Maintaining Fire in British Columbia's Ecosystems: an Ecological Perspective

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Introduction

Fire is a key process and component of ecosystems in British Columbia. Nearly all ecosystems in British Columbia have evolved with fire and have the capacity to respond to fire as an important natural disturbance event. However, since the early 1900's fire suppression efforts have been focussed towards significantly reducing fire on the British Columbian landscape (Beck et al. 2005). Two currently suggested approaches to managing British Columbia's forests and rangelands, ecosystem management and managing for ecosystem resilience, both emphasize the importance of maintaining ecological processes in order to maintain the health and productivity of ecosystems. There is a need to adjust the approach of fire suppression efforts in order to maintain the beneficial presence of fire and thereby help to ensure the health, productivity, and resilience of British Columbia's forests and rangelands.

Land managers and decision makers require a guide to assist in determining where and what type of fire should be maintained on the landscape. This report provides a review of the importance of fire for British Columbia's ecosystems and outlines ecological factors that could be considered when determining British Columbia's approach to fire management. Obviously many other values and perspectives than the ecological role of fire must be considered in fire management decisions including human safety, community values, wildlife habitat, species at risk, and so on. These, along with the ecological perspective, are being combined and compiled into fire management plans that are currently being developed across British Columbia. This report outlines considerations for incorporating ecological perspectives into fire management decisions.

This report has several parts. Section 1 presents an overview of the different fire regimes that have historically interacted with and shaped British Columbia's diverse ecosystems. Section 2 presents a review of the importance of fire in maintaining British Columbia's ecosystems. Section 3 introduces the ecological approaches to ecosystem management that guide this report and provide ecological rationales for maintaining fire on the landscape. Section 4 discusses a number of ecological factors to be taken into consideration when determining where fire is desirable.

Section 1 Fire in British Columbia's ecosystems

Fire has influenced nearly all of British Columbia's grassland and forest ecosystems (Parminter 1991). However, the types of fire and the resulting ecological effects vary considerably across the province and among ecosystems. Weather, climate, type and condition of fuel, previous fire history, season, aspect, elevation, topography, and ignition source all interact to effect the behaviour of the fire, the intensity and the extent of the burn (Walstad et al. 1990, Parminter 1991). This multitude of variables results in fire having highly variable effects on the landscape both within a single fire and between different fires (Agee 1993, Burton et al. 2008, Jensen and MacPherson 2008, Keeley et al. 2009). However despite significant variability, similar ecosystems do tend to exhibit similar fire histories, often referred to as fire regimes.

Natural Disturbance Types (NDTs) are used to classify British Columbia's ecosystems into five broad categories of natural disturbance regimes (BC MOF and BC MELP 1995). Throughout much of British Columbia, the primary disturbance described by the natural disturbance regime is fire. Each NDT describes a natural disturbance regime in terms of disturbance type, intensity, size, and frequency (DeLong 1998). The description of disturbance regimes was developed using a combination of expert opinion and research (where available) (DeLong 1998). Research has since been conducted to refine our understanding of fire regimes and the NDT classification system in some areas of the province; however, at a provincial level, the current framework of 5 NDTs is in use (e.g. Blackwell and Gray 2003, Daniels et al. 2007, DeLong 2007, Gray and Daniels 2007). For example, DeLong (2010) has developed a classification system of 10 Natural Disturbance Units (NDUs) to describe the disturbance dynamics of north eastern British Columbia. The use of a number of natural dynamics studies to develop ten NDUs for an area previously described by three NDTs illustrates the importance of conducting further research to improve a system developed at a time when available research was limited.

Natural disturbance regimes are useful for describing the disturbance pattern typical for an area; however, these regimes can oversimplify the complexity of fire history. The fire history of many ecosystems is highly variable across both space and time (Jensen and MacPherson 2008, Meyn et al. 2009). For example within the boreal forest, numerous small stand level fires maintain a mosaic of stand types until a large fire burns through affecting thousands of hectares and significantly changing the landscape (Johnson et al. 1998). Most natural disturbance regimes refer to a specific range of fire sizes and frequency. This suggests that fire regimes remain relatively constant over time. However, numerous studies have shown that fire regimes have changed significantly over time independent of the effect of changes in land management accompanying European settlement. Often these changes are driven by changes in climate (Johnson et al. 1998, Bergeron et al. 2001, Daniels et al. 2007, Krawchuk et al. 2009, Meyn et al. 2009).

