LANDSCAPE FIRE BEHAVIOUR PATTERNS ON THE FOOTHILLS MODEL FOREST

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ABSTRACT

This study investigated the historical patterns of fire over approximately 20,000 km^2 of the Rocky Mountains and foothills in Alberta. The study area included Weldwood's Hinton FMA area and other crown lands to the east of the front range, and Jasper National Park to the west. The stand origin map east of the front range was completed for spatial continuity, validated using independent data sources, and the "older than" tail of the age-class distribution defined using data from field sampling.

The analysis showed that the five major ecological natural sub-regions in the study area had unique landscape fire behaviour characteristics. Fire burning rates, sizes, and shapes were all specific to the natural sub-regions, as were differential densities of historical lightning activity. Although the age-class distributions differed between natural sub-regions, the percentages of forest in each age-class east of the front range in both 1950 and 1995 were well within historical ranges estimated through simulation with one exception; the amount of forest older than 100 years in the mixedwood area on the east side of the Rockies in 1995 was far greater than the upper limit of the historical range. The amount of cultural activity in the Park over the last century made it difficult to define a point at which the age distribution could be called "natural", but relative differences between natural sub-regions were very evident.

A comparison of the 1950 and 1995 landscape patterns east of the front range revealed that the youngest and oldest age-classes are both becoming more "fragmented" as indicated by decreasing patch sizes and interior forest area, increasing edge densities, and greater homogeneity.

Interaction of fire activity between natural sub-regions was of considerable relevance on either side of the Rockies, particularly for those areas arranged linearly. It is suspected that fire movement is significant along the Sub-alpine / Montane interface in the Park, and the Upper Foothills / Lower Foothills boundary on the east side of the Rockies.

There was some evidence to suggest that older areas may tend to be older (statistically) across a range of scales. Old areas on landscape scales are associated with areas of reduced lightning activity (meaning less ignition potential). At smaller scales, a pilot study suggests that old

areas may also be associated with specific topographic positions such as north-facing slopes and steep toe-slopes.

Although logical hypotheses could be offered to explain the movement of fires in different areas, the data did not allow a complete review of landscape fire behaviour. Within the next 6-12 months, considerably more data will become available allowing more extensive analysis of the observed patterns. What little information that was gained from this study demonstrated that fire is neither a random nor a ubiquitous process. Rather, pattern and behaviour were surprisingly landscape (*i.e.*, natural sub-region) specific. This suggests that attempts to "approximate" natural patterns and processes should proceed carefully, and in concert with educational efforts.

Overall, the amount and quality of the landscape data that will ultimately become available on both the study area will be exceptional. This will provide a unique opportunity to understand fire as both an ecological and evolutionary process, to a far greater degree than was previously possible.

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1.0 INTRODUCTION

Forest fires have long been recognized as the dominant process defining landscape "mosaic" patterns throughout most of North America (Suffling 1987). However, the importance of fire as both an ecological and an evolutionary process has only recently been fully appreciated. Fire is responsible for structures and processes at many scales, from coarse-woody and standing debris, to stand renewal and species persistence, to meta-landscape nutrient cycling, to large-scale (gamma) diversity and habitat maintenance (White 1979, Payette 1993, Malanson 1985). Realization of the importance of fire has made us take a closer look at it as a *process* that until now many considered to be both ubiquitous and random. In fact, it was not so long ago that scientific interest in fire was limited to the behaviour of individual events for prediction and control purposes (Stocks *et al.* 1989, Van Wagner 1992). More recent studies on landscape fire "patterns" suggest that the behaviour of fire on large scales is neither random nor necessarily ubiquitous.

Over the past several years, descriptions of different landscape disturbance "regimes" have emerged which describe historical types, sizes, shapes, and burning rates of wildfires, as well as other burning tendencies (Yarie 1981, Eberhart and Woodard 1987, Lorimer *et al.* 1994, Taylor *et al.* 1994). Although preliminary in nature, these studies have helped to develop a deeper appreciation of the process of fire on landscapes. Furthermore, the use of such information has become invaluable for generating more ecologically and evolutionarily sensitive management strategies. This can be achieved through active (*i.e.*, burning, cutting) and passive tactics (*i.e.*, fire management) towards the goal of maintaining biodiversity.

For these reasons, in early 1996, the Foothills Model Forest, in cooperation with Weldwood of Canada Ltd. in Hinton, Alberta, and Jasper National Park (JNP), initiated a research program to study natural disturbance in the Foothills Model Forest (see Figure 1.1 for a map of the study area). Both the Weldwood FMA in Hinton (which covers most of the study area east of the Rockies), and Jasper National Park are managed landscapes, and have been for several decades. It is the desire of each of the partners to use this research to actively pursue means of implementing natural disturbance pattern emulation, at all spatial and temporal scales. Understandably, Weldwood's use of information on natural patterns of disturbance will be more active than the Park's, but the goal of this research remains the same: to "... examine the role of disturbance in the Foothills and Rocky Mountain natural regions of Alberta." (Farr 1995).

Figure 1.1

As a part of this initiative, in March 1996, Bandaloop Landscape-Ecosystem Services was contracted by the Foothills Model Forest, in cooperation with Weldwood of Canada in Hinton and Jasper National Park, to study the landscape disturbance patterns on the Foothills Model Forest. Specifically, the work entailed:

1) advising on and designing field and office data collection methods, and the compilation, validation, and aggregation of all available data sources, and

2) using these data to provide a preliminary description of landscape fire patterns on the study area.

The timing of the 1996 study did not allow all of the relevant data sources to be gathered and used for analysis. However, since the release of drafts of this report, the disturbance dynamics project has been expanded to a 4-5 year term. Therefore, the opportunity exists for more comprehensive consideration of many of the issues raised in this document.

It should be noted that at press time the material presented in this report is in the process of being drafted as a series of articles for peer-reviewed scientific journals. It is the preference of the author and research partners that any citations of this work be restricted to these articles rather than this information report.

2.0 BACKGROUND

While reading this report, it should be kept in mind that this study is about much more than describing fire sizes, shapes, and types. Landscape mosaic patterns in forested areas are the combined result of geomorphic processes, the disturbance regime (of which fire is only one part), and forest stand dynamics (*i.e.*, initiation and succession) (Forman and Godron 1986). True, in most North American forest types, large-scale disturbance, more specifically fire, is generally accepted as being the dominant process creating landscape pattern (Johnson 1992, Sapsis and Martin 1993, Noss 1994). However, it is the associations between disturbance, geomorphic and forest dynamics as processes that allow us to begin to recognize repeatable tendencies, or "patterns". It is also these associations which other organisms recognize and respond to. For instance, it has been long hypothesized that fires tend to form edges at fuel-breaks such as creeks and rivers. Hence, the incorporation of both biotic and abiotic data sources is vital to a comprehensive study of landscape fire behaviour, beyond simple descriptions of sizes, shapes, and types.

Achieving this level of understanding can be challenging since reconstructing landscape-level events over hundreds of years involves some imperfect scientific methods in the strict sense. For instance,

1) experimentation is not an option because of the time-frames involved and inconstant climate,

2) available data were originally collected for other reasons and may not be complete, or may require assumptions or manipulation to use,

3) using historical reconstruction methods are often open to interpretation and debate and,

4) the use of statistics is either inappropriate (since spatially one has the entire population) not feasible (since replication is out of the question) or of no use (since temporally one only has a sample size of one).

Availability of any and all sources of corroborative circumstantial evidence therefore is critical. In this study, many sources of data were used to try to differentiate between that which was a *random* pattern, or wholly unpredictable, and a *stochastic* pattern, which deals with probabilities of events. Pattern is therefore recognized as having a temporal dimension here as well as the more traditional spatial one. In other words, spatially random processes may still be highly probabilistic temporally.

The last thing to keep in mind is the fact that fire, as an ecological process, acts at many different scales, from the mortality and injury of individual trees, to the creation of islands of unburnt trees, to changes in fire frequency in response to climatic changes. Although the scale of fire effects should be considered to be continuous, four relevant scales are identified for convenience: 1) region, 2) landscape, 3) meso, or sub-landscape, and 4) stand. This report deals with regional and landscape-level patterns of fire, and touches on some meso-scale issues. The larger disturbance research program under which this project falls deals with the integration of the information from all of these scales.

3.0 DATA DEVELOPMENT

Collecting and compiling data for landscape studies from scratch would take several years and several million dollars because of the sheer volume of information required. Alternatively, available data sources can be made suitable for such analyses with some modifications and additions. The first step in conducting landscape-level research then is to assess all of the existing data with respect to quantity, quality, and availability. Based on this assessment, data suitable for analysis are "developed" through augmentation, validation, and corroboration.

Considerable time and effort went into assessing all of the potential landscape-level data sources for this project, long before any analysis was done. Based on this assessment, recommendations were made to the project team regarding specific actions that would be necessary to develop a suitable dataset. This section describes all of the existing data sources that were used for the landscape analysis, and the steps taken to generate what will eventually turn out to be an exceptional landscape dataset for over two million hectares of Alberta.

The Foothills Model Forest is roughly divided in half, north to south, by the Rocky mountains. On the west side of the mountains lies Jasper National Park, and on the east side lies the Weldwood FMA (which accounts for the majority of the area), the Hinton townsite, a Provincial Park, at least one mine site, and a strip of land under the control of the Alberta Lands and Forests (see Figure 1.1). These jurisdictional differences means that the amount, type, and quality of the data differed from the east to the west side of the Rockies. For this report, these two areas are discussed separately. The area of the Foothills Model Forest to the east side of the Rockies will be hereafter referred to simply as "the Foothills", and the west side as Jasper National Park (JNP).

3.1 THE FOOTHILLS

A preliminary assessment of the large-scale data sources for the Foothills revealed that an above average quantity of information was available, due almost entirely to the efforts of Weldwood. However, questions remained regarding 1) the quality of the data, 2) the availability of the data, and 3) the ease and speed (and cost) with which the data could be aggregated and compiled from the Geographic Information System (GIS) ARC/INFO format into one suitable for analysis. The project deadline and resources were such that it was unlikely that all of the relevant data could be collected, assessed, validated, compiled, analyzed, and reported on within the allowable timeframe. Data and information were therefore priorized based on 1) utility, 2) availability (some of the data availability depended on the completion of other projects over which we had no control), and 3) cost (in terms of both time and money).

The following is the original priorized list of data and information requirements suggested to the project team:

1) Complete stand origin map.
2) Independent data with which to assess the accuracy and bias of the stand origin map.
3) Ecological natural sub-region map.
4) Timber inventory map (including species and stocking, non-forested descriptions)
5) Large-scale soils map (parent material and landform at 1:50,000 or finer)
6) Lightning strike data.
7) Digital elevation model (elevation, slope, and aspect).
8) Ecological site-series map.

The original source(s) and preparation of each of these data sources will be discussed in detail, as will any supplemental field data collection required. Not all data were available for analysis prior to drafting this report. Where there are outstanding data, an brief outline of the work remaining, and the potential benefits of having these data are discussed.

3.1.1 DEVELOPING A STAND ORIGIN MAP

One of the most important pieces of data that any landscape fire history study requires is a map showing stand origin dates (sometimes referred to as a "time since fire map"). Fortunately, a stand origin map for most of the Weldwood FMA was compiled *circa* 1960, and the remainder of the FMA completed in 1988.

The methods used to create the original stand origin map were as follows. Aerial photos from 1955 at a scale of 1:31,000 were used to delineate polygons based on age. Field crews then located boundaries from the photos and maps for site visits, and sampled trees. Priority was given to trees which were scarred by the most recent fire event but originated from the fire that preceded it. Each sample tree was either cut down, or notched such that field ring counts could be made and recorded on site. The age of the stands on either side of the located boundary was estimated. Several trees per sample site, and often several sample sites per stand were taken. The ages were recorded directly on the aerial photos, and any polygon boundary corrections were noted. The information was then transferred to coloured paper maps (Jack Wright, pers. comm.). Several years ago these paper maps were digitized as a layer in ARC/INFO.

Based on a record search and discussions with persons involved in the compilation of the original map, several weaknesses were noted that required immediate attention if it was to be of the highest and best use for this study. First, the non-FMA areas of the Foothills did not get mapped. The three largest such areas were the Hinton town site, Switzer Provincial Park, and the corridor of Provincially controlled land between the FMA and JNP (which would otherwise allow the entire study area to be considered as one seamless region). Even though these areas are not managed as part of the FMA, their absence creates some problems for spatial pattern analysis. They are essentially holes in the middle of data, and without them, spatial descriptions such as patch sizes and shapes are inaccurate.

The second problem with the original map was the use of an "older than" age category. The original purpose of the map was not to do fire history research, but to develop a reliable inventory of stand timber ages for planning purposes. Hence, no distinction was made between a stand was 200 years of age and one 250 years. The age at which field counts stopped was 150 years in 1960, translating to a limit of 188 years today. The age-class distribution (as the basis for several important descriptive attributes of the historical disturbance patterns) could only be partly defined without this information. The "tail" of age-class distributions provides valuable information (Finney 1995).

The third problem with the Foothills data was that the mapping and sampling did not include non-forested areas. Again, for planning and harvesting purposes, this information was of little value at the time, but in terms of describing spatial relationships and correlations, it may be very relevant. Non-forested areas may act as both a barrier and a facilitator to disturbance, depending on the circumstances.

A final issue with the original map was that of records. Since the original mapping did not keep office copies of field tallies, and original field notes and maps were not found, there was no way of assessing a level of confidence in the data. In short, we needed to know "how good" the age data was before proceeding, and whether or not there were any biases.

a) HOW GOOD IS THE ORIGINAL "FIRE MAP"?

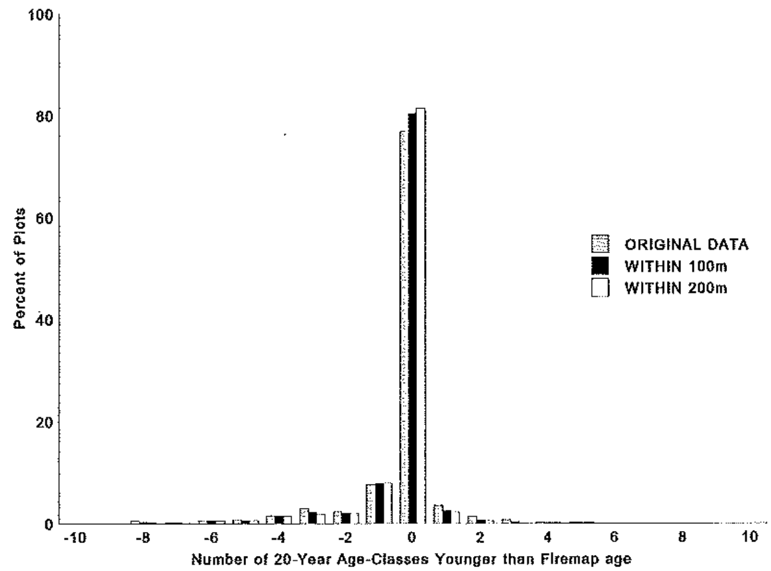
The only way to validate a stand origin map is to have an adequate number of independent age samples. If no independent age data are available, random or systematic field sampling is necessary. Since the Weldwood FMA has been under intensive management for many years, several projects requiring field data collection have taken place, and it was anticipated that at least one had reliable independent age information. The search began by compiling summaries of all fieldwork carried out on the FMA over the past 30 years.

