The Effect of Physiography and Topography on Fire Regimes and Forest Communities

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EXECUTIVE SUMMARY

The historic fire regimes found in south aspect NTD3 and NTD4 polygons sampled in 5 forest districts (Invermere, Cranbrook, Kamloops, Lillooet, and Squamish) were characterized by high fire frequency with narrow variability around the mean, and variable intensity. Mean fire intervals (MFI) recorded for the 5 sites ranges from a low of 6.5 for Lillooet and a high of 17.9 for Invermere. The MFI's recorded are some of the lowest numbers recorded in the province.

The results of the analysis on south aspects suggest frequent, mixed-severity fire regimes have influenced historic stand structure and ecosystem processes in biogeoclimatic subzones and variants currently considered to have experienced infrequent stand-replacement fire regimes. This is true for the MSdk in Cranbrook, MSdm1 in Invermere, MSxk in Kamloops and Lillooet, and the ESSFmw in Squamish. Additionally, significant issues exist in some Forest Districts concerning inaccuracies in the current mapped distributions of biogeoclimatic units. These identified discrepencies can have significant consequences where the conservation of biodiversity is concerned. The current designation of many of these biogeoclimatic units as Natural Disturbance Type 3 warrants further investigation. Fires appear to be of more mixed-severity as opposed to infrequent, high-severity.

Throughout the western U.S. on National Forest and National Park Service lands, managing to the historic, or natural range of variability, is the current management philosophy. Determining the historic fire regime, other disturbance regimes, and the range of historic ecosystem structures and species is the pre-requisite data input to this management process (FEMAT 1995; Ogle and DuMond 1997; USDA 1997; Cissel *et al.* 1998; Harrod *et al.* 1999; Hemstrom *et al.* 1999; Lint *et al.* 1999; Swetnam *et al.* 1999).

A similar approach to landscape level planning and management has been instituted in British Columbia. Across the province large landscape units encompassing thousands of hectares are currently being either managed or are in the planning stages for management of single uses in allocated areas. This approach is often based on false assumptions regarding the underlying disturbance ecology. With regards to some land allocations, their emphasized uses, and internal management strategies, there appears to be little recognition of the need for compatibility with the underlying ecosystem processes. Because most NDT4 ecosystems are well outside their HRV for structure, composition, and disturbance regime, allocations appear incompatible. Additionally, if the areas currently assumed to be NDT3 are incorrect, the future sustainability of biodiversity attributes in those locations may also be compromised.

Within landscapes there has been a high level of stand structure and species composition variability due to the highly variable fire behavior and fire effects inherent in the historic fire regime. Historically diverse landscapes in short fire return interval ecosystems owe their diversity to heterogeneous fuel complexes. The more homogeneous a fuel complex becomes the more homogeneous are the potential effects once burned. This relatively simple truth should be the driving force behind planning for biodiversity whether at the landscape-scale or at the operational -scale. Unfortunately, the planning for biodiversity

is commonly determined using forest cover inventory, and outdated information and assumptions on disturbance ecology. Landscape-level planning for biodiversity under these conditions is not accurately identifying: 1) key biodiversity attributes on the landscape (age has become the surrogate for this); 2) appropriate locations on the landscape in which to try to retain key biodiversity attributes; 3) the proper historical context of biodiversity attributes; and, 4) the threats to key biodiversity attributes

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1.0 BACKGROUND

1.1 Review of relevant literature from North America

Each forest type tends to have unique and diverse effects when burned due to variations in fire characteristics, such as frequency and intensity. These effects are also linked to the species present and to the adaptations of each to the specific combination of descriptors, which can be called a fire regime. A fire regime is a generalized description of the nature of fire occurring over long periods and the prominent immediate effects that generally characterize an ecosystem. Descriptions of fire regimes are general and broad because of the enormous variability of fire both spatially and temporally. Ecological effects of fire on an ecosystem can be more precisely described if effects can be grouped by fire regimes. However, this can lead to the same difficulties that underlie any ecological classification. One difficulty is that putting boundaries around segments of biological processes that vary continuously involves some degree of arbitrariness. The dilemma is that for a classification system to be useful to managers and non-technical persons it must be practical and easily communicated, thus free of complexity. However, to accurately reflect the nature of a complex biological process, such as response to fire, it must account for a complexity of interacting variables. A trade-off between practicality and accuracy or between simplicity and complexity is required (Brown 2000).

