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Disturbance Regimes of the North Saskatchewan Regional Plan Area

A state-of-knowledge report on fire regimes and disturbance of the forests, grassland, and ecotones

Chris Stockdale
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EXECUTIVE SUMMARY

One of the goals of the Alberta land use planning exercise is healthy ecosystems and environment. Part of the background work towards this goal is to understand the ways, and to what degree the existing landscape ecosystem differs from that which existed prior to colonization and industrial activity. This report summarizes the state of knowledge of wildfire regimes for the North Saskatchewan landscape. Wildfire is the dominant natural disturbance agent on this landscape, responsible for a significant part of landscape, watershed, and site level diversity.

The fire regimes and disturbance ecology of the North Saskatchewan Regional Plan Area are complex due to the broad geographic range spanning numerous Natural Subregions of the province of Alberta. Fire regimes of the Subalpine, Montane, Upper and Lower Foothills, and the Central and Dry Mixedwood Natural Subregions are well studied near the North Saskatchewan Regional Plan Area, but few have been conducted specifically within this landscape. This document describes the current state of knowledge of fire regimes in the Area, drawing upon the research conducted within and surrounding the Area.

Few studies use common terminology or methods to calculate fire regime parameters, which makes comparisons between studies challenging. Fire regimes are highly variable in both time and space, and research findings are heavily influenced by both the spatial and temporal scale at which the problem is studied.

Current evidence from the peer reviewed literature suggests that high severity, stand replacing fire is the norm throughout the area, and that mixed severity fire regimes and low severity fire regimes are limited to the Montane Natural Subregion and grasslands. However, a growing body of evidence, both anecdotal, and field based, suggests that spatial and temporal mixed severity fire regimes may be far more common in the Subalpine and Foothills Natural Subregions than we have believed before. Most field research done to date uses methods that *assume* the fire regime is high severity, and therefore these studies are unable to capture the detailed information required to document the existence and extent of more complex fire regimes.

The modern fire regime has been significantly altered, primarily due to fire exclusion (fire suppression and elimination of First Nations traditional burning practices), landscape alteration, and climate change. As such, forest encroachment, stand closure, and succession are all contributing to hiding the evidence of the existence of mixed and low severity fire regimes. This also increases the long-term fire risk in the region, and elevates the probability that when fires are ignited, they will be high severity. In addition to these factors, the influence of changing climate on disturbance processes is extremely dynamic and variable.

Grassland disturbance regimes in the region are poorly understood. The historical disturbance regime was largely driven by bison grazing, fire (wild and anthropogenic), and climate

(especially cycles of drought). Most of the historical grasslands within the North Saskatchewan Regional Plan Area have now been cultivated for agriculture or grazing. The Central Parkland Natural Subregion is a broad ecotone between grasslands and forests. While the northern limit of the Central Parkland is neatly defined by the soil record, the southern limit has been far more variable through time. This area of the province has always been a mix of grassland and forested land, but had a considerably higher proportion of grassland at the time of modern settlement. The effective removal of three controlling factors that acted in favour of grasslands (wildfire, First Nations fire use, and bison grazing), and the effects of climate change have resulted in significant advancement of the forest into the grasslands from both the northern and western edges. Grassland, and grassland-forest interface areas will become more important in the future in the face of climate change, however due to the complex nature of the interactions between fire, grazing, climate, insects and human land use, it is very difficult to predict how the long term processes will be modified.

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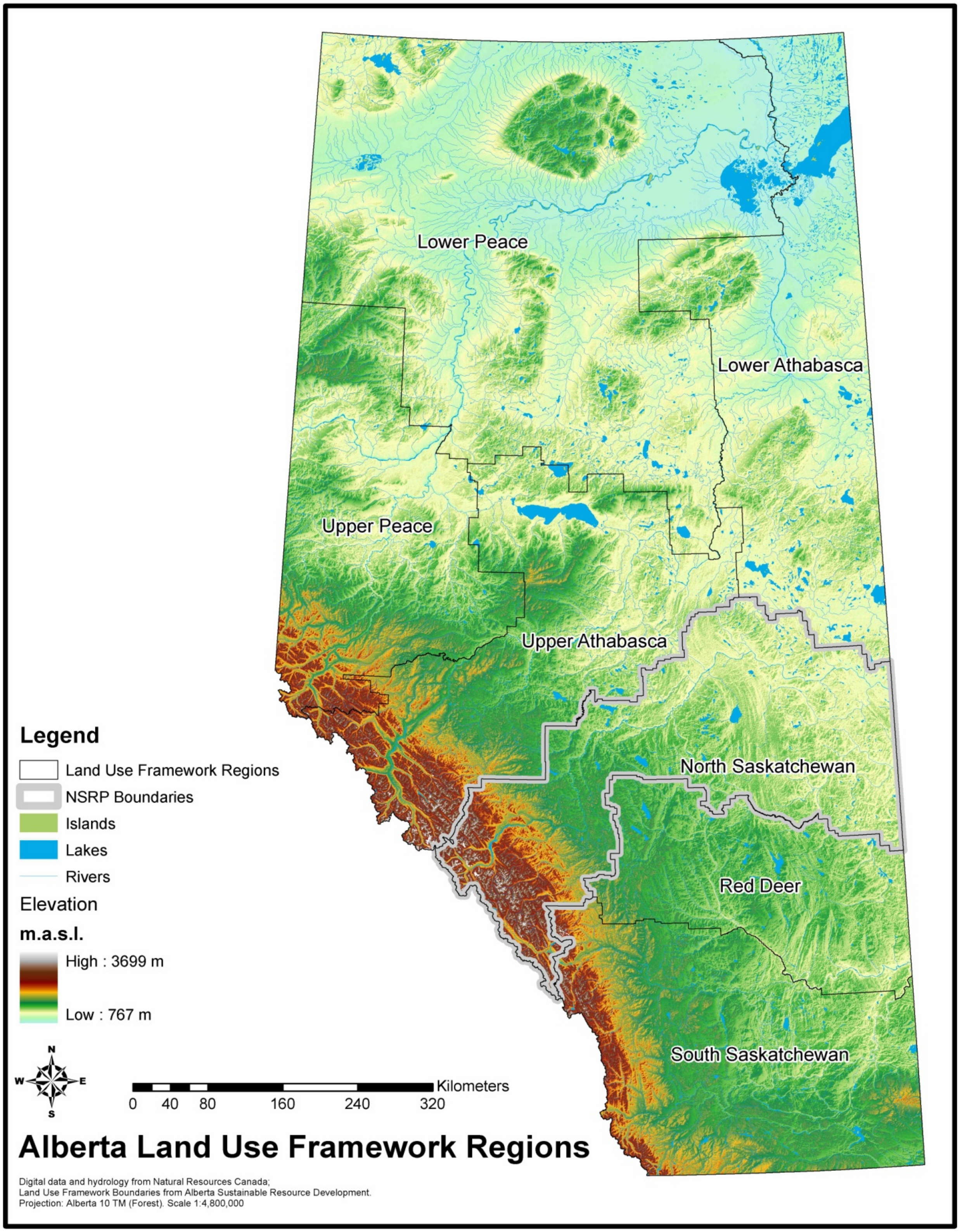
INTRODUCTION

The Alberta Land Use Framework is committed to "healthy ecosystems and environment" using a "cumulative effects management approach" (Government of Alberta 2008). Defining and monitoring *ecosystem health* is a concept that continues to pose challenges although it commonly includes minimizing environmental damage, avoiding the loss of biodiversity, maintaining ecological goods and services, and safeguarding critical biological functions (Granek *et al.*. 2010, Peterson *et al.*. 2010). One of the strategies used to help in this undertaking is to use historical (i.e., pre-industrial) disturbance pattern benchmarks as guides (Franklin 1993). Although the dynamics of natural systems are highly variable in time and space, they have thresholds (Pickett *et al.*. 1992), and beyond those thresholds lie greater risks to ecological health. Furthermore, because we "manage" natural ecosystems largely through disturbance activities, natural pattern metrics and thresholds are proving to be useful indicators for planning at any scale.

The first step in the process of using natural pattern knowledge to aid planning is to understand the local historical disturbance regime: what are the historical natural vectors of disturbance? How often did they occur? How big were they? And, how much vegetation did they kill? Although this seems a simple task, our understanding of local disturbance regimes is not only still growing, but the very way we define the problem is still evolving. As with all new areas of study, there is no shortage of disagreement within the scientific community on disturbance regime issues (e.g., Huggard and Arsenault 1999). Adding to this complexity is the fact that a considerable amount of knowledge exists as both unpublished (or "grey") literature, and long-term, anecdotal local expertise. Identifying and sorting through the relevant contribution of these many sources of information is no small task. Furthermore, given the potential importance of this information as coarse-filter ecological indicators, such a summary requires objectivity, clarity, and inclusiveness.

Towards this goal, the Alberta Land Use Secretariat engaged the Foothills Research Institute Natural Disturbance Program to provide a state-of-knowledge summary of the historical (pre-settlement) fire regimes of the North Saskatchewan land use zone. Fire is believed to be the most significant and influential disturbance agent of the region.



Alberta Land Use Framework Regions

Digital data and hydrology from Natural Resources Canada;
Land Use Framework Boundaries from Alberta Sustainable Resource Development.
Projection: Alberta 10 TM (Forest). Scale 1:4,800,000

Figure 1: The Planning Areas of the Alberta Land Use Framework. (Map courtesy of Cordilleran Ecological Research and Extension).

SECTION 1: THE PHYSICAL ENVIRONMENT OF THE NSRP AREA

Before we can describe what is known (and not known) about the fire regimes of the North Saskatchewan Regional Planning (NSRP) Area, we need to understand some basic elements of what vegetation types occur within the region, and some of their controlling factors. Climate is a key driver of both vegetation, and fire behavior, therefore it is no surprise that changes in natural disturbance regime attributes have been associated with ecological boundaries (Andison 2003a and 2003b, Tymstra *et al*. 2005).

Administrative management units in Alberta do not coincide with ecological delineations, but instead span numerous ecologically meaningful zones. The Planning Areas of the Alberta Land Use Framework (see figure 1) have been partially derived using watershed boundaries, but have also been modified to align with jurisdictional, municipal, and other administrative boundaries.

The sheer diversity of terrestrial ecosystems covered, and geographic range complicates the understanding of the fire regimes and disturbance ecology of the NSRP Area. The physical environment, climate and ecosystems of the NSRP Area are highly variable. The area extends from the high elevation of the Continental Divide, down through the mountains, across the foothills, through the parkland and into the grasslands bordering Saskatchewan. The climate is largely driven by air masses from both the Pacific and Arctic Oceans, and continental air masses from the north, south, and east.

To follow is a detailed description of the major ecological zones within the NSRP Area.

TERRESTRIAL ECOZONES OF THE NSRP AREA

The Terrestrial Ecozones of Canada (Lands Directorate, 1986) divides the country into 15 separate ecozones. Within the NSRP Area, only three of these zones are present and are described below. These zones are the Montane Cordillera, the Boreal Plains and the Prairies. Ecozones are further divided into ecoregions and ecodistricts. Relevant ecoregions will be identified within the appropriate ecozone (see figure 2). Ecodistricts break the ecoregions down into even finer units.

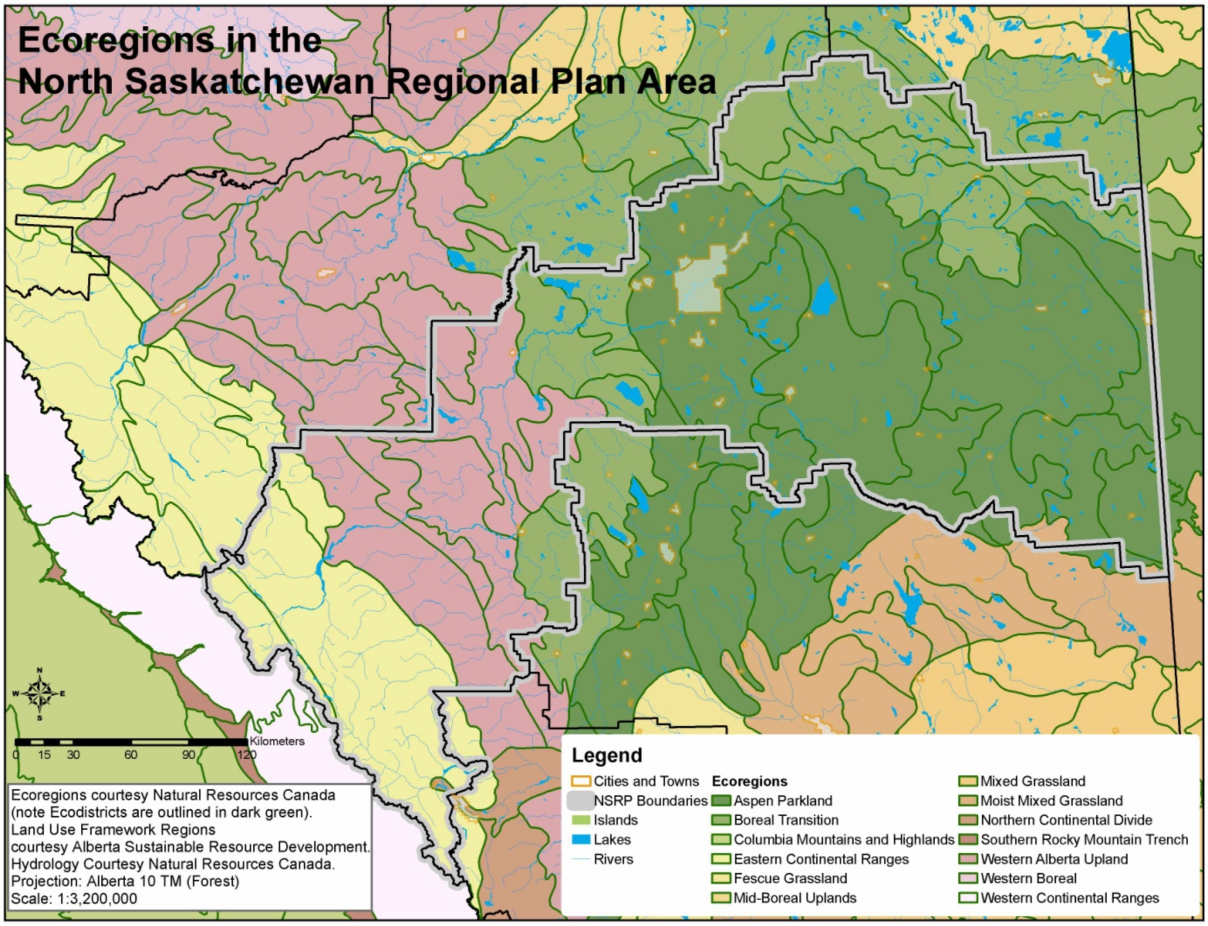


Figure 2: The Terrestrial Ecoregions of Canada within the North Saskatchewan Regional Planning Area. (Map courtesy of Cordilleran Ecological Research and Extension).

MONTANE CORDILLERA

Encompasses most of British Columbia and the mountain and foothills areas of Alberta. Climate is typified by long, cold winters and short, warm summers. Precipitation varies from the dry deserts of the southern Okanagan to very wet interior mountain ranges. Vegetation is highly variable from low elevation grasslands to high elevation tundra, with diverse forest structures in between the two. Few fire regime studies attempt to address such broad and varied ecological regions. Many such studies have occurred *within* the region, but few, if any, have studied the ecozone as a whole.

When the Montane Cordillera ecozone is divided into ecoregions, all of Alberta’s Rocky Mountains relevant to the NSRP Area is described by a single ecoregion: the Eastern Continental Ranges.

BOREAL PLAINS

The Boreal Plains ecozone extends from the Peace Country in the northeast of British Columbia in a wide band through to southern Manitoba. This area has long cold winters, but cooler summers than many parts of the Montane Cordillera. Precipitation is more uniform across the ecozone. Vegetation is more homogenous than in the Montane Cordillera, and is dominated by needle-leaf conifers such as *Picea glauca*, *P. mariana*, *Pinus banksiana* and *P. contorta*. There is a substantial component of deciduous intermixed with the conifers, principally *Populus tremuloides*, and *Betula papyrifera*. The southern margin of the Boreal Plains ecozone is dominated by these deciduous species. Unlike the Montane Cordillera, fire regimes studies examining the Boreal Plains ecozone as a whole are common.

The relevant ecoregions within the NSRP Area of the Boreal Plains ecozone are the Western Alberta Uplands, and the Boreal Transition.

PRAIRIES

The temperature and precipitation profile of the Prairie ecozone is not dissimilar to the Boreal Plains ecozone. However, the prairies are dominated by grasslands in the south, and at the northern margins deciduous tree cover becomes more common where this ecozone intergrades with the Boreal Plains.

Significantly less research effort has gone into studying the fire regimes of this ecozone as compared to the forested regions to the west and north, but a fair amount of work has been invested in examining the factors controlling the ecotones between this ecozone and the Boreal Plains, and between the Prairies and Montane Cordillera.

The Prairie ecozone has one very significant ecoregion within the NSRP Area: the Aspen Parkland, and a very small presence of the Moist Mixed Grasslands.

ROCKY MOUNTAIN VEGETATION CLASSIFICATIONS

The Montane Cordillera Ecozone, and even the Eastern Continental Range Ecoregion, is too broad a classification to be practical as a scale for studying or managing landscapes in the region. Daubenmire (1943) surveyed a wide body of literature and identified four primary vegetation formations in the entire Rocky Mountains range based on elevation:

- *Tundra*: the treeless zone at the highest altitude.
- *Upper Timberline*: zone dominated by needle-leaf conifers that abuts the Tundra Zone.
- *Lower Timberline*: also dominated by needle-leaf conifers, and is at lower elevation and extends into less steep and flatter ground.
- *Grassland* or *Desert*: the treeless zone at low elevation.

Within this four-zone elevation based-system, there are two broad ecotones; the boundary between the Tundra and Upper Treeline, and the boundary between the Lower Treeline and the Grassland/Desert. The Upper and Lower Timberline are sometimes combined as the “Needle Leaved Forest”. Ecotones are discussed later in this document.