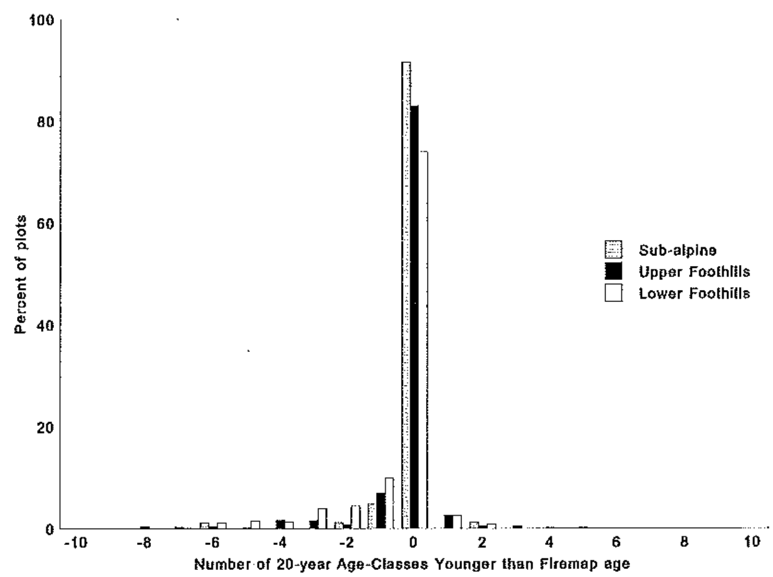
As it turned out, a grid of permanent growth sample plots (PSP) covers the entire FMA, in addition to several years worth of temporary sample plots (TSP). Both plot networks had (breast height corrected) age data, and plot locations were part of the available spatial data. This presented an ideal opportunity for age validation. This was particularly true of the PSP information since it covered the entire FMA. The TSP data was not used for this test since it tended to be clustered, subjectively located, and focused in older stands.

To use the PSP data, the locations of each plot were cross-referenced with the age of the forest polygon it landed in according to the stand origin map using ARC/INFO. In addition, the age of the next-nearest polygon was noted if PSP locations landed within 100 m or 200 m of a polygon boundary. This was to allow for errors in mapped and/or digitized plot and boundary locations. Note that this comparison can not provide evidence that either the stand origin map or the PSP data is correct, but it can increase our confidence level in both data sources if the ages are in agreement.

The comparison allowed for a 10 year error in the aging of either the PSP, or the stand origin map (in other words, 20-year age-classes were used). If both the PSP age and the stand origin map age landed within the same age-class, no difference in age was noted at that location. Areas mapped as 188 years of age were excluded from the analysis, since we already know that these ages are in error (since they are in the "older than" age-class).

The results were very encouraging. Ages from 77-82% of a total of 2,016 PSPs, fell within the same 20-year age-class as those of the stand origin map (Figure 3.1). Furthermore, 88-92% of all plots fell within ±1 20-year age-class, and 92-94% within ±2 20-year age-classes. Also encouraging was the fact that little or no bias was noted (*i.e.*, just as many plots were older than the stand origin map as were younger).


100
80
60
40
20
0
Percent of Plots
-10
-8
-6
-4
-2
0
2
4
6
8
10
Number of 20-Year Age-Classes Younger than Firemap age
ORIGINAL DATA
WITHIN 100m
WITHIN 200m


100
80
60
40
20
0
Percent of plots
-10
-8
-6
-4
-2
0
2
4
6
8
10
Number of 20-year Age-Classes Younger than Firemap age
Sub-alpine
Upper Foothills
Lower Foothills

The improvement in age matching was only marginal when polygons within 100 m and 200 m of the PSP locations were considered. Only five percent more plots were within the same 20-year age-class as the stand origin map when a 200 m error in plot and/or polygon location was allowed (Figure 3.1). This consistency suggests that both the sample plots and stand origin polygon boundaries were located and digitized quite accurately.

When the validation exercise was repeated by natural sub-region, moderate differences were noted (Figure 3.2). The Sub-alpine natural sub-region ages were the most consistent, with 96% of all plots within ±1 20-year age-class. The Upper Foothills natural sub-region had 93% of all plots within ±1 age-class, and the Lower Foothills comparison found only 86% of all plots within ±1 age-class of the PSPs. An increasing negative bias is also noted moving from the Sub-alpine to the Lower Foothills sub-regions, meaning that the PSP ages tended to be greater than the fire origin map ages (Figure 3.2).

Overall, the comparison of the fire map ages with the PSP ages indicates a high degree of accuracy. The negative bias of the ages of the Lower Foothills, and to a lesser degree the Upper Foothills, is not significant enough to peruse further. In any case, there is no way of knowing in which dataset the bias occurred; it could just as easily be the PSP ages that are biased. Considering the large sample (over 2,000 plots) and the complete, unbiased coverage of the plot network, there is more than enough evidence to suggest that the information from the original fire map can be used with confidence as is for areas younger than 188 years.

b) DATA GAPS

The data gaps in the Foothills area required immediate attention. A four month field program was planned and initiated for the summer of 1996. The purpose of the field program was to develop stand origin maps of some of the non-FMA areas of the Foothills. The methods used to map the required areas were similar to those originally used in 1960, but much more rigorous in nature. See Rogeau (1996) for a complete description of the methods and details of this sampling.

With limited field time and resources, it was necessary to set priorities for the data gaps. The highest priority areas were the Provincial Park and Hinton town sites. The lowest priority was the strip of land under control of the Alberta Land and Forest Service (ALF). It was anticipated and accepted that completing all of this work this field season was unlikely.

At the end of the field season, Switzer Provincial Park and the townsite had been mapped, sampled, and digitized. Very little of the ALF strip was sampled or mapped, although a large portion of it has had the photo interpretation completed, and sample sites chosen in anticipation for a second field season in 1997.

c) HOW OLD ARE "OLDER THAN" AREAS?

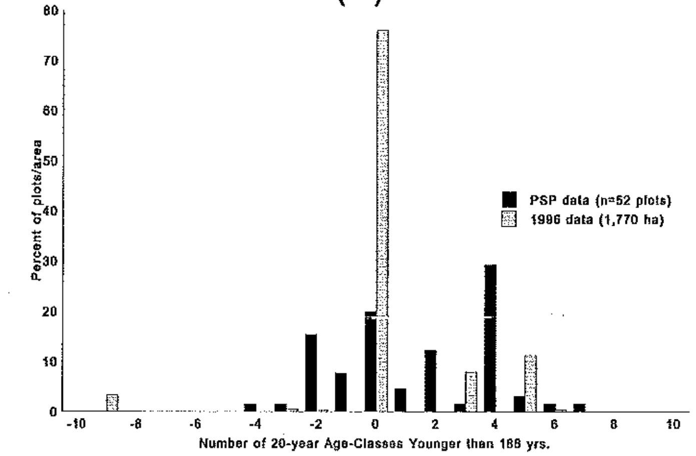
There were two potential (independent) sources of data with which to distribute the older-than age-class of the Foothills. First, the PSP information was summarized and analyzed similar to the method used for age validation. This was supplemented by re-mapping selected areas of the Foothills region.

To avoid bias, sampling for older sites should have been well distributed across the Foothills area. However, this was impractical this year for various reasons. Instead, most of the largest contiguous piece of older forest was completed (for about 40,000 hectares). The details of the sampling are given in Rogeau (1996) and will not be repeated here, but essentially, it resulted in a second, more precise, stand origin map of a small portion of the Foothills area. The most significant differences between the stand origin map produced this year and the one in 1960 is that the former was a result of much more rigorous sampling, and did not designate an "older than" age-class. In other words, the mapping this year started from scratch for approximately 40,000 hectares of what was previously classified being older than 188 years of age.

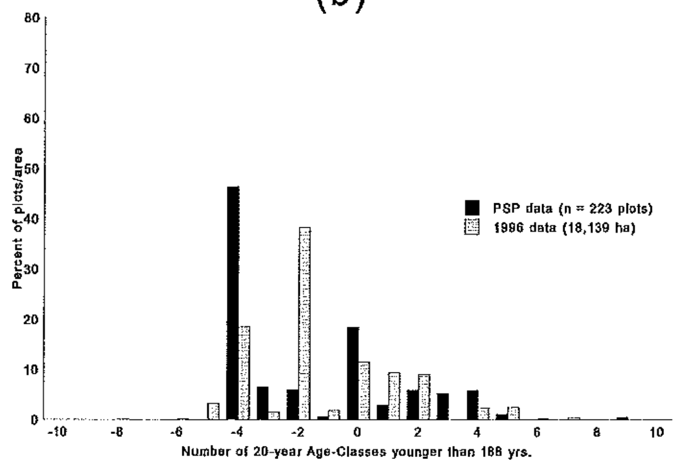
The age-class distributions of the 1) the PSP ages and 2) the 1996 sampling were compared in 20-year age-classes for this area. The age-class that the 1808 year of origin falls into (1800-1820) was used as the zero point for the x-axis in Figure 3.3. Therefore, everything to the left of zero on the x-axis was actually older than (1996-1808=) 188 years, and everything to the right was younger. Increments of 20 years define an age-class.

The results were variable. The Lower Foothills was the only area in which there was no negative age bias (Figure 3.3a). In fact, if anything there is a positive bias, meaning that the PSP ages were generally younger than 188 years. It is also the only natural sub-region in which the data from the PSPs and the 1996 sampling disagree. While the 1996 stand origin mapping indicates that the actual ages of old areas are very close to the 188 year cutoff, the PSP data suggests that the majority of area is actually *younger* than 188 years.

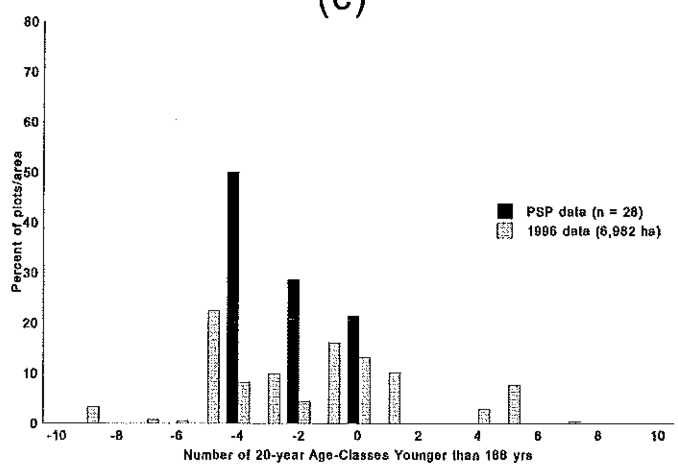
(a)


Percent of plots/area
Number of 20-year Age-Classes Younger than 188 yrs.
PSP data (n=52 plots)
1996 data (1,770 ha)

(b)


Percent of plots/area
Number of 20-year Age-Classes younger than 188 yrs.
PSP data (n = 223 plots)
1996 data (18,139 ha)

(c)


Percent of plots/area
Number of 20-year Age-Classes Younger than 188 yrs
PSP data (n = 28)
1996 data (6,982 ha)

The PSP data was used to allocate the older-than age-class for the Lower Foothills because:

1) the area sampled during the 1996 fieldwork was quite low (1,770 hectares) and spatially clustered,

2) there is little danger of a PSP "older-than" age category coming into play, (to be discussed), and

3) there is less chance that correction errors from using breast-height ages (from the PSPs) occur in younger trees.

Predictably, most of the 1808 area in the Upper Foothills area was much older than 188 years. In fact, 59-63% of the 1808 area was more than one age-class older than 188 years (Figure 3.3b). In contrast, only 15-19% of the area was more than one age-class younger than 188 years. Ironically, the Upper Foothills age data demonstrate that there was relatively little fire activity in the age-class in which the original 1808 mapping falls (Figure 3.3b). Only 22-23% of the new stand origin map fell within ± 1 20-year age-class of the 1808 origin year.

In general, the new stand origin map data, and the PSP data distribute the older-than area similarly, which lends credibility to both datasets. The main difference between the two distributions in Figure 3.3b is the large portion or area that the PSP distribution allocated in the age-class labelled "- 4". Inspection of the raw PSP data revealed that all of these plots had a recorded stand age of 255 years. The fact that the age of 255 occurred so often, yet none greater, suggests that PSP aging may also have allowed for an "older than" age category. The identical pattern was noted for PSP ages in the other two sub-regions.

Although sample sizes for either dataset are adequate, the 1996 stand origin map data was chosen to represent the 1808 areas of the Upper Foothills area for the following reasons:

1) Although there was some fear that the 1996 sampling was not well distributed spatially across the FMA, and thus potentially biased, the data generally agree with the PSP data, which is very well represented spatially.

2) The suspicion of another "older than" age-class for the PSP's is troublesome.

3) More rigorous methods of collecting age data were use (*e.g.*, field and lab counts of cookies from ground height) on a greater number of trees for the new stand origin map.
The distribution of the older-than Sub-alpine areas was also negatively biased (older) (Figure

3.3c). Between 50-79% of the ages were more than one age-class older than 188 years, depending on the data source, and only 0-11% were more than one age-class younger (Figure 3.3c). Once again, the presence of the 255 year-old age limit for the PSP data is suspected, since the 1996 sampling found many areas much older than 255 years.

The age data from the 1996 sampling was chosen to allocate the 1808 areas of the Sub-alpine sub-region. In addition to the same arguments used for choosing this dataset for the Upper Foothills, the sample size for the PSP data in this case was small (n=28 plots).

Although far from perfect, these two datasets provided the means of developing reasonable, unbiased estimates of the breakdown of the "older-than" age category for each natural sub-region. The allocation of these data to the original age-class information is discussed in Section 4.

3.1.2 ECOLOGICAL CLASSIFICATION DATA

The importance of differentiating land areas by ecological classification on large scales has already been demonstrated through the validation exercises. It is usually safe to assume that such areas possess unique disturbance behaviour tendencies, and their spatial delineation should be a high priority for this study. The natural sub-regions according to the ecological classification for West-central Alberta (Beckingham *et al.* 1996) were already available as an ARC/INFO layer.

Ecological site classification on finer scales (*i.e.*, ecosite or phase), is useful data for investigating fire tendencies at scales below the landscape-level. For instance, certain site-types may turn out to be related to higher or lower fire frequency, higher or lower burning intensities, or even different types of fire activity (crown versus surface fires).

Unfortunately, collecting this data spatially can be very expensive. The FMA has had some ecological mapping done, but only in selected pockets. As important as this data may be for future work, it was not considered a priority for this year's work.

3.1.3 FOREST INVENTORY DATA

Inventory information is useful for landscape-level correlations of cover-types, stocking, and height classes with fire return intervals, and topographic positions. These correlations serve as important links to meso, and even stand-level patterns.

Two types of timber inventory maps exist for the Foothills area: Phase III and AVI (Alberta Vegetation Inventory). Phase III is considered to be of poorer quality and lower resolution (in terms of information) than AVI. Neither one covers the entire area, but plans call for complete AVI coverage for the Foothills area within the next twelve months.

To use forest inventory information in this analysis, the two coverages would have to be merged and converted to the necessary file types. Despite the potential importance of these data, the decision was made not to peruse spatial cover-type data for this year because:

1) this first part of the project was under time constraints,
2) the development of the necessary data files would be costly and time-consuming, and
3) complete, digital AVI coverage will be available next year.

