FIRE REGIME ANALYSIS

MOUNT REVELSTOKE NATIONAL PARK

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1.0 INTRODUCTION

The natural vegetation mosaic of the Columbia Mountains forest has been shaped for thousands of years by wildfires. In fire regulated ecosystems, fire plays an important role by maintaining the biodiversity and preserving characteristics specific to these ecosystems. Large fires have been mainly excluded from most landscapes in the past sixty years with the advent of better detection systems, quicker response time, and better fire fighting technology. It is certainly true for Mount Revelstoke National Park (MRNP) where the current fire management policy still consists of extinguishing all wildfires. This is an understandable practice considering the small size of the park and the liability concern to timber licensees which extract forest resources in proximity to all corners of the park. However, the prolonged lack of disturbance within the park may be leading to ecological problems if no form of disturbance, reminiscent of the historical fire regime, is re-introduced in the near future.

The goal of this study is to improve our understanding of the fire regime characterizing MRNP, so that fire and fuel management practices can better approximate the effect of historical disturbances. The fire regime is defined by the frequency, type (man vs lightning caused), intensity (surface, passive crown fire, stand replacing) and size of fires occurring on the landscape. In order to gain insights to the fire regime, fire history studies have been a successful approach. Typically, regions of the mountain and boreal forests of British Columbia and Alberta are characterized by infrequent stand replacing fires. Lighter intensity fires, such as surface fires, also do occur but evidence of these are much more difficult to detect. Large fires have a tendency to erase evidence of previous fires over time. To partly overcome this problem, stand origin mapping has been the main method used in the mountain and boreal regions of Canada. This method consists of mapping all forest stands by their age of origin, which is assumed to have been fire originated.

However, due to the small size of MRNP, as well as the presence of the icefield in its centre, the park does not offer an adequate array of forested landscape to produce a stand origin map and, to study the size, frequency and distribution of fires within the park. Also, because the park is mainly composed of small valley headwaters, its disturbance regime is likely highly dependent on external factors (physical and anthropogenic). The size and landscape configuration of the park also fail to meet most of the criteria of the Weibull model that are necessary for calculating the fire cycle

(Johnson and Van Wagner 1985, Johnson and Gutsell 1994) First, the park is too small in relation to the largest size of forest fires that can occur in the B.C. Interior forest, and second, the rugged topography of MRNP precludes the landscape from having a homogeneous fire regime. In this regard, a recent study (Rogeau *et. al.* 2000) has shown that fire distribution on the east slopes of the Canadian Rockies is not a random event and that valley orientation, elevation, proximity to the Continental Divide and aspect, account for 64 percent of the variance in stand ages. Note that a stand origin map following methods by Johnson was developed in the late 1980's for Glacier National Park, but there are concerns about the results and conclusions drawn from that map for the reasons stated above.

Considering the issues stated above, stand origin mapping did not appear to be a viable option to fulfill the goal of this study. The forest mosaic, being a non-static element, suggests that it would actually be wiser to understand the likelihood of a landscape unit to burn by spatially quantifying probabilities of burning, rather than by dating every single hectare on the landscape. This was achieved in three ways: 1) by using a field sampling scheme designed to estimate fire return intervals and target all valley orientations, aspects and elevation within MRNP; 2) by studying causal factors of ignition and, 3) by modeling fire distribution over the landscape. To gain a better understanding and perspective of the natural processes at work within MRNP, the last two procedures were performed on a broader landscape. The size of the Greater Mount Revelstoke National Park area was determined by the size of the watersheds surrounding the park. The watersheds selected either included part of MRNP, or had orientations which were not represented by watersheds in the park.

Landscape modelling, through the use of computer simulations, allows fire managers to better understand and explain fire regimes. It allows for the calculation of fire cycles for specific areas. Also, it offers the benefit of not fully undertaking the lengthy and costly process of mapping forested stands that have originated from fire. This computer program, named STANDOR (proprietary design), generates time-since-fire data in the form of stand age-class distributions and stand origin maps. The program records the number and size of all simulated fires. This last feature is essential to calculating the true fire cycle. The ability of the program to produce numerous simulations for different fire regime scenarios (fire frequency and distribution), provides a mechanism to assess the magnitude of variation of age-class distributions that is lacking from field fire history data.

This document comprises five main chapters. Chapter 2 describes the methods of data collection, while Chapter 3 and Chapter 4 present an analysis of the field data and causal factors of ignition, respectively. Chapter 5 presents the results of the effect of topography on fire distribution. Results from these three chapters were used to produce the probability of burning map. Chapter 6 discusses the stand age modelling process and its results. Lastly, the concluding chapter discusses how these findings can be applied to fuel management practices in MRNP.

2.0 FIRE HISTORY DATA COLLECTION

2.1 General

The fire regime of MRNP area is largely dominated by stand replacing fires. Identifying the extent of low intensity surface fires, which also occur in the study area, would require a sampling strategy that is very time consuming and expensive due to the high number of sample plots required. For this reason, only stand replacing fires were targeted for this research. The common method of Time-Since-Fire mapping (Johnson and Gutsell 1994), which is also a time consuming and costly process, was not utilised considering that a stand origin coverage represents only a single snap shot in time of a landscape that has been experiencing thousands of years of fire activity. Common wisdom would indicate that it is not advisable to use information from one age-class distribution to base fire management policies on. To fulfill the goal of this research, which is primarily to understand the fire regime(s) at work, sample plots were layed out in strategic locations to cover most valley orientations, elevations and aspect. Age data was collected to obtain information on fire-return intervals for these specific areas. Following is a description of the procedure that was used to collect and interpret fire history data.

2.2 Photo Interpretation

Air photos were used to identify stand boundaries, which were defined by a change in texture and tone on the image (Heinselman 1973, Johnson *et. al.* 1990). In areas affected by a poor quality of air photos, aerial or ground reconnaissance was necessary to complement the air photo interpretation.

Black and white air photos at a scale of 1:36,000 from 1948-49 were used. This scale allows for easy boundary identification and delineation, and also for an easy transfer of fire boundaries onto 1:50,000 topographic maps. The circa 1950 series are the preferable choice because historic fires can be better detected.

2.3 Sampling location

Gathering information to reconstruct the fire history of a forested stand is best done by aging patches of remnant trees within, or on, the edges of a burn, and by sampling trees that germinated following the last fire (Arno and Sneck 1977). For this reason, Sample plots were located on each side of stand boundaries identified on the air photo.

Sampling was primarily restricted to the drier aspects and more active watersheds to address the principal objective of this research, which is to provide information to base management decisions on. In this case, areas of most concern are those that are the most fire active. The number of sampling sites was determined by road or helicopter access, while trying to cover a broad diversity of landscape in terms of elevation, aspect and valley orientation. When possible, a sampling transect was done along an elevation gradient. Sample plots were also located outside the park in recent cutblocks where the date of logging was known.

2.4 Tree selection

Trees were sampled after doing a stand assessment, which consisted of walking through the forest in the vicinity of the plot location in search of survivors that could carry a fire scar or a release. A release is a sudden and significant increase in the ring growth pattern[1] due to a lack of competition for light and nutrients. Trees that show a release are frequently the survivors living on edges of, or

[1] The release should be sustained for a minimum of 10 years to be considered fire related (pers. obs.)

within a burn. Unlike fire scars, a release can only be seen from a tree cross-section.

Sample trees were selected from survivors, which were usually the largest trees, that might carry evidence of fire. Sample trees were also collected from stands that had regenerated after the fire (Arno *et. al.* 1993). In this case, the most common size trees were sampled; these were not necessarily the largest tree. An average of four trees per stand were collected; eight trees when the sampling site fell on a fire boundary.

In stands containing several tree species, tree samples were taken from dominant and subdominant species. In Interior Cedar Hemlock (ICH) forests, western hemlock (*Tsuga heterophylla* (Raf.) Sarg.[2]) and western red cedar (*Thuja plicata* D.Don) were given preference for dating remnant stands, whereas the western white pine (*Pinus monticola* Dougl.*ex* D. Don) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), being pioneer species after a disturbance, were targeted to date more recent fires. At higher elevation, interlocked between the ICH forest and the alpine ecoregion, are mixed Engelmann spruce (*Picea engelmannii* Parry)/subalpine-fir (*Abies lasiocarpa* [Hook.] Nutt.) forests. In this case, the spruce was chosen over the fir, because the latter is considered to be a late seral species and is usually younger than the spruce (Aplet *et. al.* 1988, pers. obs.).

If the ages of the sampled trees differed by more than 20 years (as determined by a field count), up to three additional samples were collected in an attempt to more accurately estimate the date that the stand originated.

2.5 FIELD NOTES

While assessing the stand, the following information was recorded for each sampling site:

- date and sampling team
- plot number, UTM coordinates, descriptive location
- aspect, slope, elevation
- human disturbance such as logging or facilities

[2] Moss 1992 serves as the reference for all tree names used in this report.

- dominant + subdominant tree species
- fire evidence such as charcoal, burnt snags or stumps, scars
- visual observation of the amount of deadfall (few, moderate, much)
- visual observation of the duff layer (low, moderate, thick)[3]
- main understory species
- number of trees sampled with species names and presence of fire related scars or releases

The sample numbering scheme was as follows: year - plot number.

2.6 Tree samples

2.6.1 General

Tree samples consisted largely of tree cross-sections ("cookies") but occasionally cores were taken when it was impossible to use a chainsaw. However, preference was given to cutting cross-sections as they are far more accurate in tree aging (McBride 1983). All tree samples, including cross-sections and cores, are housed at the MRNP warden's office.

2.6.2 Cutting

Cross-sections were taken as close to the ground as possible to reduce the potential error due to a growth time-lag and to avoid missing growth rings (Zackrisson 1981, McBride 1983). However, no correction factor was applied for germination and growth time-lag, because field experience indicates that trees do not grow at the same rate due to several factors including genetic diversity and site.

Normally full cross-sections were not taken because of weight and space restrictions during transport to the laboratory. In addition, a dissecting scope used to count growth rings frequently cannot reach the pith of full cross-sections. Therefore, the cross section was usually cut in half along the pith. For trees showing a release, the cross-section was taken from the side facing the burned area. This side of the tree is favoured, due to reduced competition for space and light

[3] A description of the amount of deadfall and duff layer can assist in the identification of the fuel type.

exposure, and the release pattern is usually more significant.

For the samples (only 4%) that were collected in recent cutblocks, no cross-section was taken back to the laboratory due to the brittleness of the cut stumps. Stumps with the clearest rings were chosen for a field count. When necessary, a magnifying glass was used.

2.6.3 Coring

Cores were taken at about 30 cm (12 inches) above the ground (Arno and Sneck 1977), or as low as possible for the reasons stated above. No cores were taken from scarred trees or from potential fire survivors, which might show a release in the ring width pattern, because such cores are unreliable in those circumstances (McBride 1983).

2.7 Sample preparation

2.7.1 General

Preparation of cross-sections and cores, and procedures for counting rings followed the methods of Arno and Sneck (1977).

2.7.2 Cross-sections

The plot number and tree species were marked on each tree sample in the field with a waterproof pen. These samples were air dried for several days, and then sanded with an 80 grit paper on a belt sander until the surface was smooth and easily readable. A dissecting scope (10X) was used for ring counting and light oil was spread on the wood to enhance the visibility of the rings. A carving knife was used to plane areas of very constricted rings.

2.7.3 Cores

Core samples were stored in plastic straws and labelled while in the field. In the lab, they were mounted on boards with glue, and allowed to dry for several days. These samples were sanded by hand, but otherwise the ring counting method was similar to that described for cross-section samples.

2.8 Tree aging

The aging of trees and scars followed methods of Arno and Sneck (1977). Trees were dated starting from the bark inward and a tick was marked on the sample at every 10^{th} ring. Releases were searched for when a tree sample had been taken directly along an obvious fire boundary or if the sampled tree was a remnant surrounded by younger post-fire regeneration trees. It was observed that Douglas fir trees show a very similar scar formation between a fire and mechanical injury. As a result, only those scars showing some charcoal and being symmetrical were considered as a fire record.

2.9 Database

Field information, tree ages and fire years established from scars and releases were stored in a digital database program (Access 97 by Microsoft Corporation) for easy access and ease of data manipulation. This database is available from the fire/vegetation specialist of MRNP.

2.10 Analysis

Plot locations were marked on the topographic map and a sheet of mylar, showing preliminary fire boundaries, was overlayed on the map. Tree ages and dates of fire evidence were marked next to their respective plot location.

Data were interpreted in a way to identify all recent and historic fires for a general area in order to determine its mean fire return interval. No stand origin map was created as the data collection was done without regard of the extent of the stand sampled. In many occasions, only a single tree or a clump of remnant trees was targeted to date historic fires. A fire date was identified according to the following criteria:

- based on a known date from historical records such as fire reports, dated photographs, old newspapers, etc.;

- based on fire scars <u>and</u> post fire regeneration tree samples;

- based on releases <u>and</u> post fire regeneration tree samples;

- based on the oldest tree age, 5 year class ;

- based on the modal tree age, 5 year class;

- even-age stand = fairly recent fire disturbance;

- uneven-age stand = older disturbance, late seral stage

3.0 FIRE HISTORY SUMMARY

Screening of aerial photography from 1948-49 shows a fairly even distribution of recent fires. With the exception of the northern part of the park, in the Woolsey Creek area, La Forme Creek (just outside the park directly to the north of Woolsey Glacier) and the upper west facing slopes of the Columbia basin, all regions of MRNP show evidence of post 1910 fire activity. Although the Columbia Valley is as important in size as the Illecillewaet, there are fewer recent fires in that valley and its vegetation mosaic does not appear to be nearly as complex as the Illecillewaet. However, given the fact that forest growth is very rapid due to the amount of moisture it receives, stands older than 70 years can be perceived as mature stand from aerial photos. For the same reason, it was often observed that stand age data collected did not match the preliminary stand mapping and dating done from aerial photography and archival information. Multiple burns present within the same stand were usually undetected on the air photos.

In terms of fire size, it is not apparent that very large fires swept these mountains. A visual estimate from aerial photography indicate that fire sizes, between the late 1880's and 1949, ranged from 50 ha to 1,400 ha. In the vicinity of Summit Road and along the Illecillewaet valley, fires in 1885 and 1894 may have reached up to 2,000 ha. Based on air photos and fire occurrence reports, most ignitions are high on mountain faces and are largely caused by lightning.

As shown on Figure 1, a total of 95 sampling sites were visited during the summer of 1998 and 1999. Tree samples (389) were collected as described in the Method Section. As mentioned earlier, in the Introduction, samples were collected with the goal of determining fire-return-intervals (FRI) rather than attempting to develop a stand origin map. Table 1 provides a list of fire dates, whereas Table 2 presents a summary of fire statistics for each of the sampling region. Such statistics include the total number of fires sampled versus the total number of fires that occurred after 1800, the date of the most recent and oldest fire, the range of FRI and mean-fire-return-interval (MFRI) value since the oldest fire recorded, as well as post 1800, and lastly, the yearly fire frequency based on the post 1800 MFRI. Greater credibility was given to post 1800 fires because fire history data becomes unreliable after 200 years due to more recent fires obliterating evidence of past fires. Further, the year 1800 provides a benchmark from which to fairly compare FRI and MFRI among sampling regions. For this reason, it is recommended that only post 1800 data be used by managers to determine forest and fire management guidelines.