There are fundamental differences in the all of these zones along the length of the Rockies. In conjunction with the elevation driven classification system described above, there are also distinct zones that can be defined based on latitude:

- *Southern Rocky Mountains*: Mexico to near the northern borders of Arizona and New Mexico.
- *Central Rocky Mountains*: from northern Arizona and New Mexico to central Wyoming.
- *Northern Rocky Mountains:* from central Wyoming to the northern end of Banff National Park
- *Far Northern Rocky Mountains:* from the southern end of Jasper National Park to the far northern end of the Rocky Mountains.

The two zones of interest to the North Saskatchewan Regional Planning Zone are the Northern and Far Northern Rocky Mountains, as the delineation between the two occurs within the NSRP Zone. The boundary of this zone is essentially delineated by the presence of *P. mariana*

(Daubenmire, 1943). The southern limit of *P. mariana* is at the northern end of the R11 Forest Management Unit as shown by range maps in the Silvics of North America (Burns and Honkala, 1990). It is hypothesized that as climate change progresses that the southern limit of *P. mariana* will gradually shift northward, thus extending the northern limit of the Northern Rocky Mountain zone and shrinking the Far Northern Rocky Mountain zone.

Also coinciding with and largely responsible for the delineation between the Northern and Far Northern Rocky Mountain Zone is the occurrence of the northern Pacific storm track (Daubenmire, 1943). Vegetation and species occurrence correlates strongly with this storm track. At its northern limits in the northern end of Banff National Park one can still find floristic elements similar to forests found further west towards the Pacific. North of this line there is a greater influence of Arctic floristics and climate (Peet, 1988).

Billings (1990) also has a four-zone latitude based classification system for the Rocky Mountains that differentiates between the Central Rocky Mountains and the Boreal Rocky Mountains, with the boundary being defined by the northern range limits of *Pseudotsuga menziesii* and *Picea engelmanii* and the essential functional replacement of these species by *P. mariana.*

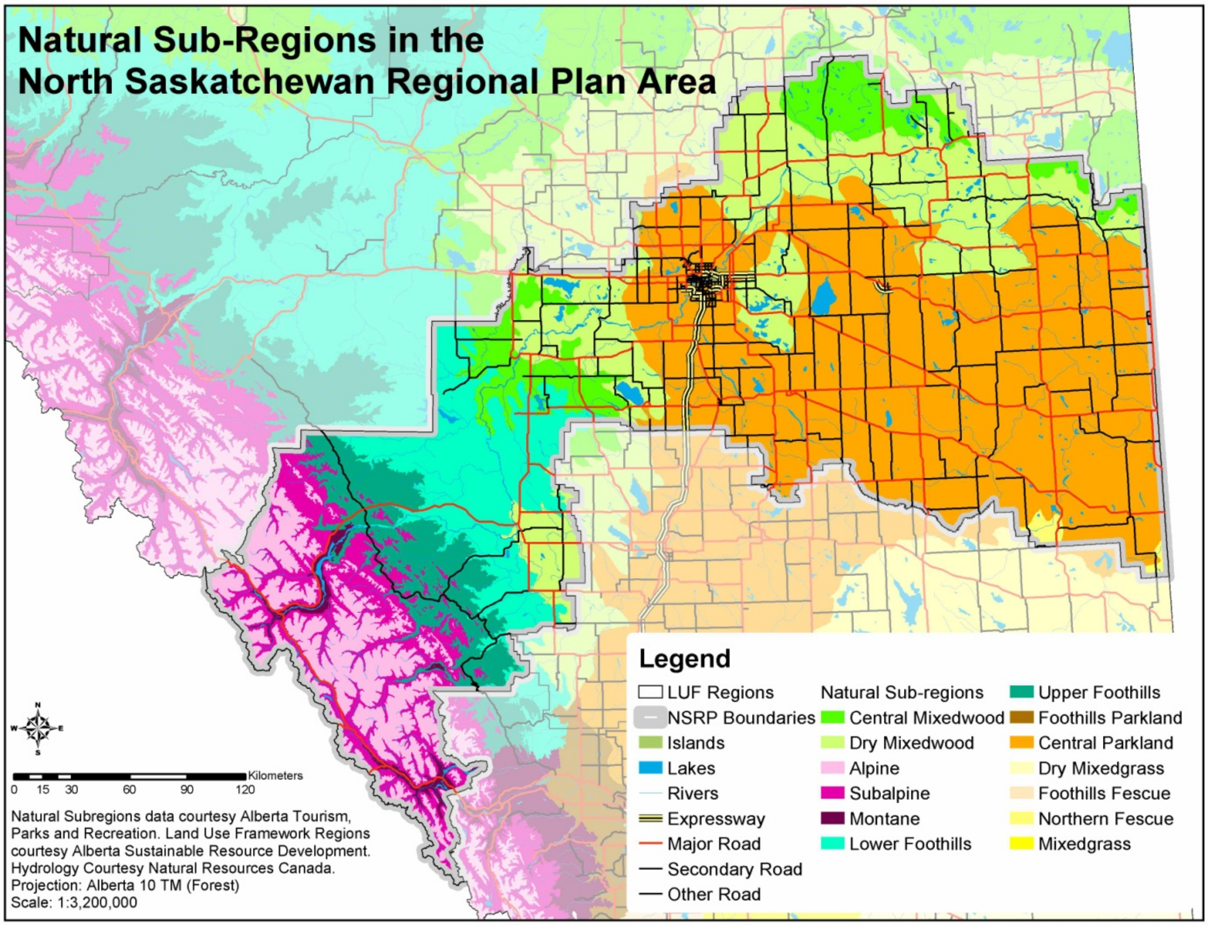
In all cases, there is little disagreement that the primary gradients controlling vegetation composition are (Billings, 1990):

- *Elevation*: As elevation increases, there are decreases in temperature and snow free periods, and increases in precipitation, wind, radiation and snow depth. Exhibits complex interactions with numerous other factors.
- *Topographic moisture*: Higher insolation on south and southwest facing slopes creates warmer and drier sites that grow significantly different vegetation complexes than cooler, wetter north and northeast shaded slopes.
- *Soil*: There can be highly diverse combination of soils, with dramatically different types occurring side by side. Some are deep, and others are very shallow, in some places there is no soil on top of the exposed rock. How soil and soil chemistry influences vegetation pattern in the region is poorly studied.

All of these factors influence the potential vegetation that may grow on a site. The first two gradients (elevation and topographic moisture content) also have a significant effect on fire behavior, independent of their influence on the vegetation itself.

NATURAL SUBREGIONS OF ALBERTA WITHIN THE NSRP AREA

The Alberta Natural Subregion Classification System (Natural Regions Committee, 2006) examines the vegetation formations of the province at a finer scale than the Terrestrial Ecozones and Ecoregions of Canada, but more coarsely than the Ecodistricts. This system recognizes 21 different Natural Subregions within Alberta, of which nine occur within the NSRP Area. The basis for the Natural Subregion classification system is the interaction between climate, topography, parent material and biotic elements. Figure 3 shows the distribution of Alberta Natural Subregions within the NSRP Area.



Natural Subregions data courtesy Alberta Tourism, Parks and Recreation. Land Use Framework Regions courtesy Alberta Sustainable Resource Development. Hydrology Courtesy Natural Resources Canada.
Projection: Alberta 10 TM (Forest)
Scale: 1:3,200,000

Figure 3: Natural Subregions of Alberta within the North Saskatchewan Regional Planning Area. (Map courtesy of Cordilleran Ecological Research and Extension)

ALPINE

Cold, wet and treeless. Largely nonvegetated, with herbaceous meadows and shrubs. Found at the highest elevations (1900-3650m).

SUBALPINE

More moderate climate than the Alpine, steep rocky terrain, found at mid elevation (1300-2300m). Vegetation is primarily mixed conifer dominated by *P. contorta* and *P. engelmanii.*

MONTANE

Warmer and drier than the Subalpine. Valleys and foothills. Found at lower elevations (825-1850m). Vegetation is a complex mix of grassland, meadows, shrubs, and open and closed canopy forests of *P. contorta*, *P. menziesii*, *P. glauca* and *P. tremuloides.*

UPPER FOOTHILLS

Rolling foothills, frequently adjacent to Montane or Subalpine Natural Subregions. Found at elevations of 950-1750m. Mainly closed coniferous forest of *P. contorta*, *P. glauca* and *P. mariana*.

LOWER FOOTHILLS

Dissected plateaus adjacent to Upper Foothills. Found at elevations of 650-1625m. Mixedwood forests of *P. tremuloides, P. contorta, P. glauca* and *P. mariana.*

DRY MIXEDWOOD

Undulating plains with hummocky uplands. Elevations of 225-1225m. Much of the region has been converted to cultivated farm and ranchland. Aspen forests with shrubby understory; *P. glauca* and *Pinus banksiana* present on dry sites. Peatlands common.

CENTRAL MIXEDWOOD

Similar terrain to Dry Mixedwood, slightly lower elevation range (200-1050m). Closed canopy mixedwood. Aspen dominant in early seral stages, white spruce with increasing age. Jack pine common on sandy sites; black spruce and tamarack on extensive peatlands.

CENTRAL PARKLAND

Similar terrain to Mixedwood Natural Subregions. Elevation range 500-1250m. Extensively cultivated. Aspen clones interspersed with grasslands dominated by rough plains fescue; tree cover increases with latitude. Graminoid wetlands.

NORTHERN FESCUE

Similar terrain to Parkland and Mixedwood Natural Subregions. Elevation 650-1100m. Plains rough fescue on moist sites, western porcupine grass on drier sites. Shrublands of buckbrush and rose. Graminoid wetlands.

Northern Fescue and Montane Natural Subregions have little representation in the region, but their importance outweighs their presence. Both areas are expected to expand under future climate change scenarios that assume drier spring and summer conditions in the region. Even without drier condition on average, we would expect the Northern Fescue grasslands to expand further north, pushing further into the NSRP Area. Higher variability in precipitation, even with higher amounts of total precipitation, can create drought conditions that will favour grasslands at the expense of forests. For the same reasons we can expect the Montane to increase in elevation, and to push further out into the foothills.

The Central Parkland Natural Subregion is essentially the ecotone between the Boreal Plains and the Prairie. In the words of Axelrod (1985), the aspen forests are the battle zone between the forests to the north and the grasslands from the south. Over millennia, this boundary has moved back and forth numerous times, and will likely shift further north in the coming decades and centuries.

SECTION 2: DISTURBANCE REGIMES OF THE NORTH SASKATCHEWAN REGIONAL PLAN AREA

Disturbance regimes are typically described by their type, frequency, size, shape and severity (Forman and Godron 1986). These elements can be directly measured from a collection of disturbance “events” (*sensu* Andison 2003b) distributed over space and time. In addition to these attributes, disturbance regimes are often examined to determine their relationship to other ecological, physical, historical and climatic phenomena to enhance our understanding of how they are driven by external factors (Veblen, 2003).

Within the NSRP study area, wildfire, wind, flooding, grazing, insect outbreaks, and diseases all have significant effects on vegetation composition and successional pathways. Available evidence strongly suggests that the most dominant historical disturbance vectors over the last several centuries have been 1) wildfire (in forested areas), and 2) grazing (in grasslands). This summary will focus on these two natural disturbance agents.

Fire is a chemical process in that it reforms what it burns. Flooding and wind are physical disturbances that rearrange soil, wood, and other natural elements. Grazing, insects and diseases are biological disturbances that consume and/or kill biomass, and modify vegetation growth. These disturbance agents all interact with each other in complex ways, in both positive and negative feedback loops. This can significantly complicate our ability to understand their isolated influences (Johnson and Cochrane, 2003; Archer, 1999; Girardin and Sauchyn, 2007). Over time, however, all of these disturbance agents have chemical, physical, and biological *effects* on ecosystems.

Although the high threat situation regarding mountain pine beetle (*Dendroctontus ponderosae*) (MPB) in Alberta today, its historical influence over the last several centuries on the North Saskatchewan landscape has been nonexistent to the best of our knowledge. There are no known historical infestations of MPB north of the Bow Corridor in Banff National Park, and even there, it is known to have only occurred twice historically in low numbers. Although many consider the future impacts of MPB to be considerable, historical evidence offers little in terms of specific guidance. That MPB is not discussed in this summary document of historical disturbance influences is a reflection of how different our current landscape conditions are from historical ones.

Forest tent caterpillar (*Malacasoma disstrium*) is a significant forest pest that also influences fire regimes by leaving large tracts of aspen forest dead, thereby increasing the fire risk significantly. The outbreaks of *M. disstrium* are strongly correlated with drought. While fire regime studies may capture variability in fire activity, they often do not describe the drivers that cause this variation. It is important to note that when statements are made regarding climate driving changes in fire regimes, that the mechanisms are often more complex than simply attributing them to changes in temperature, precipitation or fuel moisture.

FIRE REGIMES

Fire is the predominant ecological disturbance of the forested areas of the rocky mountain, foothills, boreal and parkland ecosystems (Tymstra *et al.*, 2005) as measured both by the level of vegetation mortality it causes, and area impacted. Currently, in many forested ecosystems in western Canada, including Alberta, the mountain pine beetle (*Dendroctonus ponderosae*) is a major ecological disturbance affecting even larger areas than fire (Feller *et al.*, 2005), but within the NSRP Area it has not yet reached this status. However, it would be naïve to think that mountain pine beetle in the area does not have the potential to cause major impacts in the near or distant future.

Within grasslands, while fire is a significant driver of both pattern and process, other disturbance agents and factors are much more significant than they are in forested ecosystems, these include grazing, human land use, and climate (Axelrod, 1985; Archer, 1999; Knapp *et al.*. 1999; Boyd, 2002; Bond and Keeley, 2005). Over millennia, these disturbance agents have regulated the extent of the grassland biome, and the physical location of the ecotone between grassland and forested ecosystems. Fire is the dominant disturbance agent throughout the Rocky Mountains and Boreal forests of North America (Arno, 1980; Billings, 1990; Campbell and Campbell, 2000), and these ecosystems’ flora and fauna have coevolved in the presence of this disturbance (Bond and Keeley, 2005) for millennia. With a continent-wide shift in management paradigms from even-flow resource extraction towards more ecologically based principles, much research has been invested in understanding how fire interacts with its environment so that land managers can try to emulate natural disturbances on the landscape. The term “fire regime” is often used to describe this interaction.

Fire behaviour is influenced by the three elements of the fire behaviour triangle: weather, topography and fuel. The only component of this triangle that is directly regulated by biological processes, or that can be manipulated by management actions is the *fuel*, or vegetation component. Fire interacts dynamically with the landscape, and is a primary determinant of present and future vegetation composition. These resulting patterns of vegetation affect future fire, insect and disease activity, and many other ecosystem processes (Turner, 1989) in a constant cycle of interactions and feedback loops. Conversely, by studying vegetation patterns we can glean information about past fire activity.

From a landscape perspective, fires interact with the environment in space and time, and this is the *fire regime* (Morgan *et al.*, 2001). There are numerous components of a fire regime, and these vary from researcher to researcher. While there have been attempts to define a common glossary of terms that relate to fire regimes, there is still no consensus on the specific elements of a fire regime, what they should be called, and how to measure them.

Agee (1993) provides an overview of the problem, and defines the characteristics of fire regimes as the following (see Table 1):

Table 1: Common fire regime parameters and definitions.

DESCRIPTOR	DEFINITION
FREQUENCY	The mean number of events per time period. This can be expressed in several ways: PROBABILITY: A decimal fraction of events per year. RETURN INTERVAL: The inverse of probability; years between events. ROTATION/CYCLE: Time needed to disturb an area equal in size to the study area.
PREDICTABILITY	A scaled function of the variation in frequency. Sometimes referred to as periodicity.
EXTENT	Area disturbed per time period or event. Often referred to as size, and can be represented by a distribution of size classes. Shape can be viewed as a subcomponent of extent.
MAGNITUDE	Described alternately as: INTENSITY: Physical force, or energy released per unit area and time for a fire. SEVERITY: A measure of the effect on organisms or ecosystems. Often measured by mortality.
SYNERGISM	Effect on the occurrence of the same or other disturbances in the future.
TIMING	The seasonality of the disturbance, linked to differential susceptibility of organisms to damage based on phenology.

As per ecosystem and vegetation classification schemes, fire regimes can also be classified into general categories. The most common classification methods use variation in frequency and severity (Agee, 1993; Arno *et al.* 2000). Frequency and severity are continuous variables, and delineations for the purpose of categorization are arbitrary and done solely for the purpose of easing our understanding of the phenomenon. The fire regimes of Alberta have not been subjected to a rigorous classification scheme to date. Information on fire regimes in the province is only now beginning to be compiled in such a manner to allow for this type of analysis (Foothills Research Institute, 2011).

For a general classification scheme, a useful place to start is with one created by Heinselman (1973), and reproduced in Agee (1993). The numbers used by Heinselman to represent the actual return intervals in years have been removed as they are not necessarily relevant in the Alberta context. See Table 2.

Table 2: Fire Regime Classification Scheme (Heinselman, 1973, in Agee, 1993)

FIRE REGIME TYPE	DESCRIPTION OF THE REGIME
0	No natural fire
1	Infrequent light surface fire
2	Frequent light surface fire
3	Infrequent, severe surface fire
4	Short return interval crown fires
5	Long return interval crown fires and severe surface fires in combination
6	Very long return interval crown fires and severe surface fires in combination

The Heinselman classification system results in seven categories of fire regimes. This has been simplified in recent years to a five class system, used in the Fire Regime Condition Class (FRCC) system (Barrett *et al.*, 2010) which is commonly used in the United States. Rogeau (2007) reviewed the FRCC system and its applicability to Alberta forests, and modified these classes to better suit Alberta's fire history and ecosystems. The FRCC (unmodified) and Rogeau's modifications are shown in table 3. Using this classification scheme, it is not possible to differentiate between grassland and forest fire regimes, and for the purposes of our review here, this distinction might prove critical.

Table 3: Fire Regime Condition Classes (Barrett *et al.*, 2010) and Alberta Fire Regime Classes (Rogeau, 2007)

Fire Regime	FRCC (fire cycle)	AB Fire Regime Class (fire cycle)	AB Fire Regime Class (Mean fire return interval)
I	0-35 years low-mixed severity	0-50 years low-mixed severity	0-35 years
II	0-35 years high severity	51-100 years mixed severity	36-75 years
III	36-200 years mixed severity	101-150 years high severity	36-150 years
IV	36-200 years high severity	151-200 years mixed to high severity	151-200 years
V	200+ years high severity	250+ years high severity	250+ years

Low severity = surface fire | mixed severity = < 75% canopy removal | high severity = >75% canopy removal

Rogeau (2008) developed a further modification (Table 4) of fire regime classifications for Parks Canada that is intended to address fire regimes for different ecosystems across Canada. This classification uses the "fire cycle" attribute as fire cycles have been calculated in many of Parks Canada's management areas.