3.1.4 SOILS

Soils maps are useful for delineating areas which may have unique fire regime features. For instance, areas delineated by parent material, landform, or texture-class may show different patterns of species associations. This can affect flammability (hardwoods vs softwoods), or the movement of fires (flat versus steep terrain). It may also help identify zones of the landscape which tend to be less penetrable for fire (*i.e.*, organic areas).

Basic soil information exists for all parts of the Foothills, but the formats and sources differ. A project to compile and aggregate the best of this information was initiated by Weldwood in 1996, but it will not be completed until late 1996 or early 1997.

3.1.5 DIGITAL ELEVATION MODEL (DEM)

Terrain information can be used in several ways in landscape research. As with soils information, large areas can be classified based on terrain "roughness" to see whether fire sizes or shapes are affected by topography. Slope and aspect information at the pixel level can be used at the meso-scale to test for differential fire return intervals, or fire "refugia" at different topographic locations.

The DEM for the Foothills area was available, but a considerable amount of work and computer time in ARC/INFO would have been necessary to convert the data into raster format at a suitable resolution. Instead, DEM data was complied for a single mapsheet in the Upper Foothills area to test the potential of pursuing DEM data further in the future.

3.1.6 LIGHTNING STRIKE DATA

Historical lightning activity can help give a broad picture of ignition probabilities spatially, which may correspond to fire cycles in different areas.

Alberta has a network of lightning location positioning devices which triangulate the location of every cloud-to-ground lightning strike. At least ten years of data are available, but the raw strike data requires some manipulation to render it useful. We were fortunate that this transformation had already been done by Parks Canada personnel for a study of lightning regimes in Alberta and British Columbia (M. Heathcott[1], pers. comm.). We were able to obtain a copy of the transformed data for most of the last ten years for the Foothills area.

3.2 JASPER NATIONAL PARK

The landscape database for JNP was not as deep as that of the Foothills area. Nor were time and resources such that much could be done to upgrade this database this year other than some supplemental fieldwork for age validation (discussed in a separate report by G. Mercer) Resource limitations allowed only a preliminary examination of the disturbance patterns on the JNP landscape at this time. The additional data at both landscape and meso-scales would improve the understanding of disturbance dynamics in the Park many-fold.

Considering the resource limitations and the data, the priorities for the Park were fairly straightforward. The existing data sources for JNP, in order of priority were:

1) Fire history map.
2) Ecological sub-region identification.
3) Vegetation map.
4) Lightning data.
5) Digital Elevation Model.
6) Bio-physical maps.

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[1] Fire Management Officer, Parks Canada Headquarters, Hull, Quebec

3.2.1 STAND ORIGIN MAP

Jasper National Park had a stand origin map completed and digitized in 1990. The methods used to develop the map were similar to those used for the Weldwood FMA map, and the spatial coverage was complete. This map has since been partially updated from more detailed work for some of the lower elevation Montane area (Tande 1979).

Early on in the project, Park personnel expressed concern over the quality of the data in the stand origin map. With no independent data sources with which to validate the map, a small field validation program was initiated in two areas of the Park. This age validation project was conducted under the direction and jurisdiction of the Park, so is not a part of this report. However, when completed, this report should be considered as a companion document to this one (Mercer, in draft). The results will have a large impact on the interpretations, and on the direction of future disturbance related research.

The Park also has fire history maps, some original fire scar history data from the stand origin mapping, and some fuel-loading data which would also be useful for future natural disturbance research.

3.2.2 ECOLOGICAL CLASSIFICATION DATA

As with the Foothills area, the natural sub-region information had been digitized and was readily available for use in this project. The Park also has biophysical maps at 1:50,000 in ARC/INFO format mapped down to ecosite level. This data was not available for this study, but would be extremely useful for more detailed fire behaviour studies.

3.2.3 VEGETATION MAPPING

The forest inventory data for the Park is a "dominant vegetation" map, which consists of 18 broad vegetation types from non-forested, to meadow, to leading species forested. This information was available in digital form, and converted to the necessary format for analysis. No information exists on more specific aspects of stand attributes such as stocking, dominant height, or site-class.

3.2.4 BIO-PHYSICAL MAPPING

The bio-physical maps, which include soils and other topographic data, at a scale of 1:50,000 were not compiled for this project, largely because of a lack of time and resources. Understanding of the disturbance patterns of other less mountainous areas have benefited from bio-physical information at much lower levels of resolution (Soils data at this scale, with this amount of detail, is not normally available on anything but agricultural areas). The value of this information in the Park is unknown, however, the fact that it exists is an advantage not to be overlooked.

3.2.5 DIGITAL ELEVATION MODEL

As with the Foothills area, the DEM was not included in the analysis because of time and resouce limitations. However, considering the terrain, this data would be of tremendous value to interpreting disturbance patterns. The conversion and compilation of DEM data into usable format should be a high priority for future disturbance work. The current DEM model is at 1:250,000, but a 1:50,000 model should be available by next spring, which, combined with the biophysical maps at the same scale, would provide ample opportunity to do more detailed analysis of landscape fire behaviour.

3.2.6 LIGHTNING STRIKE DATA

The same lightning dataset used for the Foothills area was available for the Park.

3.3 PREPARING THE DATA

For each of the two areas (JNP and the Foothills) the data were compiled both spatially and non-spatially. The non-spatial data was a listing of polygon information based on stand origin data. Separate files were assembled for the original stand origin map, and any new stand origin mapping completed in 1996 (for the Foothills area). A third file was created which split stand origin polygons by natural sub-region.

The spatial data consisted of a series of overlays for each of the data sources listed above, spatially referenced using Universal Transverse Meridian (UTM) coordinates at a resolution of four hectares. When completed, each of the data overlays was electronically delivered in flat ASCII comma-delimited files. The spatial data layers were then converted to 16-bit binary format, verified (using summaries and visual methods), and then merged using common spatial coordinates. Finally, the non-spatial information was embedded in this file using common polygon identification numbers. The data merging process was completed using Turbo C++ programming language.

4.0 METHODS AND RESULTS

This section is divided into logical subject areas or questions concerning landscape fire behaviour. Each topic will include an overview of the data and methods that were used to complete the analysis and the results. As in the previous section, the Foothills and JNP areas are discussed separately for each topic.

4.1 LANDSCAPE OVERVIEW

The Foothills area to the east of the Rockies covers just over one million hectares. Five natural sub-regions are found in this region, although only a small percentage of the area is covered by the Montane (1%) and Alpine (0.1%) natural sub-regions. Neither the Montane nor the Alpine sub-regions will be discussed further in this report.

Of the remaining three natural sub-regions, the Upper Foothills covers 60% by area, Lower Foothills 29%, and the Sub-alpine 10% (Table 4.1). Ninety percent of the area is forested, but this also varies by natural sub-region. The Sub-alpine has the least amount of non-forested area (2%) while the Lower and Upper Foothills areas have 12% and 10% non-forested area respectively (Table 4.1). Note that the Upper Foothills estimates were adjusted to allow for 5,444 hectares labelled as "non-forested" in the original database, but exists now as a coal mine. Lacking detailed data, it was assumed that the entire mine area was forested. Note that "non-forested" in this document refers to lakes, swamps, beaches, rock, grass or brush, and low density forest/brush mixtures.

Table 4.1 Summary of the Foothills region of the Foothills Model Forest.

	Natural Sub-region					Totals
	Upper Foothills	Lower Foothills	Sub-alpine	Montane	Alpine	
Forested (ha)	569,295*	263,073	107,100	10,925	188	945,158
Non-Forested (ha)	59,743	36,789	2,375	1,780	961	107,093
Non-Forested (%)	9.5	12.3	2.2	14.0	83.6	10.2

Total (ha)	629,038	299,862	109,475	12,705	1,149	1,052,251

* The area of a coal mine now covering 5,444 hectares was added to the "Forested" category.

Jasper National Park covers approximately the same physical area, but the summary is quite different. Almost the entire Park consists of either Alpine (45%) or Sub-alpine (48%) natural sub-regions, and the majority of it is non-forested (Table 4.2). All but 8% of the Alpine area is non-forested, and it could be argued that these forested areas are actually high elevation Sub-alpine. However, without further data, there is no way of knowing whether or not this is true. It may be that "Alpine forested" areas are the warmest sites, and thus have the potential to be forested. Until this can be confirmed one way or another, the distinction will be maintained.

Table 4.2 Summary of Jasper National Park area of the Foothills Model Forest.

	Natural Sub-region					Totals
	Montane	Sub-alpine	Alpine	Upper Foothills	Unclassified	
Forested (ha)	72,416	361,721	39,416	5,274	320	479,147
Non-Forested (ha)	7,958	171,786	461,500	117	2,293	643,654
Non-Forested (%)	9.9	32.2	92.1	2.2	87.7	57.3
Total (ha)	80,373	533,507	500,916	5,392	2,613	1,122,801

Only 7% of the Park is Montane, but 90% of that is forested. A single patch of Upper Foothills sub-region is also found within the Park, although it constitutes less than half of one percent of the area. There is also a very small amount of unclassified area (Table 4.2), but a quick spatial review showed that these were all associated with Alpine areas at the Park boundary, and thus likely digitizing discrepancies.

4.2 AGE-CLASS DISTRIBUTIONS

In Section 3.1.1 it was determined that for polygon ages less than 188 years, the stand origin map is accurate and bias-free. The proportions of the areas in 20-year age-classes from the original "older than" (188 years) age-class was determined by either the PSP data (for the Lower Foothills) and 1996 stand origin mapping (for the Upper Foothills and Sub-alpine). Combining these two distributions for each natural sub-region created new, estimated, age-class distributions. In other words, up to the 180-200 year age-class the original stand origin data was applied, and beyond this age, the PSP / 1996 mapping was required.
For each natural sub-region, one age-class distribution was calculated as of 1995, and a second as of 1950 (Figures 4.1a-c). The 1950 distribution was possible because harvesting data were available in the database, and virtually no natural fires occurred since 1950 in the Foothills area. Since prior to 1950 both harvesting and fire control activities were at a minimum, this represents a "pre-commercial" landscape. Nor is it likely that early fire control activities had much of an impact prior to this date.

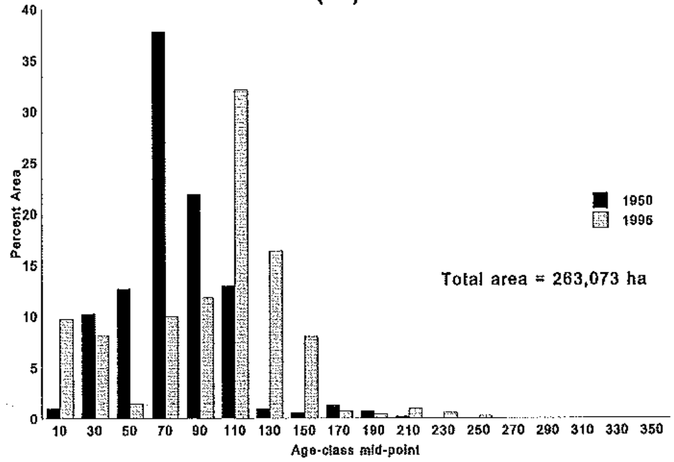
The differences in the age-class distributions for the different sub-regions is obvious visually, and justifies distinguishing historical landscape fire behaviour among the three areas. The Lower Foothills area has very little forest area older than 160 years in either distribution, while the Sub-alpine area has almost a quarter of its' area in forest older than 160 years. The Upper Foothills has an intermediate amount of older forest (Figures 4.1a-c).

There is evidence of corresponding periods of high and low fire activity between natural sub-regions. The 60-80 year age-class (as of 1950) was a period of high fire activity in both the Lower and Upper Foothills area, but only moderate activity in the Sub-alpine area. Similarly, the 80-100 year age-class had moderate fire activity in the Lower and Upper Foothills areas, but almost none in the Sub-alpine. These relationships are notable because they suggest that periods of high fire activity did not affect landscapes at this scale universally.

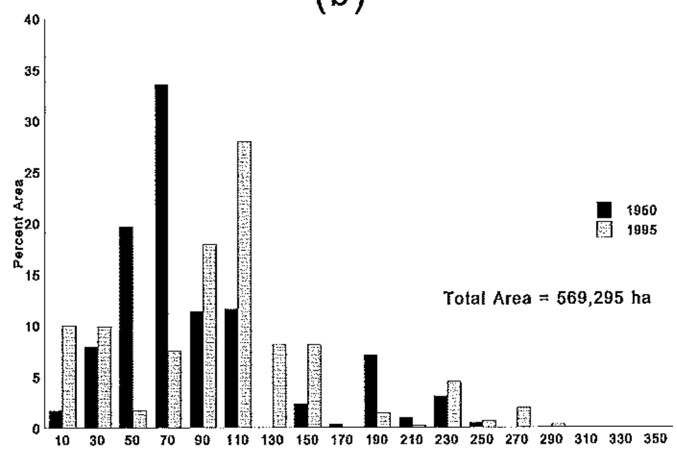
Average age differences between the 1950 and 1995 distributions range between 20 and 35 years, although the shapes are similar (*i.e.*, In most cases the 1995 age-classes can be predicted by shifting the 1950 distribution two classes to the right). A question commonly asked in landscape studies is whether one distribution is better, or more "representative" of historical ranges? As it happens, as part of a related study, this assessment was possible.

A spatially-explicit landscape pattern simulation model (LANDMINE) was calibrated for the disturbance regimes of the three Foothils natural sub-region. The stochastic nature of the model allows it to use (empirical) historical ranges of fire sizes and frequencies to create any number of *possible* landscape patterns, which can then be summarized and compared. In this case the model created 50 landscape patterns based on historical information, and the percentages of each age-class recorded and summarized. For a brief overview of the LANDMINE model, see Appendix A, and for a detailed description, see Andison (1996).

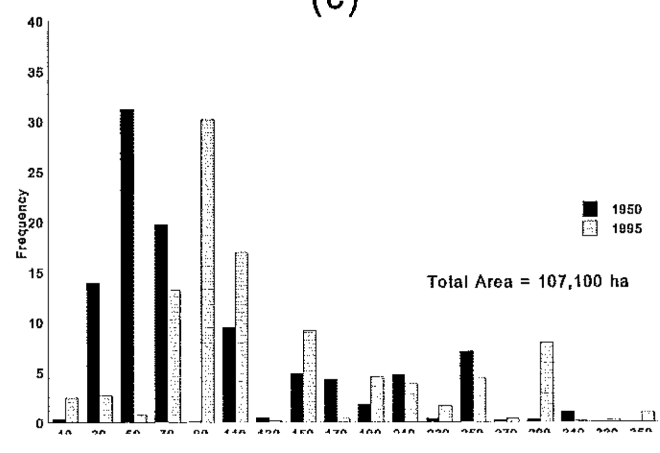
(a)


Percent Area
Age-class mid-point
1950
1996
Total area = 263,073 ha

(b)


Percent Area
Age-class mid-point
1950
1995
Total Area = 569,295 ha

(c)

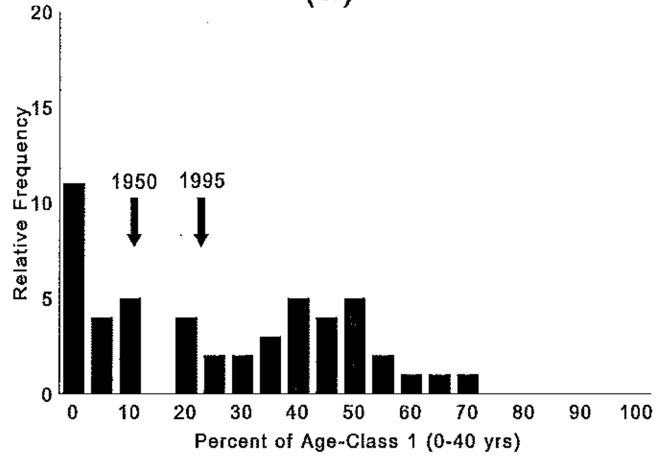

Frequency
1950
1995
Total Area = 107,100 ha

The results from the 50 model runs were summarized using frequency distributions of the observed percentages in each age-class, and then compared to the 1995 and 1950 percentages for each natural sub-region. For brevity and convenience, the original 20-year classes were grouped into broader age categories which roughly represented different stages of forest development, or "seral-stages". A total of six such classes were defined. The 1995 and 1950 percentages for the seral-stages were calculated and compared to the frequency distributions generated from the model. The result is an approximation of where the 1950 and 1995 age-class percentages lie compared to what *may* have been the "natural range" of these percentages. Keep in mind that any simulation is only a rough approximation of the actual system. The output is therefore only an estimate of reality.