Table 1 List of fire dates found per sampling region in Mount Revelstoke National Park.

Coursier - St. Cyr	Across Dam	L. Summit Rd	U. Summit Rd	Hamilton Cr.	U. Clachnac-udainn	L. Illecillewaet
1950	1930	1957	1932	1934	1826	1930
1936	1882	1930	1894	1894	1720	1896
1905	1860	1914	1885	1885		1894
1886	1847	1894	1850	1880		1885
1850	1800	1884	1820	1800		1882
1800	1770	1865	1800	1787		1870
1775	1730	1850	1625	1780		1850
1670	1685			1750		1791
	1620			1510		1780
						1770
						1750
						1720
						1700
						1635

M. Illecillewaet	U. Illecillewaet	Woolsey Cr.	W of reservoir	Martha Cr.
1930	1971	1945	1945	1905
1896	1930	1905	1920	1880
1882	1905	1880	1855	1673
1785	1882	1875	1760	
1705	1865	1855	1685	
	1855			
	1840			
	1793			
	1785			
	1755			
	1670			
	1655			
	1630			
	1580			

Lower Summit Rd: staff housing to Monachee Viewpoint
Upper Summit Rd: Monachee Viewpoint to Balsam Lake
Lower Illecillewaet: 2 km past Box Canyon to Hanner Lake
Middle Illecillewaet: Hanner Lake to 5 km past Clach. Cr.
Upper Illecillewaet: 5 km past Clach. Cr. to Woolsey Cr.

Table 2 Fire statistics for each sampling region.

Region (Nb of plots)	# of fires / fires 1800+	most recent fire	oldest fire	FRI	MFRI	FRI post 1800	MFRI post 1800	F.F. post 1800
Coursier St-Cyr (7)	8 / 6	1950	1670	14 - 105	40	14 - 50	30	0.03
Across dam (4)	9 / 5	1930	1620	13 - 65	39	13 - 48	33	0.03
L. Summit Rd (12)	7 / 7	1957	1850	10 - 27	18	10 -27	18	0.06
U. Summit Rd (10)	7 / 6	1932	1625	9 - 175	51	9 - 38	26	0.04
Hamilton Cr. (9)	9 / 5	1934	1510	5 - 240	53	5 - 80	34	0.03
U. Clachnacu-dainn (2)	2 / 1	1826	1720	106	n/a	n/a	n/a	n/a
L. Illecillewaet (14)	15 / 7	1930	1625	2 - 65	22	2 - 59	20	0.05
M. Illecillewaet (6)	5 / 3	1930	1705	14 - 97	56	14 - 97	48	0.02
U. Illecillewaet (19)	15 / 7	1971	1565	8 - 85	29	10 - 47	25	0.04
Woolsey Cr. (6)	5 / 5	1945	1855	5 - 40	23	5 - 40	23	0.04
W. of reservoir (4)	5 / 3	1945	1685	25 - 95	65	25 - 65	45	0.02
Martha Cr. (2)	3 / 2	1905	1673	25 - 207	116	25	n/a	n/a

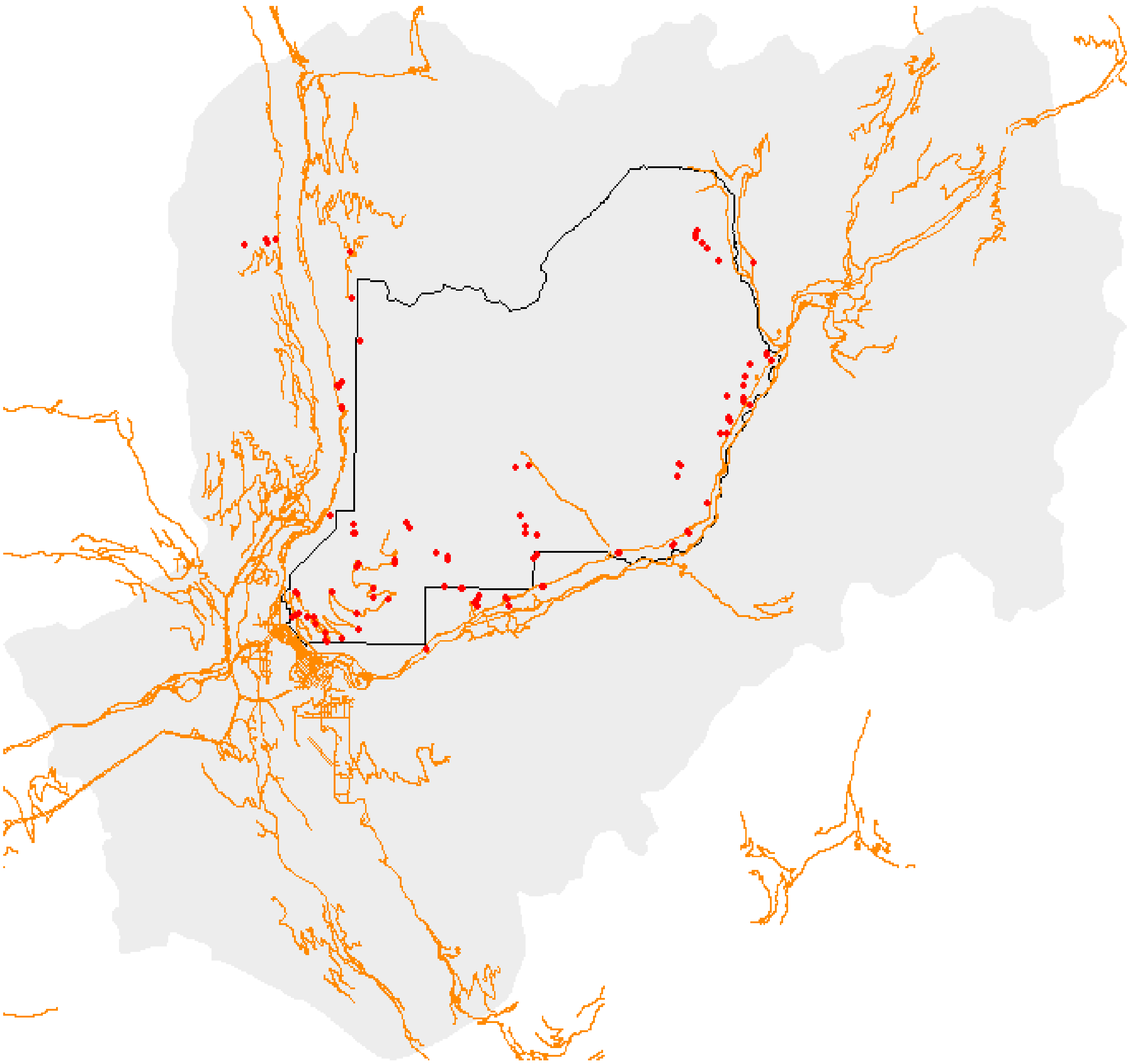

Figure 1 Distribution of fire history sample plots. The shaded area represents the Greater Mount Revelstoke National Park, the solid black line outlines the park boundary, while the yellow lines show the road system.

4.0 CAUSAL FACTORS OF IGNITION

4.1 General

The study of fire occurrence patterns on the landscape, defined here as the spatial distribution of fire by type (lightning vs man-caused), as well as the examination of fire statistics including size, specific fire cause and seasonality of fire, are both elements that contribute to the understanding of the fire regime characterizing the area. Although the study area is centred on MRNP, it is important to visualize where the target area sits in the bigger picture. Due to the small size of the park, most fires will often originate from outside of the management area (but travel into the park), so it is important to understand fire distribution patterns within the broader landscape as well. That is why this portion of the fire regime analysis will focus on the Greater Mount Revelstoke National Park. Figure 2 shows that the region, which covers 1,379 km^2 of land in comparison to 261 km^2 for MRNP, includes the Columbia, Tonkawatla and Begbie basins to the west, the southern boundary crosses the Columbia River at the same level as Mulvehill and Drimmie Creeks, the eastern side includes West Twin, East Twin and Albert basins and the area boundary is shared with Glacier National Park. The north side of the Greater MRNP encompasses Elm, Mounder and La Forme watersheds.

The sections of this chapter cover the basic fire statistics such as the total number of fires, proportion of large fires, fire causes and fire seasonality. The spatial distribution of lightning-caused fires is presented, as well as its relationship with lightning strike density. Similarly, the distribution of anthropogenic fires was assessed and its relationship with the level of human land use was considered. Lastly, from the results obtained from the fire distribution analysis, historical and present-day probabilities of ignition maps were created.

Fire statistics for the period of 1961 to 1998 were obtained from the BC Forest Protection Branch for the Greater MRNP Area, while fire statistics from 1960 to 1998 for Mount Revelstoke National Park were obtained from Parks Canada. These databases contain numerous fields of data entries pertaining to each fire, but fire location, date, size and cause were the targeted attributes for this study. The Forest Protection Branch of British Columbia also has available to the public a lightning strike database for the years 1989 to 1994. This database includes a location entry for every lightning strike detected in British Columbia.

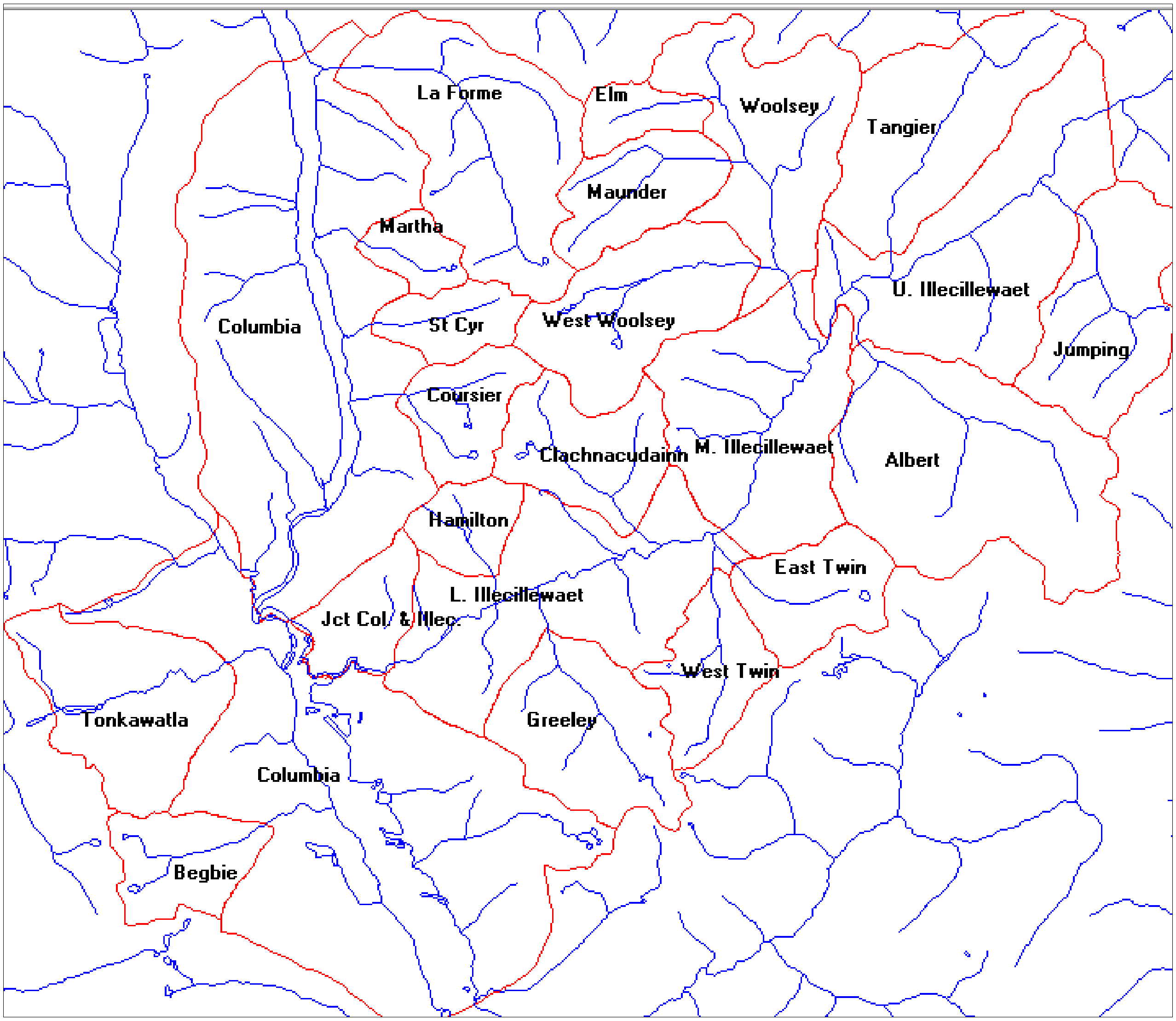

Figure 2 The Greater Mount Revelstoke National Park.

4.2 Fire occurrence statistics

4.2.1 Fire size distribution

The fire occurrence database from 1961 to 1998 includes only lightning-caused fires, which comprises very few large size fires (large size being defined as fires greater than 200 ha). Keeping in mind that fire sizes have been altered to some extent due to fire suppression, especially in recent years with better lightning detection and quicker response time, only 5 fires out of a total of 677 fires reached sizes greater than 200 ha, the largest being close to 1000 ha. All of these occurred between 1967 and 1971. Overall, close to 98% of the fires are less than 10 ha in size and no fire has reached a size greater than 100 ha since 1979, which can likely be attributed to efficient fire suppression. Table 3 shows the distribution of fire sizes for the Greater MRNP.

Table 3 Distribution of lightning fires by size classes for the Greater MRNP.

Fire size class (ha)	Number of fires	Percentage of fires
< 1	617	92
1 - 10	38	5.7
10 - 100	8	1.2
100 - 200	3	0.5
200 - 1000	5	0.8

4.2.2 Fire causes

There exists two main sources of ignition: lightning and anthropogenic. Since anthropogenic fires represent a broad category, these fires are subdivided into four classes to represent a more specific fire cause. Table 4 presents the allocation of fires for MRNP only, as the fire occurrence database for the Greater MRNP does not include man-caused fires. In summary, from 1960 to 1998, MRNP recorded 79 fires, 80% of which were lightning-caused. It is important to note that all fires larger than 100 ha were lightning-caused. The leading cause of anthropogenic fires was attributed to the railroad, followed closely by recreational forest activities.

Table 4 Fire cause distribution for fires that occurred between 1960 and 1998 in Mount Revelstoke National Park.