Table 4: Historic Fire Regime Codes (Rogeau, 2008) for Parks Canada

Historic Natural Fire Regime Code	Description
0	Little or no occurrence of fire
I	0-35 year fire cycle, low severity
II	0-35 year fire cycle, mixed severity
III	0-35 year fire cycle, stand-replacement severity
IV	35-100 year fire cycle, mixed severity
V	35-100 year fire cycle, stand-replacement severity
VI	100-200 year fire cycle, mixed severity
VII	100-200 year fire cycle, stand-replacement severity
VIII	200+ year fire cycle, stand-replacement severity

In this classification scheme, the proportion of vegetation surviving fires is >80% for Historic Natural Fire Regime I, 50-80% in II, <10% in III, >25% in IV and VI, <25% for V and VII and VIII.

FIRE IN FORESTED ECOSYSTEMS

The range in fire regimes presented in the previous tables (2, 3 and 4) express themselves in particular ways in forested ecosystems. The following describes what low, mixed, and high severity mean with relation to fire behavior and the patterns they create.

LOW SEVERITY FIRE REGIMES

In low severity fire regimes in forested ecosystems, stand structure tends to be open, with widely spaced trees, little ladder fuel, and relatively light surface fuel loading. Topography is usually gentle, as steeper slopes increases upslope radiative drying of fuels, which would result in increased candling and/or crown fire dynamics. Low severity fire regimes are considered "stand maintaining" as they cause little overstory mortality, but reduce understory competition significantly, allowing the overstory to dominate for long periods of time. Finding evidence of low-severity fire regimes generally involves examination of fire scars. In these fire regimes, overstory trees that have survived multiple low-severity fires will show multiple fire scars which can be dated.

The fire cycles and fire return intervals in low severity regimes tend to be relatively short: fuel loads are quickly eliminated, and cannot build up to sufficient volume to cause higher severity fires that result in overstory mortality. Fuel burnt in low severity fire regimes is often grass, herbaceous vegetation or shrubs. This requires a frequent and somewhat regular ignition source that coincides with flammability of the fuel. These ecosystems often occur in locations with associated weather patterns that have regular lightning storms, but can occur in lightning shadows if the ignition source is anthropogenic, where they coincide with corridors of frequent human use (Wierzchowski *et al.*, 2002; Tande, 1979). Anthropogenic influences on burning are discussed below.

MIXED SEVERITY FIRE REGIMES

Mixed severity fire regimes are complex. There are two essential types of mixed severity regimes which intergrade significantly: *temporal* mixed severity, and *spatial* mixed severity (Schoennagel *et al.*, 2004; Agee, 1993; Veblen, 2003).

Temporal mixed severity fire regimes are those that when measured over time show alternating fire behavior between low and high severity. They may have long periods of one type of fire severity, and then “switch” to a different fire severity. The reasons for this can be complex: different ignition sources may cause different severities, climate patterns can shift, or other disturbances may interact with fire. An area may be burned on a frequent basis by First Nations in the spring, with resulting low severity burns, but occasional lightning strikes at a different time of year under extreme conditions can ignite massive crown fires. Differential weather patterns can cause varying burn intensities. Climate anomalies may create unusual conditions every so often that create massive blazes (Girardin and Sauchyn, 2007). Other disturbance agents such as *D. ponderosae* can alter the fuel complex over tens of thousands of hectares within a few years.

In general, a *temporal mixed severity* fire regime is caused by variability in climate, and/or interactions with other disturbances that significantly change vegetation composition and fuel loading over time (Carcaillet *et al.*, 2001). Detecting the presence of a temporal mixed severity fire regime is challenging. If the most recent fires have been high intensity, finding evidence of previous low-intensity fires is difficult. When this happens, searching for multiple-fire scarred trees, snags and logs can be like searching for fossils, which are very difficult to locate using standard sampling schemes.

A further complication in detecting temporal mixed severity fire regimes is that a time period must be studied that is long enough to adequately capture the variation in fire history. But, this needs to be done with caution. As longer periods of time are studied, variation rises significantly in all regions as climate variation, and other disturbance agents’ variability is captured (Power *et al.*, 2007).

Spatial mixed severity fire regimes show differential burning severities across the landscape. These are driven far more by variations in topography and fuels. The influence of topography on fire behavior is well studied, and this document has described several topography derived gradients that explain significant differences in vegetation (and therefore fuel structure). In the Subalpine regions of the East Slopes there is a considerable evidence for the presence of spatial mixed severity fire regimes which will be discussed below.

While mountainous and foothills terrain variability might be obvious with regard to their influence on burning severity, even on flatter ground topography can have a big influence. In boreal landscapes, differences in elevation of only a few inches can make big differences with regard to soil moisture, which in turn can create conditions for differential fuel type expression. While patterns of fire severity impacts have been studied extensively (Andison, 1998; Andison, 2000d; Andison, 2003a; Andison, 2003b; Andison, 2003c; Andison 2004; Cumming, 1997; McLean *et al.*, 2003; Rogeau, 2005a, Rogeau, 2009, Rogeau 2010b, Rogeau, 2011), rarely has pattern been correlated to subsurficial variables such as soils, and parent material. Granted, in severe fire weather situations, the influence of these factors is overwhelmed.

A challenge with classifying spatial mixed severity fire regimes is where to draw the line between mixed severity and high severity fire? In Tables 3 and 4, the distinction is between 75% and 90% crown mortality, but where this line is drawn is purely arbitrary. As landscapes become more complex in topography and fuel variability, the level of survival within a given fire event rises. As the topography and fuels become more uniform, the level of potential mortality rises. This is, of course, ignoring weather variability *during* a fire event, which in itself is a significant driver of fire severity.

To further complicate our understanding of *spatial* mixed severity fire regimes, some researchers differentiate between ***mosaic*** fire regimes, which are spatially mixed severity fire regimes as described above, but with patches of fully burned, and patches of unburned trees within the fire perimeter, and "pure" ***spatial mixed severity*** fire regimes, where there is 25%-75% crown mortality evenly distributed within the fire perimeter. The mosaic fire is one with intermittent crown fire activity, whereas the spatial mixed severity fire is one with intermittent candling (Barrett *et al.*, 2010).

HIGH SEVERITY FIRE REGIMES

High severity fire regimes are dominated by crown fire activity. They tend to kill the majority of overstory vegetation within a fire perimeter (75%-90% or more according to Tables 3 and 4, with variability driven by the length of the fire cycle). Within a region characterized by high severity fire regimes, there tends to be lower variability in topography and fuel structure, however there are some mountain environments with high severity fire regimes that defy the topography rule. Fire activity is more binary in nature: when fires ignite they either become active crown fires, or extinguish quickly due to lack of available fuel. Over time and space, they exhibit relatively little variation in severity.

High intensity crown fires tend to maintain a landscape in a mosaic of even-age, single-species stands. Depending on the time since fire, stands may succeed towards mixed composition, but if fire cycles are not too long, stands that result from this type of disturbance tend to be fairly uniform coniferous forests which are reset by high intensity fire. These fire regimes are often referred to as stand-replacing fire regimes. The size of fires within high severity fire regimes tends to be very large, with fires occasionally exceeding 1M ha in size in Boreal landscapes.

To illustrate the point of arbitrary distinctions between mosaic spatial mixed severity fire regimes (mortality ranging from 25% to 75% mortality), consider a region with a spatially mixed severity fire regime with a mean of 70% mortality. This is much more similar to a region with a high severity fire regime with a mean of 80% mortality than it is to another mixed severity fire location with a mean of 30% mortality.

FIRE REGIMES IN GRASSLAND AND PARKLAND ECOSYSTEMS

While there is not a large amount of grassland within the NSRP Area, by either the natural subregion or terrestrial ecoregion classification systems, it is an important component of the region both in its significant presence within the Montane Natural Subregion, and also due to the likely increase of grasslands within the region over time in the face of climate change (Bachelet *et al.* 2000; Vujnovic *et al.* 2002; Henderson, 2006). The grasslands that occur within the NSRP Area, and that are forecast to increase their presence, represent the northern limit of the Great Plains of North America. While true grasslands are not common in the region, the Aspen Parkland ecoregion is part of the Prairie ecozones (the Central Parkland Natural Subregion is essentially the same place, with minor variations in the boundaries). The Parkland is a mix of grassland and forest. Forests are common in the wetter, cooler areas (riparian, swales, ravines, northerly and easterly aspects), with grasses common in the uplands, southerly and western aspects, and areas with deeper water tables.

Numerous authors have investigated the role of fire in the Great Plains ecosystems (Rowe, 1969; Axelrod, 1985; Collins and Wallace, 1990; Archer, 1999). To claim that fire is solely responsible for the maintenance of this ecosystem is a gross oversimplification. Nonetheless, fire is one of several critical processes that have shaped this ecosystem and regulated vegetation patterns and succession on the landscape over tens of millennia. Other processes include climate, grazing by large mammals, herbivory by smaller animals, human use (First Nations burning, hunting, and settlement), soils, and topography.

Much like in forested ecosystems, fire regulates the grassland system by differentially destroying vegetation and creating openings and niches for new plants to exploit. Also similar to forest ecosystems, there are species with varying degrees of adaptation to fire: some plants are stimulated by fire to sprout; some are utterly destroyed by it (Coupland, 1950; Collins and Wallace, 1990). Variations in the frequency of fire can produce large effects on the ecosystem. If the lag time is considerable between fire events, in grasslands, just as in forests, significant vegetation succession occurs. Depending when fire strikes during the successional pathway, it can have a variety of effects on the long term vegetation dynamics of a grassland system.

If we were to use Heinselman's fire regime classification method (table 2) to label grassland fire regimes, we would find that Fire Regimes 2, 3 and 4 can all be applied to grasslands. They are all surface fire regimes, but vary in their intensity/severity and frequency. The five-tier Fire Regime Condition Class system (Table 3) however, does not work well for differentiating varying fire regimes in grassland ecosystems, as only one of the categories (Fire Regime I) applies to surface fires. In Table 4, the Historic Natural Fire Regime III is common in grassland ecosystems, but like the systems in the five tier system in Table 3, this still does not differentiate within grassland ecosystems with any resolution.

The northern Great Plains have short fire return intervals, between less than one, and up to 35 years (Henderson, 2006), with mean intervals of 4 to 10 years (Wright and Bailey 1980). It is possible for fires to burn more than once in the same year, as spring fires followed by summer regrowth and senescence can burn again between fall and the following spring (Bragg 1982). Thirty five years is a theoretical maximum, which is based on known successional dynamics within grasslands: over this time frame, grasslands without fire and/or grazing pressure will succeed to shrub and/or forest land given a local seed source.

For those used to studying fire dynamics in forested ecosystems, some elements of fire regimes in grasslands are counter-intuitive. Brown *et al.* (2005) studied fire cycles and their relationship to drought in North Dakota. Moist periods correlate to high fire activity due to high productivity. Grasslands tend to be fuel limited systems, so in periods of drought, there often is not enough fuel to carry fire. This is similar to desert systems in the American Southwest, and has been shown to be relevant to the Canadian Great Plains. This is the opposite dynamic one sees in forested ecosystems, where high fire activity correlates to periods of drought, and lower activity during wet periods (Clark, 1989).

Grassland fuels provide a continuous and uniform fuel load allowing large uninterrupted fires, rapid grass regrowth and short return intervals (Henderson, 2006; Umbanhowar, 1996). Unlike forest fuel loads that store moisture and increase cumulatively between fire events, grassland fuel loads can fluctuate by an order of magnitude from year to year in response to climate and grazing, and the fire season is much longer owing to the prevailing semiarid climate and abundant fine fuels. In some regions, fire is considered essential for regenerating fire-dependent species, controlling plant pathogens, and preventing tree and shrub encroachment (Wright and Bailey 1980).

The concept of a *temporal mixed severity fire regime* also loosely applies to grasslands. Fire is not a constant steady process in grasslands, but varies with climate. Cycles tend towards 160 years between peak fire years (Brown *et al.*, 2005; Umbanhowar, 1996). This rate is observed continent wide and in Greenland, which suggests that there is a hemispheric climate cycle at play. This 160 year number is not a “fire cycle” or a mean fire return interval, but instead correlates to “peak fire activity”. This peak might be represented by area burned, depth of burn (severity), or the number of fires per year. It might be that the periods of peak fire behaviour in grasslands occurs during low periods of fire activity in the forested ecosystems which are not fuel limited, but driven largely by moisture which drives ignition potential. On this cycle, there have been massive peaks in fire activity synchronized across the Great Plains occurring between 1700-1740, and between 1850-1900.

With regard to the sizes of grassland fires, Rowe (1969) found that most lightning fires in southwestern Saskatchewan grasslands were smaller than two hectares because subsequent rain fall quickly extinguished the flames, but a few fires burned more than 1000 ha, with the largest at 4600 ha. Henderson (2006) reports that in the semiarid grasslands of Montana and North Dakota, a population of 293 fires from the mid 1900’s showed a negative exponential distribution with a fires ranging from small patches of only a few square meters, to more than 1100 hectares, with a mean of 10.8 ha. In another study in Montana fire sizes ranged from < 1 ha to nearly 4500 ha (Wakimoto and Willard 2005). Pre-settlement mean and maximum fire sizes would likely be greater than these numbers as numerous landscape level fuel breaks currently exist that limit the spread of grass fires.

Since Parkland landscapes by definition juxtapose dry south facing grassland on a south slope with mesic deciduous forest on the north slope, even during droughts there could be severe fire on north facing slopes, while having virtually no fire effects on more fuel limited south facing slopes. Fire would behave quite differently in the parklands than in either pure forests or pure grasslands because of the inherent variability in fuels caused by the inherent variability in vegetation and grazing of that vegetation. In years when even a healthy aspen forest would burn (due to drought) the grasslands would be grazed off and form a sort of fuel interruption; in years when the grassland would accumulate enough fuel to burn, the forest would be green and unlikely to carry fire. The potential interactions between fire, fuel, vegetation growth, grazing, and climate are too numerous to predict effects with any kind of accuracy.

While some research has been done on fire *behavior* and fire *effects* in grasslands in the Canadian prairies and northern USA (Engle and Bultsma, 1984; Redmann *et al.*, 1993; Archibold *et al.*, 1998; Shay *et al.*, 2001; Pylypec and Romo, 2003; Archibold *et al.*, 2003; among others), there have been virtually no studies of historic “fire regimes” as we consider them to be measured in forest ecosystems. Unlike forest fires, grassland fires do not leave readily dateable fire scars to help us determine what fire activity was like before modern fire records were kept (Bradley and Wallis, 1996). Nor can we determine fire boundaries using scars like we do in forests. It is assumed that grassland fire was more frequent than forest fire, but that size distributions were similar (few large fires, many small fires)(Bradley and Wallis, 1996). Given what we know of First Nations fire use in grasslands (see below), detailed studies of lightning fire do not give us an accurate picture of what historic fire regimes in grasslands would have looked like, as lightning likely only accounted for a fraction of total fire on the landscape.

Boyd (2002) has proposed a new method of analyzing paleo fire regimes. By analyzing grass silicophytoliths rather than using pollen, researchers can document fire records throughout the Holocene. Silicophytoliths are small, hard, rock-like bodies formed in the spaces between the living cells of a plant through the structured accumulation of silica brought into the cells with water. The identification of phytoliths from different plants preserved in archaeological material can provide an indication of the local vegetation over time. Silicophytoliths are more readily identified than pollen, and it is also easy to determine whether they have been exposed to fire, as carbon is incorporated into the molecular structure of the phytoliths (Boyd, 2002). Pollen, in contrast tends to be consumed by fire, and cannot be used to identify whether or not fire has occurred.

GRAZING

Grazing has a direct effect upon the vegetation potential of a site. Like fire, grazing removes vegetation, and alters the competitive pathways of vegetation succession (Archer, 1999; Fuller, 1966). Grazing by wildlife is fundamentally different than grazing by livestock. Under historical conditions, wildlife were less likely to overgraze a site, instead moving across the landscape to locate optimal resources. As wildlife departed one location, the grassland recovered and regenerated. Current livestock grazing practices vary significantly, but the primary difference in its effect on grassland ecosystems is that animals are generally held in one location for a much longer period of time, and grasses do not tend to get the same recovery period as they do with grazing from wildlife (Archer, 1999; Fuhlendorf and Engle, 2001). Just as in forest management, livestock grazing practices are being influenced more by our understanding of how ecosystems work, and there has been a significant shift in managing livestock grazing pressure to more closely mimic grazing pressure that occurred in the wild (Bradley and Wallis, 1996).

Why would grazing matter to our understanding of fire regimes? Firstly, grasses are fuel. In the absence of large extents of continuous, cured grass (that is, if all the grasses are consumed by grazing animals), there is no fuel to burn. Secondly, the historic wild grazing animals were primarily bison (however there are numerous other species which graze in grasslands). Bison occupy a unique place in the interactions between fire/grazing/human history which have regulated the extent of the grassland biome, but also the location of the ecotone between grasslands and forests. This complex interaction between fire, bison, humans and the grassland/forest ecotone is discussed later.

While it is difficult to know precisely how bison, fire, and the landscape interacted at the fringe of the NSRP Area, we can make a number of inferences based upon several facts that we do know from modern research.

Axelrod (1985) claims that bison and fire are the predominant forces that shaped the Great Plains. We know from historic accounts that bison formed massive herds across the Great Plains. Large herds were encountered by David Thompson near present day Fort Saskatchewan, and near Rocky Mountain House (Thompson, 1784-1812, in Tyrell, 1916; Francis, 1989). There are stories of herds that were so large that settlers travelled through them for days without interruption. We also know from southern Alberta that bison herds were massive, given the numerous “buffalo jumps” in the region.

Bison only form large herds when grasses are abundant. Where spring burns dominate, bison maintain “grazing lawns” of high productivity but relative low diversity (Trager *et al.*, 2004; Schuler *et al.*, 2006). They avoid areas with more annual grasses, forbs and legumes in favour of these lawns. Large groups will congregate, wallow, and trample vegetation (thus limiting woody plant encroachment). However, where summer burns dominate, bison show little preference for previously burned over unburned sites. Populations are more dispersed, grazing pressure is more diffuse, and there is greater structural complexity in vegetation. Therefore one can assume that where large herds of bison are encountered, that the recent fire history of the area (within only a few years) might be one of large spring burns. Lightning storms are rare in the spring (but not impossible), but common in summer, suggesting an anthropogenic hand in the equation. Timing and presence of fire is likely not the only driver of large herds of bison, but is likely a significant variable in the equation.