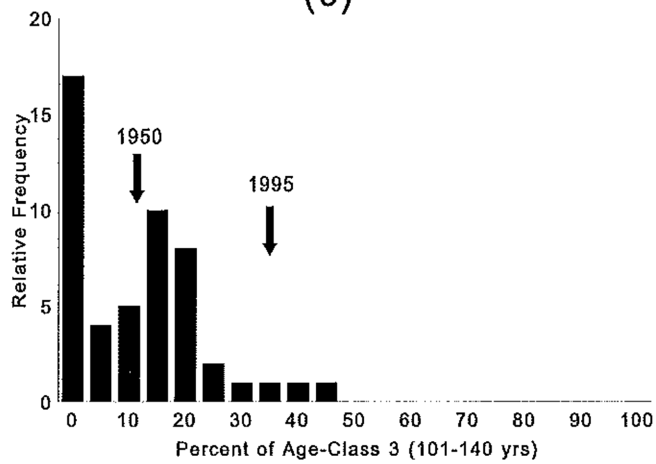
Simulated frequency distributions for five seral age-class percentages were compared to the pre-commercial (1950) and current (1995) age-class percentages for the Upper Foothills landscape. (The simulation produced only a very small amount of area in the sixth seral-stage, beyond 300 years). All were well within the range of the simulation output (Figures 4.2a-e). In other words, based on the simulated range of landscape behaviour, neither age-class distribution can be identified as being more appropriate, or "natural" than the other.

More generally, it is interesting to note how wide the range of "possible" seral-stage percentages was for the simulated landscapes. This is particularly true of he frequency distribution of the younger age-classes, which are wide and flat. This means that there is almost equal probability of any percentage of forest up to 100 years of age (Figures 4.2a and b). The older age-classes show narrower distributions of possible percentages, and also demonstrate an increasing negative bias. The oldest age-class has the strongest tendency towards low percentages, although the it still shows the (rare) potential for comprising 20% or even 30% of the landscape area (Figure 4.2e).

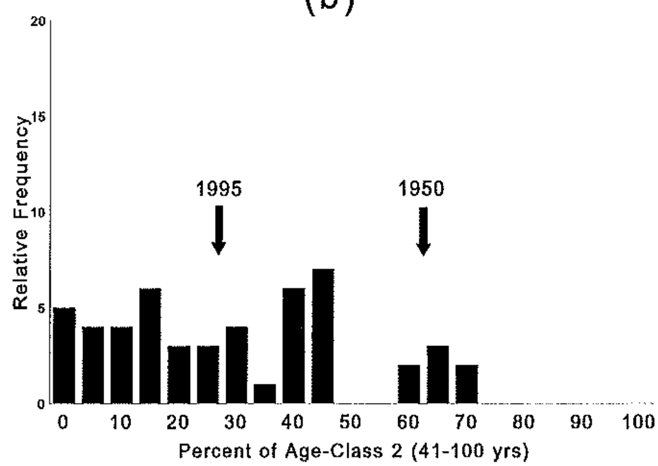
(a)

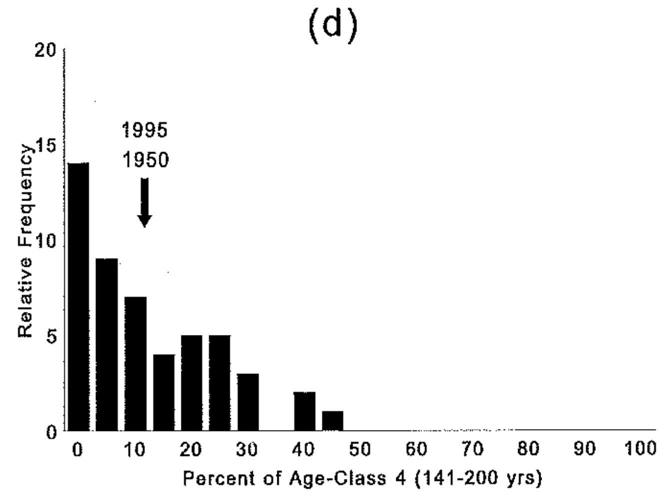

20
15
10
5
0
Relative Frequency
1950
1995
0
10
20
30
40
50
60
70
80
90
100
Percent of Age-Class 1 (0-40 yrs)

(c)


20
15
10
5
0
Relative Frequency
1950
1995
0
10
20
30
40
50
60
70
80
90
100
Percent of Age-Class 3 (101-140 yrs)

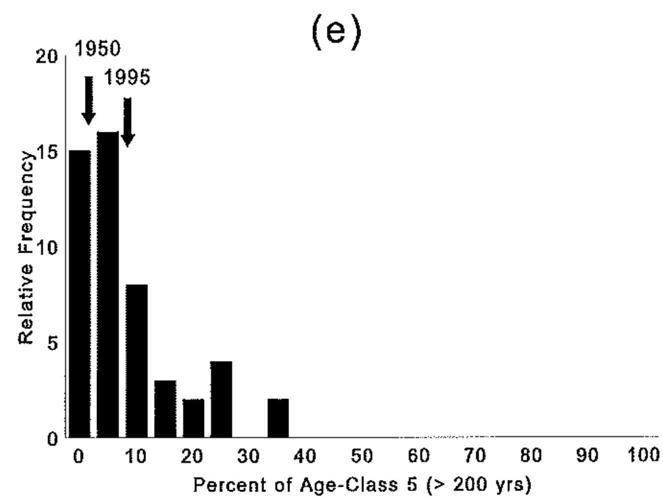
(b)


20
15
10
5
0
Relative Frequency
1995
1950
0
10
20
30
40
50
60
70
80
90
100
Percent of Age-Class 2 (41-100 yrs)

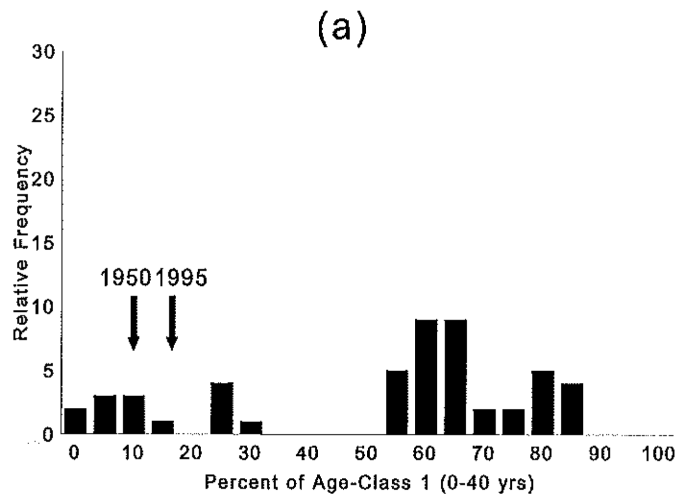


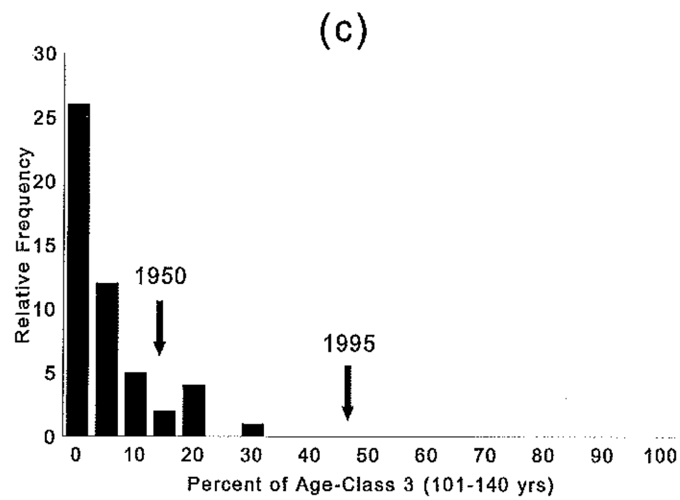
The same comparison for the Lower Foothills age-class percentages included only age-classes up to 140 years. Beyond 140 years, the percentages of areas from the simulations were very small, and highly negatively skewed.

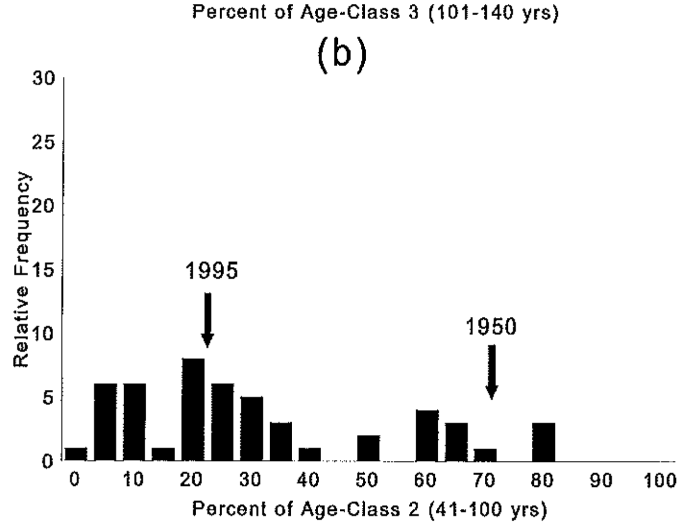
According to Figure 4.3, the 1995 and 1950 age-class percentages for the first two age-classes are well within the simulated range. In fact, it would be difficult to have a percentage of age-class 1 or 2 that was not within this range, since they are so wide. However, the 1995 percentage of age-class 3 is well beyond the range predicted by the simulations. In other



words, the simulations suggest that the amount of forest currently beyond 100 years of age in the Lower Foothills may be unusually high (Figure 4.3c).


(a)
Relative Frequency
0
5
10
15
20
25
30
1950
1995
0
10
20
30
40
50
60
70
80
90
100
Percent of Age-Class 1 (0-40 yrs)


(c)
Relative Frequency
0
5
10
15
20
25
30
1950
1995
0
10
20
30
40
50
60
70
80
90
100
Percent of Age-Class 3 (101-140 yrs)


(b)
Relative Frequency
0
5
10
15
20
25
30
1995
1950
0
10
20
30
40
50
60
70
80
90
100
Percent of Age-Class 2 (41-100 yrs)

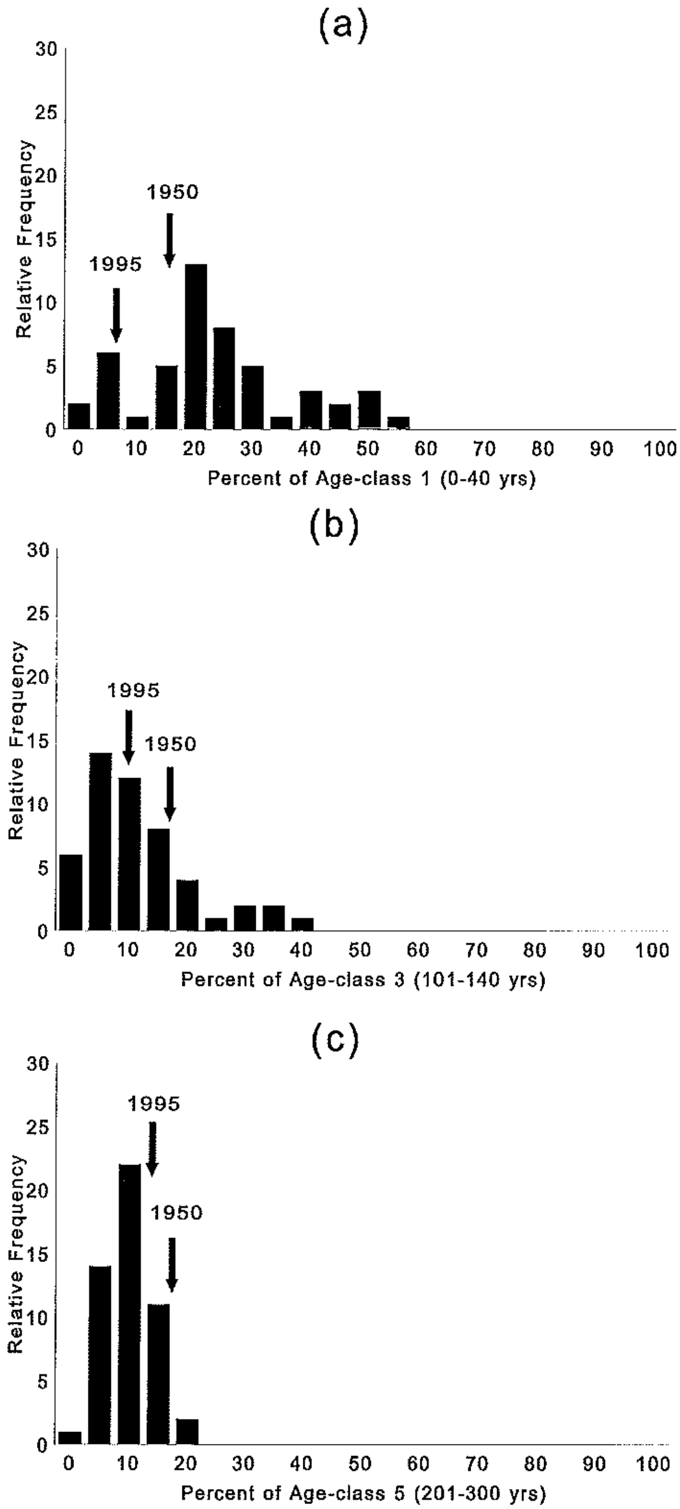
The age-class comparison for the Sub-alpine natural sub-region included only seral age-classes 1, 3, and 5 (for brevity). The age-class distribution of age-class 2 was much like age-class 1, and age-class 4 was much like age-class 5.

Comparisons to all age-classes showed that age-class percentages from both 1950 and 1995 were well within simulated limits (Figure 4.4a-c). It is also interesting that the frequency distributions for the Sub-alpine suggest a central tendency, unlike the other two simulations. The range of possible percentages for the youngest age-class is also much narrower than that of either the Upper Foothills or Lower Foothills natural sub-regions (Figure 4.4).