The fire regime concept brings order to a complicated body of fire behavior and fire ecology knowledge (Brown 2000). Systems for describing fire regimes may be based on the characteristics of the disturbance (Heinselman 1981; Johnson and Van Wagner 1985), the dominant or potential vegetation of the ecosystem in which ecological effects are being summarized (Davis *et al.* 1980; Bradley *et al.* 1992; Smith and Fischer 1997), or fire severity based on the effects of fire on dominant vegetation (Agee 1993). The fire regimes of western forests are usually described in terms of historical fires, and interpreted much the same way as potential vegetation i.e. what occurred historically and what the successional of change may be with or without management (Agee 1998). From an understanding of historic fire regimes, estimates can be made of the influence and outcomes of management actions on a wide range of ecosystem structures and processes.

In this report the 4 "pre-settlement" fire regime types described by Brown (2000) will be used. These include:

1. *Understory fire regime* (applies to forests and woodlands) – Fires are generally non-lethal to the dominant vegetation and do not substantially change the structure of the dominant vegetation. Approximately 80% or more of the aboveground dominant vegetation survives fires.
2. *Stand-replacement fire regime* (applies to forests, woodlands, shrublands, grasslands) – Fires kill aboveground parts of the dominant vegetation, changing the aboveground structure substantially. Approximately 80% or more of the aboveground dominant vegetation is either consumed or dies as a result of fires.
3. *Mixed severity fire regime* (applies to forests and woodlands) – Severity of fire either causes selective mortality in dominant vegetation, depending on different tree species' susceptibility to fire, or varies between understory and stand replacement.
4. *Nonfire regime* – Little or no occurrence of natural fire.

In Brown (2000) all ecosystem types other than forest and woodland are considered to have stand-replacement fire regimes because most fires in those ecosystem types either kill or remove most of the aboveground dominant vegetation, altering the aboveground structure substantially. Most belowground plant parts survive, allowing species that sprout to recover rapidly.

Ecosystem types that match this fire regime are tundra, grasslands, and shrublands. Because grassland, tundra, and shrublands are stand-replacement fire regime types, a more interesting aspect of fire regimes in these ecosystems is fire frequency, which can vary substantially and has a major influence on vegetation composition and structure.

The mixed severity fire regime can arise in 3 ways:

- Many trees are killed by mostly surface fire but many survive, usually of fire resistant species and relatively large size. This type of fire regime was described as the "moderate severity" regime by Agee (1993) and Heyerdahl (1997).
- Severity within individual fires varies between understory burning and stand-replacement, which creates a fine-grained pattern of young and older trees. This kind of fire regime has not been recognized in previous classifications. It probably occurs because of fluctuations in weather during fires, diurnal changes in burning conditions, and variation in topography, fuels, and stand structure within burns. Highly dissected terrain is conducive to this fire regime. In actuality, a blend of these 2 mixed severity types probably occurs.
- Fire severity varies over time with individual fires alternating between understory and stand replacement. Kilgore (1987) described this as the "variable" regime and applied it to redwood forests.

The primary ecological knowledge imparted by fire regime types is whether fires leave the dominant aboveground vegetation standing and alive or result in stand-replacement. To reflect this, the fire regime types described by Brown (2000), are characterized as nonlethal understory fire, stand-replacement fire, and mixed severity fire.

Forests of all types can be grouped into the understory, mixed, or stand-replacement fire regimes, which correspond to low, moderate, and high fire severity types described by Agee (1993). Some forest types occurring over a wide range of environmental conditions can fall into 2 fire regime classes. For example, most lodgepole pine and jack pine forests have been characterized by stand-replacement fire in contemporary literature. However, some of these forests, typically occurring on drier sites, reflect a mixed fire regime history (Gara *et al.* 1986; Stuart *et al.* 1989; Parker and Parker 1994). Evidence (Arno and others [in press]; Frost 1998; Beatty and Taylor 2001) indicates that the mixed fire regime type was more prevalent than previously thought, especially in coniferous forests. As fire moves across the landscape its behavior and effects can change dramatically due to variability in stand structure, fuels, topography, and changing weather elements. This can result in highly variable tree mortality and survival patterns within a fire's boundary (Brown 2000).