However, it is obvious that the large herds of bison were not stationary, but moving across the landscape. If they remained in one place, grazing would limit fire frequency and size by controlling the amount of available fuel. They would move in large herds from one area of recent spring burning to another after they had exhausted the local supply of forage. In years with low fire activity, they would disperse across the landscape in smaller groups, only to re-aggregate when large fires could burn in the spring. Grazing animals also prefer areas within one to three years of a fire, which reduces fuel loads and the probability of two fires in rapid succession (Erichsen-Arychuk *et al.*. 2002; Biondini *et al.*. 1999; Vinton *et al.*. 1993).

Grazing also reduces local fuel loads which would logically result in lengthening fire return intervals (Bachelet *et al.*. 2000), but the distribution of grazing varies according to several factors: animal density, forage availability, time since the last fire, slope angle, and distance to water. Forage utilization declines rapidly with distance from water, and there is little or no utilization by bison beyond 4 km (Henderson, 2006). Ponomerenko (1998) found upland grasslands far from water had very little historic use by ungulates relative to valley grasslands in Grasslands National Park. Similarly, grazing animal density and activity is known to decline exponentially with increasing slope gradient. Using these criteria, it appears grazing-induced fuel reductions should be greatest in valley grassland and shrub communities, with correspondingly longer than average fire return intervals, while sloped and upland grasslands furthest from water are expected to have shorter than average return intervals.

Not only do bison fit into the fire story by nature of their grazing pressure regulating fuel loads, but their very presence in large herds is possibly accounted for by the presence of large fires occurring in spring.

HUMAN USE – FIRST NATIONS

There is no shortage of evidence that First Nations people of the region used fire to manage the landscape. The Blackfoot First Nations included the Peigan, the Kainai (Blood), and Siksika. They are rumoured to have been named “blackfoot” due to their frequent use of fire on the prairies (Francis, 1989), hence having black feet from walking through the ashes. These First Nations used a large expanse of the prairie region of western Canada and the United States, and were the tribes encountered by David Thompson on his journey through the North Saskatchewan Landscape across the Kootenay Plains (Thompson, 1801, in Tyrell, 1916). These people were essentially landscape level ranchers, controlling the movement of animals through the use of fire, herding, hunting (Kay, 1994; Boyd 2002).

In 19th century historical accounts, summer burning was shown to be used by First Nations to *repel* bison herds (by eliminating forage), whereas spring burning was used to *attract* bison by increasing forage cover. This is consistent with the response of bison to fire described in the previous section.

It was widely believed that First Nations people were responsible for the presence of the Great Plains. Hind (1860) declared “the extension of the prairies into the aspen parkland is evidently due to fires, and the fires are caused by Indians for the purpose of telegraphic communication or to divert the buffalo”. In 1838, Nicolett (in Boyd, 2002) observed that the great grasslands of the Great Plains (“all the land watered by the Mississippi and Missouri”) were chiefly the work of natives who burned the rich vegetative cover for the purposes of providing forage for game. In his opinion, if the people were removed (and therefore the fires) the land would revert to forest.

The use of fire by First Nations peoples was neither accidental, nor random. Nelson and England (1971) document numerous uses of fire in the early 1800s by aboriginals for game management, warfare and other purposes. Nor was fire use restricted to Plains tribes. It was a common tool used by First Nations in the forested regions to the north in the boreal regions of Alberta and Saskatchewan (Lewis, 1982), and in the hardwood forests of Ontario and Quebec (Clark and Royall, 1995).

Human fire use is so influential that Sauer (1950, cited in Axelrod, 1985) noted there was little evidence globally for a climate driven grassland climax. Grasslands occur globally with a range in precipitation of less than ten inches of rain annually, to more than a hundred. Grasslands occur with long dry seasons and short dry seasons. What grasslands all have in common is the presence of fire. The amount of fire derived from lightning, and contributed by humans varies from region to region, but there is significant evidence of continual human burning around the world. Archer (1999) also concludes that fire and human use are major drivers of the grassland biome.

Although lightning has historically been a major cause of fire throughout the region, there is mounting evidence that native peoples were responsible for the bulk of fires not only regionally and continentally, but also globally (Nelson and England, 1971; Lewis, 1982; Kay, 1984; Arno, 1985; Gruell, 1985; Boyd, 2002).

ECOTONES, FIRE, BISON, AND HUMANS

An ecotone is a boundary between adjacent ecosystems. Ecotones can be examined at a variety of scales. At the level of biomes, ecotones are broad boundaries that often measure in the tens of kilometres. On a landscape scale, the ecotones are the mosaic pattern. At the forest stand level, the ecotones are between the various vegetation patches. And, at the population level, the ecotones are between plant groups and even individuals (Risser, 1995).

At the Natural Subregion scale there are ecotones between each Natural Subregion, and this is also true of any classification scheme. An ecotone can be a distinct line (such as that between a stand of trees and a meadow, which in itself also depends upon the scale with which you examine it), or can be very broad. The entire Aspen Parkland Terrestrial Ecoregion is an ecotone between the Boreal Plains to the north and the grasslands to the south. A similar broad ecotone exists in the lower foothills, dividing the grasslands from the forests.

In some cases ecotones are distinct, and their location moves very little. This usually occurs in areas with distinct changes in surficial materials that create fundamentally different soil types. These types of ecotones move very slowly over geological time scales. Other ecotones shift significantly because they are regulated by climate, interspecies competition and disturbance dynamics, all of which are themselves mobile on observable timescales. Ecotones that are due to fire activity are dynamic in space and time. In the previous sections we have outlined how fire, grazing, and humans influence vegetation. The story is considerably more interesting, and complex, as all of these factors interact in time and space to drive ecosystem states, landscape patterns and therefore ecotone locations.

The primary ecotone of interest for the NSRP Area is the one between the grasslands and the forest at the edge of the Foothills and across the Aspen Parkland. At its northern and western limits, the Aspen Parkland boundary coincides closely with the boundary between Chernozemic and Luvisolic soils (see Figure 4). Chernozems are known to be the product of grassland processes. However, the southern limit of the Aspen Parkland does not coincide with any neat boundary of soil types. Historical evidence shows that this ecotone has shifted considerably in favour of forests over the past century, largely as a result of infilling from existing groves and small pockets of forest land within the grassland matrix. According to Bailey and Anderson (1980), brush cover within the Parklands was between 5-10% in the early 1900s, but is now 60-100% in the more mesic areas. In the Foothills and in the Aspen Parkland, leading theories on what has caused the expansion of aspen over the past century have ascribed it to fire suppression and homesteading that began in the late 1800s and early 1900s. This may not be the case.

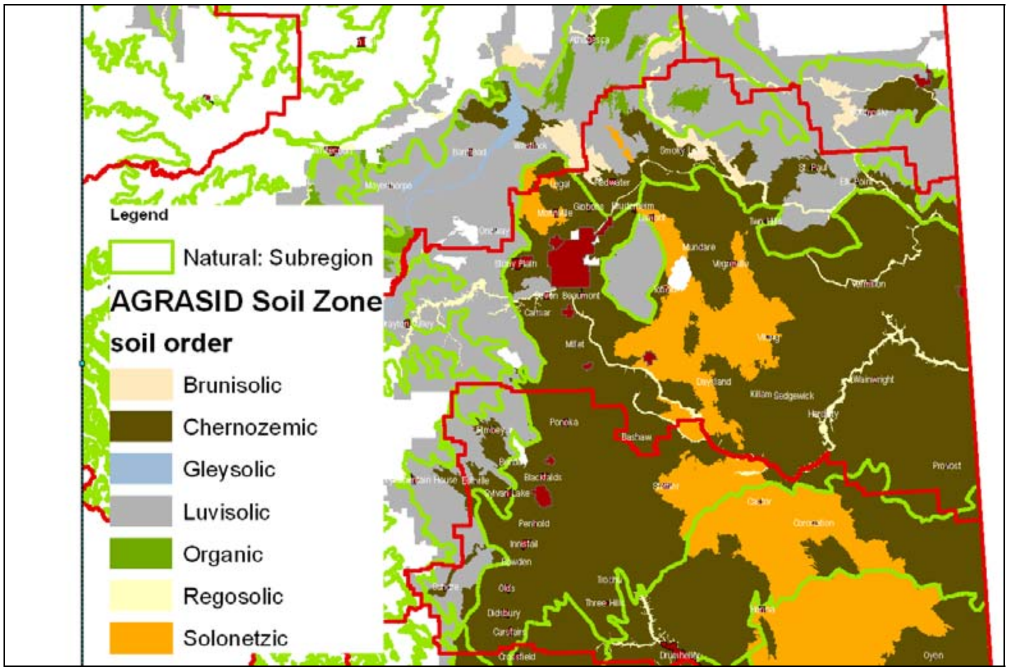


Figure 4: Soil zones within North Saskatchewan Regional Plan Zone (figure courtesy of Alberta Sustainable Resource Development)

Campbell *et al.* (1994) describes, by using pollen analysis, that it has been shown that aspen shows up in the pollen record in former grassland ecosystems in the 1880s and 1890s (i.e., encroaching on grasslands). Given that aspen does not pollinate until it has reached 10-20 years of age, the actual increase of aspen spread must date to the 1870s and 1880s. This predates settlement in the region, which began to increase in the late 1890s as the railway was being built (Francis, 1989). Plains bison, however, were nearly exterminated in the region in the 1870s.

The influence of grazing on woody plant encroachment has been extensively studied across many regions. Conflicting research shows that grazing can facilitate woody species encroachment (Archer 1999), or inhibit woody species establishment (Bartolome *et al.* 2000, Carmel and Kadmon, 1999). Neither of these studies is from the region, but both are cited in Henderson (2006) as examples of conflicting information regarding the influence of grazing on forest/grassland ecotones. Where grazing is shown to increase woody species recruitment, it is the result of grazing reducing competition for sunlight and other resources needed by woody species. It also assumes that herbaceous vegetation is more attractive to the grazing animal than the woody vegetation. Grazing also reduces the fuel load, thus decreasing fire frequency/intensity, leading to greater woody species recruitment.

Where the reverse has been shown (decreased woody species establishment due to grazing), it is due to A) the slow growth rate of palatable woody species, which leads to their grazing induced mortality, B) grazing induced shoot loss, and biomass loss, *especially among aspen which is a palatable species for cattle, bison, and ungulates* which reduces seedling establishment, and therefore recruitment, C) trampling damage on seedlings and D) rubbing damage by animals against treebark of mature trees, which damages and kills mature trees and reduces or eliminates their ability to produce shoots.

Singer (1996) and Smith *et al.* (1972) have documented that a variety of wildlife inhibit aspen biomass and suckering and therefore restrict aspen advancement into grasslands. Because Douglas-fir and pine are not palatable species to most wildlife, one might conclude that they would advance into grasslands. These species, however, can suffer significant trampling damage due to grazing animals, which limits encroachment.

With extirpation of bison, there would be two opposing forces at play. Without grazing, the forest/grassland ecotone should shift in favour of forest as seedlings can establish and invade grassland; however, with increased fuel loads in grasslands due to the loss of bison grazing, fire intensity and frequency would increase, thereby burning into the forest. With increased fire intensity, some mortality of trees would be expected. Further complicating matters is the fact that fire can increase aspen sprouting depending on the severity and frequency of the fires. Concurrent with the loss of bison in the region is the elimination of historic First Nations fire use, and the birth of the modern fire suppression era. This web of complicated factors make it difficult to make definitive conclusions about what happened and what the causes of the effects were.

Like bison and ungulate grazing, fire is usually considered to act in favour of increased grassland at the expense of trees and woody vegetation. Current research with trial burning has demonstrated that species composition shifts in grasslands that are exposed to regular burning. Svedarsky *et al.* (1986) showed that annual burning over 13 years at an aspen-grassland ecotone reduced aspen sucker production and *Poa pratensis* (Kentucky bluegrass) cover, but produced a threefold increase in *Andropogon gerardii* (big bluestem). Additionally long term effects of burning reveal increases in diversity, forage availability, increased flower, seed, fruit and nut production. However, fire that is not too frequent or too intense can have the effect of increasing sucker production in aspen and *increasing* tree cover (Gom and Rood, 1999; White *et al.*. 1998). Camill *et al.* (2003) demonstrate that shifts in fire regime at the forest grassland ecotone are the *result* of changing vegetation rather than the *cause* of changing vegetation, implying that the cause of vegetation change is climate and/or other ecological factors.

By removing or reducing three major factors that formerly acted in favour of grasslands (First Nations, bison, and fire), we have overwhelmed the previous balance in the system (Arno and Gruell, 1983). Forests have encroached into grasslands from the Subalpine into the Montane, into meadows, and onto the grasslands from the Aspen Parkland. While climate change may favour grassland at the expense of forest, it is very difficult to predict *where* in space this ecotone balance will be struck due to the complexity of interacting factors at play.

SECTION 3: FIRE REGIMES OF THE NSRP AREA AND SURROUNDING LANDSCAPE

Although considerable research has been done throughout North America on fire regimes throughout the boreal forest, the east slopes of the Rocky Mountains, and at the forest-grassland interface, the NSRP Area has not been thoroughly investigated. There have been few research studies done specifically within the region (Campbell *et al.*, 1994; Rogeau, 1999a; Campbell and Campbell, 2000; Lorenz, 2009; Rogeau, 2006b; Rogeau 2009; Rogeau 2010a; Rogeau 2010b). A provincial scale analysis was conducted across a broader region, that *includes* the NSRP Area (Tymstra *et al.*, 2005), but was not exclusive to the area. The area itself has had less attention than areas to the north and the south.

In the Rocky Mountains (Eastern Continental Cordillera ecoregion), many studies have been done within Banff National Park, Kananaskis Country, Jasper National Park, and the Foothills Model Forest landscape. In the Boreal forest regions there have been numerous studies both within Alberta and in Saskatchewan.

FIRE REGIME AND FIRE HISTORY STUDIES

There is an important distinction between a “fire history study” and a “fire regime analysis”: the two are not the same. A fire history study examines how often fires occur in a geographical area. A fire regime analysis often *incorporates* a fire history study, but examines fire history in considerably greater detail. Fire regime analyses involve measuring the patterns or shapes of fires, their size, their severity, and often examine the relationship of these factors with other ecological variables such as climate, fuel types, soils, or management activities.

The fire regimes and landscape patterns of the Subalpine, Montane, Upper Foothills and Lower Foothills Natural Subregions near the NSRP Area have been extensively studied by White (1985a, 1985b), White *et al.* (1998, 2003, 2004), Rogeau (1999a, 1999b, 2004, 2005a, 2005b, 2007, 2008, 2009, 2010a, 2010b, 2011) Rogeau *et al.* (2004), Tande (1979), Rhemtulla (1999), Andison (1998, 1999, 2000a, 2000b, 2000c, 2000d, 2002, 2003a, 2003b, 2004), Fryer and Johnson (1988), Johnson and Fryer (1987), Hawkes (1979), Johnson and Larsen (1991), Johnson and Wowchuck (1993), Johnson *et al.* (1994), Reed *et al.* (1998), and Van Wagner *et al.* (2006), among others. Not all of these studies have specifically studied one or more of these Natural Subregions, but the studies have occurred *within* and *across* these Natural Subregions.

The NSRP Area includes a large portion of the Central Parkland Natural Subregion, a substantial amount of the Dry Mixedwood Natural Subregion, and a small portion of the Central

Mixedwood. The mixedwood subregions represent the southernmost fringe of the Boreal Plains ecozone, and the ecoregion is the Boreal Transition. There is not a large body of research that has been conducted on fire regimes in the Dry Mixedwood and Central Parkland Natural Subregions. The work of Rogeau (2006b) in the Beaver Hills is the only example that fall within the NSRP Area. While the Central Mixedwood represents a larger area in the NSRP than the Montane or Northern Fescue Natural Subregions, it likely will be *less* important over time than the other two due to projected shifts in Natural Subregions northward due to climate change. Weber and Flannigan (1997) demonstrate that under climate change scenarios that fire activity in the boreal forest will increase substantially due to longer burning seasons, lower moisture, and higher variability in weather. Soja *et al.* (2007) demonstrate that *globally* the boreal forest is undergoing rapid change due to climate change. Forecasts include significant dieback of *P. glauca*.

The areas within the Dry Mixedwood and Central Mixedwood that fall within the NSRP Area have been heavily developed and converted to agricultural land. Very little forest remains in the region that is intact, except for protected forests within the Beaver Hills. Furthermore, with climate change forecasting a northward movement of ecosystems and vegetation, areas to the south likely hold more clues to the future of the fire regimes of the NSRP Area.

Studies will be presented in roughly chronological order to reflect the evolution of knowledge about fire regimes in the region. Some are grouped by author, some by geographic regions to focus the discussion.

HAWKES, 1979, KANANASKIS

One of the earliest studies of fire history and fire regimes in the Alberta mountain environment was conducted by Hawkes (1979) in what is now known as Kananaskis Country. This study was within the Subalpine and Montane Natural Subregions. Fires were identified using fire scars, and 20 fires dating back to 1712 were identified and mapped. The mean fire return interval (MFRI) for large fires (>1000ha) in the overall study area was 21 years, with a range of 11-38 years. Including smaller fires lowered the MFRI value to 14 years (range 2-38). MFRI’s at the highest elevation forests (above 1830m) were the longest, at 153 years. MFRIs were only 90 years at the lower elevation. North aspects had long MFRIs of 187 years as compared to only 104 on south aspects. The “upper subalpine” ecological subzone (using different ecological classification than current Natural Subregion classification) had a long MFRI of 304 years as compared to the lower subalpine which had an MFRI of 101 years. Most fires in the lower elevation sections of the park were large (>1000ha) and of stand-destroying intensity, and climate appeared to be a primary driver of this fire behaviour.