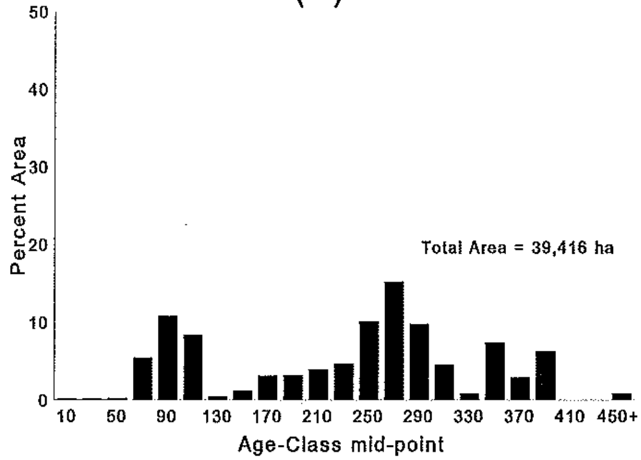
The age-class distributions for Jasper National Park were used as is. In the absence of validation data (which is forthcoming) there is no way of assessing either the accuracy or bias of these data. On the positive side a) there is an "older than" age-class, but it is beyond 450 years and applied to very little area, and b) about a third of the Montane area was mapped at a very high level of detail several years ago (Tande 1979). To allow for some degree of inaccuracy, the age-classes used for the Park were 40 year intervals.

Cultural activity in the Park extends back further than in the Foothills area, and includes both fire suppression and ignition, as well as settlements and grazing. Until historical re-creation projects currently initiated in JNP are completed, it is difficult to define any particular point at which the Park may not have been influenced culturally. Therefore no attempt was made to do so, and the age-class distribution from 1995 is given.

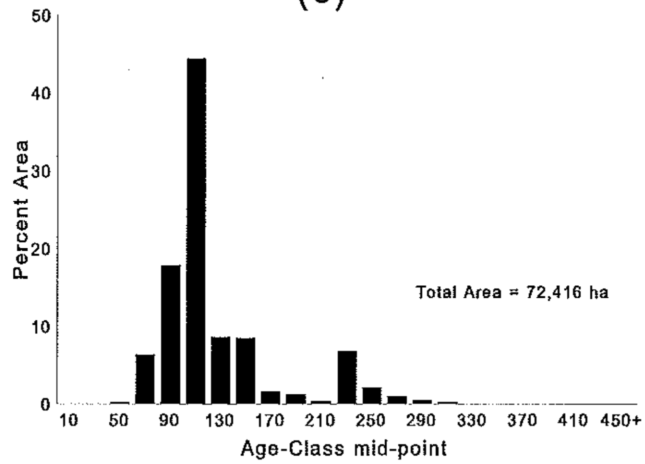
The age-class distributions for the natural sub-regions in JNP are at least as distinctive (from each other) as they were for the Foothills area. Both the Alpine and the Sub-alpine sub-regions have much larger areas in older forests compared to any of the areas of the FMA (Figures 4.5 a-b). It is interesting that the forested areas defined as Alpine continue to show evidence of being distinctive from those defined as Sub-alpine. The dominance of the 100-120 year age-class in the Sub-alpine is not nearly as notable for the Alpine area, and the Alpine has a higher proportion of older stands. In contrast, the Montane is almost completely dominated by the 100-120 year old age-class, and shows only small amounts of older forest (Figure 4.5c). The only other notable feature of the Park's age-class distributions is the absence of very young stands. No age-class simulations were done for the Park, so there is no way of knowing how "natural" this phenomenon is.


(a)
1950
1995
Relative Frequency
Percent of Age-class 1 (0-40 yrs)
(b)
1995
1950
Relative Frequency
Percent of Age-class 3 (101-140 yrs)
(c)
1995
1950
Relative Frequency
Percent of Age-class 5 (201-300 yrs)

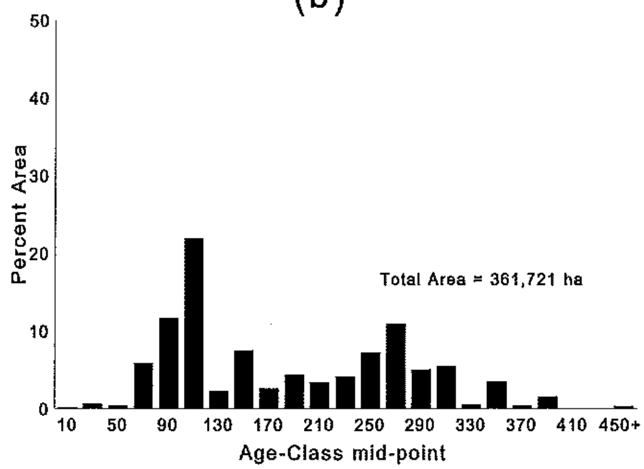
(a)


Percent Area
Total Area = 39,416 ha
Age-Class mid-point
0
10
20
30
40
50
10 50 90 130 170 210 250 290 330 370 410 450+

(c)


Percent Area
Total Area = 72,416 ha
Age-Class mid-point
0
10
20
30
40
50
10 50 90 130 170 210 250 290 330 370 410 450+

(b)


Percent Area
Total Area = 361,721 ha
Age-Class mid-point
0
10
20
30
40
50
10 50 90 130 170 210 250 290 330 370 410 450+

4.3 HOW MUCH AREA BURNED

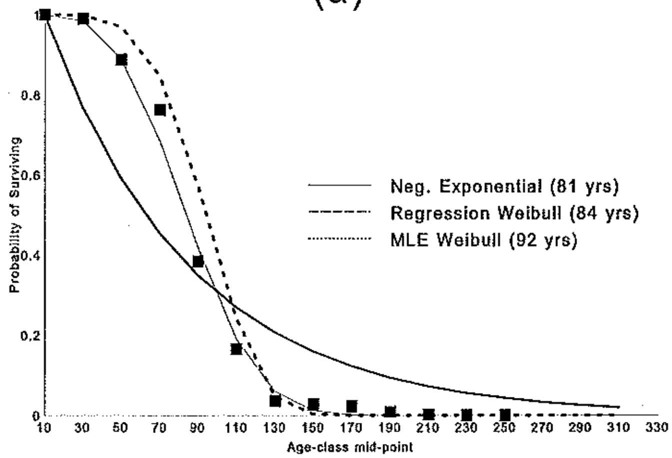
Estimating the amount and range of annual disturbance is virtually impossible over such a large area for all but the most recent years. However, estimates of the average annual amount can be made, as well as some estimates of this range.

There are several ways of estimating average burn rates. The simplest is to take the reciprocal of the average age as determined from age-class distribution data. The average age can also be interpreted to be the average time required to burn an area equivalent to the area of the landscape - or the "fire cycle" (Johnson 1992). However, using this method to determine the fire cycle assumes that all areas of the landscape are equally susceptible to fire at all ages. This is called "age invariance". Unfortunately, age invariance is rare in boreal-type forests (Rowe *et al.*1975, Van Wagner 1978, Yarie 1981, Baker 1989).

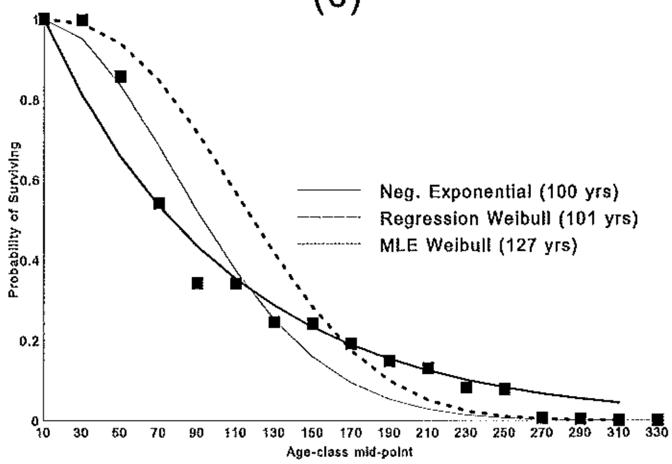
To test for (degree of) age invariance, theoretical functions are fit to age-class data and tested. The negative exponential function reflects absolute age invariance. Other forms of the Weibull function (of which the negative exponential is one type) suggest increasing susceptibility of forests to fire with increasing age. Three functions were fit to the Model Forest age-class data and compared: the negative exponential, and two ways of fitting Weibull models; a regression method, and a one using maximum likelihood estimates (MLE) (Menon 1963, Harter and Moore 1965). The three functions, and the fire cycles associated with each are presented in Figures 4.6a-c for each of the sub-region's age-class distributions. The year 1950 was chosen as the base since this was the same year chosen for the pre-commercial pattern of the Foothills area. I did not bother presenting statistical tests of curve fitting since they were generally inconclusive. In any case, trends are visually obvious, and there are questions regarding the legitimacy of using Weibull models to examine fire cycles (Rogeau 1996b).

The Lower Foothills age-class data fit the negative exponential function very poorly (Figure 4.6a). Thus, it is unlikely that the fire cycle estimate of 81 years is accurate. On the other hand both of the alternative Weibull models seem to fit the observed data equally well. The fire cycle estimates for the regression and MLE models were 84 and 92 years respectively. Undoubtedly, all estimates of fire cycles will vary depending on what "snapshot" of the age-class is used for the estimate, but we can at least conclude that the Lower Foothills area has the shortest fire cycle, and it is probably somewhere between 84 and 92 years.

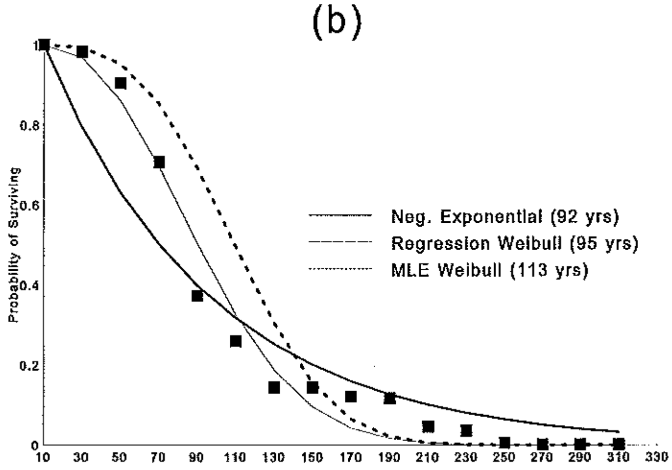
(a)


Probability of Surviving
Age-class mid-point
Neg. Exponential (81 yrs)
Regression Weibull (84 yrs)
MLE Weibull (92 yrs)

(c)


Probability of Surviving
Age-class mid-point
Neg. Exponential (100 yrs)
Regression Weibull (101 yrs)
MLE Weibull (127 yrs)

(b)


Probability of Surviving
Age-class mid-point
Neg. Exponential (92 yrs)
Regression Weibull (95 yrs)
MLE Weibull (113 yrs)

The large degree to which the data do *not* fit the negative exponential model for the Lower Foothills data is notable (Figure 4.3a). It is unknown whether or not this may be a temporal anomaly, but the simulation exercise suggests it may not be. Recall that it was rare for stands to survive much beyond 120 years in the Lower Foothills. This suggests that the forests in the Lower Foothills increase in susceptibility to disturbance to a relatively large degree with increasing age. This does not necessarily mean that forests become increasingly susceptible to fire - it could just as easily be other types of disturbance such as windthrow.

The negative exponential model does not fit the Upper Foothills data well either, casting doubt on that fire cycle estimate of 92 years (Figure 4.6b). Nor does the MLE model seem to fit the data well. Although the regression model does not fit the lower portion of the data well, it does the best overall, suggesting a fire cycle of 95 years. Again, the pattern of data compared to the negative exponential model suggests that forests increase in susceptibility to disturbance with age. However, unlike the Lower Foothills a threshold is not evident, and areas can reach ages of well over 200 years (Figure 4.6b).

The Sub-alpine natural sub-region data comes close to following a negative exponential model of disturbance survival, but the regression Weibull also does an adequate job of representing the data. This leaves virtually identical fire cycle estimates of 100 or 101 years (for the negative exponential and regression Weibull respectively) (Figure 4.6c). Only a limited degree of age dependence is evident, and survival beyond 200 years is common.

The age-class function comparisons were also made based on 1950 for the Park. This is not to say that human activities were not a factor prior to this date here, we at least know that fire control activities have been very active since then, and little or no ignitions were intentional. It also allows direct comparison to the estimates from the Foothills area.

The 1950 data from the Park are not as smooth as with the Foothills area, making it difficult to choose the most appropriate model. The best choice for both the Alpine and Sub-alpine areas seems to be the regression Weibull function giving average ages of 220 and 160 years (Figures 4.7 a-b). The fire cycle differential of 60 years between these two areas emphasizes how different the fire regimes of these two forested areas are, despite the fact that they are so closely associated spatially.

The Montane data comes very close to fitting the negative exponential function (Figure 4.7c). Neither of the other two Weibull functions sufficiently explains the presence of the older tail of the age-class. Once again, the Montane data is perhaps of the highest quality of any of the stand origin data on either the Foothills area or JNP, so it is doubtful that the age-class "tail" is not real. If we accept the negative exponential function as best defining the Montane data, this gives us an average fire cycle of 85 years.

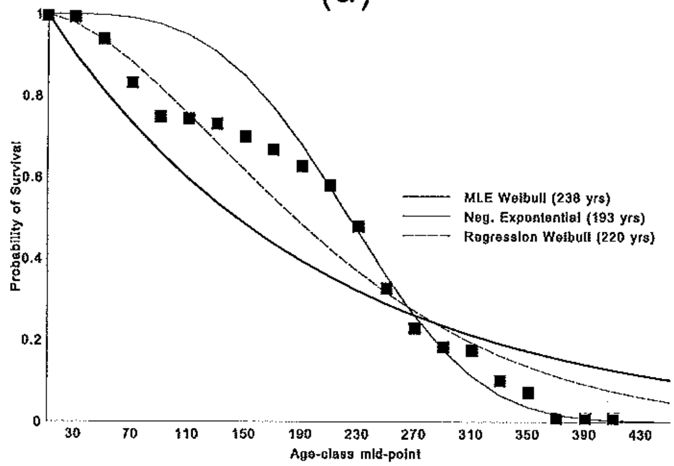
Having average fire cycle estimates is helpful, but only partially describes the long-term activity of fire over large areas. More helpful would be estimates of the *range* of disturbance rates over time. Unfortunately, these are much more difficult to estimate.

The most intuitively simple method of making such estimates is to "roll back" the age-class distribution to calculate several historical 20-year disturbance levels. The logic of rolling back age-classes is as follows: The youngest 20-year age-class is the only one that represents the actual amount of disturbance in a 20 year period. Each successively older age-class increasingly underestimates the amount of disturbance in a 20 year period, because younger disturbances have overlain some of the area previously disturbed. So although the oldest age-class may represent only 5% of the landscape right now, we know that the original area disturbed during that particular 20 year period was higher.