Fire cause	*N* fires	% of fires
Lightning	63	79.75
Railroad	7	8.86
Recreation	5	6.33
Misc.	4	6.06
Total	79	100

4.2.3 Seasonality of fires

Fire occurrences were classified by month to assess if there were any periods during the fire season[4] where the number of fires were greater. This classification was also used to identify which months were more conducive to lightning-caused fires. As shown in Table 5, the months of July and August clearly are the most fire prone months in MRNP with a total of 22 and 42 fires, respectively. These numbers are much higher considering that the number of fires for the remainder of the fire season varied from 3 to 6. For the Greater MRNP area, the lightning fire season appears to be slightly longer, running from May to August. During this period the number of lightning-caused fires vary from 45 to 389, peaking in the month of July. Otherwise, the remainder of the season sees very little lightning fire activity (1 to 3).

As for lightning-caused fire distribution, in comparison to man-caused, data from MRNP indicate that lightning accounts for 91% to 100% of the fires during the months of July, August and September.

[4] The fire season in the Greater Mount Revelstoke Area extends from the months of May to September.

Table 5 Monthly occurrence of total number of fires and lightning-caused fires in the Greater MRNP Area and MRNP from 1960 to 1998.

	Greater MRNP		MRNP	
Month	Lightning fires	*N* fires	Lightning	% Light.
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	2	3	0	0
May	45	3	0	0
June	114	6	2	33.3
July	389	22	20	91
August	123	42	38	90.5
September	3	3	3	100
October	1	0	0	0
November	0	0	0	0
December	0	0	0	0
	677	79	63	79.75

4.3 LIGHTNING-CAUSED FIRES

Another interesting method used to learn about the fire regime of an area is to study the causal factors of fire ignition and their distribution over the landscape. Lightning and anthropogenic fires are the two main sources of ignition, but while man-caused fires are more predictable in terms of location, lightning-caused fires are often believed to be more random. However, the study of lightning strike density over the landscape has often identified clusters of strikes over certain regions, an indication that those regions would be subject to higher fire incidence (Rogeau 1999a, Rogeau 1999b). To determine if such is the case in the Greater MRNP, actual lightning fire occurrences from 1961 to 1998 were plotted over a lightning strike density map. The density map was produced with a GIS by recording the frequency of lightning strikes[5], from 1989 to 1994, on a 25 km^2 grid system (5 km x 5 km cells).

[5] The lightning strike database, provided by the British Columbia Forest Protection Branch, consists of a list of geographical coordinates for every strike recorded by lightning strike detection systems.

4.3.1 Lightning strike density

Results show that over a six year period (1989 to 1994), the number of lightning strikes per 25 km^2 ranged from 20 to 80. Lightning strike density values were classified into three broad classes representing a low, moderate and high density of lightning strikes. On a yearly basis, lightning strike density values are broken down as such:

low density: 3 to 6 strikes / yr
mod. density: 7 to 9 strikes / yr
high density: > 10 strikes / yr

Figure 3 shows the lightning strike density distribution for the Greater MRNP. The lightning strike density map represents an area of 2,259 km^2. It can be observed that there are four regions of high strike densities, the largest being in the southwest corner of the study area centred on Begbie and Tonkawatla Valleys. Other high density zones are the Hiren Creek area, to the west of Greater MRNP and, Holyk Valley and the confluence of the Akolkolex River with Pulley Creek, both to the southeast of Greater MRNP. The high density of lightning strike zones account for 13.3% of the area, whereas the moderate and low density zones represent 52.2% and 34.4% of the total area, respectively. Looking at the distribution of moderate and low strike densities, the moderate density zones are prevalent to the south and west of MRNP. A few clusters of moderate lightning strike activity also occur in the Woolsey and West Woolsey Valleys of MRNP.

4.3.2 Spatial distribution of fire

The study of lightning strike distribution over the landscape is informative, but it does not provide information on the proportion of actual fire starts resulting from lightning activity. This is why, as a second step to this analysis, all recorded lightning-caused fires during the period of 1960 to 1998 were plotted over the lightning strike density map (Figure 4) and subsequently, overlaid onto the same 25 km^2 grid system to create a density of lightning fire map. As shown in Figure 5, the lightning-fire density values for the 38 year period were classified in the following manner:

Very low density: 0 - 3 fires (< 8% chance of fire / yr)

Low density: 4 - 10 fires (11 - 26%)

Mod. density: 11 - 16 fires (29 - 42%)

High density: 17 - 24 fires (45 - 63%)

Very high density: 25 - 30 fires (> 66%)

A cross-tabulation analysis of both density maps using the GIS provided answers as to whether or not the lightning strike density map can be used as a good predictor of lightning fire occurrences. As shown in Table 6, very low and low incidence of lightning-caused fires largely tend to occur in zones of low to moderate lightning strike densities. However, there are areas that have very few lightning-caused fires even though they are located in high incidence zones of lightning. Moderate occurrences of fire are mainly seen in moderate lightning strike density zones, but so are the high and very high occurrences of fire. Oddly enough, one third of the regions showing high occurrences of lightning-caused fires are actually located in low lightning strike density zones. These results suggest that the lightning strike density distribution map may not be that useful to predict occurrences of lightning fires. Further, the chi-square test of independence provided by the Idrisi GIS declared these two populations to be independent ($P^2_{.05}$), and Cramer's V, a measure of association on a scale of 0 to 1, rated a poor association of 0.29.

Table 6 Percentage of lightning-caused fire occurrence over a 38 year period per lightning strike density zones.

		Lightning caused fire density				
		Very low	**Low**	**Mod.**	**High**	**Very high**
Strike density	**Low**	42.42	39.39	27.27	0.00	33.33
	Mod.	54.55	42.42	63.64	60.00	66.67
	High	3.03	18.18	9.09	40.00	0.00

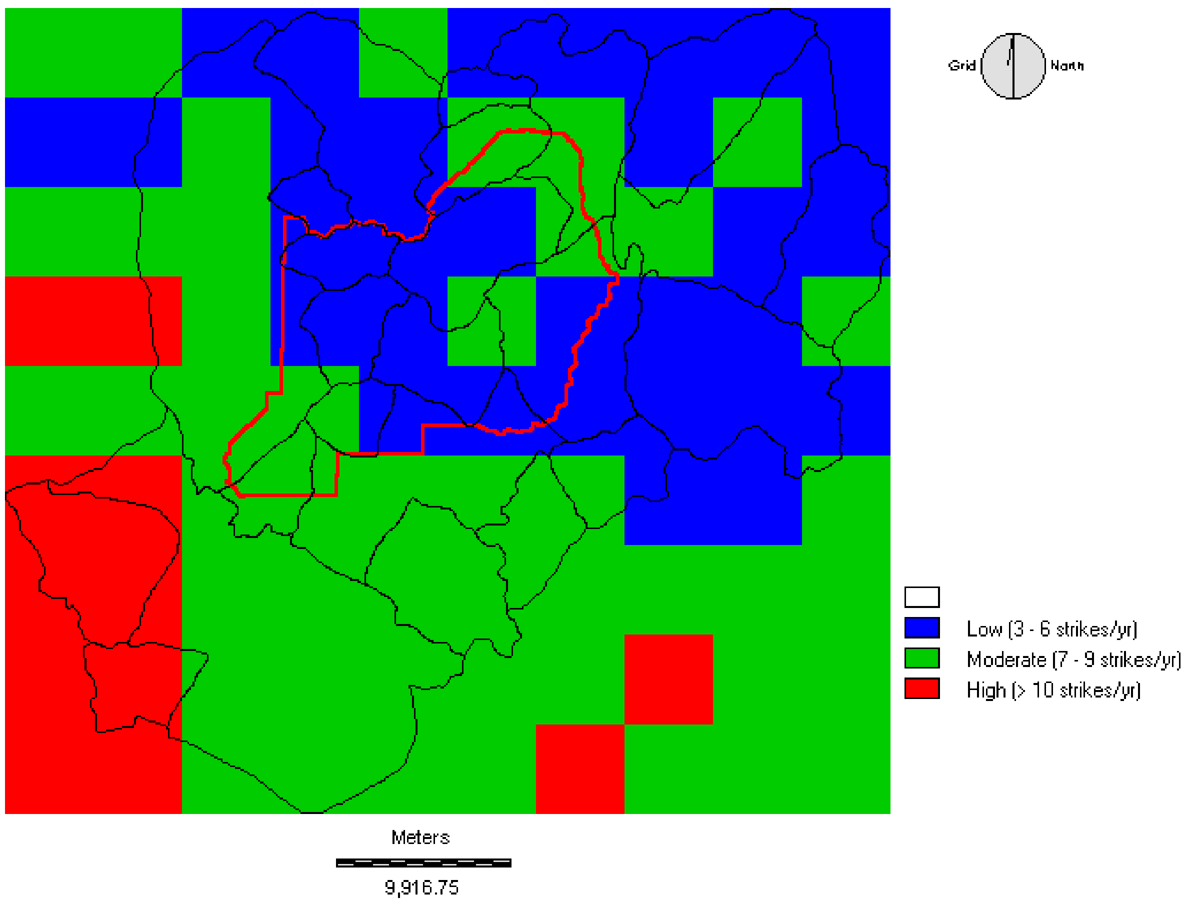

Figure 3 Yearly lightning strike density per 25 km^2 for the Greater MRNP.

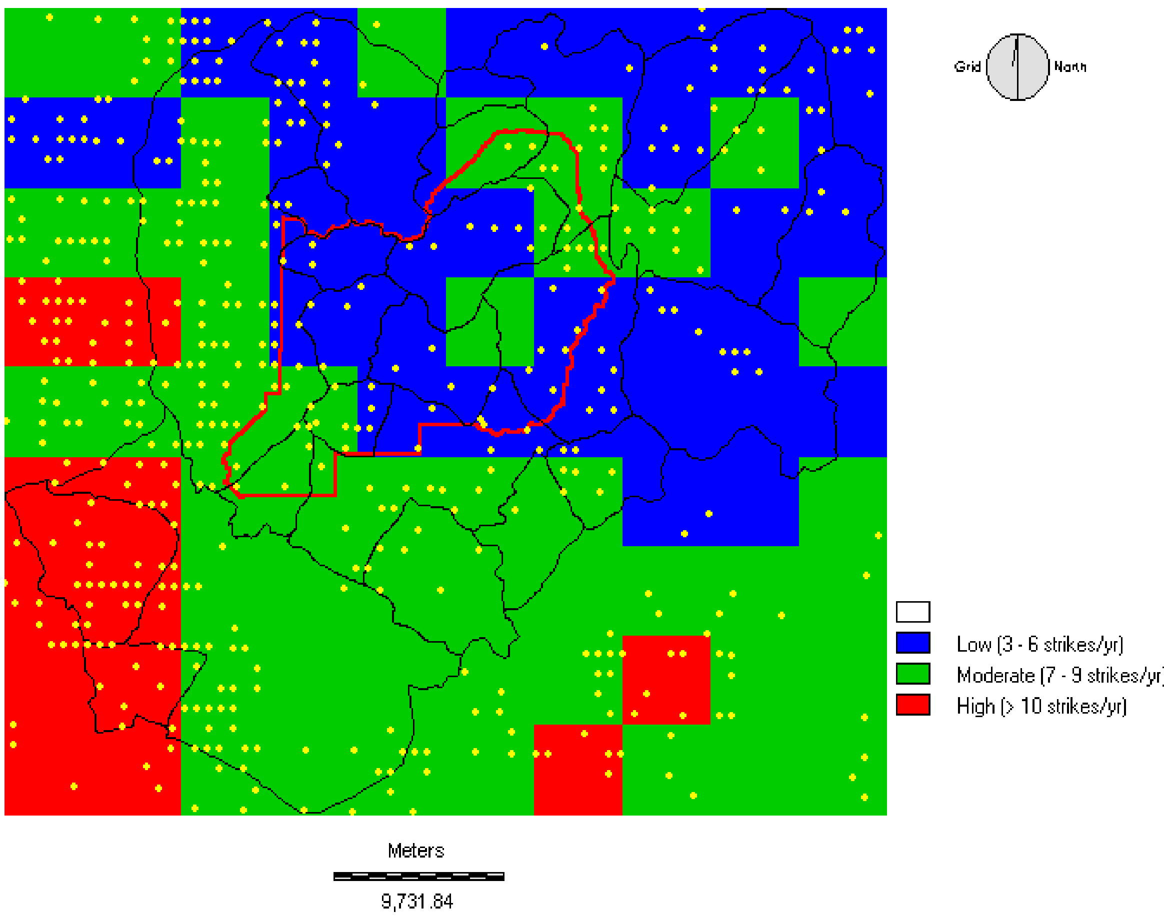

Figure 4 Lightning fire occurrences from 1961 to 1998 overlaying the lightning strike density map

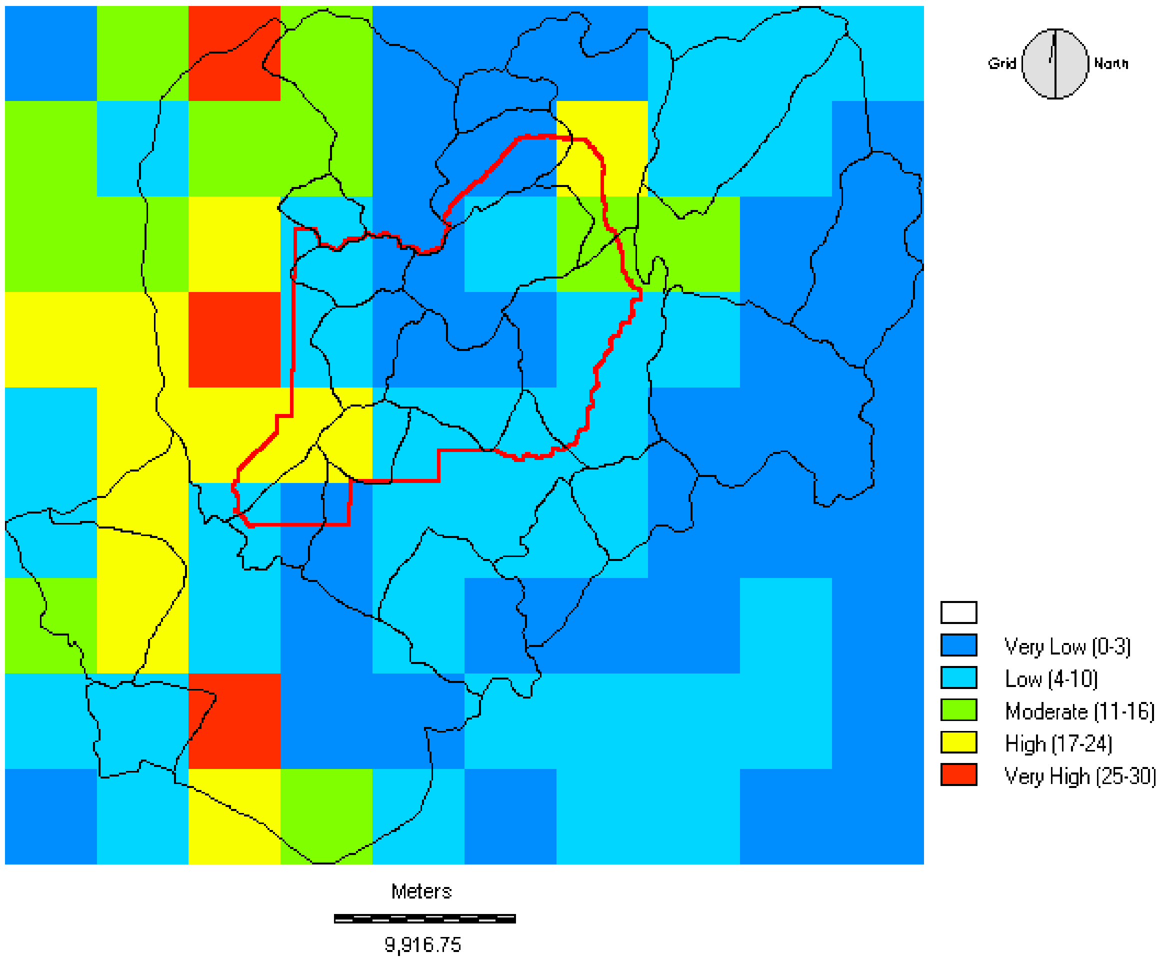

Figure 5 Total number of lightning-caused fires per 25 km^2 for the period of 1961 to 1998.