TANDE, 1979, JASPER NATIONAL PARK

At the same time as Hawkes' work in Kananaskis, which is to the south of the NSRP Area, Tande (1979) studied fire regimes using fire scars, primarily in the Montane Natural Subregion of Jasper National Park, to the north of the NSRP Area. Fires were dated from 1665 to 1975, therefore covering a similar time period to Hawkes. Before 1913 (to account for fire suppression), Tande found that the MFRI of the study area was 5.5 years for all fires. Using only fires greater than 500ha, he found the MFRI to be longer, at 8.4 years. Fires covering more than 50% of the area (those greater than 20,000 ha) occurred with a MFRI of 65.5 years. The majority of fires found were of low intensity, but larger, more intense fires did occur periodically. Stand structure varied from even-aged to multi-aged over short distances, which indicates that there is both a mosaic mixed severity, and a temporal mixed severity fire regime operating in the area over the time period in question. Since 1913, fire frequency and extent have been markedly reduced, and landscape heterogeneity has also been reduced, which has been confirmed by Rhemtulla (1999).

WHITE, 1985 +, BANFF NATIONAL PARK

Studying fire regimes in Banff National Park, White (19885a, 1985b) found that fire cycles were short. Fire cycles were 10 - 50 years for most parts of the Montane, and 50-100 years for other parts of the Montane. Lower subalpine fire cycles ranged from 50-150 years, and the upper subalpine had a fire cycle of 150-200 years (White *et al.*, 2003). Historical fires burned with low intensity on valley bottoms. Fire suppression and exclusion since the early 1900s in the Park have had similar effects as they have had in Jasper National Park, with considerable forest in-filling and loss of heterogeneity. These observations are borne out by the Mountain Legacy Project photo collection (Higgs *et al.*, 2009). Fires at higher elevations may have been larger and more severe, and this is borne out by the findings of Hawkes (1979). Key similarities between the findings of White and Tande are that both Jasper and Banff National Parks' Montane Natural Subregion areas have been historical high use travel corridors by First Nations for centuries, whereas the Kananaskis region studied by Hawkes certainly would have been used for hunting, but less as a travel route across the Rockies than the other areas. White was able to determine based on analysis of lightning fire frequency and analysis of fire scar position in trees that the majority of fires in Banff National Park were due to traditional burning of First Nations.

JOHNSON *ET AL.*, 1987+, KANANASKIS AND SOUTHERN ROCKIES

A number of researchers looked at fire regimes in Kananaskis Country and the southern Rockies during the 1980s and early 1990s using the same fire history data set (Johnson and Fryer, 1987; Fryer and Johnson, 1988; Johnson and Larsen, 1991; Johnson and Wowchuck 1993; Johnson *et al.*, 1994; Weir *et al.*, 1995; Reed *et al.*, 1998).

Johnson and Fryer (1987) dispute the claims of White (1985a, 1985b) and Tande (1979) that the forest structure, and therefore disturbance regime, has changed in the region since the 1800s due to settlement and fire exclusion. They reconstructed fire frequency for the periods 1783-1882, and 1883-1972. They concluded that fire frequency did not change between the two periods. What this assumes, however, is that the presence of European settlers and effective fire exclusion occurred simultaneously. Effective fire suppression hardly began at the time of first European settlement: at best this may have removed First Nations burning from the landscape, but most of that burning was low severity spring fires. Lightning fires would continue to be ignited. We have ample evidence from all over North America that the late 1800s and early 1900s were a period of high wildfire activity and large blazes that would have been well beyond any fire suppression capabilities of the era.

They also used a forest survey conducted in 1883 to compare to one in 1972 to see how forest structure has changed, and determined that sites with *P. contorta* or *P. engelmanii* tended to remain constant over time. There is photographic evidence that disputes the notion there was little vegetation change in the subalpine and foothills over this time period (Higgs *et al.*, 2009).

While Johnson and Fryer’s (1987) findings regarding vegetation change may be accurate within Kananaskis, to use this to negate the findings of White (1985a, 1985b) and Tande (1979) is taking their study beyond its scope of inference. Additionally, the sampling scheme utilized by Johnson and Fryer assumes a crown fire system, and therefore does not detect lower severity surface and mosaic mixed severity fires. Leaving these out of the analysis may well have coloured the findings.

Fryer and Johnson (1988) reconstructed the 1936 Galatea fire in Kananaskis, which supported the findings of White (1985a, 1985b), Hawkes (1979) and Tande (1979) that in the subalpine, fires can be severe, leaving little remnant vegetation. A single fire analysis, however, does not necessarily imply that all fires, all the time, in the subalpine burn at stand replacement intensities. Fire regime studies require the analysis of *multiple* fires in time and space.

Johnson and Larsen (1991) established the idea that a break in slope of a line showing time since fire must reflect a change in burning frequency. They attributed this break in the line in 1730 to be evidence of climatic change and influence over the fire regime. This finding has been disputed by numerous authors (Rogeau *et al.*, 2004; Van Wagner *et al.*, 2006; others) who have demonstrated that breaks in age class distribution can occur under a homogenous fire regime and within the natural range of disturbance rates (Rogeau, *in press*). Weir *et al.* (1995) and Johnson and Wowchuck (1993) also present arguments for the case of climatic rather than human activity control over fire regime changes. A number of authors have responded to the claim (see Achuff, 1996) that climate, rather than human activity, must be responsible for changes in burning rate. They invariably conclude that while climate factors may indeed have been less favourable for burning through some of this period of time, the evidence presented by Johnson *et al.* does not disprove that human activity (and fire exclusion) has been a major force reshaping fire regimes and vegetation patterns.

ROGEAU, 1999+, BANFF NATIONAL PARK, SPRAY LAKES, KANANASKIS, UPPER SASKATCHEWAN

Rogeau (1999) studied the fire history of the Upper Saskatchewan Unit, which is within the current NSRP Area. This study was targeted at the North Saskatchewan River watershed region outside Banff National Park for the purposes of filling in a significant knowledge gap in the region for fire regime information. At the time, Parks Canada and Alberta Environment (as it was known then) were involved in joint fire management planning. While Banff National Park had detailed fire regime information, the province of Alberta did not have the same information for the region immediately adjacent to the Park. The study covered the North Saskatchewan River Basin from the Banff National Park boundary to the mouth of the Cline River at Abraham Lake, including the Whitegoat and Siffleur Wilderness Areas. This included the Whiterabbit, Cataract, Coral and McDonald drainages.

A time-since-fire map was constructed to represent a mosaic of forest stand ages that are known or believed to have originated from stand replacing fires. It was recognized that this sampling scheme would not capture low severity and mixed severity fire information, which was known to exist on broad south facing slopes and valley bottoms along the North Saskatchewan River, but was predicated upon the assumption that the *majority* of fire activity in the region was of high severity, or *mosaic* mixed severity.

In addition to the fire history study that created stand origin maps for the region, Rogeau describes the fire regime of the modern fire data era (.i.e., that covered by the Province of Alberta Wildfire Database from 1961-present). Older forests were found closer to the Divide, and valley orientation in relation to prevailing winds also was noted to have a significant effect, with smaller valleys that are perpendicular to main valleys having lower fire frequency and longer fire cycles. Stand age (time since fire) was also found to increase in direct proportion to elevation.

Topography was noted as a key driver of fire frequency and sizes, and Rogeau concluded that area-wide averages for fire regime parameters are not very useful for driving management activities. By partitioning the analyses based on topography, important patterns emerge. Across the study region, the largest pulse in stand initiation in the area occurred in 1910, which is consistent across much of western North America, as 1910 was one of the largest, most widespread severe fire years on record. Along the main drainage of the North Saskatchewan River in this study it was observed that there had been stand replacing fires occurring every 20 years or less, between the years 1800 - 1910. Fire cycles lengthened in smaller valleys compared to large ones. Occasionally fires as large as 20,000 hectares occur in the region. The area is in a lightning strike shadow, and First Nations traditional burning is suspected to be the primary cause of many fires. This valley was a major travel corridor used by First Nations for centuries, and by explorers and settlers since the time of David Thompson in the early 1800s.

Rogeau (2004, 2005a, 2005b) examined fire regimes throughout the southern Rockies in the Spray Lakes Sawmills FMA and the entire District of Kananaskis. These overlap the areas studied by Hawkes and Johnson *et al.*. The modern fire regime (as per Rogeau, 1999a, above) was measured from the Alberta Provincial Wildfire Database, and compared to the historic fire regime. The historic fire regime was measured using aerial photography from 1949-1951, which allowed Rogeau to examine fire history from approximately 1930-1950. Note that what Rogeau refers to as the "historic" fire regime is within the time period referred to by Johnson *et al.* as the "modern" fire regime. To document all the findings of these studies would be onerous, but the major findings will be summarized here.

The modern fire cycle of Kananaskis calculated in 2004 was 1,457 years, which has lengthened considerably from the fire cycle of the historical period of 104 years. If it were possible to accurately include the scale of the 1910 fires in these figures, the fire cycle would be even shorter for the "historical" period. The modern fire regime is typified by many small fires that account for less than 1% of the total area burned, and occasional large fires that account for more than 50% of the area burned. Lightning fires are mostly constrained to July and August, whereas human caused fires occur evenly throughout the April-September time frame. Fires burning late in the season burn far more area than those early in the season.

A modeling approach was used to calculate historic fire regime parameters using data from the preceding work in the region to calibrate the model. This allows multiple potential forest age class structures to be created that are assumed to represent the Natural Range of Variability of the region. MFRI's were 25-35 years for the Upper Foothills-Montane region, and in the Montane-Subalpine, 40 years on southwest slopes, 50-100 years on northeast slopes. When verified in the field (Rogeau, 2005a), the MFRIs are even shorter: 9 years in the Upper Foothills and 7.6 years on the Montane. Fire cycles calculated by the modeling methodology were 149 years for Subalpine north of Highway 1, 93 years for Subalpine south of Highway 1, 41 years in the Montane, 37 years in the Upper Foothills and 111 years in the Lower Foothills.

The air photo screening process used by Rogeau revealed that the landscape in 1950 had very high vegetation complexity (complexity being a proxy measure for fire severity on the landscape, with low complexity occurring in high severity fire systems, and high complexity occurring in areas with low severity fire systems). Many areas of the landscape in the Montane and Foothills

Natural Subregions showed high to very high vegetation complexity, whereas the Kananaskis Valley studied by Hawkes and Johnson *et al.* showed moderate to low vegetation complexity. These facts (long MFRIs, and low vegetation complexity together) support the notion that the Kananaskis Valley (proper) studied by Hawkes and Johnson has a longer fire cycle and longer MFRIs than other parts of the landscape that are not far away.

Regarding the overall “fire regime”, according to work done by Johnson *et al.*, and Hawkes, one would conclude that the landscape is a high severity fire regime. However, given a broader picture of the region, there is considerable evidence that there is a mixed severity fire regime (both temporal and spatial) operating over the Montane and Upper Foothills. The sampling methods used by all of these researchers (including Rogeau) assume a crown fire system, as sampling for low severity fire regimes requires much more intensive field work. Rogeau notes that during field work there was considerable evidence of multiple fire scarred trees, indicative of low severity fire activity.

Rogeau *et al.* (2004) determined that between 64-70% of variation in fire cycles in Banff National Park in the Subalpine and Montane Natural Subregions could be explained by valley orientation, elevation, aspect, and distance from the Continental Divide. Global (area wide) averages do not tell the story by smoothing out variability in the region. Due to Rogeau’s work on developing a topographic burning model, the variation seen within and across the landscape by watersheds *which tend to constrain fire spread* reveals many interesting patterns and drivers.

ANDISON, 1998+, FOOTHILLS MODEL FOREST

There is a large volume of work generated by Andison from the Foothills Model Forest (now known as the Foothills Research Institute (FRI)). The Natural Disturbance Program has been conducting research into many components of fire regimes in the region dating from the late 1990s. Much of this work has covered Jasper National Park, which includes the Subalpine and Montane Natural Subregions, and the West Fraser - Hinton Wood Products FMA, which is largely in the Upper and Lower Foothills Natural Subregions. This body of work is the most comprehensive analysis of Foothills Natural Subregions’ fire regimes. The main outputs of Andison’s research on the FRI landbase have been: calculation of fire cycles by natural subregions, stochastic landscape modeling to identify ranges of age class distributions, and detailed pattern analysis to identify the shapes and degrees of mortality caused by fire events and degrees of mortality within island remnants of fires. There have been many other outputs from this research program, but management applications of fire regime knowledge are beyond the scope of this document. Stand origin data was obtained from different sources (data collected by Jack Wright from St. Regis Pulp in the 1960s, Rogeau 1996b, 1997).

The initial assumptions (Andison, 1999) were that stand replacement fire (high severity) was the dominant disturbance process operating on the landbase, which directed the research program to use stand ages as proxies for time-since-fire, and numerous modeling exercises have been run using varying disturbance rates to see how they affect landscape level age-class distribution (Andison 2003c). Age-class distributions were determined to be unstable, or highly variable, which indicates that the disturbance process is highly variable too.

Andison (1998) found that fire cycles over the period 1790-1950 to be 80 years in the Lower Foothills, 100 years in the Upper Foothills and 125 years in the Subalpine. Not unlike findings by Tande, Rogeau, White, Hawkes and others previously described, disturbance rates were considerably higher in the 1800s than they were in the 1900s. In Andison (2000d), there was already acknowledgement that stand-maintaining fire (i.e., mixed severity fire, both spatial and temporal) was likely a factor on the landscape. Rather than Natural Subregion-wide estimates of disturbance rates as reported in Andison (1998), a more spatially stratified approach was taken in Andison (2000a). Fire cycles were reported by Natural Subregion and by "operating area" (Jasper National Park, Weldwood FMA {now West Fraser, Hinton Wood Products}, and Alberta Newsprint Company (ANC) FMA). In Jasper National Park the fire cycle was calculated as 70-90 years in the Montane, and 130-190 years in the Subalpine. On the Weldwood FMA, the fire cycle was 110-140 years in the Subalpine, 65-75 years in the Lower Foothills and 80-90 years in the Upper Foothills. On ANC's FMA, the Subalpine had a fire cycle of 80-90 years, 50-60 years in the Lower Foothills and 60-70 years in the Upper Foothills.

Within Jasper National Park, the forested area of the Montane NSR was estimated to have increased from 21% cover to 78% cover between 1930 and 2000 (Andison 2000c), and is attributed to fire control. The change in vegetation cover in the region is consistent with the findings of Rhemtulla (1999) and Tande (1979). It is difficult to directly compare the fire regime statistics of Andison and Tande, however, as one is using the fire cycle for reporting and the other using MFRI.

Natural Subregions were determined to have a significant impact on fire regime parameters. Even-age patch sizes are considered a proxy for fire sizes. Andison (2000b) shows that the Upper Foothills has the most area in large patch sizes, where the Lower Foothills has the least. It is not surprising that fire regime parameters vary by Natural Subregion, as the Natural Subregions are defined by many of the same factors that are known to drive fire behavior: vegetation type (fuel), topography, and climate (weather) (Rogeau, *in press* b).

Andison (2002) describes the influence of riparian zones on fire disturbance. It was found that fire burns as often through riparian zones as it does across the rest of the landscape. In other words, in west central Alberta's Upper and Lower Foothills Natural Subregions, riparian zones show little to no effect on landscape burning patterns, but within fires themselves, there tends to be higher tree survival within riparian zones than outside them. This has spawned an entire research program investigating large woody debris dynamics in streams and the role that fires play in generating this material which is critical to riparian system functioning (Daniels *et al.*, 2011).

The bulk of work by Andison has been regarding patch and event sizes, quantifying and measuring island remnants, analyzing fire-edge architecture, and creating models to analyze landscape metrics to compare to natural ranges of variability. This work has been done across the Foothills Natural Subregions and also much of the Boreal forest region as well. The number of patches increase as fire size increases (Andison, 2000e), so too do the number of island remnants (Andison, 2004). Even in the boreal, where “stand replacing fire” is considered the norm, patches are not always even-aged. In fact they frequently are not (Andison, 2001).

What these analyses of within-fire survival of patches and edge studies have shown, is that even within what is considered a “high severity” fire regime, there is considerable evidence to suggest that spatial mixed severity fire regimes are common throughout the foothills. A pilot study by Amoroso *et al.* (2011) has shown that there is significant evidence of frequent low severity fire within the Upper Foothills well to the north of the NSRP Area.

CUMMING, 1997+, ALBERTA PACIFIC FMA

Perhaps the most comprehensive overview of landscape dynamics of fire in the mixedwood region close to the NSRP Area is that conducted by Cumming (1997). Fire suppression in the region is not considered to have been an *effective* limiter of fire until the 1960s, therefore, unlike the Foothills, Montane and Subalpine Natural Subregions, there has been less impact of modern settlement on the fire regime of the area studied by Cumming.

Over the period 1940-1993, Cumming estimates that the fire cycles for the Alberta Pacific FMA to be over 400 years in aspen and mixed stands, 185 years in white spruce, over 250 years in black spruce, and 200 years in pine. This recognizes, however, that burning rates have been significantly reduced over much of this study period. Fire cycles in the 1940s were less than a quarter of the values reported over the whole time frame. The 1940s seem to be a period of high fire activity, however, and using modeling techniques, Cumming concludes that after correcting for fire suppression the fire cycles would be roughly 20% lower than the fire cycles reported above. Like Andison, Cumming also agrees that disturbances are highly variable and age class distributions are not stable. The notion of non-equilibrium dynamics is also backed up by Turner and Romme (1994). Landscape fire mosaics are not infinitely variable, however, and are significantly limited by the topography and vegetation patterns that occur within the area (Turner and Romme, 1994). Cumming (2000) demonstrates that fire initiation is decidedly non-random, and that fire rarely starts in deciduous stands: if these stands burn, it is from fire coming into them that were ignited somewhere else. Deciduous stands are often situated in locations with different soil chemistry/water balance profiles. The same is true of different vegetation types in the Montane and Subalpine, and fire patterns in those locations are likely constrained not only by topography, but by edaphic characteristics. Patterns of forest fires are rarely studied to determine the correlation to these variables, however.

There are large pulses of stand initiation in 1840 and 1880, which may indicate large fire events, or significant climatic or cultural events. Cumming also finds that given the disturbance rates calculated (based on stand age inventory), that the amount of "old" forest on the landscape is significantly higher than it should be for such a disturbance rate. He concludes that gap dynamics must be occurring in the region, and that in reality the age class structure of the forest is more complex than inventories assume.