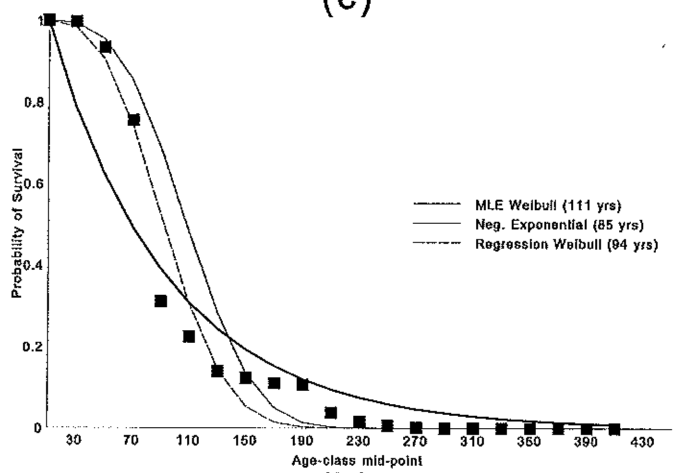
Rolling back works by "peeling off" the area of the youngest age-class, and assuming that underneath is area from all of the other existing age-classes. The proportion of the area underneath in each of the other age-classes is identical to the proportion of the area of those age-classes existing on the landscape today. This is obviously an imperfect means of making 20-year disturbance rates, but serves at least as a general guide. The roll-back used the 1950 landscape age-classes as the base for consistency. Since this method becomes increasingly inaccurate as more layers are peeled off, this estimation was limited to the first eight 20-year classes.

The roll-back produced a very wide range of disturbance rate estimates for the Lower Foothill and some very high levels of disturbance activity. For instance, in two of the eight 20 year periods, it was estimated that more than half of the entire Lower Foothills was burnt over (Table 4.3). On the other hand very low levels of disturbance activity were noted here as well; two of the rate estimates were below 10%.

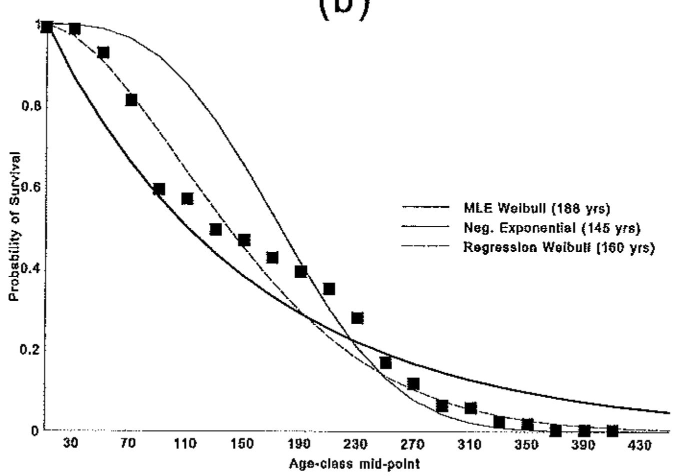
(a)


Probability of Survival
1
0.8
0.6
0.4
0.2
0
30 70 110 150 190 230 270 310 350 390 430
Age-class mid-point
MLE Weibull (238 yrs)
Neg. Expontential (193 yrs)
Regression Weibull (220 yrs)

(c)


Probability of Survival
1
0.8
0.6
0.4
0.2
0
30 70 110 150 190 230 270 310 350 390 430
Age-class mid-point
MLE Weibull (111 yrs)
Neg. Exponential (85 yrs)
Regression Weibull (94 yrs)

(b)


Probability of Survival
1
0.8
0.6
0.4
0.2
0
30 70 110 150 190 230 270 310 350 390 430
Age-class mid-point
MLE Weibull (188 yrs)
Neg. Exponential (145 yrs)
Regression Weibull (160 yrs)

The Upper Foothills also showed a wide range of disturbance activity, although not as dramatic as with the Lower Foothills (Table 4.3). Finally, the Sub-alpine estimates suggest that it was rare for more than a third of the entire sub-region to burn in a single 20 year period. Despite it's small area, the Sub-alpine area is very linear in shape and bordered by the Upper Foothills sub-region. Thus single fire events are not likely to affect much of the Sub-alpine at any one time without travelling tremendous distances through the Upper Foothills, burning most of this sub-region in the process. The data do not suggest that the Upper Foothills landscape experienced such events.

Table 4.3. Roll-back estimates of 20 year disturbance rates for each of the natural sub-regions of the Foothills area of the Model Forest.

Period	Estimated original area burnt (percent of landscape)		
	Lower Foothills	Upper Foothills	Sub-alpine
1930-1950	1	2	<1
1910-1919	10	8	14
1890-1909	14	21	36
1870-1889	47	46	35
1850-1869	51	28	<1
1830-1849	60	39	26
1810-1829	10	1	2
1790-1809	7	13	18
Average	25	20	16
(fire cycle)	80 yrs	101 yrs	123 yrs

Fire cycle estimates are also given in Table 4.3 as an internal check of consistency against previous estimates. It is encouraging that both the Upper Foothills and Lower Foothills fire cycle estimates from the roll-back are quite near the estimates made from fitting Weibull models. The much higher value of the Sub-alpine fire cycle made from the roll-back estimates of Table 4.3 compared to the Weibull estimates suggests that if anything, the rolled back disturbance rate estimates were too low.

The roll-back method was also applied to the first eight estimates of 20-year disturbance rates prior to 1950 in JNP. The Alpine showed the least variability in disturbance rates (1-12% per 20-year period). However, the average age of 333 indicates that there were some 20-year periods in which much more than the average of 6% of the area burnt (since larger amounts of areas burnt translates into lower average ages). Had the roll-back gone another 2 periods, the average age would have been 202 years.

Table 4.4. Roll-back estimates of 20 year disturbance rates for each of the natural sub-regions of Jasper National Park.

Age-class	Estimated original area burnt (percent of landscape)		
	Alpine	Sub-alpine	Montane
1930-1950	5	6	6
1910-1929	12	12	19
1890-1909	10	30	59
1870-1889	1	4	28
1850-1869	2	13	38
1830-1849	4	5	12
1810-1829	5	9	10
1790-1809	6	8	4
Average	6	11	22
(fire cycle)	333 yrs	182 yrs	91 yrs

The next highest levels of 20-year disturbance rates in the Park was in the Sub-alpine natural sub-region. Between 4-13% of the Sub-alpine burned every 20 years (Table 4.4). Again, going to ten estimates from the roll-back rather than eight would result in a range of 4-20%. Although the patterns seem to be quite similar, it is interesting to note that the periods of high fire activity in one sub-region do not necessarily translate to high fire activity in the other. For instance, between 1890-1909, the estimate of the amount of area burnt in the Alpine sub-region is 10%, but in the Sub-alpine 30%. One would suppose that this fire activity during this period was concentrated at lower elevations, considering the very large percentage of the Montane that was consumed by fire in the same period (Table 4.4).

The Montane sub-region had both the greatest average amount, and greatest range of fire activity historically. Between 4-60% of the Montane burnt every 20 years. One should be particularly careful interpreting this since the Montane area is likely where most of the human activity was focused over the last century.

Overall, one begins to get a picture of two areas that experienced great change over a time-scale of decades to centuries. This is true of all natural sub-regions, but particularly so for the Lower Foothills and Montane area. It is also important to keep in mind the spatial relationships of the natural sub-regions. Since the Montane, Sub-alpine, Alpine, and Lower Foothills areas are all oriented linearly, fire activity most often would have transcended the ecological boundaries.

4.4 HOW BIG WERE THE FIRES?

Unfortunately, there is no way of determining historical fire sizes with a high degree of confidence. Between the skips and jumps of individual fires, fire control activities, and stand aging, it is extremely difficult to reconstruct a single historical fire event many years later, let alone several hundred of them. Fire maps could be used, but they go back only several decades, and only during the period of fire control. The existing patch information could be used, but over time, older patches are burnt over by more recent disturbances, biasing the size estimates. The best compromise in this case is to use patch information from very young patches (to eliminate bias) that are known to have originated prior to intensive fire control activities. Keep in mind that these data do not summarize *fire* sizes, but only *patch* sizes.

Since we are interested in defining patch-size distributions by natural sub-regions, the patch-size data of the youngest patches were summarized in two ways. First, the patches were assigned to the natural sub-region in which most of the area of that patch lies (hereafter referred to as "pooled data"). Second, for patches that crossed natural sub-region boundaries, the original polygons were split in two (or more) patches using the natural sub-region boundaries (hereafter referred to as "divided data").

A comparison between these two methods of calculating patch sizes is informative. Table 4.5 shows the percent area in each of three patch size-classes for both the pooled and divided data. There are no significant differences between the two sets of data, except for the Lower Foothills. While the pooled data shows 72% of the area in patches over 1,000 hectares, when the polygons are split by natural sub-region, the area in patches over 1,000 hectares is only 53%. There is a corresponding increase in the proportion of patches between 80-1,000 hectares (Table 4.5). In other words, the largest patches of the Lower Foothills are generally associated with even larger patches from the Upper Foothills area (the only natural sub-region that borders the Lower Foothills). This may seem obvious because of the linear nature of the Lower Foothills area, but notice that the same phenomenon does not occur in Sub-alpine sub-region although it is also linear, and much smaller.

Table 4.5. Comparison of pooled and divided patch size data for each natural sub-region for the Foothills area of the Model Forest.

Natural Sub-region	Data source	Percent area (ha) by Patch Size Range		
		< 80 ha	80-1,000 ha	> 1,000 ha
Lower Foothills	Pooled	8	20	72
	Divided	8	39	53
Upper Foothills	Pooled	5	17	78
	Divided	4	21	75
Sub-alpine	Pooled	9	17	75
	Divided	4	20	76

In order to better understand the relative differences in patch-sizes between natural sub-regions, the divided data was used. In addition, more frequent breaks in the patch sizes were imposed, where shifts in patch-size dominance would be more obvious.

Breaking up patch sizes above 1,000 hectares proved very informative. The most striking contrast was the Lower Foothills sub-region, which had no patches over 5,000 hectares. In general, the Lower Foothills had far more smaller patches than the other two natural sub-regions. In every patch size-class below 2,000 hectares, the percentage of area for the Lower Foothills exceeded that of either of the other two areas - often by a factor of two or more (Table 4.6).

Table 4.6. Distribution of (divided) patch sizes for the youngest three age-classes for the three natural sub-regions for the Foothills area of the Model Forest.

Natural Sub-region	Percent area by size-range (hectares) for the 3 youngest age-classes							
	< 40	40-79	80-199	200 - 599	600-1,999	2,000 - 5,000	5,000 - 9,999	10,000+
Lower Foothills	4	4	9	22	43	18	-	-
Upper Foothills	2	2	5	12	11	15	8	45
Sub-alpine	2	2	6	9	13	20	14	34

The Upper Foothills and Sub-alpine sub-regions had more than half of their area in patches over 5,000 hectares, and far less in smaller patches (Table 4.6). Above 10,000 hectares, the area in the Sub-alpine and Upper Foothills accounted for 34% and 45% of the total respectively (Table 4.6). This is not all that surprising for the Upper Foothills area since it is large and contiguous. However, it is notable for the Sub-alpine sub-region because it is barely 100,000 hectares in total and arranged linearly.

A comparison of the two types of patch-size data for the Park revealed strong spatial relationships between the natural sub-regions. For both the Alpine and Sub-alpine areas, the pooled data showed much higher proportions of large patches (Table 4.7). The Sub-alpine had by far the highest amount of area in patches over 1,000 hectares from either the Foothills or JNP (93%), but the percentage dropped to 79% when polygon data were divided. This indicates that large patches overlapped natural sub-region boundaries. Obviously the Alpine boundary is important, but the Alpine forested patches are quite small on average (53 ha compared to 2,681 ha and 12,132 ha for the Sub-alpine and Montane sub-regions respectively), and their inclusion does not account for the large discrepancy between the two percentages (79 to 93%). It is actually the Montane boundary that created most of the difference. Note that the percentage of larger patches in the Montane area actually *de*creased when the data were pooled. This happened because the majority of the patches in the Montane are associated with larger portions of the same age-class polygon in the Sub-alpine. For instance, a single polygon that had 400 hectares in the Montane, and 600 in the Sub-alpine would be counted as a 1,000 hectare Sub-alpine patch when data were pooled. This phenomenon occurred to two thirds of the area of the Montane. In other words, most of the largest patches on the Park overlap the Montane and Sub-alpine boundary.

Table 4.7. Comparison of pooled and divided patch size data for each natural sub-region for Jasper National Park.

Natural Sub-region	Data source	Percent area (ha) by Patch Size Range		
		< 80 ha	80-1,000 ha	> 1,000 ha
Alpine	Pooled	6	63	31
	Divided	28	72	-
Sub-alpine	Pooled	<1	7	93
	Divided	2	19	79
Montane	Pooled	4	52	44
	Divided	3	30	67

The Alpine / Sub-alpine boundary was more influential in creating many artificial *small* patches of Alpine forest. The amount of area in patches less than 80 hectares dropped from 28% to 6% when data were pooled, and natural sub-region boundaries ignored (Table 4.7).

An expanded version of Table 4.7 using only the divided data shows much the same patterns. The Alpine has a very high number of small patches, and virtually none over 1,000 hectares (Table 4.8). This indicates the importance of the Alpine / Sub-alpine boundary.

Table 4.8. Distribution of (divided) patch sizes for the youngest three age-classes for the three natural sub-regions for Jasper National Park.

Natural Sub-region	Percent area by size-class (ha) for the 3 youngest age-classes.							
	<40	40-79	80-199	200-599	600-1,999	2,000 - 5,000	5,000 - 10,000	10,000+
Alpine	14	14	39	26	7	-	-	-
Sub-alpine	1	1	4	9	20	13	31	22
Montane	1	2	6	13	34	18	27	-

The Sub-alpine area had the greatest percentage of large patches, but the patches were not nearly as large as those found on the Upper Foothills area of the Foothills. Rather, almost 1/3 of the Sub-alpine area is covered by patches between 5-10,000 hectares (Table 4.8). There are only two patches larger than 10,000 hectares. Surprisingly, patches below 80 hectares are almost non-existent.

The Montane also had very few smaller patches. This may be a function of mapping resolution. However, if this was the case, one would think that the number of small patches in the Alpine would also be very low. In both situations the boundary of natural sub-regions comes into play, but if anything, the Montane / Sub-alpine boundary is more fracturous than the Alpine / Sub-alpine. This leads one to believe that the small number of small patches may be real (and not due to mapping resolution). A study in neighbouring Banff National Park came to similar conclusions (Rogeau 1996b).

The Montane area of the Park still has a high proportion of patches over 1,000 hectares, and still a fair amount of area in patches over 5,000 hectares. This is surprising given the fact that it is linear, and these data are not pooled. In other words, even considering the Montane area in isolation (without the Sub-alpine), patch sizes are quite large.

4.4.1 HARVESTING IMPACTS ON LANDSCAPE PATTERNS

Since actual spatial data exits for both the 1950 and 1995 landscape patterns, it is possible to compare the two. The comparison will focus on the youngest (0-40 years) and oldest (>200 years) age-classes, since these the two most influenced by harvesting.

Harvesting activities over the last 45 years have had an impact on the pattern of both the youngest and the oldest age-class. Perhaps the simplest demonstration of this is mean patch size (MPS) which declined from 421 to 208 hectares for the youngest age-class, and from 703 to 130 for the oldest age-class (Table 4.9). The range of older patch sizes also declined, as indicated by the decrease in patch-size standard deviation (PSSD), from 2,440 hectares to 893 hectares over the last 45 years (Table 4.9). A decline in patch-size standard deviation generally corresponds to less very large patches.