4.4 ANTHROPOGENIC FIRES

4.4.1 Spatial distribution of fire

A similar process to that applied to the lightning strike density analysis, was used to determine if there exists a pattern in anthropogenic fire distribution. More precisely, is the intensity of human use on the landscape directly related to the number of fire occurrences. Land uses such as towns and villages, as well as travel corridors such as highways, secondary roads, gravel roads and trails, reflect different levels of human use over the landscape. The premise is that zones of highest human land use have the greatest number of man-caused fires. Unfortunately, the data set for man-caused fires was not available for the Greater MRNP and, since the fire regime is dominated by lightning-caused fires, a shortage of data exists to truly test this hypothesis. Instead, the 16 man-caused fires, that occurred between 1960 and 1998 for MRNP, were plotted over the road network and a simple visual assessment of the distribution was performed. Figure 6 presents the distribution of these fires within MRNP.

4.5 PROBABILITY OF IGNITION MAP

As a result of 38 years of fire statistics, some patterns in fire distribution could be determined and used to produce both historical and present-day probabilities of ignition maps. The historical map reflects probabilities of lightning fire ignition alone, prior to the arrival of settlers which would be around the 1830s (MacDonald 1996). A second map, taking into account the effect of human use on the landscape, was produced and is referred to as the present-day probabilities of ignition map.

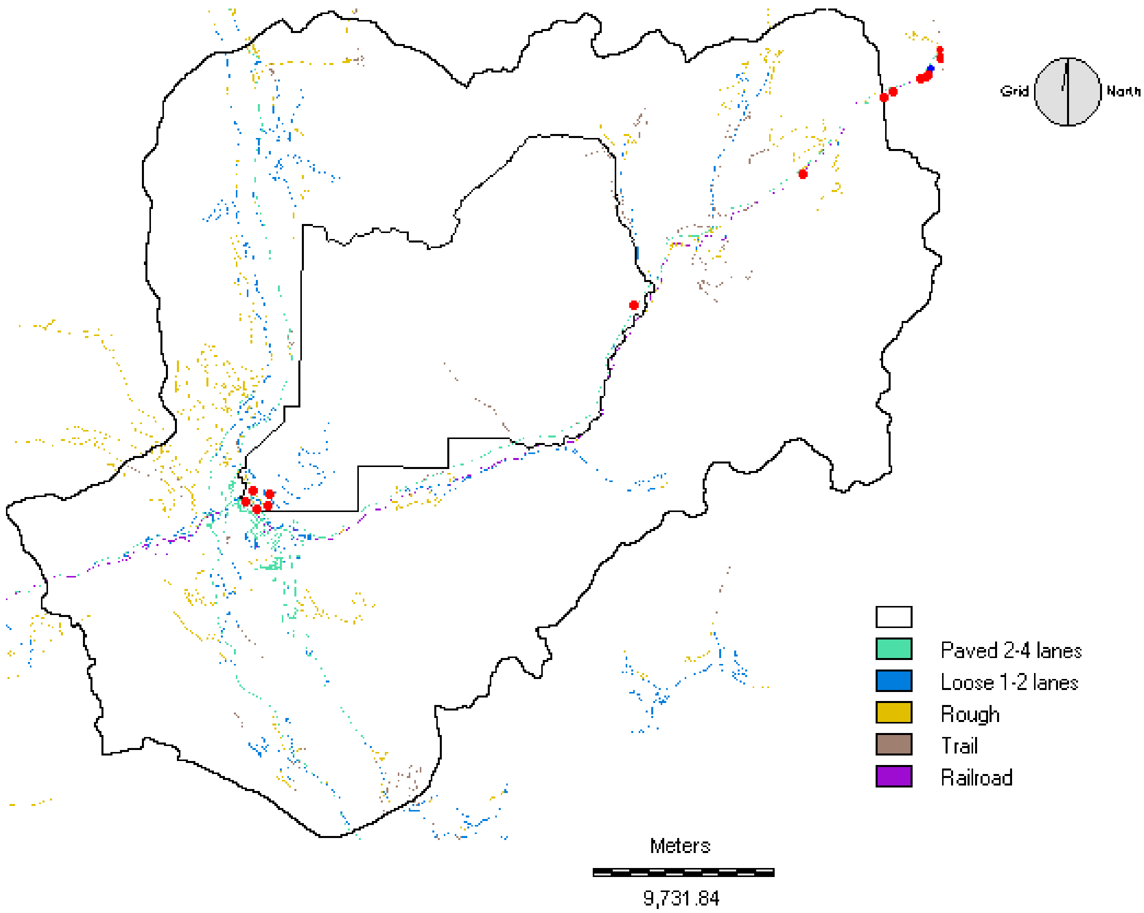

Figure 6 Distribution of man-caused fires for MRNP during the period of 1960 to 1998.

4.5.1 Historical

The fire occurrence database from the last 38 years was used to assess the density distribution of lightning-caused fires over the landscape, as well as their distribution by elevation and by aspect . Table 7 shows that 61% of lightning-caused fires occur on E, SE and S facing slopes and 81% occur between 1000 m and 2000 m. With the use of a GIS, a weighting method was then applied to determine probabilities of ignition. The weighing process ranks the data on a scale of 1 to 5 (5 representing the highest likelihood of getting an ignition) and also ranks, as a percentage, the importance of the data layers used. The ranking of the information was done as follow:

60% Distribution of lightning-caused fires

- 1 - Very low density (< 8 % chance of fire / yr)
- 2 - Low density (11 - 26 %)
- 3 - Moderate density (29 - 42 %))
- 4 - High density (45 - 63 %)
- 5 - Very high density (> 66 %)

25% Chance of lightning-caused fires by elevation

- 2 - < 1000 m
- 5 - > 1000 m

15% Chance of lightning-caused fires by aspect

- 1 - NE-W-flat
- 3 - SW-NW-N
- 4 - E-SE-S

p_ignition *= ([ltg_distribution * 60] + [ltg_elevation * 25] + [ltg_aspect * 15]) / 5* **(1)**

This map manipulation process resulted in obtaining a range of probabilities of ignition that vary spatially over the landscape (anywhere from 12 to 97%). The historical p_ignition map is shown in Figure 7.

Table 7 Distribution of lightning-caused fires by elevation and aspect for MRNP from 1960 to 1998.

Aspect	% of occurrence	Elevation (m)	% of occurrence
NE: 22.5° - 67.5°	3.92	500 - 750	10.2
E: 67.5° - 112.5°	25.49	750 - 1000	8.16
SE: 112.5° - 157.5°	11.76	1000 - 1250	20.41
S: 157.5° - 202.5°	23.53	1250 - 1500	14.29
SW: 202.5° - 247.5°	9.8	1500 - 1750	28.57
W: 247.5° - 292.5°	3.92	1750 - 2000	18.37
NW: 292.5° - 337.5°	13.73	2000 +	0
N: 337.5° - 360°, 1° - 22.5°	7.84		
	100		100

4.5.2 Present-day

This map was simply built by taking the historical p_ignition map and adding percentages of man-caused fires along three types of human use corridors: low use roads, high use roads and the railroad. Each level of human use was represented by a vector layer map provided by Mount Revelstoke National Park, which was rasterised at a resolution of 0.5 km^2. This resolution was chosen to define the highest zone of human influence along travel corridors in terms of fire ignition. In other words, the high risk of fire ignition zones were arbitrarily determined to be of about 250 metres on either side of a road. Percentages of yearly chance of man-caused fires are distributed as follows:

low use roads: 3%
high use roads: 11%
railroad: 24%

The end result provides us with a map (Figure 8) showing present-day probabilities of ignition that vary spatially from 12 to 100%.

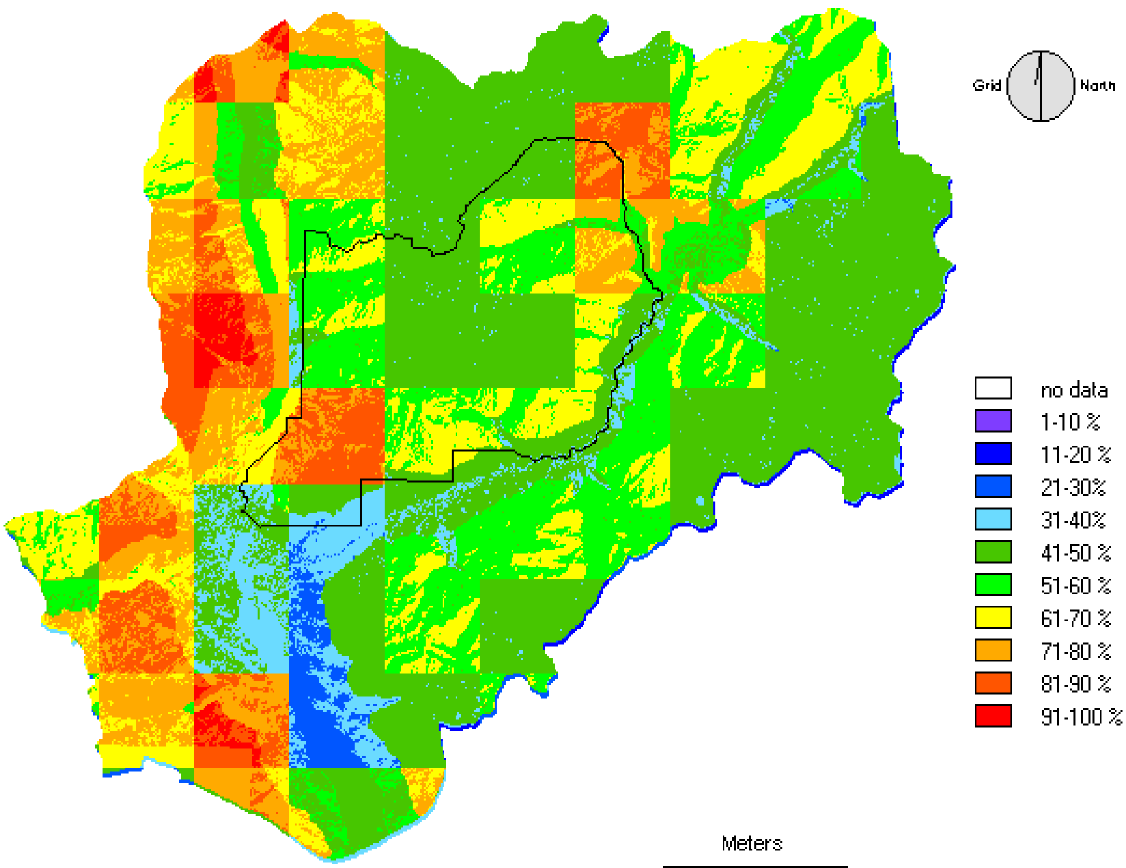

Figure 7 Historical probability of fire ignition for the Greater MRNP

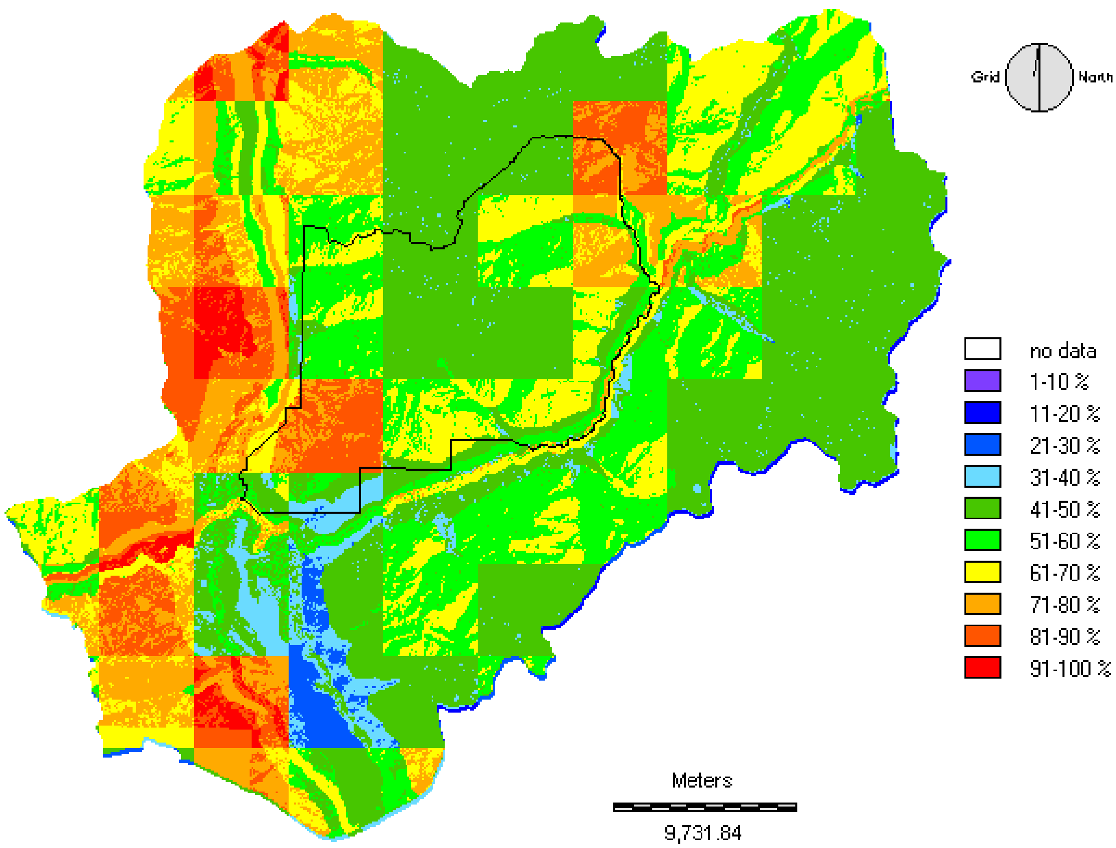

Figure 8 Present-day probability of fire ignition for the Greater MRNP.