TYMSTRA *ET AL.*, 2005 - ALBERTA WILDFIRE REGIME ANALYSIS

Tymstra *et al.* (2005) conducted a fire regime analysis for the entire province of Alberta. This was done using the Province of Alberta Wildfire Database, therefore limiting analysis to the period 1961-2002.

Fire regime parameters are reported as province-wide averages, and by Natural Subregion averages. Only those Natural Subregions that are represented in the North Saskatchewan Regional Plan Area will be discussed. However, as has been discussed previously in this document, there are significant differences *within* some Natural Subregions. Both the Upper and Lower Foothills Natural Subregions are found from the Bow River watershed to the Kakwa Wilderness Area, representing a long north-south gradient. Fire regime conditions at the southern end of the region are likely different than they are at the northern end, based on the findings of Rogeau (2004, 2005a, 2006a, 2010a, 2010b), and based on the Rocky Mountain Vegetation regions created by Daubenmire (1943).

Tymstra *et al.*'s findings by Natural Subregion are as follows:

- Central Mixedwood, fire cycle = 226 years, characterized by areas with infrequent large fires, and areas with frequent small fires.
- Dry Mixedwood, fire cycle = 1,053 years, characterized by frequent, human caused small wildfires.
- Lower Foothills, fire cycle = 475 years, characterized by frequent, medium sized wildfires.
- Upper Foothills, fire cycle = 627 years, characterized by mostly lightning caused, frequent, medium sized wildfires and infrequent large wildfires.
- Alpine, above treeline, so fire is uncommon.
- Montane, fire cycle = 4,736 years, characterized by frequent small human caused fires.
- Subalpine, fire cycle = 4,542 years, characterized by infrequent small wildfires and rare large high intensity wildfires.
- Central Parkland, no statistics reported.
- Northern Fescue, no statistics reported.

The fire cycles in the Subalpine and Montane regions are extremely long, and well beyond the natural range of variability. The fire cycle in the Montane is similar to the findings of Rogeau for

R11, who found a fire cycle of 3,590 years. However in the subalpine, the Natural Subregion-wide average in fire cycle is only half the value observed by Rogeau within the R11, meaning that R11 is even further departed in the subalpine than the rest of the province. Tymstra's estimate in the Upper Foothills of a fire cycle of 627 years is only a fraction of what has been found in R11 by Rogeau (more than 51,000 years), which shows significant spatial variability in fire activity.

As noted in Tymstra *et al.* (2005) and shown above: there are no fire records in the Alberta Provincial Wildfire Database from which to calculate fire cycles or any other statistics for the Central Parkland, because so little of the region falls inside the Forest Protection Area (the only region where wildfire records are kept). Given what we know of aspen advancement into grasslands over the past 140 years based on pollen analysis studies, much of what is the Central Parkland today likely was grassland in the pre-settlement era, and therefore the relevant historical fire regime information for the area would be grassland fire regimes. However, as has been discussed previously, fire regime studies in the Northern Fescue are lacking.

OTHER RESEARCHERS, BOREAL

Numerous fire regime studies have been conducted on the Boreal Plains at a national scale (Rowe and Scotter, 1973; Johnson *et al.*, 1998; Parisien *et al.*, 2006), in Saskatchewan (Parisien *et al.*, 2004) and in Alberta (Armstrong, 1999; Tymstra *et al.*, 2005). There is a wide consensus that the fire regime is dominated by frequent, large, high severity wildfire. Given the definitions provided earlier on the delineation between *high severity* and *mosaic spatial mixed* severity there is room for debate as to which is the case, but the only real difference between the two is what total proportion of affected area is burned, and what proportion survives in remnants. As has been previously mentioned, significant work has been done by Andison to quantify and describe these patterns using the NEPTUNE model (Foothills Research Institute, 2009). Using 75% mortality as the cutoff between high and mixed severity, we might find that much of the Mixedwood's fire regime is indeed a mosaic spatial mixed severity fire regime. In the Central and Dry Mixedwood Natural Subregions, this likely is true due to the high proportion of aspen in the region, which burns infrequently.

Climate variability also drives the fire regime in the Central and Dry Mixedwood zone given the high level of interannual variability in fire frequency and severity. Future climate change scenarios largely predict an increase in variability, with a net increase in mean annual area burned and fire severity (Flannigan *et al.*, 2001).

How applicable this is to areas even further south is unknown. While the distance from the AlPac FMA to the North Saskatchewan Regional Plan is not great, there are large differences in ecosystems along that gradient. Also, given the heavy development in the region and large scale conversion of forests to agricultural land, the utility of borrowing fire regime information from areas to north is questionable.

ROGEAU, 2009-2010, R11 FOREST MANAGEMENT UNIT

This study is the most relevant to the NSRP Area as this is the most detailed, and one of only three fire regime analyses to occur within the region itself (in addition to Rogeau, 1999 and Rogeau 2006). The R11 Forest Management Plan was developed by Alberta Sustainable Resource Development (SRD) beginning in 2004. With this plan, the government chose to use historical fire regimes as an overall guide to management planning in the region. Alberta SRD contracted Rogeau to conduct a more detailed fire regime analysis of the entire R11 Forest Management Unit. Three reports were created to describe this work (Rogeau, 2009; Rogeau 2010a; Rogeau 2010b) and all of these are discussed in this section.

The objectives of this research were to 1) identify the fire regimes within the R11 FMU; 2) assess the spatial distribution of forest age classes; 3) assess the variation in fire sizes; 4) assess the fire cycle; and 5) calculate the degree of departure from historical fire regime conditions.

The modern fire regime described in this research refers to the period between 1961-2008, which is the time period covered by the Province of Alberta Wildfire Database. The historic fire regime was measured using aerial photography from 1949-1951, which allowed Rogeau to examine fire history from approximately 1650-1950, and calculate fire cycles from 1920-1950. Fire regime departures were calculated using a method described in Rogeau (2008). The modern fire regime was calculated across the entire FMU with a significant buffer region to the east (all area within the NSRP Area). The historic fire regime was calculated for the R11 FMU only (no buffer) and excluding the area that was studied in Rogeau (1999a).

The modern day fire regime has abnormally low fire frequency and long fire return intervals and fire cycles. Fire cycles are 51,772 years for the Upper Foothills, 3,590 years in the Montane, and 1,055 years in the Subalpine. Given the age class distributions observed within Rogeau (1999a) and what we know of fire cycles in other parts of the Rocky Mountains, it is apparent that these modern figures are well beyond normal.

The historic fire regime analysis by air photo screening does not enable calculations of the fire cycle to be done as accurately as using actual spatial fire data records. However, approximations, and identifying fires on the photos that occurred between 1920-1950, an approximate fire cycle for the time period yielded 378 years for the Subalpine Natural Subregion. However, valleys with the most complex vegetation patterns (and therefore potentially numerous overlapping fires) were excluded from this analysis. The actual fire cycle for all of R11 would have been shorter.

Air photo screening confirmed some of what was found in Rogeau (1999a), and Rogeau *et al.* (2004) regarding valley orientation and topographic influences on fire regime parameters. The oldest forests are found in the most remote and small valleys, but there were no clear trends in burning severity based on valley orientation as per Rogeau *et al.* (2004). Fuel continuity seemed to have the biggest bearing on burning severity.

Rogeau (2010a), generated more detailed fire return interval statistics, and a better understanding of how topography influences burning frequency and severity was gained. MFRI within valleys ranged from 23 years to 84 years. In Rogeau's words:

> "When travelling through this homogeneous sea of lodgepole pine forests, one would expect these forests to be even-aged, but many are not. Numerous sampling sites showed evidence of multiple fires through fire scars and / or multi-aged stands. For instance, both Elk and Peppers watersheds had sites with evidence of four fire events, while both Lower-Ram and Lynx watersheds had locations that captured up to six fire events. Healed-over fire scars were not uncommon. They attest to the lower severity of some of these fire events when very small diameter trees can scar and survive. That said, fire intensity was variable and 37% of the stands showed a single age cohort"

The importance of field assessments for fire regime analysis is illustrated in the preceding quote, but also is illustrated by an error observed the other way (assuming low intensity fire where there is none):

> "When screening the 1950 photos, it appeared that a few "recent" fires had burned from the meadows into the forest. During the field sampling, this hypothesis was dismissed. What appeared to have been lower severity burns on the fringe of meadows, were actually very slow forest in-filling."

Within watersheds, the observations and statistics are very detailed. For example, within the Lower Ram watershed, fire return intervals of significant fire events was between 35-45 years between 1670-1745, lengthens to 77 years to 1822, and then there is frequent fire activity with a MFRI of 3-21 years until 1942.

Rogeau also determines that the majority of the historical fires occurred in the spring, or dormant season for trees, with only 20-25% of fires occurring during the summer. This stands in stark contrast to the evaluation of the modern fire regime, where the vast majority (more than 80%) of fires occur between June and August. This is yet another line of evidence to suggest that First Nations burning may be the driving factor behind the fire regime of the region.

The last piece of Rogeau's fire regime analysis of the region was to calculate the degree of departure between the present fire regime and the historical one. As the field sampling to determine fire return intervals and fire cycles is limited to only reproducing a single snapshot in time in the forest, a modeling approach was used to calculate the historic fire regime using data from the preceding work in the region to calibrate the model. This allows multiple potential forest age class structures to be created that are assumed to represent the natural range of variability of the region.

Modeled historic fire cycles for the region ranged from 180 years in the Brazeau-Coral Creek area, to 50 years along the North Saskatchewan River. These fire cycles are concordant with neighbouring regions (Kananaskis (Rogeau, 2004) and Banff National Park (Rogeau, 1996a)) despite using a different methodology in Banff. The fire cycle for the Montane North Saskatchewan River valley (50 years) was similar to that found in other Montane regions in

Alberta. In the Upper Foothills Natural Subregion, Rogeau observes that in the R11, the fire cycle is twice as long as it is in Kananaskis, and 15-20 years less than it is in the Hinton region to the north (Andison, 1997), suggesting a lengthening fire cycle on a northward gradient.

Fire regime departures were calculated for fire cycle, fire cause, size, severity, seasonality, pattern and a cumulative index. To reproduce all the findings here would be onerous. The overall conclusion, however, is not surprising. Nearly 40% of the R11 FMU shows signs of "critical" fire regime departure, which is principally driven by lengthening fire cycles. This in turn is driven by fire exclusion in the region. At current rates, it is expected that by 2020, more than 50% of the region will be in the "critical" class.

ROGEAU, 2006, BEAVER HILLS AND ELK ISLAND NATIONAL PARK

At first glance, Rogeau (2006b) is one of the few fire regime studies conducted within the Central Parkland Natural Subregion, but in fact is within an island of Dry Mixedwood forest. Nonetheless, fires that originate on the landscape within this area would undoubtedly have had an effect on the surrounding Central Parkland, and conversely, fires originating in the Central Parkland would have burned into this area. While the Tymstra et al (2005) report does not provide any measures for the fire regimes in the Central Parkland, we might be able to make inferences about it from this study.

The landscape was examined using aerial photography from 1949 to identify fire boundaries from 1900-1949, with more accurate measures of recent fires from 1920-1949. Using the fire boundaries identified in this manner, field sampling was directed to selected locations to document fire scars and age forest stands. As with other studies by Rogeau, vegetation complexity was examined across the study landscape. The resulting measures of complexity are "high" through much of the area, which is suggestive of frequent, low to moderate intensity fire. Furthermore, the southern portion of the study area had the highest complexity, which would be consistent with a more frequent and lower severity fire regime associated with a higher proportion of grasslands within the Parkland system (to the north, the landscape graduates towards the boundary of the Chernozem soils shown in Figure 4, and therefore the boundary of the "true" forest).

Much of the vegetation complexity observed within this study is not as much the result of frequent burning, but the effect of relatively complex topography, with abundant wetlands that create complex vegetation patterns, which in turn create more variable fire patterns on the landscape.

The surrounding area had been heavily settled in the late 1800's to early 1900's, which likely resulted in a significant increase in fire frequency due to landclearing and railroad construction. The aerial photo screening revealed that most of the study landscape had burned over between 15-35 years prior to 1949, with a large area also burned in the late 1890's. These findings correlate to anecdotal information regarding fire history in the area. In the 1880’s much of the region was surveyed for vegetation, and these surveys indicate that most of the landscape was vegetated with brush and small diameter trees, which is consistent with the findings of Campbell et al (1994) and their claims that bison extirpation may be a driving factor behind increases in woody vegetation cover in the region at this point in time.

Unfortunately, this study was not completed as funding was unavailable to continue the work. There is a significant amount of archival research within the interim report document

SEDIMENT CORING AND FIRE HISTORY STUDIES

Not all fire regime knowledge has been gained by examining the modern forest and fire records. There are methodologies that are used to examine fire occurrence over much longer timescales. One of these methods is using lake sediment cores to document changes in vegetation cover and fire frequency by measuring and counting pollen and charcoal that sinks to the bottom of lakes. Over time these materials settle, and are packed down by new layers settling above them. Few of these studied have been done in the region, but these are described below.

LORENZ, 2009 - CHAUVIN LAKE

This study was conducted at Chauvin Lake, which is in the Central Parkland Natural Subregion on the Alberta-Saskatchewan border. The research is focused on using two lake sediment cores to evaluate changes in pollen and charcoal over a 2,100 year period between 5,400 and 3,300 years before present. The findings are correlated to climate chronologies to determine the relationship between vegetation at northernmost edge of the Great Plains.

The general findings support other lines of evidence previously presented that during periods of drought, productivity (and therefore fuel loading) declines. The ecotone between grassland and forests shifts in favour of grasses during these periods. The more interesting and relevant portion of the research was focused on evaluating variation in burning over the same time period. During short periods of drought, there was no net reduction in fire frequency, but during prolonged periods of drought, fire frequency was decreased, likely due to lack of available fuel. Fire intensity/severity, however, was higher during periods of drought as measured by the increase in charcoal layer thickness during dry periods. The sample size in this study is far too small to draw many useful area-wide conclusions.

CAMPBELL, 1994+ - ELK ISLAND NATIONAL PARK, PINE LAKE

Campbell and Campbell (2000), like Lorenz (2009), used lake sediment cores to examine vegetation change and fire frequency. Samples were taken from three lakes in Elk Island National Park, and in Pine Lake near Red Deer. Unlike Lorenz, these samples were examined from the time period of the present (2000 AD) to ~ 1500 AD. Therefore, they were able to calibrate their charcoal findings with known fires occurring in the 1900s.

All sites seemed to record the local fire history well, and reveal declines in fire frequency in the 1900s and significant increases in aspen cover beginning in the late 1800s, which is consistent with Campbell *et al.* (1994). The 1994 study reveals a similar story at Pine Lake, which is further south, near Red Deer, and on the grassland-forest ecotone.

The charcoal assays support historical accounts cited by the authors of high fire activity in the 1790s, 1812-1813 and in 1895. These events correlate to the arrival of fur traders in the region in the late 1700s, the beginning of railway construction in the 1890s, and the creation of the first settlements.

SECTION 4: DISCUSSION AND CONCLUSION

FOREST FIRE REGIMES IN ALBERTA - GENERAL

Current evidence published in the peer reviewed literature suggests that much of the foothills and boreal regions of Alberta have a typical “stand-replacing” fire regime, with long fire cycles, and infrequent, high intensity fires. Whether these are “high severity fire regimes” or “mosaic fire regimes” is a matter of where one chooses to draw the distinction between high and mixed severity. Regardless of the name, in the mountain regions, the fire regime tends to be dominated by high intensity stand-replacing fires (White 1985a; Johnson and Fryer, 1987; Johnson and Larsen 1991; Rogeau 1996a; Rogeau 1999a; Jevons and Donelon, 2008). These fire regimes are also dominant in some portions of the foothills regions adjacent to Jasper National Park, and throughout much of the boreal region of Alberta (Rowe and Scotter, 1973; Cumming, 1997; Andison, 1998; Andison, 2000d; Andison, 2003a; Andison, 2003b; Andison, 2003c; McLean *et al.*, 2003; Andison 2004).

There is, however, growing evidence from throughout the North American Rocky Mountain east slopes, and especially in the Montane, Upper and Lower Foothills Natural Subregions of both forms of mixed severity fire regimes, with spatially and temporally variable mixtures of stand-maintaining and stand-replacing fires (Gruell, 1983; Arno *et al.*. 2000; Rogeau 2004, Rogeau 2005a, Rogeau 2006a, Rogeau, 2009; Rogeau, 2010a; Rogeau 2010b; Amoroso *et al.* 2011). The biggest challenge to identifying, locating, and quantifying the extent of non-mosaic spatial and temporal mixed severity fire regimes is that they require a unique sampling methodology (Rogeau, 1999).

There is ample anecdotal, little field-based, and virtually no published evidence for the existence of low intensity surface fires occurring throughout the region. The identification of their extent requires sampling strategies that are very time consuming due to the high number of sample plots required, and other methodologies required to investigate the presence of fires which leave no readily visible signs. The historical extent and/or frequency of a mixed severity fire regime is largely unknown. Determining the extent of the various forms of mixed severity fire regimes along the east slopes is a question well worth answering. The impacts of a mixed fire regime on landscape structure and species mix have serious implications for wildfire and mountain pine beetle risk, timber harvesting and silviculture, and wildlife habitat (woodland caribou for example).

Misinterpretation of the fire regime of an area, and thus the resulting natural range of variability, can lead to significant management errors: if the historical disturbance severity and extent is overestimated, resulting land management actions based upon natural disturbance dynamics may be too large and severe. This can lead to larger-than-natural disturbance events that retain too few islands and too little coarse woody debris (CWD). Conversely, underestimating disturbance severity and extent can lead to disturbance events that are too small and retain large amounts of CWD and islands, which can lead to significant forest health issues due to higher than "normal" levels of landscape forest continuity.

THE TOWER OF BABEL – CONFUSING TERMINOLOGY

One of the leading problems in fire regime analysis, not unlike other fields of science, is the varying, and often confusing use of terminology. This document is not designed to create a common set of definitions for fire regime analysis in Alberta, and in many ways, if Alberta were to invent its own terminology that was different from other regions, we would likely find that confusion would increase still further. What we can do, however, is be more aware of what different terms mean, and recognize that numerous questions need to be asked of any research study we look at to be sure we know what it is really saying.

While terms like "fire cycle" appear to be universally understood, there are different *methods* of calculating it, using different equations that make different assumptions. The methods for calculating a fire cycle that have been largely used as created by Johnson and Van Wagner (1985) assume that fires start in random locations, but Cumming (2000) has shown this assumption is not true. Numerous other mathematical models have been developed, but the point is that there are several ways of doing this. This makes direct comparison of fire regime studies difficult if the methods were different, even if the terminology is the same.