While keeping in mind that use of NDTs results in the simplification of a collection of complex processes, NDTs do provide a useful general description of the average fire regime of an ecosystem and a framework for classifying British Columbia's ecosystems. The following paragraphs provide brief summaries of each NDT and the disturbance regimes characteristic to these types primarily prior to European settlement. Within these descriptions are references to ecosystems using the biogeoclimatic ecosystem classification (BEC) system of British Columbia. Descriptions of these ecosystems are available within Ecosystems of British Columbia (Meidinger and Pojar 1991) or on the BEC website: http://www.for.gov.bc.ca/hre/becweb/. Complete listings of the ecosystems that fall within each NDT type can be found in the table: http://www.for.gov.bc.ca/hre/becweb/Downloads/Downloads_BECdb/BGCunits_Ver7_(2008).xls. Unless otherwise specified, the following NDT descriptions are referenced from the Forest Practices Code of British Columbia: Biodiversity Guidebook (BCMOF and BCMELP 1995).   For the purposes of this report, Natural Disturbance Units developed for northeast B.C. are not described in detail. For more information on these, more detailed and specific, natural disturbance regime descriptions see DeLong 2010.

Natural Disturbance Type 1: Ecosystems with rare stand-initiating events

Ecosystems with rare occurrences of stand initiating events are classified as NDT 1. These ecosystems tend to be uneven-aged or multi-storied even-aged stands where regeneration occurs in gaps created by the death of individual trees or small patches of trees. Disturbances that form these gaps include wind, small fires, landslides, insects, and disease. Based on expert opinion, mean disturbance return intervals range from 250 years for the Coastal Western Hemlock and Interior Cedar Hemlock ecosystems to 350 years for Engelmann Spruce – Subalpine Fir and Mountain Hemlock ecosystems. Landscapes typically consist of contiguous tracts of primarily mature and old forests with complex stand structure (including a variety of canopy layers and spatial patchiness). Stands typically exhibit old forest attributes when they exceed 250 years of age.

NDT 1 ecosystems include subzones within the Coastal Western Hemlock, Interior Cedar Hemlock, Engelmann Spruce – Subalpine Fir, and Mountain Hemlock zones. However, not all subzones within each zone are classified as NDT 1.

Natural Disturbance Type 2: Ecosystems with infrequent stand-initiating events

NDT 2 ecosystems are those which typically experience infrequent stand-initiating events. As a result NDT 2 ecosystems can be generalized as even-aged stands with extended post-fire regeneration periods. This results in stands with uneven-aged tendencies, most notably Engelmann Spruce – Subalpine Fir and Spruce Willow Birch ecosystems, where multi-storied forest canopies often result when undisturbed for significant periods of time. Wildfires tend to be moderate in size (20 to 1000 ha) with areas of unburned forest resulting from sheltering terrain features, higher site moisture or chance. Larger fires do occur after periods of extended drought but the landscape is dominated by extensive areas of mature forests surrounding patches of younger forest. The mean return interval for fire is approximately 200 years. Landscapes typically consist of extensive areas of even-aged stands with snags and veteran trees that have survived previous fires. Small areas that fire skipped may result in smaller patches of older forest occurring within a younger stand.

NDT 2 ecosystems include subzones within the Coastal Douglas-fir, Coastal Western Hemlock, Interior Cedar Hemlock, Engelmann Spruce – Subalpine Fir, Sub-Boreal Spruce, and Spruce Willow Birch zones. Not all subzones within each zone are classified as NDT 2.