5.0 EFFECT OF TOPOGRAPHY

5.1 GENERAL

In mountain landscapes, the forest mosaic shaped by fire is dissected by alpine peaks and ridges, and deep valleys of different sizes and orientations. Topographic components such as aspect, elevation and valley orientation to prevailing winds, are all factors that potentially affect, to some extent, fire distribution, and hence, stand age distribution. Notably, discernable patterns of old age forest have been observed in the Rockies, a fact suggesting their survival is not by random chance alone (Rogeau 1996). It would appear that factors of ignition coupled with topography may affect the burn patterns and consequently, the age distribution of forest stands.

These four topographic variables are thought to have the most impact on fire dynamics in the mountains: elevation, aspect, proximity to the Continental Divide[6] and valley orientation (Rogeau *et. al*. 2000). For MRNP, the Continental Divide is too remote for it to influence fire distribution. Elevation has often been identified as being a controlling factor of landscape patterns (Barrows 1951, Hawkes 1980, Kushla 1996, Rogeau *et. al.* 2000). Depending on the type of ecosystems under study, elevation can affect fire behaviour in different manners. Kushla (1996) found that in the Oregon Coast Range, lower elevations favoured a lower fire frequency due to wetter fuels, whereas in the Northern Rocky Mountain forests, older stands are more commonly found at higher elevations, even though lightning occurrence is greater than that of lower elevations (Hawkes 1980, Barrows 1951). At higher elevations, fires tend to be inhibited due to limited fire spread caused by a combination of fuel discontinuity created by rock outcrops, less standing fuel close to treeline, and greater fuel moisture contents. The latter of these results from lower temperatures and a fewer number of frost-free days. Barrows (1951) also concluded that the fire season diminished with higher elevation zones such as the subalpine and alpine.

Aspect is another terrain feature that affects landscape forest patterns through differential fuel drying. Generally, north facing slopes burn less frequently but with a higher intensity than south and west facing slopes (Zackrisson 1977, Tande 1979, Hawkes 1980, Hemstrom and Franklin 1982,

[6]The Continental Divide is defined as the dividing line that runs along the height of the land and which parts the water to different areas of the continent.

Clark 1989, Rogeau *et. al.* 2000). This is usually explained by the fact that north facing slopes, which receive less sunlight, are normally cooler. Therefore, evaporation is less, fuels are wetter and will tend to accumulate due to a lack of periodic burning.

Finally, valley orientation to prevailing winds in mountainous areas is also a factor affecting the frequency of burning (Masters 1990, Rogeau *et. al.* 2000). Smaller valleys, that run perpendicular to main ones or to prevailing winds, have a lesser chance of being affected by raging fires from the main valleys.

The sub-sections of this chapter present the range of fire-return-intervals (FRI) and mean-fire-return-intervals (MFRI) values by valley orientation, aspect and elevation classes. These values were calculated based on the results of field data collection for MRNP. Following is an analysis of variance that determined if MFRIs among each topographic variable are significantly different. Lastly, mean ages were plotted for each topographic class of each variable.

5.2 Valley orientation

Table 8 shows that MFRIs for the main valleys of the Columbia and Illecillewaet are half the length of time of those from small valleys. Although the Summit Road area is influenced by both main valleys, an access road and the urban traffic of Revelstoke, which are all factors that increase the potential for ignition, it appears to be on a slightly longer MFRI than the main valleys. This may be explained by the fact that this area is smaller in size and not as many fires were sampled. Another reason would be that two large fires in 1885 and 1894 erased most evidence from previous fires.

5.3 Aspect

To the contrary of all expectations, Table 9 shows that E and SE facing slopes have shorter FRIs and MFRIs than SW, W and NW facing slopes. The MFRI of south aspects is comparable to those of the E and SE aspects. Insufficient data were collected on NE and N facing slopes to draw any conclusions.

Table 8 Number of fires, FRI, MFRI and range of stand ages since the oldest fire detected per valley orientation. On the second line, similar parameters are listed for post circa 1800 fires.

Valley orientation	# fires / # post 1800 fires	FRI	MFRI	Range of stand dates
Main SW-NE	35 / 16	1 - 47	12	1971 - 1565
(Illecilewaet)		2 - 47	11	1971 - 1793
Main N-S	23 / 10	2 - 50	16	1972 - 1620
(Columbia)		2 - 47	12	1972 - 1800
Summit Rd area	11 / 10	3 - 165	33	1957 - 1625
(jct. of Illec. & Columbia)		3 - 30	19	1957 - 1790
Small NW-SE z SW-NE	14 / 8	5 - 205	35	1934 - 1510
(Hamilton & Clach.)		5 - 40	24	1934 - 1800
Small N-S z SW-NE	5 / 5	5 - 40	23	1945 - 1855
(Woolsey)		5 - 40	23	1945 - 1855
Small E-W z N-S	4 / 2	3 - 177	78	1905 - 1670
(St Cyr & Coursier)		55	n/a	1905 - 1850

Table 9 Number of fires, FRI, MFRI and range of stand ages since the oldest fire detected per aspect. On the second line, similar parameters are listed for post circa 1800 fires.

Aspect	# fires / # post 1800 fires	FRI	MFRI	Range of stand dates
NE (45)	4 / 2	106	n/a	1826 - 1720
		n/a	n/a	
E (90)	23 / 18	4 - 85	27	1971 - 1510
		4 - 27	16	1971 - 1840
SE (135)	65 / 37	1 - 60	11	1958 - 1565
		2 - 25	8	1958 - 1800
S (180)	31 / 18	1 - 75	20	1957 - 1620
		2 - 34	14	1957 - 1820
SW (225)	27 / 13	3 - 50	17	1957 - 1720
		3 - 50	18	1957 - 1800
W (270)	16 / 11	3 - 102	30	1972 - 1670
		6 - 50	25	1972 - 1800
NW (315)	14 / 13	3 - 47	26	1930 - 1620
		3 - 47	22	1930 - 1800
N (360)	n/a	n/a	n/a	n/a

5.4 ELEVATION

As shown in Table 10, most elevation strata share similar MFRIs that range from 12 to 15 years. The land falling between 1000 m and 1250 m is the only exception with a MFRI of 23 years. Although MFRIs are similar, higher elevations, notably between 1250 m and 1750 m, experience shorter fire intervals (FRI) than at valley bottom or near treeline. The logical explanation would be that this zone is in a higher lightning strike density coupled with the fact that it is influenced by the "thermo-belt effect". The thermo-belt effect, which occur in early August for two to three weeks, is a locally known phenomenon to fire and climate specialists. Above 1200 m, warm air gets trapped at night between a layer of cold air below due to heat inversion and a layer of cold air above. Relative humidity in the thermo-belt remains low (around 20%) until about 4:00 am in the morning. As a result, fire activity levels are high from four o'clock in the afternoon until four o'clock in the morning (Archie McConnachie pers. com.).

Table 10 Number of fires, FRI, MFRI and range of stand ages since the oldest fire detected per elevation strata. On the second line, similar parameters are listed for post circa 1800 fires.

Elevation	# fires / # post 1800 fires	FRI	MFRI	Range of stand dates
1: < 750 m	64 / 31	1 - 47	13	1958 - 1565
		1 - 47	12	1958 - 1793
2: 751 - 1000 m	34 / 19	2 - 65	18	1957 - 1630
		2 - 50	13	1957 - 1800
3: 1001 - 1250 m	18 / 12	2 - 77	25	1945 - 1670
		2 - 63	23	1945 - 1787
4: 1251 - 1500 m	21 / 17	2 - 110	27	1934 - 1510
		2 - 34	13	1934 - 1800
5: 1501 - 1750 m	24 / 22	1 - 50	17	1971 - 1625
		2 - 29	14	1971 - 1791
6: 1751 - 2000 m	18 / 15	1 - 65	22	1945 - 1635
		2 - 54	15	1945 - 1791

5.5 Analysis of variance

To test the hypothesis that mean-fire-return-intervals are significantly different among topographic classes of each topographic variable, a one-way analysis of variance (ANOVA) was performed and Duncan's multiple range test, which is a very powerful test used to find differences among population means (Ott 1993), was applied to each group of topographic means.

Results from the ANOVA, as shown in Table 1, show that all means are equal among the different valley orientations. Similar results were found for the different aspect classes and elevation classes. However, Duncan's multiple range test did find that W and NW facing slopes have different MFRI than E, SE, S and SW facing slopes with a significance level of 0.05. No data was available for N and NE facing slopes, but based on the common knowledge that north aspects are generally cooler and moister due to the lack of sun exposure, these two aspects were grouped with the W and NW aspects under the assumption that their MFRI would be similar.

Table 11 Results from One-way ANOVA for the three topographic variables tested.

Topographic variable	Degrees of Freedom	F ratio	F prob.	F %0.05
Valley orientation	4, 44	2.06	0.103	5.7
Aspect	5, 55	2.54	0.0384	4.4
Elevation	5, 60	0.68	0.6408	4.4

5.6 Topographic mean ages

Figures 9 shows histograms of average stand ages calculated by topographic classes for the valley orientation, aspect and elevation variables. These were plotted out of curiosity as these values should not be used for forest management. Mean forest ages are normally calculated from stand origin maps by tabulating weighted forest ages (stand age x stand area). Further, there is also a lack of representative data for some of the topographic classes, which will add to the distortion of the mean forest age value.

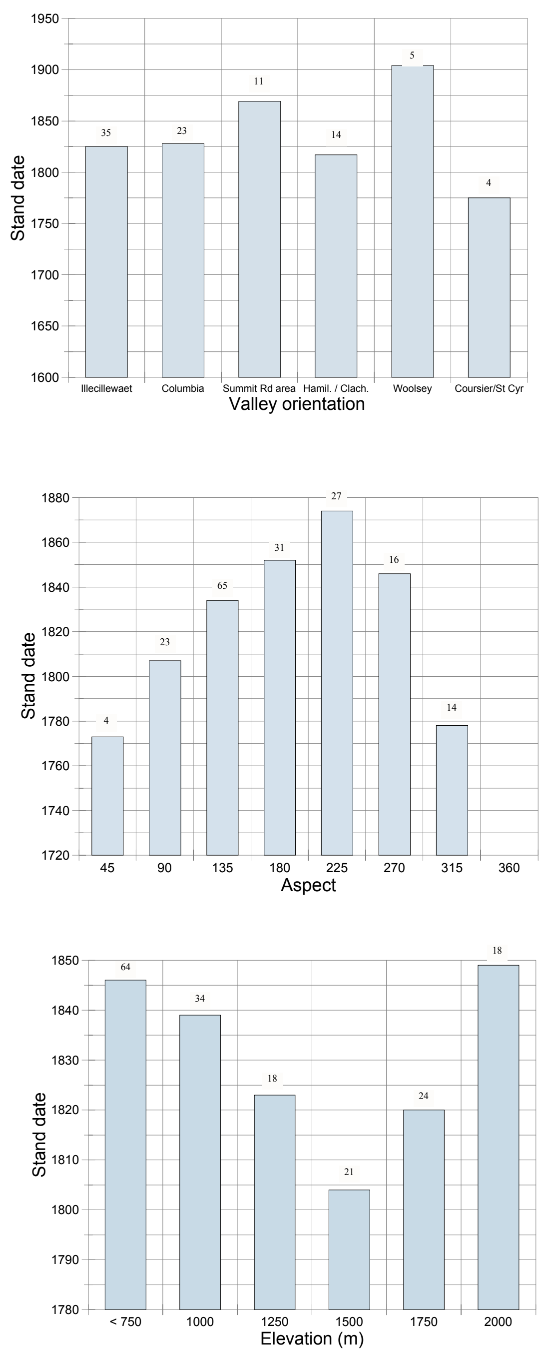

Figure 9 Forest average stand date calculated by valley orientation, aspect and elevation classes. The small numbers indicate the number of plots used to estimate the average age.

The two main valleys, the Columbia and the Illecillewaet, appear to be similarly aged, while Summit Rd, at the junction of these two main valleys show younger aged forest. The forest of Hamilton and Clachnacudainn, two small valleys running perpendicular to the Illecilewaet Valley, are only slightly older in age than the main valley. As for the Woolsey, Coursier and St-Cyr Valleys, insufficient data was collected to make any kind of interpretation. When looking at the age distribution by aspect, stand ages range from about 35 years up to 100 years. The greatest age differences occur between the northerly facing slopes and southwest facing slopes, but the insufficient data collected for the NE-NW and N facing slopes may account for this large difference. As for elevation, it is interesting to observe that the age increases as elevation increases, but only up to 1500 m. Above this altitude, the pattern is reversed and stand ages are becoming increasingly younger. This is an interesting phenomenon contrary to stand age patterns observed in the Rocky Mountains which become increasingly older with altitude. This may be attributed to the thermo-belt effect that takes place yearly in early August. This time of the year also coincides with the period of greatest lightning-caused fires, which also tend to occur above 1000 m.

5.5 PROBABILITY OF BURNING MAP

The probability of burning (p_burn) map (Figure 10), which represents likelihoods of burning based on topographic locations, ended up being a simple procedure due to the apparent lack of topographic effect on fire distribution patterns within MRNP. The Greater MRNP p_burn map was produced by dividing the landscape into two aspect groups: 1) E-SE-S-SW and 2) N-NE-W-NW facing slopes. The first subset, with an average MFRI of 14 years was assigned a 100% chance of burning (no burning restrictions), while the second subset, with an average MFRI 64% greater (23 years) than subset one, was assigned an equivalent probability of burning value (i.e. 64%). This means that all landscape with N-NE-W and NW facing slopes have a chance to burn that is 36% less than the remainder of the landscape.