Fire return intervals and mean fire return intervals are used interchangeably by some, which confuses the issues of fire regimes even further. There are so many different definitions of "severity" that literature reviews have been written on that subject alone.

Given A) the variety of parameters used to *measure* fire regimes (see Table 1), B) that each parameter has numerous attributes that can be measured, and C) that each of those attributes has different methods associated with how to calculate them, the potential for confusion is immense. What is important is to ensure that fire regime studies are conducted with clear objectives in mind, and that when land managers wish to use fire regime information to aid in decision making, they need to be sure the objectives and assumptions attributes of each piece of information they are using are understood, and that the attributes measured are useful to the management activities that are planned.

In some regions, some information is more valuable than others. As Parisien at al (2006) noted, fires are more complex in shape, pattern and predictability in the Boreal Plains ecozone (which includes the Foothills and Mixedwood Natural Subregions) than they are in the Montane Cordillera. In some ways this is counterintuitive, we might expect that due to the variability in topography that fires in the Montane and Subalpine would be more complex, but it appears that the topography constrains fires and more predictable patterns emerge. As such, detailed pattern analyses in the Montane and Subalpine as conducted by Andison and Cumming might be less important than understanding the topographic influences on fire behavior as per Rogeau. However, in Foothills and Mixedwood locations, the detailed pattern analysis approach is very important, and topographic drivers perhaps less so.

SCALE AND ITS INFLUENCE ON CLASSIFICATION AND FIRE REGIMES

Vegetation classification schemes vary significantly, and for numerous regions. Parks Canada , uses a slightly different definition of Montane and Subalpine subregions than the Province of Alberta’s Natural Subregion definitions. Therefore much of the work done by Rogeau, White, Tande, and Barrett needs to be viewed through this lens.

When the Terrestrial Ecozones and Ecoregions are overlain with the Alberta Natural Subregions on the same map the boundaries of the two classification systems do not align. There are two primary reasons for this:

First, the classification systems are done using aerial photography at different scales. The Ecozones have been classified using maps at a scale of 1:250,000, whereas the underlying ecoregions were classified using more detailed biological and geological knowledge, and by relying on the 1994 version of the Alberta Natural Subregions document (which itself was updated in 2006).

A second reason they do not align, is that classification systems rely upon interpreting environmental conditions at a particular point in time. While a few years may make little difference in where visible boundaries between major vegetation forms are observed, decades can move these lines significantly. Furthermore, when the Terrestrial Ecological Classification system (see figure 2) is broken down to the ecodistrict level, soils become a very important factor.

One of the challenges we have with interpreting fire regime studies is that fire regimes are spatially variable. As the unit of analysis shifts by making areas larger or smaller, the statistics change accordingly. This is illustrated by differences in the modern fire cycle calculated by Tymstra *et al.* (2005) and Rogeau (2010b) for the Upper Foothills (627 years versus 51,772 years respectively). Rogeau and Tymstra *used the same dataset* to calculate this figure, but due to the variability in fire occurrence across the Upper Foothills, the results are different by an order of magnitude. A similar issue is illustrated in Andison’s estimates of fire cycles by Natural Subregion when broken down by the operating unit. The range in fire cycles reported in the Subalpine Natural Subregion varies from 80-90 years within the ANC FMA, to as high as 130-190 years in Jasper, which overlaps the fire cycle of the Montane, which is 70-90 years. This does not mean any of these calculations are incorrect, but it does mean that broad generalizations can be very misleading, and may not capture the dynamics occurring within a particular region. “Borrowing” data from other regions to fill in for missing information should be done with great caution, and full recognition of the assumptions required in so doing.

The same problem (differential calculation of fire regime parameters) is bound to occur when we change the temporal depth that we use to examine a fire regime. Many of the studies reported above use fundamentally different data sets. Even when field-based data is collected, in regions with longer fire cycles there tends to be a longer fire record one can obtain (assuming that with a longer fire cycle, there are older trees that record scars from fires further back in time). When modeling is used to generate “historic” conditions, even more caution must be placed on interpretations as there are many assumptions that go into models.

What is obvious, however, is that as the spatial unit of analysis changes, AND as the temporal depth changes, the fire "regime" changes. This is a phenomenon known as the Modifiable Areal Unit Problem (MAUP), which is a well understood problem in geography and spatial analysis (Jeliniski and Wu, 1996. Keeping this problem in mind, if one researcher examines fire regimes in the Subalpine, for example, at the exclusion of any other Natural subregion, and another examines a larger area that overlaps the *same Subalpine* region, but also examines the neighbouring Montane and Upper Foothills, they are bound to come up with different measures of fire regime within the Subalpine based solely on differences in what data they have collected and analysed. This is not even taking into account that there is also variation in how different researchers calculate statistics such as Annual Area Burned, or Mean Fire Return Interval, or how they deal with the fact that recent fires hide evidence of earlier fires. Rather than focusing on which one is right and which one is wrong, it is more appropriate to focus on which one is most *applicable* to a given problem.

Fire regimes are a set of *statistics* to help us measure how fire interacts with a given piece of ground. They are not "inherent characteristics" of an ecosystem (Johnson *et al.*, 1998). Fire regimes are a complex expression of the interactions between fire and short term weather, climate, soils, topography, human history, grazing, browsing, and vegetation succession. No two are the same, they are like fingerprints. And this fingerprint changes as the scale changes. The notion of a “stable” fire regime is falling victim to the same fate that the “climax” forest community has over the past several decades. While useful as a conceptual framework for understanding ecosystems, it has little bearing in the real world. There are too many other constantly moving variables to ever allow for a stable fire regime to emerge.

CONCLUSION

Lest this sound like I am stating that fire regimes are so variable that they are meaningless and don't matter, nothing could be farther from the truth. The only way to understand current ecosystems is to understand the processes and events that formed them, and the only way to manage for the future is to understand how the present came to be. In the words of Steven Pyne (from his keynote address at the International Association of Wildland Fire 2010 Annual General Meeting in Spokane, WA):

> "We are more likely to use the present to attempt to reconstruct the past, than we are to use the past to understand the present and guide the future."

As the discussion on the influence of scale reveals, what is important in applying research to inform management is that the scale of analysis needs to match the scale of management. A fire regime analysis of the R11 FMU works for managing R11, or the C5 Fire Regime Analysis for the C5 management plan, or the body of Andison's work for managing the Hinton Wood Products FMA, but it does NOT work well when you try to use a study conducted at one scale or in one location to manage a different scale or location. It would be inadvisable to use the R11 Fire Regime study to manage the entire East Slopes, or use Natural subregion averages according to Tymstra *et al.* to manage a specific watershed, or use Johnson's work in Kananaskis Valley to manage anything beyond that watershed

The scale of both the analysis of a fire regime, and the implementation of a disturbance strategy through harvest, prescribed fire or other means is critical. To suggest, for example, "our area has a fire cycle of 100 years" might be true. But, this would possibly lead to a management plan treating the area as homogenous with regard to disturbance frequency when we know that the fire cycle varies considerably by topography. It might more accurately be stated as "north aspects show a long fire cycle of 250 years, south facing slopes have a fire cycle of 50 years, and valley bottoms have a 125 year fire cycle". This would lead to a much more finessed approach, and likely a more ecologically relevant and scientifically defensible management plan.

We know from repeat photography (Higgs *et al.*, 2009) that the landscape of the east slopes of the Rocky Mountains, including the foothills, has changed considerably, and we also know from other lines of evidence that the forest grassland ecotone has shifted considerably in favour of forests over this time period. This landscape has an elevated risk of wildfire, mountain pine beetle infestation, detrimental changes in hydrology, and loss of critical wildlife habitat. Negative impacts of changes in the fire regime have cascaded through the ecosystem (Keane *et al.* 2002). Understanding the forces that created the landscape, and which forces have altered it, is fundamental to developing sound ecologically-based management plans.

The overall proportion of historic fire attributable to First Nations and that to lightning is difficult to determine, but we do know that traditional aboriginal land practices were a major force on the landscape. This region was heavily used by the Peigan and Stoney peoples as documented by David Thompson in his journals. Between 1781 and 1782 there was a massive smallpox epidemic throughout western North America that devastated First Nations people, and likely significantly reduced the number of fires they would have been lighting (Francis, 1989). Even lightning strike patterns likely have changed since the 1800s and 1900s as the climate of the region is known to have changed.

While many of the authors reviewed in this document have found what appears to be conflicting evidence for changes in fire regimes, relationships between fire regimes and climate, and effects of fire exclusion on the landscape, it is important to note that none of the studies are *wrong*. They all need to be examined within the appropriate scale (temporal and spatial), and by understanding the assumptions and objectives that went into the design and interpretation of the results.

LITERATURE CITED

Achuff P. 1998. Memorandum: Scientific issues - fire management. *Parks Canada Correspondence*. 29 pages.

Agee JK. 1993. Fire ecology of Pacific Northwest forests. *Island Press, Washington DC*. 493 pages.

Amoroso M, Daniels L, Bataineh M, Andison D and C Stockdale. 2011. Preliminary evidence of mixed-severity fire regimes in the east slopes of the Rocky Mountains. *In Draft.*

Andison DW. 1998. Patterns of temporal variability and age-class distributions on a Foothills landscape in Alberta. *Ecography* 21:543-550.

Andison, DW. 1999. Laying the groundwork for natural disturbance research. *Alberta Foothills Disturbance Ecology Research Series report No. 1*. 21 pages.

Andison DW. 2000a. Disturbance rates and cycles. *Foothills Model Forest Natural Disturbance Program Quicknote No. 1*.

Andison DW. 2000b. Natural subregions: are they meaningful? *Foothills Model Forest Natural Disturbance Program Quicknote No. 2*.

Andison DW. 2000c. Fire control impacts: real or imagined? *Foothills Model Forest Natural Disturbance Program Quicknote No. 3*.

Andison DW. 2000d. Landscape-level fire activity on foothills and mountain landscape of Alberta. *Alberta Foothills Disturbance Ecology Research Series, Report No. 2*. Foothills Model Forest, Hinton, AB.

Andison DW. 2000e. Historical fire sizes. *Foothills Model Forest Natural Disturbance Program Quicknote No. 4*.

Andison DW. 2001. The even aged boreal forest myth. *Foothills Model Forest Natural Disturbance Program Quicknote No. 6*.

Andison DW. 2002. Disturbance in riparian zones on foothills and mountain landscapes of Alberta: *Alberta Foothills Disturbance Ecology Research Series report No. 3*. 40 pages.

Andison DW. 2003a. Patch and event sizes on foothills and mountain landscapes of Alberta: *Alberta Foothills Disturbance Ecology Research Series report No. 4*. 48 pages

Andison DW. 2003b. Disturbance events on foothills and mountain landscapes of Alberta: *Alberta Foothills Disturbance Ecology Research Series report No. 5*. 31 pages.

Andison DW. 2003c. Natural levels of forest age-class variability on the AlbertaPacific FMA. *Contract report prepared for* Alberta-Pacific Forest Industries. 36 pages.

Andison DW. 2004. Island remnants on foothills and mountain landscapes of Alberta: Part II on residuals: *Alberta Foothills Disturbance Ecology Research Series report No. 6*. 38 pages.

Archer S. 1999. Woody plant encroachment into southwestern grasslands and savannas: rates, patterns and proximate causes. *In*: Vavra M, Laylock W, and RD Pieper (*editors*), *Ecological Implications of Livestock Herbivory in the West*. Society for Range Management, Denver, pages 13–69.

Archibold OW, Nelson LJ, Ripley EA and L Delanoy. 1998. Fire temperatures in plant communities of the northern mixed prairie. *Canadian Field Naturalist* 112:234-240.

Archibold OW, Ripley EA and L Delanoy. 2003. Effects of seasonal burning on the microenvironment of fescue prairie in central Saskatchewan. *Canadian Field Naturalist* 117(2): 257-266.

Armstrong GW. 1999. A stochastic characterization of the natural disturbance regime of the boreal mixedwood forest with implications for sustainable forest management. *Canadian Journal of Forest Research*. 29:424–433.

Arno SF. 1980. Forest fire history in the Northern Rockies. *Journal of Forestry* 78 (8):460-465.

Arno SF, and GE Gruell. 1983. Fire history at the forest-grassland ecotone in Southwestern Montana. *Journal of Range Management* 36(3):332-336.

Arno SF, Parsons DJ, and RE Keane. 2000. Mixed-severity fire regimes in the northern Rocky Mountains: consequences of fire exclusion and options for the future. In *Wilderness Science in a Time of Change Conference. Vol. 5: Wilderness Ecosystems, Threat, and Management, Missoula, Montana, 23–27 May 1999*. USDA For. Serv. RMRS-P-15-VOL-5. pages 225–232.

Axelrod DI. 1985. Rise of the grassland biome, central North America. *Botanical Review* 51:163-201.

Bachelet D, Lenihan JM, Daly C and RP Neilson. 2000. Interactions between fire, grazing and climate change at Wind Cave National Park, SD. *Ecological Modelling* 134:229-244.

Bailey AW, and ML Anderson. 1980. Fire temperatures in grass, shrub, and aspen forest communities of Central Alberta. *Journal of Range Management* 33 (1): 37-40.

Barrett S, Havlina D, Jones J, Hann W, Frame C, Hamilton D, Schon K, Demeo T, Hutter L, and J Menakis. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0 [Homepage of the Interagency Fire Regime Condition Class website, USDA Forest Service, US Department of the Interior, and The Nature Conservancy]. [Online], Available: www.frcc.gov.

Bartolome J, Franch J, Plaixats J, NG Seligman. 2000. Grazing alone is not enough to maintain landscape diversity in the Montseny Biosphere Reserve. *Agriculture, Ecosystems and Environment* 77:267–273.

Billings WD. 1990. The mountain forests of North America and their environments. *In* Osmund CB, Pitelka LF, and GM Hidy *Editors*. *Plant biology of the basin and range*. Springer Verlag, New York. Pages 47-86.

Biondini ME, Steuter AA, and CE Grygiel. 1989. Seasonal fire effects on the diversity patterns, spatial distribution and community structure of forbs in the Northern Mixed Prairie, USA. *Plant Ecology* 85:21-31.

Bond WJ, and JE Keeley. 2005. Fire as a global ‘herbivore’: the ecology and evolution of flammable ecosystems. *Trends in Ecology & Evolution* 20(7):387-394.

Boyd M. 2002. Identification of anthropogenic burning in the paleoecological record of the northern prairies: a new approach. *Annals of the Association of American Geographers* 92(3):471–487.

Bragg TB. 1982. Seasonal variations in fuel and fuel consumption by fires in a bluestem prairie. *Ecology* 63:7-11.

Brown KJ, Clark JS, Grimm EC, Donovan JJ, Mueller PG, Hansen BCS and I Stefanova. 2005. Fire cycles in North American interior grasslands and their relation to prairie drought. *Proceedings of the National Academy of Sciences of the United States of America* 102(25):8865-8870.

Burns RM and BH Honkala. 1990. Silvics of North America. *Agricultural Handbook 654*. USDA.

Campbell C, Campbell ID, Blyth CB and JH McAndrews. 1994. Bison extirpation may have caused aspen expansion in Western Canada. *Ecography* 17(4):360-362.

Campbell ID, and C Campbell. 2000. Late Holocene vegetation and fire history at the southern boreal forest margin in Alberta, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164:263-280.

Camill P, Umbanhowar CE, Teed R, Geiss CE, Aldinger J, Dvorak L, Kenning J, Limmer J, and K Walkup. 2003. Late-glacial and Holocene climatic effects on fire and vegetation dynamics at the prairie–forest ecotone in south-central Minnesota. *Journal of Ecology* 91:822–836.

Carcaillet C, Bergeron Y, Richard PJ, Fréchette B, Gauthier S, and YT Prairie. 2001. Change of fire frequency in the eastern Canadian boreal forests during the Holocene: does vegetation composition or climate trigger the fire regime? *Journal of Ecology* 89:930–946.

Carmel Y, and R Kadmon. 1999. Effects of grazing and topography on long-term vegetation changes in a Mediterranean ecosystem in Israel. *Plant Ecology* 145:243–254.

Clark JS. 1989. Effects of long-term water balances on fire regime, northwestern Minnesota. *Journal of Ecology* 77(4):989-1004.

Clark JS, and PD Royall. 1995. Transformation of a northern hardwood forest by aboriginal (Iroquois) fire: charcoal evidence from Crawford Lake, Ontario, Canada. *The Holocene* 5:1-9.

Collins S, and LL Wallace *editors.* 1990. *Fire in North American tallgrass prairies*. University of Oklahoma Press. 176 pages.

Coupland RT. 1950. Ecology of mixed prairie in Canada. *Ecological Monographs*. 20:273-315.

Cumming SG. 1997. Landscape dynamics of the boreal mixedwood forest. *PhD Thesis*. University of British Columbia, Vancouver, BC. 231 pages.

Daniels L, Jones T, Bataineh M, Thorpe H, Jones E, Nicoll A, Powell S, Ewan M, Henderson E, Amerongen-Maddison J, Chavardes R and D Andison. 2011. Temporal dynamics of large woody debris in the Foothills of Alberta. *Foothills Research Institute Report*.

Daubenmire R. 1943. Vegetation zonation in the Rocky Mountains. *Botanical Review* 9:325-393.

Engle DM, and PM Bultsma. 1984. Burning of northern mixed prairie during drought. *Journal of Range Management* 37:398-401.

Erichsen-Arychuk C, Bork EW and AW Bailey. 2002. Northern dry mixed prairie responses to summer wildfire and drought. *Journal of Range Management* 55:164-170.

Feller MC, Plett M, White C,and J Dordel. 2005. Forest fires, mountain pine beetle, and forest structure relationships in Canada's southern Rocky Mountains. 48 pages.

Flannigan MD, Campbell I, Wotton M, Carcaillet C, Richard P, and Y Bergeron. 2001. Future fire in Canada's boreal forest: paleoecology results and general circulation model - regional climate model simulations. *Canadian Journal of Forest Research* 31:854-864.

Foothills Research Institute. 2009. NEPTUNE (version 2.0). The Forestry Corp, Edmonton, AB

Foothills Research Institute. 2011. Natural Disturbance Database. *At URL* http://uat.ndr.encaps.com/ndr/

Forman RTT, and M Godron. 1986. *Landscape ecology*. J Wiley and Sons, New York, New York.