In describing fire regimes it is often advantageous to refer to a variety of fire characteristics in order to define the fire regime more precisely. Common characteristics used to define fire regimes include fire frequency, predictability, magnitude (intensity or severity), extent, seasonality, synergism with other disturbances, and gap, or patch-size dynamics (Martin and Sapsis 1991; Agee 1993; Agee 1998; Brown 2000). The determination of the range of variability for each of the fire characteristics can rely on a number of sources depending on the availability of biophysical evidence, written records, historic photographs, and oral reports. The historic "depth" of the data varies by location; however, for most of North America, detailed information is only available for the last 300 or so years (Brown 2000).

The period of time between successive fires on an area is the characteristic often used alone to describe fire regimes. Frequency is one of the easier and more quantitative characteristics to describe because it is often based on fairly simple empirical data. Fire frequency statistics often include the mean plus some indication of dispersion around the mean such as the minimum and maximum intervals. Fire history studies used to develop the frequency statistics should state whether or not cross-dating was used to correct the chronology of fires as recorded by separate trees in a study with a master tree ring chronology (Martin and Sapsis 1991).

Predictability, or variation in fire frequency, helps explain the presence or absence of some species in ecosystems. It is often useful or beneficial to describe fire regimes by fire effects on individual species that are adapted to that regime. Such adaptations can be to the mean fire frequency or to the range of variability around the mean. For example, shrubs may be adapted to fire by 1 of 2 mechanisms either they sprout, or they have seeds that are able to survive the fire and help replace the mature individuals killed by the fire. In this example the seeding-type shrubs need 5 years before they reach maturity and set seed. In a fire regime where fire frequency is exactly 30 years (very predictable) or even 20 to 40 years, both types of species will be found because the disturbance allows each type of species to complete its life cycle. However, fire regimes and their associated fire behavior are rarely this exact. Expanding on the example of the shrub species, in a portion of the landscape, 1 fire cycle is missed but is made up by 2 fires in close succession; 2 to 3 years apart. At the time of the second fire, the population of seeder-type shrubs, all of which were killed by the first fire, has no mature individuals. The seedbank created by the previous generation has germinated, resulting in a population of seedlings 2 to 3 years old, none of which is capable of setting seed yet. After the second fire, which kills the immature individuals, the shrub population will consist primarily of sprouting species, a result not of the average fire frequency, which may have stayed the same, but rather the predictability of the event (Agee 1993; Agee 1998).

Two of the earliest fire regime classification systems, Heinselman (1978) and Kilgore (1981), used fire frequency and intensity to form the basis of their classification systems. A difficulty with fire intensity is that a wide range of intensities, including crown fire and surface fire, can cause stand-replacement because mortality to aboveground vegetation is complete or nearly complete. Generally, the severity and intensity of fire are inversely related to fire frequency (Swetnam 1993). For example, stand-replacement fires tend to occur in forests with low fire frequency, and understory to mixed severity fires tend to occur in forests with high fire frequency (Brown 2000). Another issue is the significant difference in meaning between the terms "intensity" and "severity" when used to describe fire effects. Fire intensity relates only generally to fire severity (Brown 2000). Fireline intensity is derived from the energy content of fuel, the mass of fuel consumed, and the rate of spread of the fire. The units of fireline intensity reflect energy release (kW or btu's) per unit length (m or ft) of fireline per second; energy release along a linear fire front. The length of the flames of a fire can be related to its fireline intensity (Agee 1993). The severity of fire reflects the immediate or primary effects of fire that result from the intensity of the propagating fire front and heat released during total fuel consumption. Some of these primary effects include: degree of crown scorch and consumption, bark char, injury or mortality of plant species, organic matter consumption, and the degree of exposure, discoloration, or other immediate changes in the soil (Martin and Sapsis 1991; Brown 2000). The units of fire severity reflect energy release (kW or btu's) per unit area (m^2 or ft^2) per minute: energy release over a set location for a period of time (reaction intensity). This value gives an indication of heat residence time and its ecological impacts (Rothermel 1983).