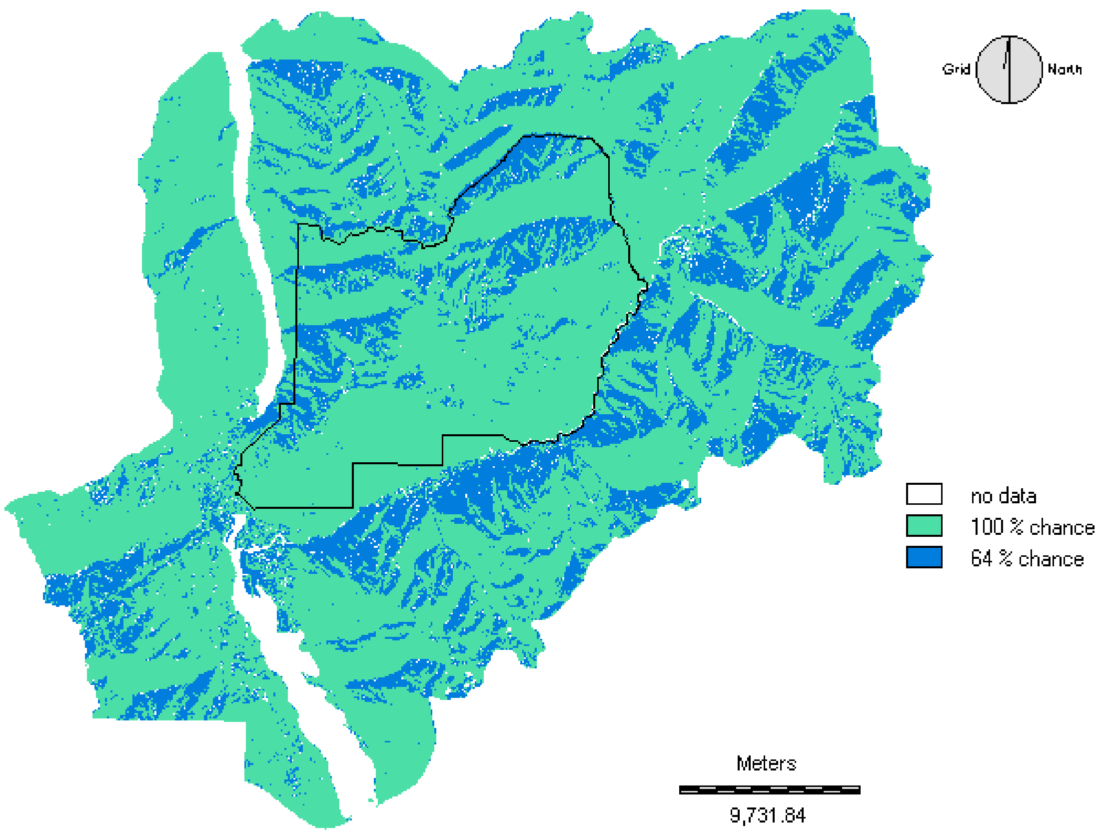

Figure 10 Probability of burning map based on the effect of topography on fire distribution.

6.0 STAND ORIGIN MODELLING

6.1 General

The stand origin modelling technique used to study fire distribution patterns over the landscape is thought to be a reasonable approach for areas with limited or lack of stand age information. As a general rule, fire history data has its own set of limitations which include: the insufficient amount of fire evidence due to the overlap of fires over time, life expectancy of trees sometimes being shorter than the fire return interval, poor quality of tree samples for accurate dating (rotten cores), restricted access and, the inability to sample every single stand due to time and cost of such research. However, the greatest drawback of the stand origin mapping technique is that we are limited to a single snapshot in time, which amounts to a sample of one, of a landscape that has been shaped for thousands of years by fire. The modelling approach becomes a good competing technique as it provides a series of stand origin maps and stand age distributions from which basic statistics (average, standard deviation, minimum and maximum) can be drawn. The strongest asset of the STANDOR model, used in this study, is its ability to keep track of the sizes of burned areas before being over-burned. This feature allows managers to calculate the true fire cycle. Another useful feature of the model is that it allows the user to keep stand age information only for areas of interest: such as ICH or ESSF forests.

This chapter first describes the data layers used to run the model and then provides a description of how STANDOR works. Following is a presentation of the results and their interpretation. Simulation results are described for the entire landscape, by fuel type and by main valley orientation.

6.2 Data inputs

A set of map layers is needed to run the model, as well as information on fire frequency and its distribution over the landscape under study. The procedure to create each map layer is described in Appendix A along with information on the source and format of the data used. It is strongly recommended to refer to this appendix while reading this Section. The data layers are:

a) fuel type map

This map represents the type of forest fuels as described by the Canadian Forest Fire Behaviour Prediction System (CFFBS). The model uses formulas from the CFFBS to calculate the rate of spread based on a combination of these elements: fuel type, slope, wind speed, FFMC and BUI. Unfortunately, for the Mount Revelstoke area, Interior cedar hemlock (ICH) forest has no designated fuel type from the CFFBS. Based on personal communications with Bruce Lawson from Ember Research Services in Victoria, Brad Hawkes and Marty Alexander, both from the Canadian Forest Service, and Archie McConnachie from the B.C Forest Service in Revelstoke, the C5 fuel type was used for the ICH. Typically, the fire behaviour of the Engelmann spruce - subalpine fir (ESSF) forest is modelled with a modified crown height of the C3 fuel type. However, STANDOR does not allow for the modification of crown height and as a result, the M1/M2 fuel type was used as suggested by the fuel experts mentioned above. According to MRNP and B.C. Forest Service fire/vegetation experts for the area, test runs of the STANDOR model using these fuel types do reflect similar fire behaviour as wildfires. In summary, the following fuel types were used:

- C5: ICH
- M1/M2 (50% conifers, 50% deciduous): ESSF
- D1: avalanche paths, shrub land
- Non forested: rock and ice, water bodies, roads, urban areas

b) elevation map

An unclassified 1:20,000 digital elevation model at a 25 m resolution was used as part of a base layer to grow fires on. Elevation values are used by the model to determine terrain slope and calculate the appropriate rate of fire spread.

c) valley orientation map

This map is used to determine the initial direction of burning of the fire during day 1. This feature was implemented because the fire weather data comes from weather stations that can often be located in a valley with a different orientation, hence experiencing different wind directions than where fires are actually burning. To account for valley wind, the fire spreads at a 50/50 rate in either direction of the valley. For example, in a valley running west to east, 50% of the fire will spread to the west while the other 50% will spread to the east.

d) weather zone map

This map is used to outline zones of homogeneous fire weather data. Each zone is linked to a weather station. This is an important feature for mountain landscapes, as higher elevations portray higher levels of humidity and reduced FFMC and BUI values. As a result, under calm conditions, fires at higher elevations tend to burn cooler than at valley bottom. The exception to the rule is during the occurrence of temperature inversions.

e) initial stand age map

This is the initial stand age layer used to grow fires on. When stand origin coverage is non-existent for the area, as such is the case for Mount Revelstoke National Park, a simulation of 1000 years is run to create the initial stand origin map. The initial simulation starts using an even-aged forest of 100 years throughout the landscape.

f) probability of ignition (p_ignition) map

The probability of ignition map represents the chance (from 0 to 100) a pixel has of getting an ignition. The model generates a random number from 0 to 100. If the random number is less than the p_ignition value of the pixel, then the fire starts.

There is a p_ignition map for each fire regime modelled. STANDOR allows the user to model up to 5 fire regimes within one simulation. A change in fire regime will be associated with a known datable event that will modify the frequency and/or spatial distribution of fires. Such events include: long term climate change, decimation of aboriginal people by the small pox, arrival of European explorers and settlers, railway construction, early logging and mining, and fire suppression. For this study, we are interested in historical fire distribution before the strong influence of man kind. Although one can argue that anthropogenic fires are also part of a historical fire regime, fire occurrence data since the 1960's show that human caused fires only account for 20% of the total number of fires in the GMRNP area . Assuming that in the pre-settlement days, the number of anthropogenic fires would have been further reduced, it was decided that our best understanding of the historical fire regime for the area would come from a lightning fire regime only.

g) probability of burning (p_burn) map

In mountainous terrain, probabilities of burning vary spatially according to aspect and elevation. This effect is pronounced during the spring/fall season where north facing slopes and higher elevations can have snow on the ground or a much higher fuel moisture content which inhibits the spread of fire. Like the probability of ignition map, each pixel is assigned a p_burn value ranging from 0 to 100. Before spreading into neighbouring pixels, the p_burn value of the pixel is compared to that of the ignition pixel. If the p_burn value of the pixel is less than at ignition time, the fire will not spread in that direction.

The spring/fall season is determined in the fire weather database (sub-section (i)). Summer days in the GMRNP area were set from July 1st to August 31st. During this period, all pixels are assumed to have the same probability of burning and no p_burn map is used. For all other dates, the fire spread will be determined in part by the p_burn map. For example, if a fire starts at low elevation and on a south facing slope, that fire will not be allowed to spread higher than a certain elevation or on to north or east facing slopes. But, if that fire starts at a high elevation or on a north facing slope, it will be able to spread anywhere as other p_burn values would be higher than the p_burn value at the place of ignition.

h) mask map

This map layer is only utilised if the user is interested in obtaining fire cycle information for a specific area. The mask has a value of one for the area of interest and a value of zero for the remainder of the landscape. For the GMRNP area, masks were used to focus on ESSF forest, ICH forest and on valley orientations. Results from valley orientation simulations were kept only for the Columbia Valley, the Illecillewaet valley and for all small valleys that run perpendicular to these ones. Note that during these simulations, fires are distributed normally throughout the landscape but any information that is not of interest is discarded.

i) fire weather data

Fire weather data came from four weather stations: Goldstream (571m), Revelstoke (525m), Big Mouth (832m) and Upper Beaver (1524 m) in Glacier National Park. Goldstream and Revelstoke stations had very similar temperatures, RH and BUI during the same periods. As a result, these two databases were merged together. The fire weather database contains the following fields:

- year
- month
- day
- wind direction
- wind speed
- FFMC
- BUI
- fire season (spring/fall or summer)
- number of daily burning hours (1/3 of the day light hours)
- daily light hours
- weather zone (from the weather zone map)

Before a fire is allowed to spread on the landscape, the program looks in the fire weather database to find fire weather data associated with the proper weather zone (based on the weather zone map). It then randomly picks a date and reads the fire weather values for that day. To ensure that we are modeling only stand replacing fires, the database contains only the dates where BUI values are greater than 50. The rule is that a fire will burn as long as there are consecutive days with BUI values greater than 50.

j) other inputs

- simulation length: 1000 years
- age class: 10 year
- disturbance lapse time: 20 years

(this is the number of years after a disturbance that are necessary before the forest is able to carry a subsequent fire)

- fire frequency: 20 to 40 fires every 10 years (see Appendix A)

6.3 STANDOR MODEL: HOW IT WORKS

This section describes the step by step procedure that the model takes for seeding disturbances over the landscape.

1. Randomly select the number of fires for the time period.

This is defined by the minimum and maximum number of fires during that time period.

2. Verify the likelihood of a randomly selected pixel supporting a fire. Repeat step 2 until the fire is allowed to start.

generated random number # p_ignition value Y fire starts

3. Verify the fuel type. If the pixel is categorized as non-fuel, repeat step 2 and 3 until the pixel is coded as fuel.

4. Verify the lapse time since the last disturbance. If fuel is not yet available for burning (i.e. regen. is too young), repeat step 2 to 4.

5. Look in which weather zone the fire will start. Randomly pick a start date within the appropriate weather zone from the fire weather database.

5.1 If the date of the ignition is not during the summer, the spring/fall fuel availability map is chosen.

a) determine the valley orientation for initial spread V_i

b) determine the probability of burning of adjacent pixels by looking at their fuel type, time-since-last fire and their p_burn value. If it is not available for burning, the fire will not spread in that direction.

c) read the fire weather values from the selected database to determine fire growth

d) repeat step 5.1 b) and c) until fire weather values are too low to support a fire or until allowable burning time has expired.

5.2 If the date of ignition is during the summer period, the p_burn map will not be used.

a) determine the valley orientation for initial spread V_i

b) determine the probability of burning of adjacent pixels by looking at their fuel type and time-since-last fire. If it is not available for burning, the fire will not spread in that direction.

c) read the fire weather values from the selected database to determine fire growth

d) repeat step 5.1 b) and c) until fire weather values are too low to support a fire or until allowable burning time has expired.

6. Repeat step 2 to 5 until the number of fires chosen for the time period (step 1) is reached.

7. Verify if the fire regime has changed in order to select the appropriate database of fire frequency and map of the likelihood of getting an ignition.

8. Repeat step 1 to 7 for the length of the simulation divided by the length of the time period.

6.4 Results and interpretation

Prior to running the simulations, test runs were performed until the proper range of fire sizes for the ESSF and ICH was obtained. FFMC values from the fire weather database had to be modified in the following manner in order to obtain reasonable fire sizes. For upper elevations (wxzone 3: > 1150 m), FFMC values were increased by 10 while values were decreased by 5 for the low elevations (wxzone 1: < 700 m). Mid-elevations retained their normal values. In an effort to take into account the thermobelt effect in August, the number of daily burning hours was doubled during those days. However, the fires became so large that this modification had to be removed. There was no other way to implement the thermobelt effect with this software. To obtain the desired range of typical fire sizes for this region, the number of burning days was set to two.

Once the set of model parameters was determined, several simulations were run to obtain the magnitude of variation in stand age distribution and fire cycles. Simulation data were produced for the entire landscape, by main fuel type (ICH and ESSF) and by valley orientation (Columbia, Illecillewaet and small valleys). A total of 45 simulations were done: 10 each for the entire landscape, ICH and ESSF, and 5 simulations were run for each valley orientation. The number of simulation was reduced for the valley orientation as it was found that for the previous set of simulations, the full range of fire sizes, and fire cycles could be covered within the first 5 simulations.

6.4.1 Model testing

Today's landscape mosaic, combined with fire knowledge from the last 50 years, was used as a benchmark to evaluate how well the modelling exercise was emulating natural disturbances. Consequently, the simulation test runs were done using two fire regimes: prior to 1830 a lightning fire regime was used, while post 1830 fires were a result of a mixed regime of lightning and man-caused fires. By taking into account the occurrence of man-caused fires, the number of fires increased by 20 percent under the mixed fire regime. The probability of ignition map was also modified for post 1830 fires so that there would be an increased chance of fire start along the railroad and main roads. Figure 11 is an example of a stand origin map that was modelled under a mixed regime. This fire distribution pattern seemed to best emulate today's wildfire distribution within the Greater MRNP. Although there seems to be more younger aged forests than in reality and that some fires seem larger, one has to keep in mind that fires in the Greater MRNP have been actively and effectively suppressed in the last 50 years. A number of these would have likely developed into larger size fires. Figure 12 is an example of a stand origin map modelling fire distribution patterns under a lightning fire regime only. One can observe the lesser extent of young age forest patches. This phenomena is more clearly represented in Table 12 when comparing areas by age-classes from both types of fire regimes.

Table 12 Example of an age class distribution from a mixed and lightning fire regimes.