Natural Disturbance Type 3: Ecosystems with frequent stand-initiating events

Ecosystems with frequent stand-initiating events are classified as NDT 3. These ecosystems are characterized by frequent wildfires that range from small spot fires to conflagrations covering tens of thousands of hectares. This results in a landscape mosaic of stands of different ages with individual stands being even-aged. The average fire size is 300 ha in some parts of the Boreal White and Black Spruce zone but as high as 6000 hectares in other parts of the zone where topographic features do not limit fire spread. The largest fires in the province are found in this NDT type and often exceed 100 000 hectares and sometimes 200 000 hectares. Fire dominated ecosystems with prominent components of deciduous species have a mean return interval of 100 years (Sub-boreal Pine – Spruce and Boreal White and Black Spruce). For Sub-boreal Spruce and Boreal White and Black Spruce ecosystems with primarily coniferous components a mean return interval is approximately 125 years. For Interior Cedar Hemlock, Engelmann Spruce – Subalpine Fir, and Montane Spruce ecosystems, the mean return interval is estimated to be about 150 years.

Coastal Western Hemlock wind dominated ecosystems are included in this NDT type. These ecosystems have a mean return interval of 100 years.

NDT 3 ecosystems include subzones within the Boreal White and Black Spruce, Interior Cedar Hemlock, Engelmann Spruce – Subalpine Fir, Montane Spruce, Sub-Boreal Spruce, and Sub-boreal Pine – Spruce zones. However, not all subzones within each zone are classified as NDT 3.

Natural Disturbance Type 4: Ecosystems with frequent stand-maintaining fires

Ecosystems with frequent stand-maintaining fires are classified as NDT 4. This NDT includes grasslands, shrublands, and forested communities that normally experience frequent low intensity fires. Frequent fires in grassland communities maintain the ecosystem state by limiting encroachment and establishment of most woody trees and shrubs. Less arid sites are characterized by open forests of large, old trees with thick fire-resistant bark. Patches of less fire-resistant species are found in areas that have escaped low-intensity surface fires. The varied intensity and frequency of fires across the landscape create a natural mosaic of mostly uneven-aged forests interspersed with grassy and shrubby openings. Common for this NDT are periodic surface fires that consume woody fuel, rejuvenate some herb and shrub species and select against others, thin younger stands and raise the height to live crown of the larger trees. A mixed severity fire regime characterizes this NDT as, in addition to low-intensity surface fires, larger stand-initiating fires do occur. Surface fire return intervals range from 4 to 50 years depending upon the ecosystem. Larger stand-initiating crown fires may be rare in the Ponderosa Pine zone but historically occurred at intervals ranging from at least 150 to 250 years or more in the Interior Douglas-fir zone. Much of this NDT is rangeland (both forested and unforested). Old forests are considered those greater than 250 years of age.

NDT 4 ecosystems include subzones within the Bunchgrass, Interior Cedar Hemlock, Interior Douglas-fir, and Ponderosa Pine zones. Not all subzones within each zone are classified as NDT 4.

Natural Disturbance Type 5: Alpine tundra and subalpine parkland

NDT 5 characterizes ecosystems found above or immediately below alpine treeline. These areas are characterized by a short, harsh growing season. Vegetation is strongly patterned by variations in local topography. Fire is rare as a disturbance type but where it occurs it has a dramatic effect by weakening or killing plants and causing long-term shifts in the position of the treeline. The harsh climate and short growing season restrict the rate of plant growth following stand initiating disturbance. The vast majority of the ecosystems within NDT 5 were considered to be climax communities prior to early settlement.

NDT 5 ecosystems include subzones within the Boreal Altai Fescue Alpine, Coastal Mountain-heather Alpine, Engelmann Spruce – Subalpine Fir, Interior Mountain-heather Alpine, and Mountain Hemlock zones. However, not all subzones within each zone are classified as NDT 5.

Section 2 Importance of Fire in British Columbia's Ecosystems

> *"Fire has been a part of nearly all the world's ecosystems for millennia.*
> *It plays a crucial and irreplaceable role in the ecosystems that support*
> *all life, but it understandably provokes fear in humans"*
> (p. 3 Jensen and McPherson 2008)

This section provides a broad overview of some of the important roles fire plays in the ecology of British Columbia. These roles include promoting diversity and complexity at multiple scales in forested and range landscapes and maintaining productive and functioning ecosystems. The potential negative ecological effects of removing fire from ecosystems through fire suppression is also discussed.