Dimensions of fires commonly characterized for a fire regime includes definitions of the areal extent that the fire reaches, the characteristics and effects of unburned areas within the fires, and the juxtaposition of each fire and its islands to other fires, both temporally and spatially (Brown 2000). In short-interval, low-severity fire regimes such as southwestern ponderosa pine, it is not possible to reconstruct the exact perimeter of historic low-intensity burns. This is in contrast to lower frequency, stand-replacement fire regimes (such as boreal, or montane spruce-subalpine fir) where the extant stand structure (e.g., ages or heights of trees) can be used to estimate the perimeters of some past burns (Swetnam and Baisan 1996). Often the size of a fire may be for an entire complex of fires that burned in the same vicinity at the same time. This is frequently the case for groups of lightning caused fires, which tend to be grouped in time and locale. These fires often burn together, and for practical purposes, they constitute a single fire when assessing size. The second aspect of fire regime dimension, which is extremely important from the standpoint of fire effects, is the unburned areas, or "islands" within the fires (Brown 2000). These unburned islands are important as refugia for the biota from which burned areas may be repopulated. The size, number, and distribution of unburned islands, as well as their physiographic characteristics and subsequent weather, will govern their effectiveness in restoring populations to the burned areas. Similarly, fire shape is an important characteristic that influences the patterns of edge – where burned areas interface with unburned areas. The significance of dimensions of past and present fires changes when future fires are taken into consideration, as effects accumulate (Martin and Sapsis 1991). These effects can include those associated with recurrent fire and effects caused by a significant lapse in fire activity.

Determining the areal extent of past fires in short-interval fire regimes where individual fires do not result in large-scale stand mortality is difficult to do (Agee 1998). In infrequent, stand-replacement fire regimes, the boundary, and hence the area of individual fires, is easily determined from aerial photographs and age-class analysis across the boundary between the 2 types. In short-interval fire regimes the areal evidence of individual fires can best be determined by linking point locations of specific fire dates (Schellhaas *et al.* 2000a; Schellhaas *et al.* 2000b; Kaufmann *et al.* 2001) and speculating on the physical boundary of the fire by equating probable fire behavior with the sites topography and physiography (Everett *et al.* 2000; Schellhaas *et al.* 2000a; Schellhaas *et al.* 2000b; Kaufmann *et al.* 2001; Schellhaas *et al.* 2001; Gray *et al.* [in press]). This method is best used where plot density is high relative to the landscapes being studied.

Seasonality of fires describes the propensity of fires to occur during certain seasons of the year (Martin and Sapsis 1991). As with the periods between fires, the season of the year during which fires occurred could have a profound effect on the results (Agee 1993). Not only the characteristics of the fires might be different, but also the phonological or ontogenetic state of the plants, activity of arthropods that might attack plants, and the reproductive stage of other animals might be such as to bring about different effects, resulting in variability in ecosystem response (Martin and Sapsis 1991).

Fire may interact with other disturbances in a synergistic manner. Insects, disease, and wind may follow fire events with more than endemic background effects, and conversely, accelerated fire effects may follow other disturbances (Agee 1998). The reduction in forest canopy can cause hydrologic disturbances to take place or to increase their destructive potential. At a finer scale the creation of hydrophobic soil layers can lead to smaller-scale hydrologic disturbances. Other abiotic synergistic relationships involve wind, and snow. Biotic relationships include fungi accessing living trees through wounds created by fire, and fires weakening trees and increasing susceptibility to insect attack (Agee 1993).

Canopy "gap" or "patch" size and distribution is another characteristic of fire regimes. Low-severity fires that result in very little to no overstory mortality don't change the size or distribution of canopy patches on the landscape. With increasing fire severity (lethality), which is correlated with increasing mean fire interval and the accumulation of fuels, landscape patches increase in dimension (Table 1; Agee 1998; Agee 2001).

Table 1. Patch size character associated with western forest fire regimes (from Agee 1998).

Severity of fire regime	State/Province of study	Forest type	Patch size (ha) Mean	Median	Range
Low	AZ	Ponderosa pine (Cooper 1960)	-	-	0.06-0.13
Low	AZ	Ponderosa pine (White 1985)	-	-	0.02-0.29
Low	OR	Ponderosa pine (West 1969)	0.25	-	-
Low	OR	Ponderosa pine (Morrow 1985)	-	-	0.025-0.35
Low	CA	Mixed conifer (Bonnicksen and Stone 1981)	-	-	0.03-0.16
Moderate	OR	Red fir (Chappell and Agee 1996)	2.67	0.84	0.11-31.09
Moderate	OR	Red fir (Chappell and Agee 1996)	1.34	0.39	0.12-10.08
Moderate	OR	Douglas-fir (Morrison and Swanson 1990)	8.46	2.22	0.13-74.71
Moderate	OR	Douglas-fir (Morrison and Swanson 1990)	11.03	2.70	0.15-253.23
High	WA/OR	Western hemlock-Douglas-fir (Agee 1993)			>10,000
High	ID	Western hemlock (Stickney 1986)			>10,000
High	MT/WY	Lodgepole pine-subalpine fir (Romme and Despain 1989)			>10,000
High	OR	Mountain hemlock (Dickman and Cook 1989)			>3,200
High	AL	White and black spruce (Eberhart and Woodard 1987)			0.01-17,700