Age class	Lightning	Both (km^2)	Age class	Lightning	Both (km^2)
40	1.49	11.33	240	43.38	36.07
60	14.90	32.56	260	36.81	31.71
80	37.03	43.62	280	33.86	26.29
100	44.32	60.80	300	28.68	26.80
120	56.14	62.46	400	108.37	100.30
140	57.19	54.28	500	72.08	62.47
160	57.89	58.38	600	46.84	48.19
180	44.27	49.65	1000	96.03	89.72
200	38.99	42.64	2000	68.71	57.22
220	50.56	43.05			

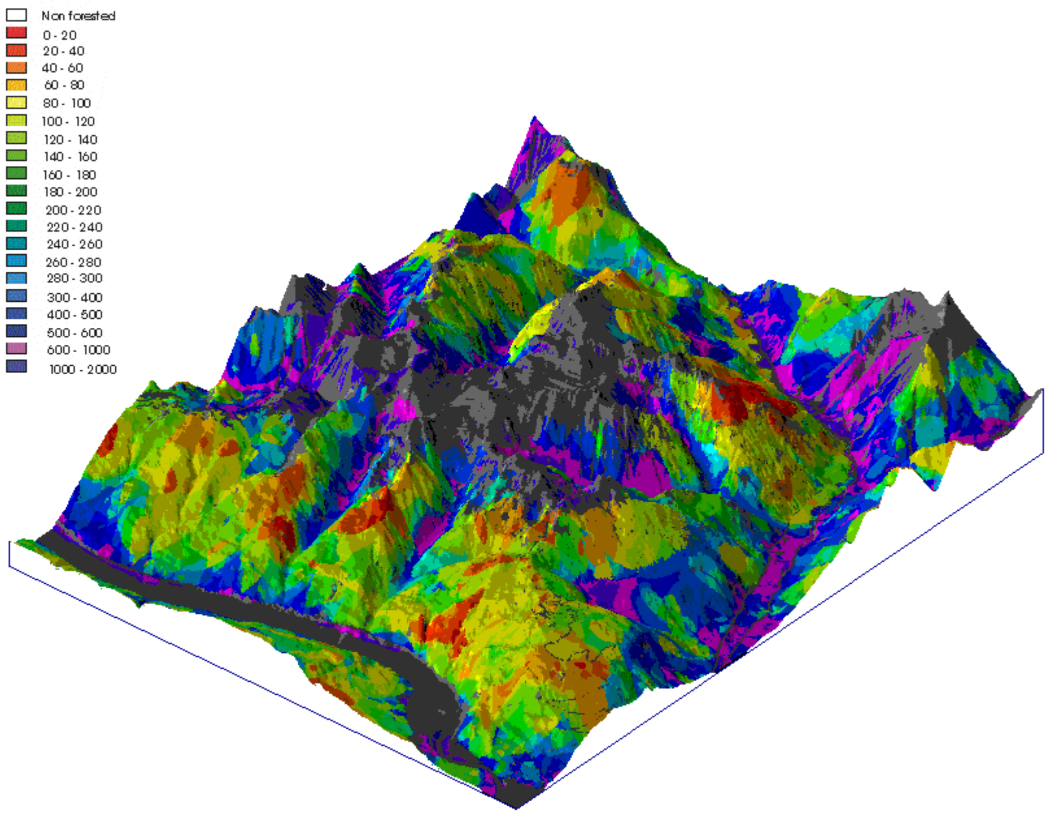

Figure 11 Example of a stand origin map modelling a mixed regime of lightning and man-caused fires.

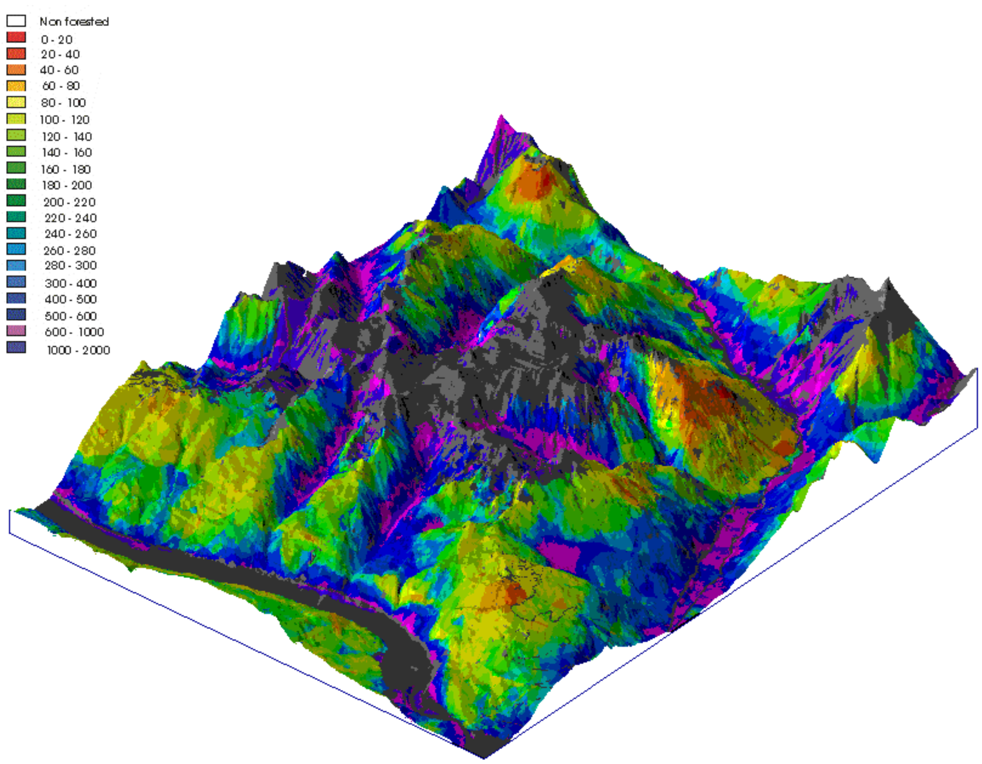

Figure 12 Example of a stand origin map modelling a lightning fire regime.

6.4.2 Stand age distribution

The STANDOR model produced a range of stand origin maps and age-class distributions from each set of simulations ran. Stand origin maps were added together and divided by the number of simulations to obtain a mean stand origin map as shown in Figure 13. For analysis purposes, age-classes were subdivided in to 10 year age-class from 10 to 300 years, in to 100 year age-class from 300 to 600 years, and for the oldest surviving forests, 2 broad age classes were formed: from 600 to 1000 years and, from 1000 to 2000 years. Tables 13, 14 and 15 present the percent area, average area, standard deviation, minimum and maximum area attributed to each age class, for respectively, the entire landscape, by fuel type and by valley orientation.

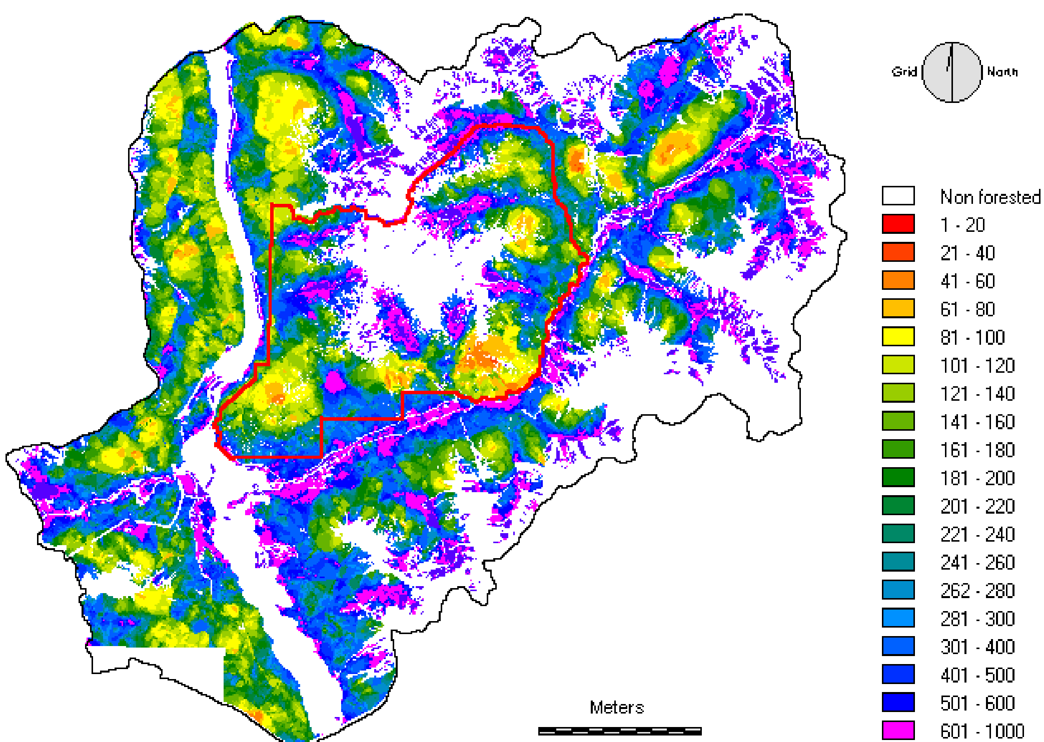

Figure 13 Mean stand origin map from 10 simulations.

Table 13 Percent of total area, average area (ha) with standard deviation, and minimum and maximum area attributed to each age-class for the entire landscape.

Age	% Area	Avg area (ha)	STD	Min	Max
10	4.43	3986.3	1076.21	2680	6546
20	3.27	2942.6	1516.2	1431	5942
30	4.12	3701.6	1380.64	1994	6552
40	3.47	3119.7	1639.45	961	6535
50	2.99	2685.4	1373.12	1219	5606
60	3.76	3379.8	1438.43	1413	5722
70	2.84	2552.8	1273.59	919	4840
80	2.64	2370.3	1286.42	482	4326
90	2.90	2607.7	1062.33	1115	4423
100	2.59	2330.7	1196.36	502	4818
110	2.64	2372.4	987.13	957	4256
120	2.58	2322.5	1354.07	530	4958
130	2.55	2297.1	1148.28	977	4436
140	2.37	2132.1	1111.88	642	4627
150	2.10	1890.3	1256.85	88	4271
160	2.08	1873.1	1253.34	772	5058
170	2.24	2016.9	1602.13	157	5551
180	1.45	1307.1	650.83	442	2350
190	2.32	2087.7	1692.32	278	5015
200	1.66	1496.8	724.11	614	2848
210	1.63	1462.4	664.50	123	2356
220	1.15	1030.7	527.98	25	1731
230	1.04	937.4	431.87	218	1744
240	1.46	1311.2	733.28	271	2574
250	0.99	892.3	571.72	85	2036
260	1.19	1069.9	790.14	239	3041
270	1.26	1131.4	615.91	320	2035
280	0.89	803.7	424.46	240	1798
290	1.44	1298.7	1056.00	101	3291
300-390	7.77	6990.5	513.04	275	7999
400-490	5.71	5752.2	1143.51	4084	7781
500-590	3.86	3750.9	633.98	2991	4981
600-990	7.32	7696.2	1680.34	5662	11484
1000-2000	6.35	6315.7	803.43	5229	7630

Table 14 Percent of total area, average area (ha) with standard deviation, and minimum and maximum area attributed to each age-class by fuel type.

	ICH	ESSF	ICH		ESSF		ICH	ESSF	ICH	ESSF
Age class	% area	% area	Avg area	STD	Avg area	STD	Min	Min	Max	Max
10	7.75	5.70	7070.3	2953.8	5186.1	2389.3	3597	2902	12394	11367
20	6.77	6.18	6176.1	2152.8	5617.0	2268.9	2818	2697	10396	10631
30	6.83	4.90	6232.7	1887.4	4457.7	1309.0	3894	2229	9917	6781
40	4.88	5.60	4456.6	1244.1	5096.5	1808.5	2303	1640	6097	7488
50	5.61	4.90	5124.9	1430.1	4457.0	1548.4	2737	2129	7260	6706
60	3.61	5.22	3297.7	1044.3	4744.5	1350.9	2242	2510	5872	6774
70	3.36	4.32	3064.9	1321.9	3928.2	1608.0	1369	1436	5277	6684
80	4.18	4.01	3813.4	1876.9	3643.0	1279.9	1328	1399	8080	6022
90	2.27	2.99	2073.9	782.8	2722.0	1538.6	1181	1068	3287	6444
100	3.62	3.50	3309.1	1079.6	3187.2	733.9	2139	2084	5642	4621
110	2.72	2.47	2484.3	1238.8	2250.2	1062.8	917	738	4501	4353
120	2.43	2.33	2222.8	939.7	2116.9	916.2	874	824	4028	4220
130	2.76	2.81	2515.1	910.1	2556.2	1371.9	1226	1109	3838	5457
140	2.45	1.94	2236.7	923.4	1763.0	1124.4	1164	618	4290	4603
150	1.95	1.90	1780.5	940.9	1727.0	695.2	472	689	3478	2767
160	2.42	2.30	2212.1	1133.5	2094.2	917.7	1042	1028	4808	3805
170	2.03	1.66	1854.5	854.6	1508.3	735.1	479	590	3220	3081
180	1.84	2.07	1675.5	648.3	1879.0	998.1	778	643	2864	4057
190	1.45	1.55	1327.7	767.5	1406.9	667.8	439	362	3016	2388
200	1.25	1.40	1142.1	586.5	1271.3	775.1	424	509	2309	2540
210	1.11	1.44	1015.3	552.7	1305.9	700.8	264	329	2017	2251
220	1.40	1.44	1276.6	361.5	1312.0	883.0	643	237	1771	3022
230	1.37	1.04	1249.6	313.6	946.4	401.6	656	514	1737	1841
240	1.22	0.83	1111.9	666.5	757.1	359.0	359	60	2084	1186
250	1.03	1.12	937.1	273.8	1017.4	417.4	430	190	1470	1622
260	0.89	1.13	814.9	257.4	1030.5	466.0	500	158	1325	1930
270	0.96	1.05	878.1	368.8	951.0	375.5	331	483	1487	1628
280	0.83	1.09	758.3	389.7	991.0	263.7	300	463	1647	1388
290	0.76	1.00	694.4	422.2	909.5	628.7	253	199	1836	2447
300	1.08	0.92	1077.4	527.9	837.8	455.4	301	361	1782	1842
300-390	5.82	5.88	5990.8	878.2	6026.3	1102.3	4071	3810	7357	7867
400-490	3.71	3.78	3650.2	665.1	3706.4	788.6	2350	2871	4702	5274
500-590	2.55	2.91	2446.3	489.0	2799.4	462.0	1588	1942	3197	3467
600-990	4.11	4.61	4089.6	643.6	4620.0	823.5	3117	3638	5743	6017
1000-2000	2.52	3.24	2303.0	175.6	2948.3	368.1	1986	2150	2588	3525

Table 15 Average area (ha) with standard deviation, and percent area attributed to each age-class by valley orientation.