Francis, RD. 1989. *Images of the West: Changing Perceptions of the Prairies, 1690-1960*. Western Producer Prairie Books, Saskatoon, SK.

Franklin,JF. 1993. Preserving biodiversity: species, ecosystems, or landscapes? *Ecological Applications* 3: 202-205.

Fuhlendorf SD, and DM Engle. 2001. Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. *Bioscience* 51:625-632.

Fuller WA. 1966. The biology and management of bison at Wood Buffalo National Park. *Wildlife Management Bulletin Series* 1:1-52.

Fryer GI, and EA Johnson. 1988. Reconstructing fire behaviour and effects in a subalpine forest. *Journal of Applied Ecology* 25:1063-1072.

Girardin MP, and D Sauchyn. 2008. Three centuries of annual area burned variability in northwestern North America inferred from tree rings. *The Holocene* 18(2):205-214.

Gom LA and SB Rood. 1999. Fire induces clonal sprouting of riparian cottonwoods. *Canadian Journal of Botany* 77:1604-1616.

Government of Alberta. 2008. Land Use Framework. Government of Alberta, Edmonton Alberta, http://www.landuse.alberta.ca/AboutLanduseFramework/LUFProgress/documents/LanduseFramework-FINAL-Dec3-2008.pdf

Granek EF, Polasky S, Kappel CV, Reed DJ, Stoms DM, Koch EW, Kennedy CJ, Cramer LA, Hacker SD, Barber EB, Aswani S, Ruckelshaus M, Perillo GME, Sillman BR, Muthiga N, Bael D, and E Wolanski. 2010. Ecosystem services as a common language for coastal ecosystem-based management. *Conservation Biology* 24(1):207-216.

Gruell GE. 1983. Fire and vegetative trends in the northern Rockies: interpretations from 1871-1982 photographs. *USDA General Technical Report INT-158*.

Gruell GE. 1985. Fire on the early western landscape: an annotated record of wildland fires 1776-1900. *Northwest Science* 59:97-107.

Hawkes BC. 1979. Fire history and fuel appraisal of Kananaskis Provincial Park. *Report prepared for*: Resource Assessment and Management Section, Planning and Design Branch, Parks Division, Alberta Recreation and Parks. 190 pages.

Heinselman, ML. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. *Quaternary Research* 3:329-382.

Henderson D. 2006. Background for fire management plan for Grassslands National Park. Parks Canada internal document, 15 pages.

Higgs ES, Bartley G, and AC Fisher. 2009. *The Mountain Legacy Project. Second ed*. pp. 80

Hind HY. 1860. *Narrative of the Canadian Red River exploring expeditions of 1857 and of the Assiniboine and Saskatchewan exploring expeditions of 1858.* Rutland, VT: Charles E. Tuttle Company 1971..

Huggard, D.J. and Arsenault, A. 1999. Comment – Reserve cumulative standing age distributions in fire frequency analysis. *Canadian Journal of Forest Research* 29: 1449-1456.

Jeliniski DE and J Wu. 1996. The modifiable areal unit problem and implications for landscape ecology. *Landscape Ecology* 11(3)129-140.

Johnson, EA, and CE Van Wagner. 1985. The theory and use of two fire history models. *Canadian Journal of Forest Research* 15: 214–220.

Johnson EA, and GI Fryer. 1987. Historical vegetation change in the Kananaskis Valley, Canadian Rockies. *Canadian Journal of Botany*. 65:853–858.

Johnson EA, and DR Wowchuck. 1993. Wildfire in the southern Canadian Rockies and their relationship to mid-tropospheric anomalies. *Canadian Journal of Forest Science* 23:1213-1222.

Johnson EA, Miyanishi K and H Kleb. 1994. The hazards of interpretation of static age structures as shown by stand reconstructions in a Pinus contorta – Picea engelmanii forest. *Journal of Ecology* 82:923-931.

Johnson EA, Miyanishi K, and JMH Weir. 1998. Wildfires in the western Canadian boreal forest: Landscape patterns and ecosystem management. *Journal of Vegetation Science* 9: 603–610.

Johnson EA. 2003. Disturbance regime interactions. *Advances in Applied Biodiversity Science* 4:39–44.

Kay CE. 1994. Aboriginal overkill: the role of Native Americans in structuring western ecosystems. *Human Nature* 5(4):359-398.

Keane RE, Ryan KC, Veblen TT, Allen CD, Logan J and B Hawkes. 2002. Cascading effects of fire exclusion in Rocky Mountain ecosystems. *USDA Forest Service General Technical Report RMRS-GTR-91.*

Knapp AK, Blair JM, Briggs JM, Collins SL, Hartnett DC, Johnson LC and Towne EG. 1999. The keystone role of bison in North American tallgrass prairie. *Bioscience* 49:39-50.

Lands Directorate. 1986. *Terrestrial Ecozones Of Canada, Ecological Land Classification* No. 19, 26 pages

Lewis HT. 1982. *A time for burning*. Boreal Institute for Northern Studies, Occasional publication No. 17, University of Alberta. Edmonton AB.

Lorenz PC. 2009. Assessing changes in pollen assemblage and charcoal accumulation during known changes in climate from c. 5,400 to 3,300 Years Before Present at the forest-prairie ecotone in Alberta, Canada. *Masters Thesis*, Queens University.

MacLean K, McCleary K, Farr D, and DW Andison. 2003. Island remnants on foothills and mountain landscapes of Alberta: *Methods: Alberta Foothills Disturbance Ecology Methodology Series report No. 1*. 41 pages.

Morgan P, Hardy CC, Swetnam TW, Rollins MG and DG Long. 2001. Mapping fire regimes across time and space: Understanding coarse and fine-scale fire patterns. *International Journal of Wildland Fire* 10:329-342.

Natural Regions Committee 2006. *Natural Regions and Subregions of Alberta.* Compiled by D.J. Downing and W.W. Pettapiece. Government of Alberta. Pub. No. T/852.

Nelson JG, and RE England. 1971. Some comments on the causes and effects of fire in the northern grasslands area of Canada and the nearby United States, Ca. 1750–1900. *Canadian Geographer* 15:295–306.

Parisien MA, Hirsch KG, Lavoie SG, Todd JB, and VG Kafka. 2004. Saskatchewan fire regime analysis. *Canadian Forest Service, Northern Forestry Centre, Information Report NOR-X-394*.

Parisien MA, Peters VS, Wang Y, Little JM, Bosch EM, and BJ Stocks. 2006. Spatial patterns of forest fires in Canada, 1980-1999. *International Journal of Wildland Fire* 15:361-374.

Peet RK. 1988. Forests of the Rocky Mountains. *In* Barbour MG, and WD Billings, *editors*. 1988. *North American terrestrial vegetation*. New York: Cambridge University Press. Pages 63-101.

Peterson MJ, Hall DM, Feldpausch-Parker AM, and TR Peterson. 2010. Obscuring ecosystem function with application of the ecosystem services concept. *Conservation Biology* 24(1): 113-119.

Pickett STA, Parker VT, and PL Fielder. 1992. The new paradigm in ecology: Implications for conservation biology above the species level. *In* PL Jain (Editor). *Conservation biology: The theory and practice of nature conservation, preservation, and management.* Pages 65-88. Chapman and Hall, New York, NY.

Power MJ *et al.*. (plus 83 authors) . 2007. Changes in fire regimes since the Last Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data. *Climate Dynamics* 30:887-907.

Pylypec B, and JT Romo. 2003. Long-term effects of burning *Festuca* and *Stipa-Agropyron* grasslands. *Journal of Range Management* 56:640-645.

Redmann RE, Romo JT, Pylypec B and EA Driver. 1993. Impacts of burning on primary productivity of *Festuca* and *Stipa-Agropyron* grasslands in central Saskatchewan. *American Midland Naturalist* 130: 262-273.

Reed WJ, Larsen CPS, Johnson EA, and GM MacDonald. 1998. Estimation of temporal variations in historical fire frequency from time-since-fire map data. *Forest Science* 44(3):465-475.

Rhemtulla JM. 1999. Eighty Years of Change: The Montane Vegetation of Jasper National Park. *Thesis (MSc)*. University of Alberta.

Risser PG. 1995. The status of the science examining ecotones. *Bioscience* 45(5):318-325.

Rogeau MP. 1996a. Understanding Age-Class Distributions in the Southern Canadian Rockies. M.Sc. Thesis. Dept. of Forest Science, University of Alberta, Edmonton, AB. 139 pages.

Rogeau MP. 1996b. Landscape Disturbance Project, Stand Origin Mapping 1996. *Contract report prepared for the* Foothills Model Forest, Hinton, AB. 50 pages + 6 map sheets.

Rogeau MP. 1997. Landscape Disturbance Project, Stand Origin Mapping 1997. *Contract report prepared for the* Foothills Model Forest, Box 6330, Hinton, AB. T7V 1X3. 69 p.

Rogeau MP. 1999a. Fire history study of the Central Rockies, Ecosystem InterAgency North Saskatchewan Unit.. *Contract report prepared for* Banff National Park 61 pages.

Rogeau M-P. 1999b. Detailed Disturbance History Mapping of the Montane, Jasper National Park: 1997-1998. *Contract report prepared for* the Foothills Model Forest, Hinton, AB. 44 pages.

Rogeau MP. 2004. Fire regime study of Kananaskis district, Alberta. *Contract report prepared for* Spray Lake Sawmills Ltd and Alberta Community Development, Parks and Protected Areas. 111 pages.

Rogeau MP. 2005a. Fire history study Kananaskis District, Alberta – 2004 field results. *Contract report prepared for* Spray Lake Sawmills Ltd., Alberta Community Development and Alberta Sustainable Resource Development. 67 pages.

Rogeau MP. 2005b. Fire regime study of C5 FMU. *Contract report prepared for* Alberta Sustainable Resource Development, Forest Protection Division. 136 pages.

Rogeau MP, Pengelly I, and MJ Fortin. 2004. Using a topography model to map historical fire cycles and monitor current fire cycles in Banff National Park. Pages 55-69 *in* R.T. Engstrom and W.J. de Groot, (eds.). Proceedings of the 22nd Tall Timbers Fire Ecology Conference: Fire in Temperate, Boreal, and Montane Ecosystems. Tall Timbers Research Station, Tallahassee, FL.

Rogeau MP. 2006a. Fire history study Kananaskis District, Alberta – 2005 field results. *Contract report prepared for* Spray Lake Sawmills Ltd., Alberta Community Development and Alberta Sustainable Resource Development. 40 pages.

Rogeau MP. 2006b. Fire History of the Beaver Hills. *Contract report prepared for* The Beaver Hills Initiative Group, County of Strathcona, AB. 26 pages.

Rogeau MP. 2007. Implementing the fire regime condition classification model to Alberta: an evaluation process. *Contract report prepared for* Alberta Sustainable Resource Development.51 pages.

Rogeau MP. 2008. Fire Regime Departure Rating in Canadian National Parks. Pilot Project: Jasper National Park. *Contract report prepared for* Parks Canada. 66 pages.

Rogeau MP. 2009. Fire regime study FMU R11: Part 1. *Contract report prepared for* Alberta Sustainable Resource Development.

Rogeau MP. 2010a. Fire history study 2009 field results, R11 FMU: Part 2. *Contract report prepared for* Alberta Sustainable Resource Development. 95 pages.

Rogeau MP. 2010b. Fire regime departure R11 FMU: Part 3. *Contract report prepared for* Alberta Sustainable Resource Development. 94 pages.

Rogeau MP. 2011. Fire history study of the Elbow Fire Management Compartment, Alberta. *Contract report prepared for* Alberta Sustainable Resource Development. 57 pages.

Rogeau MP. In Pressa. Recreating historical fire return intervals and stand origin maps to capture historical fire regime conditions. *In* Proceedings of the 3rd Fire Behavior and Fuels Conference, Oct. 25-29, 2010, Spokane, WA.

Rogeau, M-P. In Pressb. Fire regimes of Alberta's southern Canadian Rockies and important fire years. *In* Proceedings of the 3rd Fire Behavior and Fuels Conference, Oct. 25-29, 2010, Spokane, WA.

Rogeau MP and D Gilbride. 1994. Stand Origin Mapping of Banff National Park. *Contract report prepared for* Resource Conservation Branch, Banff National Park, Alberta. 70 pages + 8 map sheets.

Rowe JS. 1969. Lightning fires in Saskatchewan grassland. *Canadian Field Naturalist* 83:317-324.

Rowe JS and GW Scotter. 1973. Fire in the Boreal Forest. *Quaternary Research* 3(3):444-464.

Schoennagel T, Veblen TT, and WH Romme. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. *BioScience* 54:661-676.

Schuler KL, Leslie DM, Shaw JH, and EJ Maichak. 2006. Temporal-spatial distribution of bison in a tallgrass prairie fire mosaic. *Journal of Mammalogy* 87(3):539-544.

Shay J, Kunec D and B Dyck. 2001. Short-term effects of fire frequency on vegetation composition and biomass in mixed prairie in south-western Manitoba. *Plant Ecology* 155:157-167.

Singer FJ. 1996. Effects of grazing by wild ungulates in Yellowstone National Park. *Technical Report NPS/NRYELL/NRTR/98-01*. United States Department of the Interior, National Park Service, Yellowstone National Park.

Smith AD, Lucas PL, Baker CO, and GW Scotter. 1972. The effects of deer and domestic livestock on aspen regeneration in Utah. *Publication No. 72-1*. Utah Division of Wildlife Resources.

Soja A, Tchebakova N, French N, Flannigan M, Shugart H, Stocks B, Sukhinin A, Parfenova E, Chapin F, and P Stackhouse. 2007. Climate-induced boreal forest change: Predictions versus current observations. *Global and Planetary Change* 56:274-296.

Svedarsky WD, Buckley PE and TA Feiro. 1986. The effect of 13 years of annual burning on an aspen-prairie ecotone in northwestern Minnesota. *The prairie: Past, present, and future, Proceedings of the 9th North American Prairie Conference*, Moorhead, Minnesota, ed. GK Clambey and RH Pemble, 118–22. Fargo, ND: Tri-College University Center for Environmental Studies

Tande GF. 1979. Fire history and vegetation patterns of coniferous forests in Jasper National Park, Alberta. *Canadian Journal of Botany* 57:1912–1931.

Thompson D. 1784-1812. David Thompson's narrative of his explorations in Western America. *Edited by* Tyrell JB. *Published* 1916 *by* The Champlain Society. 740 pages. *Viewed online at:* http://link.library.utoronto.ca/champlain/item_record.cfm?Idno=9_96855&lang=eng&query=thompson%20AND%20david&searchtype=Author&startrow=1&Limit=All

Trager MD, Wilson G, and DC Hartnett. 2004. Concurrent effects of fire regime, grazing and bison wallowing on tallgrass prairie vegetation. *American Midland Naturalist* 152(2):237-247.

Turner MG. 1989. The effect of pattern on process. *Annual review of Ecology and Systematics* 20:171-197.

Turner MG, and WH Romme. 1994. Landscape dynamics in crown fire ecosystems. *Landscape Ecology* 9(1):59-77.

Tymstra C, Wang D, and M-P Rogeau. 2005. Alberta Wildfire Regime Analysis. Alberta Sustainable Resource Development. 171 pages.

Umbanhowar CE. 1996. Recent fire history of the northern Great Plains. *American Midland Naturalist* 135:115-121.

Van Wagner CE, Finney MA and M Heathcott. 2006. Historical fire cycles in the Canadian Rocky Mountain Parks. *Forest Science* 52(6):704-717.

Veblen TT. 2003. Key issues in fire regime research for fuels management and ecological restoration. Pages 259-276 in: P. Omi and L. Joyce (technical eds). *Fire*, Fuel Treatments and Ecological Restoration: Conference proceeedings; 2002 16-18 April; Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 475 p.

Vinton MA, Hartnett DC, Finck EJ, and JM Briggs. 1993. Interactive effects of fire, bison (Bison bison) grazing and plant community composition in tallgrass prairie. *American Midland Naturalist* 129(1):10-18.

Vujnovic K, Wein RW, and MRT Dale. 2002. Predicting plant species diversity in response to disturbance magnitude in grassland remnants of central Alberta. *Canadian Journal of Botany* 80:504-511.

Wakimoto RH, and EE Willard. 2005. Historic fire regimes and change since European settlement on the Northern Mixed Prairie: Effect on ecosystem function and fire behavior. Joint Fire Science Program. University of Montana. Missoula MT. 174 pages.

Weber MG, and MD Flannigan. 1997. Canadian boreal forest ecosystem structure and function in a changing climate: impact on fire regimes. *Environmental Review* 5(3-4):145-166.

Weir JMH, Chapman KJ, and EA Johnson. 1995. Wildland fire management and the fire regime in the southern Canadian Rockies. In: Brown, JK, Mutch, RW, Spoon, CW, Wakimoto, RH, technical coordinators. 1995. *Proceedings: symposium on fire in wilderness and park management;* 1993 March 30-April 1; Missoula, MT. Gen Tech. Rep. INT-GTR-320. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

White C. 1985a Wildland fires in Banff National Park, 1880-1980. *Occasional Paper No.3*. National Parks Branch, Parks Canada, Environment Canada. Catalogue No.: R61 2/8- E. 108 pages.

White CA. 1985b. Fire and Biomass in Banff National Park Closed Forests. *MSc Thesis*, Dept. of Forest and Wood Sciences, Colorado State University, Fort Collins, Colorado. 205 pages.

White CA, Pengelly IR, Zell D, and MP Rogeau. 2003. Landscape fire regimes and vegetation restoration in Banff National Park, Alberta. *Parks Canada Occasional Paper BNP-2003-01*.

White CA, Olmsted CE and CE Kay. 1998. Aspen, elk, and fire in the Rocky Mountain National Parks of North America. *Wildlife Society Bulletin* 26(3):449-462

White CA, Pengelly IR, Zell D, and MP Rogeau. 2004. Restoring heterogenous fire patterns in Banff National Park, Alberta. *Paper presented at-* Mixed fire regimes: ecology and management. Proceedings of the symposium. November 17-19, 2004. Washington State University. Pullman, WA.

Wright HA, and AW Bailey. 1980. Fire ecology and prescribed burning in the Great Plains - A research review. *USDA Forest Service*, *Report INT-77*. Ogden UT.