Fire promotes diversity on the landscape at a variety of scales. In general, fire is one of the primary disturbance processes that prevents an entire landscape from developing into a climax or old forest state (Parminter 1991). At a broad spatial and temporal scale, fire contributes to a landscape composed of a mosaic of stand sizes, seral stages, and forest stand attributes and structures (BC MOF and BC MELP 1995, Keeley et al. 2009). Fire plays a key role in developing ecosystem structure through the creation of young forests, open habitats (at a variety of scales), and burned snags (BC MOF and BC MELP 1995, Burton 2005). This in turn results in habitat and species diversity. Fire skips or islands of unburnt forest result from spatial variation in fire intensity, severity, and fuel (stand) types. This creates a significant level of variability on the landscape (DeLong 2007, Burton et al. 2008). Burton et al. (2008) found that these sources of variability and the complexity of the stands at the edges of the fire increase as fire size increases. Plant and animal diversity is also enhanced by fire as numerous rare species depend upon fire and the habitat it creates (Angelstam 1998, Keeley et al. 2009). Fire selectively favours certain species or creates conditions for new species to invade thereby also increasing species diversity over the landscape (Agee 1993).

In addition to diversity, fire plays a significant role in contributing to the complexity of ecosystems. Complexity is the interactive processes that occur within ecosystems that enable a system to resist stress and self-organize (recover) after disturbance and is considered a key component for resilient ecosystems. Complexity differs from diversity in that complexity, or viewing ecosystems as complex systems, involves recognizing not only diversity in terms of species and structure, but also the processes acting within the ecosystem, the interactions between the component parts and processes, feedback loops, forest ecosystem “memory” (biological legacies of previous states that influence present and future states), and that forest ecosystems are comprised of smaller units of biological organization that are also complex systems (Campbell et al. 2009, Puettmann et al. 2009). Recognizing and maintaining fire as one of the fundamental processes within British Columbia’s ecosystems is therefore key to maintaining their complexity and resilience.

The presence of fire in ecosystems is also considered a critical element for conserving and maintaining ecological function and productivity in the fire-driven ecosystems of British Columbia. For example, an important component of productive ecosystems is functioning nutrient cycling. Fire plays a role in nutrient cycling by changing the availability of nutrients and decomposing and recycling what other aspects of the ecosystem have not (Pyne 1989, Agee 1993). In promoting vegetation that turns over leaf matter quickly (herbaceous and deciduous species), the occurrence of fire builds the nutrient capital of the forest floor before the site returns to domination by conifers and conifer litter fall. Fire also contributes to the productivity of northern forests through reducing forest floor depth, reducing permafrost, and offsetting paludification (process leading towards thick, waterlogged, cold soils with low rates of decomposition and reduced forest growth) (Agee 1993, Fenton et al. 2005).

Fire resets ecosystems; the degree to which the ecosystem is reset is determined in part by the intensity, forest cover type, and size of the fire, among other characteristics (Pyne 1989, Kaufmann et al. 2005). Fires, across the spectrum from low intensity to high intensity, change the physical forest structure from creating vast open spaces which allow shade intolerant species regenerate to simply removing the herbaceous and woody understory below a sparse canopy of ponderosa pine. Depending upon intensity and cover type, fire provides for regeneration of different species by creating conditions such as higher light environments and improved seed bed conditions. This in turn provides habitat for the species that depend upon these attributes to regenerate and grow (Agee 1993, Kaufmann et al. 2005). For example, willow thickets form where fire has been very intense exposing mineral soil. This provides important habitat for many species of wildlife and birds (DeLong pers. comm. 2010).