	Illecillewaet			Columbia			Small valleys		
Age	**Avg area**	**STD**	**% Area**	**Avg area**	**STD**	**% area**	**Avg area**	**STD**	**% area**
10	8676.0	2861.7	9.4	8868.2	4580.1	9.7	9573.0	1453.5	10.4
20	7401.0	3103.5	8.0	5973.2	2841.4	6.5	7897.2	2662.2	8.6
30	9581.8	3299.3	10.4	5055.0	1363.3	5.5	6243.0	1492.0	6.8
40	6524.8	2841.7	7.1	6478.8	3339.3	7.1	6549.6	1860.7	7.1
50	5266.0	857.8	5.7	5596.8	2161.3	6.1	4845.0	1986.3	5.3
60	4915.2	2821	5.3	3629.6	1529.8	4.0	4752.8	998.3	5.2
70	3759.8	805.6	4.1	3592.4	715.7	3.9	4563.8	1424.4	5.0
80	5382.8	824.8	5.8	2845.0	1039.2	3.1	4471.4	2186.6	4.9
90	3607.6	1315.4	3.9	5130.0	1564.2	5.6	3627.0	1672.9	3.9
100	2442.2	805.9	2.6	2675.6	1420.5	2.9	2761.8	1369.0	3.0
110	3239.2	1203.3	3.5	2972.4	972.7	3.2	2032.2	492.4	2.2
120	2563.8	1025.6	2.8	2817.8	630.8	3.1	1904.0	802.9	2.1
130	2077.0	470.6	2.3	2280.6	732.2	2.5	2287.4	1066.1	2.5
140	2269.2	454.8	2.5	1440.6	960.7	1.6	1926.6	658.4	2.1
150	1972.4	1252.9	2.1	1441.4	598.2	1.6	1084.6	276.8	1.2
160	1687.2	631.3	1.8	1722.6	771.5	1.9	1494.0	527.9	1.6
170	1102.4	510.8	1.2	2273.4	897.6	2.5	1455.6	605.7	1.6
180	1210.6	523.6	1.3	2252.4	618.6	2.5	2231.0	735.7	2.4
190	1437.6	413.6	1.6	1735.2	441.8	1.9	953.4	319.5	1.0
200	1100.4	555.9	1.2	1280.8	491.7	1.4	934.2	398.1	1.0
210	1231.4	578.7	1.3	1223.6	568.5	1.3	936.6	427.9	1.0
220	863.8	481.0	0.9	615.2	295.8	0.7	1300.0	335.4	1.4
230	613.6	303.6	0.7	1362.8	670.2	1.5	533.2	186.6	0.6
240	639.0	217.6	0.7	1010.4	561.8	1.1	1189.2	324.7	1.3
250	583.4	278.0	0.6	975.6	328.4	1.1	881.6	228.5	1.0
260	695.2	173.2	0.8	645.2	314.1	0.7	685.6	329.4	0.7
270	573.0	314.2	0.6	641.8	321.1	0.7	455.0	215.6	0.5
280	595.4	132.5	0.6	788.8	374.5	0.9	498.4	290.0	0.5
290	381.0	147.2	0.4	650.6	200.6	0.7	466.0	135.3	0.5
300	449.0	268.7	0.5	430.6	217.0	0.5	705.0	419.2	0.8
300-400	3052.8	437.5	3.1	4515.8	1444.9	4.5	4707.0	1644.4	4.7
400-500	2190.8	570.3	2.3	2798.4	711.2	2.9	2458.4	354.6	2.5
500-600	1219.8	375.6	1.3	1655.4	184.6	1.7	1665.6	330.4	1.8
600-1000	1907.6	169.0	2.0	3262.2	356.7	3.3	3092.6	203.5	3.2
1000-2000	1035.4	92.3	1.1	1568.0	152.6	1.7	1483.4	151.7	1.6
			100			100			100

Based on the stand origin distributions simulated for the entire landscape, 31% of the area is composed, on average, of old growth forest (300+ years), 39% is composed of mature forest ranging in age from 100 to 300 years, while the remaining 30% is composed of immature forest (< 100 years old). Over a 1000 year period, close to 7% of the land will escape fire, while 6% of the land will go fire free for 2000 years or more. When simulated stand origin maps are evaluated by fuel type, ESSF forests encompass a slightly larger extent of old age forest than ICH forests (20.4% vs 18.7%) and slightly less immature forests (47.3% vs 48.9%). When assessing the distributions by valley orientation, it was found that although the Illecillewaet and the Columbia are both main valleys, the Illecillewaet tends to contain larger areas of young aged forest than the Columbia (62.4% vs 54.3%). Interestingly enough, small valleys running perpendicular to the main ones also have a greater extent of young aged forests than the Columbia valley (60.1% vs 54.3%). This is contrary to the east slopes of the Rockies where small valleys are generally older (Rogeau *et. al.* 2000) due to the fact that fires burning in main valleys have a difficult time hooking back into perpendicular, smaller size valleys. For the Greater MRNP, the similar extent of young aged stands between main and small valleys can be explained by the fact that there is a greater source of ignitions at higher elevations, which corresponds to the location of small basins. The old growth forest distribution evaluated by valley orientation indicates that the Illecillewaet contains the least amount of older aged forest (9.8%) in comparison with the Columbia valley (14.1%) and small valleys that run perpendicular to main valleys (13.7%). Although there are proportional differences in terms of old growth and immature forests among fuel types and valley orientations, paired-t tests calculated for the paired variables of ESSF-ICH, Illecillewaet-Columbia, Illecillewaet-small valleys and, Columbia-small valleys, found no significant differences among the paired distributions (Table 16). These results seem to indicate that fire distribution and size are not highly influenced by fuel type nor by valley orientation. This corroborates findings from field data collection which showed that mean-fire-return intervals are not significantly different by valley orientation.

6.4.3 Fire regime statistics

The minimum fire size was 0.1 ha, which represent the pixel resolution. These occurred when the combination of fuel type and fire weather data could not support fire spread. During the spring/fall season, the average fire size was about 60 ha ± 200 ha and the maximum fire size ranged from about

Table 16 Paired-t test results show no significant difference among the paired variables tested.

Paired variables	Correlation	t-test, d.f.=34, a=0.5
ICH - ESSF	0.94	-0.16
Illecillewaet - Columbia	0.89	-0.01
Illecillewaet - small valleys	0.94	-0.08
Columbia - small valleys	0.95	-0.1

22 to 34 km^2. As for the summer burning period, which was set to be from July 1st to August 31st, the average fire size was about 132 ha ± 310 ha, while the maximum fire size ranged from about 34 to 40 km^2. The smaller fire size during the spring/fall period is as expected, since probabilities of burning were limiting fire spread on cooler slopes and higher elevations. The proportion of fires by size classes for the spring/fall and summer seasons are presented in Table 17.

Table 17 Percentages of simulated fires by size classes for the spring/fall and summer seasons.

Size class	Spring /fall	Summer
< 10 ha	58.6 %	34.4 %
10 - 100 ha	28.9 %	43.2 %
100 - 1000 ha	11.5 %	22.0 %
> 1000 ha	1.0 %	2.4 %

The fire cycle and the weighted mean forest age were calculated for every simulated stand age distribution. The fire cycle was simply calculated by counting the number of years it took to burn an area equivalent to the forested area of the Greater MRNP. For simulations that focussed on particular regions according to fuel type or valley orientation, the burn area had to be equivalent to the forested area from that specific region. Weighted mean ages were calculated using Equation 2.

$$Weighted\ average\ age\ = \sum (age - class\ x\ \%area) \qquad \textbf{(2)}$$

Table 18 presents the average, minimum and maximum fire cycle values calculated for the entire landscape, by fuel type and by valley orientation. It can be observed that as a general rule the mean forest age calculated from the age-class distribution is always greater than the fire cycle. This is due to the fact that the distributions do not follow perfect negative exponential distributions and because many historical burned areas disappear overtime and hence, cannot be recorded in the age-class distribution. Analysis of variance determined that, contrary to the age-class distributions, fire cycles are significantly different among fuel types ($F_{1, 110, 0.05} = 124.04$) and valley orientations ($F_{2, 125, 0.05} = 47.16$). Lastly, fire cycle values, which are fairly short, would appear to agree with the relatively short mean-fire-return intervals that were calculated from field data collection.

Table 18 Average, minimum and maximum fire cycles, and weighted mean forest ages for the entire landscape, by fuel type and by valley orientation.

	Landscape	Forested area (ha)	Fire cycle $_{avg}$	Fire cycle $_{min}$	Fire cycle $_{max}$	Wgt age
	Entire	93754	266 ± 29	200	300	312 ± 14
Fuel type	ICH	43511	181 ± 19	150	240	198 ± 10
	ESSF	42364	145 ± 15	110	180	216 ± 12
Valley Orientation	Illecillewaet	25804	102 ± 13	70	130	134 ± 7
	Columbia	31731	111 ± 15	80	140	167 ± 12
	Small valleys	37281	133 ± 15	90	170	156 ± 11

7.0 CONCLUSION

In summary, field data collection, coupled with the information gained from the stand origin modeling, demonstrated that the level of fire activity was historically high. Mean-fire-return-intervals for MRNP ranged from 18 to 48 years in the last 200 years, while the stand origin modelling exercise estimated a mean fire cycle of 266 years for the Greater MRNP, with cycles varying spatially from 102 years for the Illecillewaet basin to 181 years for ICH forests. Although fire frequency is high (2 to 4 fires / year), the average fire size remains small: 100 ha or 1 km^2.

Mean-fire-return-intervals do not seem to vary spatially, with the exception of W, NW, N and NE facing slopes, which experience longer fire free intervals. Due to the higher frequency of lightning fire occurrence at higher elevations and the thermo-belt effect, elevation does not appear to be a critical factor in governing fire occurrence and spread. Similarly, valley orientation is not a significant factor. This is largely explained by the spatial auto-correlation between valley orientation and elevation (i.e. small valleys are also located at higher elevations).

Simulated age-class distributions did not vary spatially in a significant manner. Proportion of stand ages are distributed in a similar fashion between ICH and ESSF forests, as well as between the Illecillewaet and Columbia valleys and the small valleys that run perpendicular to these main ones. However, fire cycles vary significantly among fuel types as well as among valley orientation. ESSF forests experience shorter fire cycles due to their higher elevation and greater number of lightning ignitions. The Illecillewaet basin has the shortest fire cycles of all. The reason for this is difficult to explain since the occurrence of lightning-caused fires is less than for the Columbia Valley. This may be attributed to a limitation of the model which uses fire weather data from remote weather stations. These stations may be located in a valley with different orientation than that where the fire is burning and this would affect the calculation of the fire's rate of spread and direction.

7.1 RECOMMENDATIONS

As an outcome of this study, the main recommendation for MRNP is to initiate a fire re-introduction program with the goal of approximating historical rates of disturbances. The mean-stand-origin map created from modelling can serve as a benchmark for locating areas under shorter fire cycles and mean-fire-return-intervals. These areas should be given priority for re-introducing fire. The magnitude of the age-class distribution should also be used as a guideline to evaluate how much land needs to burn over a 5 to 10 year period. Additional field data collection may be required to date areas with a lack of stand origin information in order to assess the magnitude of fire deficiency.

Due to the fact that Mount Revelstoke National Park is small in size and shares its boundaries with other land agencies which operate under a full fire protection program, the park may face some difficult challenges. However, because the park benefits from a favourable fire regime which is dominated by high elevation lightning fires that tend to stay small in size, it should be able to implement different levels of fire protection across the park and still be successful in implementing a prescribed and let burn policy program.

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APPENDIX A

Description of map layers and databases

a) fuel type map

Fuel maps from the BC Forest Service and Mount Revelstoke National Park were merged together to provide a seamless fuel cover map. However, prior to merging both fuel maps, reclassification of some vegetation cover classes needed to be performed.

<u>MRNP data</u>

The habitat classification map created by Medina Deuling[7] was used to generate the MRNP fuel map. This map is at a scale of 1:20,000 (25 m resolution) and was reclassified in the following manner:

(numbers in brackets are classification id numbers)

- M1/M2: ESSFvc (10)
Parkland (11)

- C5: ICHwk (9)
50% conifer - Immature forest (4)
recent cut (1) (0 - 22 years)
recent burn (2) (the majority of these fell in or nearby ICH forests)

- D1: avalanche path (5)
open cover (6)
riparian (8)
recent unknown disturbance (3)

-Non-Forested: open cover rock (7)
alpine (12)
ice/snow/rock/road (13)
shadow (14)

[7] This map was created for the Habitat Fragmentation Analysis Project done as a partnership between Parks Canada and the University of Calgary. The project was completed in September 1999.

BC Forest Service data

Two types of map, Timber Stand Agreement (TSA) and Tree Farm Licence (TFL), both at a resolution of 20 m, were provided by Val Beard, GIS Technician for the Columbia Forest District. The two maps were merged together to obtain a complete coverage. The vegetation classification was broken down as such: *(numbers in brackets are classification id numbers)*

- M1/M2: forested ICH (40)
- C5: forested ESSF (41)
- D1: non-productive brush (60)
  other non-productive (61)
- Non forested: ice (50), alpine (51), rock (52), gravel pit (53)
  lake (54), river (55), swamp (56)
  road (57), urban areas (58)

Note: There were a lot of uncategorized patches below the alpine zone. These were classified arbitrarily as ESSF. There were also some patches of unproductive brush mixed up with ICH and ESSF fuels. These patches of land had two land classification but for this project, they were re-assigned to the corresponding fuel type class.

b) elevation map

The digital elevation map coverages, at a scale of 1:20,000, were obtained from the Parks Canada Vancouver Service Center. Coverages were merged by Murray Peterson from MRNP.

c) valley orientation map

Watersheds were outlined by M-P. Rogeau, digitized by Melanie Hindle and were categorized as follows:

- M1: main NW-SE valley (Lower Columbia)
- M2: main SW-NE valley (Illecillewaet including the Summit Road area)
- M3: main N-S valley (Upper Columbia, part of Illecillewaet)

- S12: small NW-SE valley running z to a SW-NE valley (all valleys z to the Illecillewaet)
- S32 small N-S valley running z to a SW-NE valley (all valleys z to the Illecillewaet)
- S21 small SW-NE valley running z to a NW-SE valley (all valleys z to the Lower Columbia)
- S43 small E-W valley running z to a N-S valley (valleys on both sides of the Clachnacudainn Icefield)

d) weather zone map

The elevation map was used to break down the landscape into three zones believed to experience similar fire weather. Fire weather data from these weather stations were applied to the following elevation zones:

Zone 1: Goldstream & Revelstoke stations : < 700 m

Zone 2: Big Mouth: 700 to 1150 m

Zone 3: Upper Beaver G.N.P.: > 1150 m

e) probability of ignition map

See Section 4.6.

f) probability of burning map

See Section 5.5

The p_burn map created from the results of the effect of topography on stand age distribution had to be modified during the model testing process. Fires during the spring/fall season were burning too large, so additional restrictions had to be implemented to reduce areas of burning. Elevation was the obvious parameter that would limit fire spread as high elevations remain snow covered for longer periods of time. The percentages of burning were defined as follows:

100 % : E-SE-S-SW facing slopes, elevation < 1000 m

64 % : N-NE-W-NW facing slopes, elevation < 1000 m

10 % : E-SE-S-SW facing slopes, elevation > 1000 m

1% : N-NE-W-NW facing slopes, elevation > 1000 m

e) fire frequency

The frequency of stand replacing fires on a 10 year period for the Greater MRNP was determined using the fire occurrence database It was assumed that without fire suppression, fires larger than 0.5 ha could have potentially developed into larger size fires. The fire occurrence database for fires >0.5 ha determined that during a 10 year period, on average 20 lightning-caused fires (± 20 fires) can occur. During any single year, the frequency of fires > 0.5 ha can range from 0 to 10. For a fire regime including both types of fires, lightning and anthropogenic, the frequency of fire increases by 20% (24 ± 24 fires per 10 years).