The rest of the metrics say much the same thing in different ways. For instance, between 1950 and 1995, edge density (ED) increased dramatically, landscape shape (LSI) became more complex, average interior or core area percentage (TCAI) declined, and the average distance to the nearest neighbour of the same patch-type (MNN) declined in both the youngest and oldest age-classes (Table 4.9). It is also interesting to note that a metric measuring the degree to which patches of the same age bordered all other patch-ages (IJI) showed a sharp increase for the oldest patch ages (from 80 to 95). In other words, harvesting creating a more "even" or homogeneous landscape patch mosaic.

Table 4.9 Comparison of landscape metrics for the youngest and oldest age-class between the pre-commercial (1950) and current (1995) landscapes.

Age-class	Year	Landscape Metric							
		PCT.	MPS	PSSD	ED	LSI	TCAI	MNN	IJI
0-40 yrs	1950	11	421	1,682	2.9	23	57	701	75
	1995	18	208	1,557	6.4	32	47	329	77
>	1950	8	703	2,440	1.3	19	71	796	80

200 yrs	1995	9	130	893	3.6	26	50	454	95

PCT = Percent area
MPS = Mean Patch Size (ha)
(%)
PSSD = Patch Size Standard Deviation
Neighbour (m)
ED = edge density (m/ha)
Juxtaposition Index

LSI = Landscape Shape Index
TCAI = Total Core Area Index
MNN = Mean Nearest
IJI = Interspersion and

4.5 PATCH SHAPES

The "shape" metric was defined in this study is the actual perimeter distance relative to the minimum distance required for the perimeter of the simplest possible shape (a circle). So, a shape index of three means a patch has three times the perimeter of that of a circle of the same area.

Landscape patch shapes usually become more complex as the patches become larger. Perimeters become more convoluted, and more and larger interior unburnt patches occur as patch size increases (DeLong and Tanner 1996). This pattern was evident for all natural sub-regions on the Foothills area (Table 4.10). The smallest patches (less than 200 hectares) were consistently the simplest in shape, since it is unlikely that fires less than 200 hectares leave large unburnt islands. Beyond 200 hectares, small patches of unburnt forest begin to occur within fires, adding to shape complexity. Once fires reach tens of thousands of hectares, shape complexity increases dramatically (Table 4.10).

Table 4.10. Average patch shape by (divided) patch-size class the youngest three age-classes for the three natural sub-regions for the Foothills area of the Model Forest.

Natural Sub-region	Patch shape by size-class (ha) for the 3 youngest age-classes.							
	<40	40-79	80-199	200-599	600-1,999	2,000 - 5,000	5,000 - 10,000	10,000+
Lower Foothills	1.4	1.5	1.7	2.2	3.2	2.9	-	-

Upper Foothills	1.4	1.5	1.8	2.1	2.6	3.2	4.9	6.5
Sub-alpine	1.4	1.7	1.7	2.2	2.0	2.7	4.1	6.0

Up to 600 hectares, shapes of patches are very consistent (Table 4.10). Beyond 600 hectares, the Sub-alpine patches seem to be the simplest, and the shape of larger patches on the Lower Foothills the most complex.

Shapes of patches in JNP also become increasingly complex with increasing patch size (Table 4.11). If anything, the larger patches of the Park are slightly more complex than in the Foothills area. The larger Montane patches seem to be particularly susceptible to shape complexity. This is particularly surprising considering the moderate to low percentage of non-forested area within the Montane natural sub-region (10%). The shapes of the larger Sub-alpine patches are not unlike those of the Sub-alpine of the Foothills region (Tables 4.10 and 4.11). An alternative explanation for this is that JNP mapping was done at a higher level of resolution than in the Foothills area.

Table 4.11. Average patch shape by (divided) patch-sizes classes for all patches 1890 or younger by natural sub-regions for Jasper National Park.

Natural Sub-region	Patch shape by size-class (ha) for the 3 youngest age-classes.							
	<40	40-79	80-199	200-599	600-1,999	2,000-5,000	5,000-10,000	10,000+
Alpine	1.3	1.7	1.7	1.6	2.9	-	-	-
Sub-alpine	1.2	1.6	1.9	2.0	2.7	3.2	4.5	6.4
Montane	1.2	1.7	1.7	2.4	2.7	3.3	6.6	-

4.6 ARE PATTERNS RELATED TO LIGHTNING ACTIVITY

The previous two Sections concerned themselves with how fires burn once they ignite. However, we should expect differences in the probabilities of ignition as well. Lightning "hits" represent potential fire starts. Assuming that historical human-caused fires are distributed randomly spatially (which is likely not true), and that recent (last ten years) lightning activity is not significantly different - in a relative sense - than that experienced historically, hypotheses concerning the association of lighting and landscape patterns can be made.

The most logical question is; over large areas (on the order of several thousand hectares at least) is increased lightning activity associated with lower average stand ages? The corollary of this is; is *decreased* lightning activity associated with *higher* than average stand ages? This could be tested for both the Foothills area and JNP. Lighting data was summarized in terms of density of observed "hits" per 1,000 hectares.

The average number of hits per 1,000 hectares over the entire Foothills area was 46. However, lightning density varied significantly by natural sub-regions. The highest lightning density was found in the Lower Foothills sub-region (56 hits per 1,000 hectares), followed by the Upper Foothills (44 hits per 1,000 hectares), and then the Sub-alpine area (34 hits per 1,000 hectares) (Table 4.12). Recall that this is the same order of average fire cycles, from shortest (Lower Foothills) to longest (Sub-alpine).

Table 4.12. Lightning activity by natural sub-region for the FMA and JNP.

Natural Sub-region	No. of lightning hits / 1000 ha by Landscape	
	Weldwood FMA	Jasper National Park
Alpine	21	9
Sub-alpine	34	11
Montane	29	17
Upper Foothills	44	13
Lower Foothills	56	-
OVERALL AVERAGE	**46**	**10**

The lightning strike density calculation was then made for all areas of the Foothills that were younger than 188 years old, and compared to the density of all areas that were older. The differences were significant. The older areas averaged 35 hits per 1,000 hectares, while the rest of the Foothills averaged 49 per 1,000. However, we cannot necessarily conclude from this evidence alone that older areas occur where they do *because of* historically less lightning activity. This test may be biased by the natural sub-region patterns of lightning activity. For instance, the area with the highest lightning activity, the Lower Foothills, has few stands that are 188 years or older.

The same calculation was then repeated for a smaller area within the Upper Foothills natural sub-region. The Berland (working circle) covers almost 230,000 hectares, and has a very high proportion of older forest. It is unknown whether or not that particular piece of older forest is simply an artifact of random burning patterns, or is an area that historical burnt less frequently than the rest of the landscape. When lightning densities were recalculated for older and younger areas of the Berland, the old forest in the Berland averaged only 21 hits per 1,000 - the least active area of lightning on the entire Foothills east region.

When the tests were repeated for young areas, no differences in lighting activity were found between these areas and the rest of the landscape. The lightning density per 1,000 hectares for all pixels younger than 60 years (of the pre-commercial 1950 landscape) was 45, while for the rest of the forested area the lightning density was 47. This means that increased lightning activity does not necessarily coincide with younger forests.

Lightning density for Jasper National Park averaged only 12 hits per 1,000 hectares, and the differences between natural sub-regions were far less dramatic. The pattern of lightning activity that emerged in the Park was much the same as that of the Foothills, with elevation being the main factor corresponding to lighting activity (Table 4.12). The pattern also loosely relates to the average fire cycles of each natural sub-region in the Park; Montane having the shortest fire cycle, and the greatest density of lightning activity. Keep in mind that lightning data are more reliable in flat, open country. Thus the accuracy of the lightning location data for JNP may be much less than that of the Foothills area.

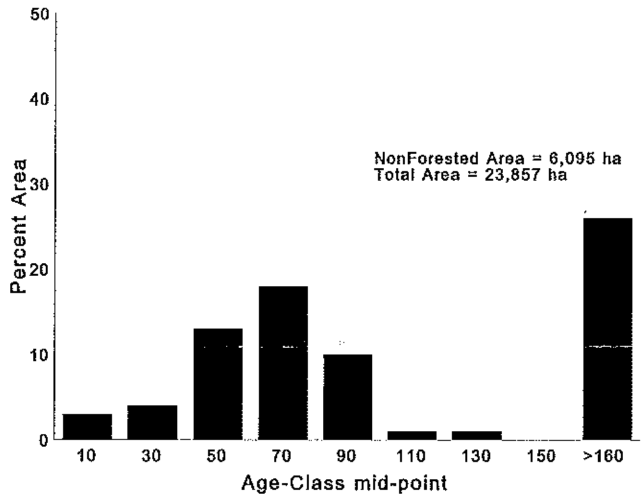
Of greater interest is the difference in lighting activity *between* the two landscapes. The average lightning density on (the forested areas of) the Foothills east are four to five times greater than the lightning activity of the Park (Table 4.12). The only corresponding natural sub-region with significant areas in each landscape (the Sub-alpine) showed triple the lightning density on the Foothills compared to the Park. The Sub-alpine area of the Foothills also had an estimated fire cycle more than 40 years greater than that of the Sub-alpine of the Park. This relationship (between lightning activity and fire cycle) is intuitively appropriate.

As with the Foothills, the test of the younger areas against lightning activity was inconclusive. However, there were other opportunities for testing available in the Park because of the presence of the vegetation-type information. These tests became somewhat tautological, but the most striking ones are worth mentioning, because they raise interesting questions For instance, on the Montane, lightning activity was highest in meadows and grasslands (24 hits / 1,000) compared to forest (17 hits / 1,000). Other patterns of lightning activity were related to species dominance, suggesting it may have played an evolutionary role in it's presence (in the Park). For instance, high lightning densities were noted for areas where Douglas Fir is the leading species. To a lesser degree this was true of areas dominated by white-bark pine. There is no way of knowing how coincidental such relationships are, and lightning data used at this level of resolution is highly questionable, but they at least allow the formation of some hypotheses for when more data becomes available next year.

4.7 MESO-SCALE PILOT STUDY

A single mapsheet within the Weldwood FMA in the Foothills area was chosen for a pilot study of some meso-scale disturbance regime analysis. The purpose of this was to provide a preview of what the addition of a DEM would contribute to the interpretations. It also investigates how having more detailed data (at a resolution of 50 m rather than 200 m) may benefit analysis. For instance, digital terrain information is of limited value at 200 m resolution in subtle terrain.

The total area of the mapsheet is just under 24,000 hectares. The mapsheet was all within the Upper Foothills natural sub-region. However, this should not be taken to mean that this mapsheet is representative of the Upper Foothills area. There are several important differences, including over double the percentage of non-forested area, and a very high proportion of older forest (> 160 years) in this mapsheet as compared to the Upper Foothills overall (Figure 4.8). The amount of lightning activity is close to the Upper Foothills average (40 hits per 1,000 hectares), and the elevation range from 1,531 - 1,121 meters indicates a moderately rolling terrain. Most of the non-forested area is associated with the lower elevation areas in the central part of the mapsheet.



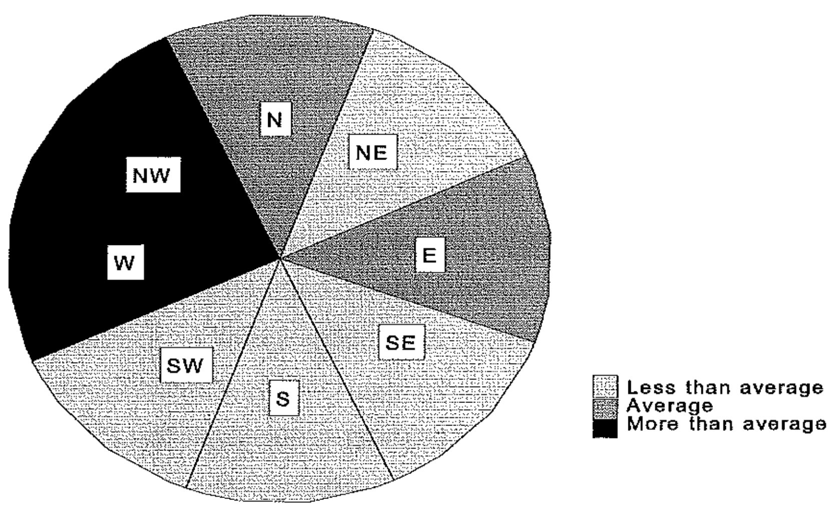
Using these data, it is possible to test for fire "refugia", or areas that are statistically more likely to survive a fire because of skips or lower fire intensity and/or severity (Camp 1995). These areas will be older today, because they survived at least the last fire. The hypothesis in this case is that aspect influences refugia behaviour. Other studies (Hawkes 1979) have found that northern aspects tend to survive better than other aspects.

To test this for the occurrence of refugia by aspect on the Upper Foothills mapsheet, the number of forested pixels at least 188 years old was counted for each aspect and compared to the total number of forested pixels. If aspect has no influence on the occurrence of older forest, the percentage of older forest to total forest (in percent) should be constant across all aspects. As Table 4.13 shows, an average of 30% of older forest exists on all pixels with slopes greater than 10%. Everything from Northeast to Southwest had percentages of older forest lower than this overall average, but Southwest, South, and Southeast were particularly low (22%, 19%, and 20% older forest respectively). The highest percentages of older forest were on the West (40%) Northwest (37%) and North (33%) aspects. (Table 4.13).

When the same calculations were repeated for slopes of 20%, much the same pattern emerged (Table 4.14) but more exaggerated. The average percentage of older forest was only 20%, but the West and Northwest shad 40 and 37% older forest respectively. This suggests that the tendency of patches to survive fire increase on West and Northwest-facing slopes as slope percent increases. The patterns of aspect on percentages of older forest on 20% slopes is more obvious in Figure 4.9.

Table 4.13. Percent of area greater than 188 years old on slopes of greater than 10 and 20%, by aspect.

Aspect	Percent of pixels 188 years or older	
	On 10% slopes	On 20% slopes
North	33	23
North-east	23	14
East	29	21
South-east	20	14
South	19	13
South-west	22	16
West	40	39
Northwest	37	30
TOTAL	**30**	**20**



Another way of considering refugia is in terms of terrain complexity, or slope. To test for slope influence the calculations done for Table 4.13 above were repeated by slope-class. The results were prominent and consistent. On the flattest sites, almost half of the forest was over 188 years old, and once slopes increased to 20% or greater, the percentage of older forest dwindled to 20% or less (Table 4.14).

Table 4.14. Percent of area greater than 188 years by slope-class, with and without stream influence.

Slope-Class	Percent forested area > 188 years of age	
	All	Stream present
< 2 %	44	14
2-4 %	43	13
5-9 %	43	10
10-19 %	31	7
20-40 %	20	6
> 40 %	16	11
TOTAL	**35**	**10**

It was noted that there was an overall influence of the presence of a stream on the proximity of older forest. For example, the expected number (statistically) of pixels that would have older forest and streams co-occurring was 1,545, while the observed number on the mapsheet was 2,528. A second calculation was then done to test for the occurrence of different slope-classes plus the presence of streams, as a demonstration of how stream and slope information can combine to provide more detailed information. The assumption is that if slopes and streams occur together in the same pixel, it indicates a toe-slope position.