Low intensity surface fires may play a significant role in reducing the risk of uncharacteristic high severity fires in some ecosystem types (Jensen and McPherson 2008). Many argue that the current era of forest suppression has resulted in excessive regeneration and fuel build-up in ecosystems which previously experienced frequent low intensity surface fires (Kauffmann et al. 2005, Myers 2006). In the past, frequent surface fires served to suppress woody plant regeneration and resulted in a bimodal vertical structure in the stands: a fuel gap existed between the tree crowns and the forest floor (Keeley et al. 2009). This limited the transfer of fire into tree crowns and therefore minimized the opportunity for low intensity surface fires to develop into higher intensity crown fires (Keeley et al. 2009). However, in areas with typically short fire return intervals and where effective fire suppression has occurred for a sufficient period of time, tree regeneration has survived to form a more uniform, dense, multilayered canopy and fuel has accumulated. In these areas the potential for large scale high intensity crown fires is much greater (Weaver 1943, DeBano et al. 1998, Shlisky et al. 2007, Keeley et al. 2009).

Shifting from primarily low intensity fire regimes to high intensity fire regimes leads to a number of ecological concerns in addition to immediate and obvious threats to human safety, rural structures, and community stability (Beck et al. 2005). A significant change in the disturbance regime to which an ecosystem has evolved and adapted will trigger many ecological changes, some unpredictable (Chapin et al. 2004). A much greater period of time may be required for forest recovery (Kaufman et al. 2005). During the recovery period, increased runoff and associated erosion, shallow soil mass movement, and long term sediment loading in watersheds may occur (Agee 1993, Kaufman et al. 2005, Keeley et al. 2009). High severity fires may also result in the spread of non-native and invasive species and the development of water-repellent soils (Kaufman et al. 2005).

It is important to note that this discussion of change in fire regime driven by fire suppression applies primarily to areas with frequent, low intensity fire regimes. As Jensen and McPherson (2008) and Johnson et al. (1998) discuss, fire suppression is not likely to have significantly affected ecosystems with high severity fire regimes where crown fires are typical. The forests with these fire regimes typically have a longer fire return interval than frequent low intensity fire regimes. Even in areas where fire suppression has been effective, the period of time over which it has occurred is much shorter than the average fire return interval. Therefore fire suppression is not likely to have resulted in a significant increase in fuel accumulation beyond what these ecosystems would normally experience (Jensen and McPherson 2008, Keeley et al. 2009). In addition, for these fire regimes, weather has been found to be the primary driver determining the occurrence of fire; fuel accumulation, stand age, and stand type play lesser roles (Jensen and McPherson 2008, Johnson et al. 1998).

Effective fire suppression over time may have negative consequences for any ecosystem, regardless of the characteristic fire regime. However, the length of time required for changes to the ecosystem to become evident will differ depending upon the ecosystem and the average fire return interval. A fundamental change to the ecosystem as a result of continuous fire suppression is a change in plant community composition (Beck et al. 2005, Kaufmann et al. 2005, Shlisky et al. 2007, Jensen and McPherson 2008). As discussed previously many species, especially in fire dependent ecosystems, depend upon fire for regeneration or for providing specific habitat requirements (Myers 2006). Therefore, limiting the occurrence of fire can result in a change in plant community and an associated loss of biodiversity as the conditions for numerous plants, animals, lichens, and many other organisms become scarce (Beck et al. 2005, Shlisky et al. 2007). Such significant changes in plant and animal community composition will have a multitude of cascading effects upon the ecosystem and the economic and social systems developed around the ecosystem. For example, a change in plant community from an herbaceous understory to a woody understory devoid of forage species has implications for range management and the ranching community (Kaufmann et al. 2005).

Section 3 Background to ecological approaches to fire management

British Columbia is internationally recognized for its spectacular natural environment. Much of British Columbia's economy including recreation, tourism, forestry, rangelands, and agriculture is dependent upon the maintenance, health and productivity of our forest and range ecosystems. As outlined in the previous two sections, fire plays a key role in supporting and maintaining the health and productivity of our ecosystems. In recent history the emphasis of wildfire management has been to suppress fire. However, the importance of maintaining the occurrence of wildfire on the landscape is increasingly being recognized in forest and wildfire management. In order to guide wildfire managers in difficult decisions regarding the degree to which fires are suppressed, ecologically based approaches to management may be useful.

