. Aerial support for mitigation actions desirable or necessary.
Multiagency Coordination or Involvement Weighting Factor 1	No major involvement with other agencies. No major concerns	Simple joint agency project. Some concerns.	Complex multiagency project. High Concerns