1.2 The BC context

In British Columbia, individual plant associations are assembled into similar groups based on historic disturbance regimes. These natural disturbance types (NDTs) are further stratified by the relative effect of the historic disturbance regime on plant community composition and structure (Ministry of Environment, Lands and Parks and Ministry of Forests 1995). Biogeoclimatic subzones (Krajina 1963) that historically experienced frequent, stand-maintaining fires are categorized as NDT4, while adjacent subzones that experienced frequent stand-initiating (also referred to as stand-replacement) wildfires are categorized as NDT3. The mean return interval of stand-maintaining fires in NDT4 ecosystems ranges from 4 years to approximately 20 years (Gray and Riccius 1999; Riccius 1998; Gray 2000; Blackwell *et al.* 2001; Gray *et al.* 2002). Adjacent NDT3 sites are assumed to have mean fire intervals ranging from 100 to 150 years (Ministry of Environment, Lands and Parks and Ministry of Forests 1995).

Biogeoclimatic subzones that were historically associated with frequent stand-maintaining fires are: bunchgrass (BG), ponderosa pine (PP) (*Pinus ponderosa* Dougl. Ex Laws.) and interior Douglas-fir (IDF) (*Pseudotsuga menziesii* [Mirb.] Franco. Natural disturbance type 3 subzones that are often located adjacent to NDT4 subzones include: coastal western hemlock (CWH), montane spruce (MS), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)/subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) (ESSF), and moist interior cedar/hemlock (ICH) series. The historic NDT4 subzones were maintained in a seral state through frequent fire; ignited by either First Nations people or lightning. The concept of "old growth" with climax, shade-tolerant vegetation, as a self-perpetuating stage of succession (Bormann and Likens 1979; Habeck 1988; Franklin and Spies 1991; Oliver and Larson 1996) derived along a linear, relay floristics pathway (Zwolinski 1994; Oliver and Larsen 1996), has no real validity in the context of the historic NDT4 ecosystem (Wenatchee National Forest 1997). Succession is instead characterized by initial floristics and a mostly stable stand structure (Zwolinski 1994; Oliver and Larsen 1996). Researchers studying historic fire regimes and stand structure in NDT4 ecosystems have found significantly altered stand structure conditions since approximately the late 1800's. This includes increased surface fuel loading, increased stand density, and an increased number of shade-tolerant species (Agee 1993; Covington *et al.* 1994; Camp *et al.* 1995; Arno 1996; Everett *et al.* 1997; United States General Accounting Office 1999). The primary cause of the structural changes is a cessation in frequent fires (Arno 1996). With this change in ecosystem structure has come an altered fire regime that more closely resembles that associated with NDT3 ecosystems (Camp *et al.* 1995).

The shift in NDT4 ecosystem structure and composition, and the subsequent departure in disturbance regime from the historic range of variability (HRV) (Morgan *et al.* 1994; Swanson *et al.* 1994; Swetnam *et al.* 1999), has been studied and the conclusions accepted for a large portion of western North America. Management decisions, including species composition, stocking standards, understory composition, fuel management treatments, and the schedule of maintenance prescribed burning, are being applied across wide geographical areas within this disturbance type (Wenatchee National Forest 1997; Kootenay/Boundary Land Use Plan 1997). In contrast, far less is known about historic stand structure and disturbance regimes in adjacent NDT3 ecosystems. The definition of this NDT implies a linear succession process from high-severity disturbance, to pioneer (seral) community, and eventually "old growth."

On many landscapes NDT4 BEC subzones transition directly into NDT3 subzones along an aspect and elevation gradient (Figure 1). Under this model, wherever NDT3 subzones are located, the principal disturbance regime (wildfire) occurs rarely. However, when wildfire does occur it results in the death of the majority of the stand. These fires are assumed to be large in extent, more often than not resulting in large-scale even-aged forests (Ministry of Environment, Lands and Parks and Ministry of Forests 1995).