Ecosystem management, which includes natural disturbance-based management, and more recently managing for ecological resilience and complexity, are two ecologically based approaches to natural resource management that have influenced management in British Columbia since the 1990s. Common to both approaches is an emphasis on the importance of maintaining the natural processes that ecosystems have evolved with and adapted to in order to maintain diverse, resilient, productive, and healthy systems (Holling 1973, Swanson et. al 1993, Harvey et al. 2002, DeLong 2007, Campbell et al. 2009).

Ecosystem management or managing to emulate natural disturbance dynamics are approaches to natural resource management that emphasize the importance of maintaining healthy functioning ecosystems and biodiversity by maintaining the characteristic structures and processes of the ecosystem (Franklin 1993, Hunter 1993, Bergeron et al. 2001). Biodiversity is difficult to describe or identify as a discrete entity due to its inherent complexity because we lack tangible models of sustainable ecosystems and because the majority of the component species and processes of northern ecosystems remain unknown (Franklin 1993, Morgan et al. 1994). In response to our lack of complete understanding of ecosystems and their component biodiversity, ecosystem management was developed. The assumption is that the biodiversity and healthy functioning of the ecosystem can be maintained and sustained, if the structures and processes that the ecosystem has evolved with are maintained (Franklin 1993). This is based upon the premise that the species within the ecosystem have evolved with and adapted to the natural disturbance events of their environment over the past 10 000 years. If this environment changes substantially and rapidly beyond the range of conditions to which it has adapted the potential for species loss or other undesirable ecological change to occur is increased (Swanson et al. 1993).

In order to apply these concepts, how do managers assess whether ecosystem structures and processes are sufficiently maintained? The concept of natural range of variability (also referred to as historical range of variation or range of natural variation) has been presented as a solution. The natural range of variability provides a guide for understanding the set of conditions and processes that sustained ecosystems prior to their recent alteration by humans (Morgan et al. 1994). It also provides a benchmark for managers to assess the current condition of the landscape by comparing it to the past ‘natural’ condition and for developing targets for management. One frequently used measure is the natural range of variability of fire return intervals. This has been used in British Columbia in the development of ecosystem-based management for the Great Bear Rainforest, portions of the Northern Interior Forest Region, and in timber supply reviews (BCMSRM 2004, DeLong 2007, Price et al. 2009).

The concept of managing for ecosystem resilience also recognizes the importance of maintaining key ecological processes on the landscape. Managing for ecosystem resilience has arisen with the recognition that climate change will likely result in climates changing beyond the historical boundaries experienced by ecosystems over the past several centuries to millennia (Millar et al. 2007). Therefore managing ecosystems strictly within the range of historical natural variability will be neither realistic nor potentially even achievable (Millar et al. 2007, Campbell et al. 2009). Managing for ecological resilience is an alternative approach to ecosystem management or emulation of natural disturbance based dynamics that promotes managing for ecosystems that are resilient in the face of a changing climate and other pressures such as cumulative land use effects. Ecosystem resilience describes the "capacity of an ecosystem to absorb disturbance without collapsing into a qualitatively different state." (www.resalliance.org/567.php, Holling 1973). Expressed alternatively, maintaining resilience minimizes the risk of undesirable future outcomes arising from forests ill-adapted to future conditions (Millar et al. 2007)

How can resiliency be achieved? One primary means for managing for ecosystem resilience is through maintaining "the inherent complexity of ecosystems and therefore ecosystem response diversity to environmental change so that ecosystem vulnerability to any single future disturbance event is low and the potential to reorganize following disturbance remains high (p.8 Campbell et al. 2009). Key to maintaining and generating complexity in ecosystems is maintaining characteristic ecological processes including nutrient and water cycling and fire (Millar et al. 2007, Campbell et al. 2009).

What is clear from this review of models of ecosystem management is the importance of maintaining fire as an ecosystem process on the landscape in order to maintain healthy, functioning ecosystems in an uncertain future. Natural range of variability can be used a guide to assist fire managers in assessing where, with what frequency, and what size of fire would be typical of the natural occurrence of fire on the landscape and would support healthy, productive ecosystems.

Section 4 Managing fire on the landscape: key factors from an ecological perspective.

Balancing the ecological importance of fire on the landscape with the needs and values of our expanding population and the considerable impact of human settlement and resource management is difficult. From an ecological perspective nearly any naturally occurring fire is beneficial to a fire adapted ecosystem. Human caused fire may also be ecologically beneficial so long as it is characteristic of the natural fire regime. This section discusses some ecological factors that are important to incorporate into a fire management strategy that recognizes the ecological importance of fire on the landscape.

Historical Fire Regime and Mature and Old Forests Components of the Ecosystem

As discussed in the previous section, the basic assumption behind ecological approaches to management is that the further an ecosystem is altered from the natural range of conditions to which it has adapted and developed, the higher the risk to biodiversity (BC MSRM 2004). Both maintaining fire and maintaining representative components of mature and old forests on the landscape are important factors for managing for healthy ecosystems and biodiversity.

The natural range of variability of fire regimes can be used to guide fire managers in determining what type, frequency, and size of fire historically occurred on the landscape. Across British Columbia, Natural Disturbance Type information can be used to provide this information (BCMOF and BCMELP 1995). For some areas of the province, more detailed analyses of the natural disturbance regimes are available including DeLong (2010) and Morgan (2009).

Further refinement of our understanding and description of the natural range of variability of fire regimes is important for ecosystem management including fire management. Fire regimes are not static or frozen in time (Jensen and McPherson 2008). They describe systems with significant variation in fire return intervals (Bergeron et al. 2001). In addition there are significant limitations to easily determining the range of variation of a fire regime including a lack of historic data, difficulty in interpreting historical records, a future that is likely without historical precedent, the infrequent nature of disturbance, and the catastrophic nature of disturbances that often destroy evidence of past disturbances (Morgan et al. 1994). Despite challenges to describing fire regimes, DeLong (2007) has shown that with further research, significant improvements can be made to the basic Natural Disturbance Type framework.

It is consistently recognized that mature and old forest on the landscape is important for maintaining resilient and functioning ecosystems (Pojar et al. 1992). Fire has the ability to significantly affect the amount of old and mature forest on the landscape. There are different measures that may be used to assess if the current old and mature forest on a landscape falls within the natural range of variability (NRV) of that ecosystem. One that has been used in Timber Supply reviews and by the ecosystem-based management approach developed for the Great Bear Rainforest and portions of the Northern Interior Forest Region is a comparison of the amount of old forest remaining on a landscape to the amount of old forest that would naturally occur on that landscape without human intervention. These processes have established targets for the minimum amount of old forest retained on a landscape as a percentage of that which would naturally occur based upon the fire return interval (BCMSRM 2004, DeLong 2007, Price et al. 2009).

The minimum targets established for old forest are based upon evidence in the literature that thresholds exist for the amount of habitat required to support certain ecosystem components. However, there is limited consensus on how much habitat is required to avoid crossing a threshold, beyond an agreement that the amount will vary among organisms and across ecosystems (Price et al. 2009). Price et al. (2007) conducted a review of studies on ecological thresholds suggesting that above a threshold of 70% of the minimum range of natural variation, risk to biodiversity is low. When retention of old forest falls below 30% of the minimum range of natural variation, risk to biodiversity is high. If the amount of old and mature forest within the area of a specific ecosystem (BEC subzone) on the landscape, falls below this threshold value, it is recommended to strive to maintain the remaining mature and old forest and suppress fires that threaten further loss of old forest. The amount of old and mature forest that would naturally occur on a landscape, given a specific fire return interval, can be calculated using the negative exponential equation presented by Johnson and Van Wagner (1985). This equation uses the fire cycle to directly calculate the area of forest remaining at a given time. For the purposes of the Fire Response Decision Matrix developed for Northern Interior British Columbia, a threshold value of 50% was utilized.

Mountain Pine Beetle

The mountain pine beetle (MPB) has affected vast areas of British Columbia's forests and killed a significant component of mature lodgepole pine. However, the mortality of pine is not currently reflected in the provincial VRI inventory mapping. Therefore, when fire managers consider how much mature and old forest remains on a landscape with considerable MPB attack, the amount of live old forest may currently be overestimated. Without considerable study and surveying effort, it is difficult to assign an age class or comparable value to MPB attacked stands. A significant portion of stands with MPB attack may still contain a significant proportion of live trees of other species both in the canopy and the subcanopy (secondary structure). Depending upon the degree of MPB attack, the amount of live trees remaining, and the structure of the stand, these stands may or may not provide the same ecosystem function and services as mature or old live stands. Therefore the degree and intensity of MPB attack provides an interesting twist for the fire manager who is considering the desirability of fire on a landscape.

Climate Change and Carbon Emissions

Weighing the importance of maintaining fire in order to support a healthy functioning ecosystem against the impact of carbon emissions from fire contributing to climate change and thereby potentially threatening the ecosystem is complicated. In order to minimize the impact of carbon emissions from fire, local ecologists have emphasized the importance of minimizing fire in two forest types with high carbon storage implications (Pojar, Haeussler, Banner pers. comm.). These are: young, rapidly growing forests and moist, rich, high productivity forest types. Young forests grow rapidly and sequester considerable amounts of carbon. Moist, rich, high productivity forests have the capacity to store large quantities carbon at all stand ages. In addition to carbon sequestered within the trees themselves, all other organic components of the ecosystem also sequester significant quantities of carbon (i.e. understory shrubs, herbs, moss, coarse woody debris, organic soil layer, etc.).

Young rapidly growing forests will generally be given high priority for protection due to timber values considered in other aspects of the fire response decision process. Moist, rich, high productivity forests tend to be ecosystems with longer fire return intervals (NDT 1 and some areas of NDT 2) which reflect the low risk of fire occurring in these types. Therefore the occurrence of fire in these ecosystems is generally minimal to infrequent, fire size is small, and the emission of carbon is reflected similarly. Fire occurrence and area burned in these types should be monitored over time especially in areas affected by climate change.

Species at Risk, Critical Wildlife Habitat, and Climate Refugia

Species at risk, critical wildlife habitat, and climate refugia are also important ecological factors that should be considered by fire managers when determining where fire occurs on the landscape. Species at risk information and critical wildlife habitat data are available and can be incorporated into fire management plans.

Climate refugia are unique areas on the landscape with local climates that are not projected to change significantly in the near future as the landscape surrounding these spots change. These refugia will be valuable for providing habitat and sources of recruitment for species as surrounding areas change and disturbances occur. Work has begun to identify climate refugia in British Columbia (see Rose and Burton 2009). As research continues and new information becomes available for species at risk, critical wildlife habitat and climate refugia, this information should be incorporated into fire manager's decision making processes.

Ecological Impact of Fire Suppression Activity

Jensen and McPherson (2008) argue that fire suppression, although playing an important role in human safety, must also be recognized as an inherently harmful effort. In addition to potentially changing historical fire regimes in some areas from typically low intensity surface fires to high severity, high intensity crown fires, the process of fire suppression itself can cause significant damage. Building roads and fire guards contribute to fragmentation of landscapes, provide avenues for the spread of nonnative and invasive species, and increased soil erosion due to clearing and compaction of the soil. Use of water from nearby aquatic systems can significantly reduce water levels and fire suppressant foams and chemicals are known to be toxic to aquatic flora and fauna.

Conclusion

Fire is a naturally occurring process and has also been used for centuries by first nations peoples to shape and form the landscapes and resources familiar to British Columbians (Beck et al. 2005). Fire has occurred in nearly all ecosystems in British Columbia and most ecosystems are resilient to fires within a broad range of variation of frequency and intensity (Keeley et al. 2009). As a result, fire is integral to maintaining the productive and healthy functioning ecosystems upon which all British Columbians depend. It is important for fire management to maintain the presence of fire as a functioning process on the British Columbian landscape recognizing the ecological importance of fire and the negative implications of fire exclusion. This is one key part of maintaining forests that are resilient to our changing environment and that continue to function as productive ecosystems supporting British Columbia's ecological, societal and economic sustainability goals (Campbell et al. 2009).

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