The results from this test were much the same as those of the slope test. The one exception was the increase in the amount of older forest on the steepest toe-slopes (>40%). The percentage of older forest on steep slopes (on all positions) was very low (16%), relative to all slopes (35%). However, the percentage of older forest on steep toe-slopes was only 11% compared to 10% on toe-slopes of all slope-classes. Another way of looking at this result is that on the flattest sites, 30% of older forest is not on toe-slopes (44-14=30%) (Table 4.14). However, on the steepest slopes, only 5% of older forest is not on a toe-slope (16-11=5%).

The results suggest that fire may burn more completely on flat terrain, and more selectively in complex terrain. In complex terrain, west to north aspects, and toe-slopes tend not to burn, while very steep mid to upper slopes, on south to east aspect are the most likely to burn.

Keep in mind that the meso-scale analysis is far from complete. As mentioned, not all data sources were available, only one mapsheet was analyzed, and the time and effort that went into this analysis and summary was minimal. It is meant only as a demonstration of what sorts of information may be gleaned from these sorts of data in the future. Having said that, what little analysis was done suggests there are very real meso-scale burning patterns in the Upper Foothills area. The patterns noted are certainly enough to suggest that a more thorough investigation of refugia should be initiated based on hypotheses formulated from these observations.

5.0 DISCUSSION

The analysis covers a broad range of issues, using many different data sources and tests. However, as explained earlier, it allowed a variety of largely circumstantial evidence to be pulled together and compared. Even without the benefit of all of the data, a logically consistent picture of landscape fire behaviour begins to emerge.

Beginning with the Foothills area, the three natural sub-regions undoubtedly have their own landscape fire behaviour patterns. The Lower Foothills had the greatest lightning activity, and burned the most often (averaging 84 years). On the other hand, the frequencies of burning were erratic in the Lower Foothills. Estimated historical disturbance rates indicate that either very large or very small amounts of the Lower Foothills burned every 20-years. Rarely did a moderate amount of forest burn, unlike either the Upper Foothills or Sub-alpine landscapes. This may be a result of the high hardwood content of the Lower Foothills. In full leaf, hardwoods are poor fuel for fires. However, early in the spring, before leaf-out, moisture content is very low, and there is a far greater risk of crown fire activity. The chances of extreme fire weather in the spring is rare enough that one can imagine that high fire activity in the Lower Foothills area would be equally rare. Furthermore, at these and other times of low fuel moisture (perhaps late season droughts), there were enough ignition sources to take advantage of favourable fire weather conditions.

The high rate of lightning activity and the flammability of hardwoods may also be related to the well-spaced, relatively small size of same-aged forested patches in the Lower Foothills. However, this may also be related to the amount and spacing of non-forested patches. The Lower Foothills had the greatest amount of non-forested area, and it was distributed in small to medium-sized, regularly spaced patches.

There is also evidence that the largest patches of the Lower Foothills probably spread from the Upper Foothills area (or vice versa). Recall that the percentage of patches over 1,000 hectares drops significantly when the patch data are summarized by natural sub-region rather than pooled. This indicates that many of the larger patches of the Lower Foothills are associated with even larger patches in the Upper Foothills. One could argue that this phenomenon will occur between all artificial breaks in age polygons, however the same thing does not occur between the Upper Foothills and the Sub-alpine areas.

Smaller fires and higher frequencies often suggest lower fire intensities. Although this cannot be confirmed using these data, it was interesting to note that the age validation exercise of the Lower Foothills indicated a strong negative bias. One reason this may have occurred is that stand aging was influenced by (older) survivors. The greater the number of (older) survivors that were present, the greater the potential for negative bias in stand aging.

The suspicion that fires may burn with less intensity in the Lower Foothills is also supported by relatively complexity of patch shapes beyond 600 hectares. This suggests the formation of more and larger interior islands, and/or more convoluted edges. In other words, fuels in mixedwood areas are heterogeneous, forcing fires to be more selective to find suitable fuel.

Perhaps the most dominant feature of the Lower Foothills landscape pattern today is the prevalence of forest greater than 100 years of age. Both the simulation exercise, and the time-since-fire distribution suggest that stands typically do not last much beyond 100 years, and rarely if ever beyond 120. This is presumably as much to do with the lack of harvesting activity as it is the success of fire control activities. For whatever reason, today, about half of the Lower Foothills area is over 100 years of age.

Visual observation of these areas suggests that the impact of this is that the hardwood component of the Lower Foothills area is declining. Ultimately, this means that the landscape pattern is becoming simplified or more homogeneous. Changes in species composition will certainly impact resident fauna that rely on hardwoods, and may even influence natural disturbance patterns. For instance, the softwoods that are replacing the hardwoods will be much more flammable (Mutch 1970).

The Upper Foothills area is the largest area of the Foothills area, is very contiguous spatially, and is intermediate in terms of fire activity. The Upper Foothills area is intermediate in terms of both lightning activity, and fire cycle (average of 95 years). Every indication is that fires in the Upper Foothills sub-region covered a wide range of sizes, but most of the area is accounted for by patches of more than 10,000 hectares. This is that much more impressive considering the fact that almost as much of the landscape is non-forested as in the Lower Foothills. However, non-forested patches tend to clump spatially, and in any case, there is no way of knowing what the patches are. It may be that non-forested patches in the Lower Foothills tend to be bogs, and in the Upper Foothills they are non-productive brush or low density forest.

It is interesting to note that there was also a slight negative bias to the stand aging in the Upper Foothills sub-region. As with the Lower Foothills area, this may indicate the survival of trees from fire, which bias stand age counts. The meso-scale analysis suggests that site-specific survival from fire is not uncommon, and may even be predictable (statistically), and shape complexity suggests a moderate amount of remnant island formation occurs.

The simulation results suggest that the current age-class distribution is well within simulated historical limits, but harvesting activity is creating a very different spatial pattern here. Most of the historical harvesting activity has taken place as very small, well spaced patches within the oldest forest. This is commonly known as fragmentation, and pattern metrics show all of the symptoms: increase in edge density, decrease in patch size and patch size range, decreased interior forest area, and a more "even" distribution of patch types (or increased gamma-level diversity).

The last area of the Foothills area, the Sub-alpine, is perhaps the most enigmatic. Possessed of the longest average fire cycle, every other indication is that the area is highly flammable. Patch sizes are very large considering the small, linear nature of the Sub-alpine landscape. Patches are also quite simple in shape, and there was no bias associated with stand ages, suggesting that fire intensities were relatively high, and mortality fairly complete. The Sub-alpine area also had a very small portion of non-forested areas. Nor was there any indication that larger fires are necessary associated with larger patches of the Upper Foothills. On the contrary, fires starting and spreading from the Upper Foothills are not nearly as likely to stop or even slow down once they reach the Sub-alpine. Both slopes and fuel would be favourable to fires taking long runs through the Sub-alpine with favourable winds.

Despite all of these factors in favour of high burning potential, the Sub-alpine burns the least often of all of the areas. There may be several reasons for this. First, the lightning activity here is the lowest of all three sub-regions in the Foothills, so ignition sources are limited. Second, although it may be susceptible to fire spread from the Upper Foothills, the area is so linear that even conflagrations in the Upper Foothills may not burn more than a few thousand hectares at a time in the Sub-alpine simply because of physical proximity. Third, unlike pine (which dominates the Upper Foothills) spruce and fir species may not create suitable fuel conditions for a crown fire until stands reach maturity. Perhaps surface fires do not play any significant role in the fire regime of the Sub-alpine.

The landscape areas of Jasper National Park are even more complex. The Alpine area has most of the non-forested areas, with small, well-spaced forest patches associated with upper Sub-alpine forested patches. Despite the strong physical association with the Sub-alpine forests, the fire cycle in the Alpine is sufficiently longer than the Sub-alpine such that a distinctive fire regime is evident (220 years versus 160 years respectively).

Same-aged patch sizes are understandably small in the Alpine area since the forested patches are so small. It is fairly safe to conclude that almost all of the forested patches in the Alpine are associated with patches in the Sub-alpine. This is evident from the differences between the pooled and divided patch-size data. However, even the pooled data show very high numbers and areas of small patches in the Alpine area. As the steepest part of the park, one wonders whether this is a mapping artifact caused by changes in stand composition or density in response to dramatically different site-types.

The Montane is dominated by very large patches of forest, with small, closely-spaced non-forested patches. However, the change in the percentage of large patches in the Montane from the divided to the pooled data suggests a spatial relationship between the Montane and Sub-alpine areas that is unprecedented in either landscape. There is evidence that most of the largest patches on the JNP landscape occur across the Montane / Sub-alpine boundary. It is unknown where such fires originate, but the Montane area is the suspected source of most. It has higher lightning activity, and presumably a longer, drier fire season.

Even when patch-size data are split by natural sub-region, the Montane area of the Park still has a high proportion of patches over 1,000 hectares, and still a fair amount of area in patches over 5,000 hectares. This, combined with the low number of small patches suggests that historical disturbance events were consistently quite large in the Montane, and more often than not spread into the Sub-alpine creating even larger patches.

This raises several interesting questions. For instance, although the lightning density of the Montane area of the Park is very low relative to the Foothills area of the study area, it still has a fairly short fire cycle. Does this mean that the Montane area is highly flammable, and the chances of a "hit" starting a fire far greater here? This explanation would certainly explain the lack of smaller patches, and prevalence of large ones. It is also notable that lightning activity was highest in meadows and grasslands (24 hits / 1,000) compared to forest (17 hits / 1,000). Is the shift from meadow to forest that sensitive that differential ignition probabilities is one of the factors controlling forest/meadow mosaics?

The Montane seems to be particularly susceptible to shape complexity, which is surprising considering the moderate to low percentage of non-forested area within this natural sub-region. Other possibilities are that fire movement is highly sensitive changes in fuel-loading and/or wind, both of which are likely to be common occurrences in the valley.

The Sub-alpine area of the Park covers the greatest amount of forested area, and has an intermediate fire cycle. It has a moderate amount of non-forested area, but it exists in very large, well-spaced patches. Again, the most interesting feature of the Sub-alpine area is the interaction with the Montane area, but the contrast from Montane to Alpine strongly suggests that the Sub-alpine area is one large transition zone. It may therefore be misleading to summarize the landscape fire behaviour of this area as a contiguous, homogeneous ecological unit.

This raises an important point concerning the landscape behaviour of fire throughout the entire Park. Consider that the Park is a mixture of both forested and non-forested areas, and most of the forested areas are arranged linearly. As a result, average forested patch size is quite small, and only 77% of the area is "interior" forest (compared to close to 90% for the Foothills landscape). This small, linear area is further divided up into three natural sub-regions, which display very distinctive fire behaviour characteristics. This raises the question of the appropriate scale at which to look for and describe behaviour and patterns in the Park.

For the Foothills area, it was appropriate and highly enlightening to describe fire behaviour on the landscape in terms of natural sub-regions. The sub-regions were quite large, and the changes in behaviour between them were only moderate. In the Park, over a distance of only several kilometres, fire regimes change dramatically. Not to say that the landscape summaries provided here are of no value, but it seems as if the true essence of the behaviour of fire in the Park would be better captured at smaller scales. It is difficult to imagine even a medium-sized fire not crossing through many different regions of unique fire behaviour. Luckily, a large part of the data required for such analysis are available.

Regarding the estimation of fire cycles in the Park, it is interesting that Van Wagner (1995) suggested a temporal break in the fire cycle for the Park somewhere around 250 years ago using different mathematical techniques than used here. Prior to this point, his estimate of the fire cycle is 150 years, and afterwards, 55 years. However, this was pooled data for the entire Park, and as he properly points out, there are unfortunately many ways of interpreting these data. What this study clearly shows is that spatially, there are at least two very clearly different fire regimes within the Park, and possibly a third, and that fire cycles between these areas are quite different.

Still, on average, Van Wagner's fire cycle estimates are lower than those calculated here by about 20 years. The difference could be simply be accounted for by using 1930 as the basis for fire cycle estimates rather than 1950 (it is difficult to determine when cultural activity began having a large impact on the Park's forest patterns). For instance, the fire cycle estimates for 1930 from the regression Weibull model were 196, 135, and 71 years, compared to 220, 160, and 94 years for 1950, for the Alpine, Sub-alpine, and Montane sub-regions respectively. However, if it can be agreed that we are "in the ballpark", there is no point in pursuing more precise answers. The small amount of long-term pollen work that has already been done in the Park suggests that species mixtures (and probably fire cycles) varied widely historically. As Van Wagner (1995) discusses, perhaps precise figures are less important than what the goals are for the Park, and what species mixtures and/or structures are most desirable in the future.

The meso-scale analysis was far from complete, but provided interesting information. The suggestion of refugia sites from fire is not necessarily surprising, but it is interesting that the west-facing slopes had so much older forest. One would have expected western aspects to be warmer and drier, thus more likely to burn, not less. One reason this may not be the case is the strong and directional wind that occurs in this area. Being so close to the mountains, this area receives steady westerly winds throughout the year, which may influence fire behaviour in unexpected ways, such as creating skips on west-facing slopes. Other suspected fire refugia sites were steep toe-slopes, and moderate to steep northerly aspects.

It is unfortunate that only one mapsheet in one sub-region was analyzed. It is conceivable that the different sub-regions have different refugia tendencies and probabilities. For instance, one would hypothesize that the Lower Foothills would have more obvious safe sites, and more predictable landscape fire behaviour spatially since fire sizes are small, and intensities lower. The Sub-alpine on the other hand, may have very few consistent areas of fire refuge, considering the size and intensity of fires there, and the terrain complexity.

6.0 CONCLUSIONS

This project has clearly demonstrated landscape-specific fire behaviour. Each natural sub-region had it's own pattern of rates, sizes and shapes of fire. Many unanswered questions still remain concerning more detailed attributes such as intensity, shapes, and fire refugia, but even this limited coverage of these topics suggests that there may be very real differences between these parameters as well.

Yet, it would be wrong to consider the landscape behaviour of fire on a natural sub-region in isolation. In every possible case there was spatial dependence of some feature of disturbance movement between bordering sub-regions, on both landscapes. Again, questions remain concerning the exact nature of the interaction, but the summaries suggest that these interfaces are quite important. The Park in particular should be focusing on interactions between areas, across elevational gradients rather than trying to better define within-region fire dynamics. Overall, it was surprising to find such depth to the disturbance behaviour characteristics. Patterns of behaviour emerged where randomness was previously assumed. This has important implications for the management of such areas. It also makes us consider the idea of natural pattern "approximation" much more seriously, and on different levels. On one hand, it is clearly an indication that landscape patterns are unique in both ecological and evolutionary terms. It makes us realize that it will not simply be a matter of using larger patches of more complex shapes to accomplish the goal of maintaining the full range of biodiversity.

On the other hand, it is humbling to have this much information revealed in a single short-term study. How much is left unknown? How much of what is both known and unknown is important to "approximate"? Even armed with this information, how do they translate into management actions? Against these questions, the confident attitude expressed by some government agencies regarding how approximation will achieve all forms of sustainability is not warranted. Accepting the use of approximation as a forest management strategy comes with unprecedented responsibility.

The wisest use of such information as it becomes available is twofold. The first use of the information is obvious: to move forward regarding management strategies. This is not to say that management should now embrace the findings of this or any other current landscape research as new targets for management patterns. Rather, strategies should begin to evolve towards means of allowing for these, and inevitable future research findings through education, experimentation, and further research.

The second use of this information is for education and understanding. The impact of new information concerning forest system dynamics should not be under-estimated. Fires have long been assumed by most to be unpredictable events creating little more than random patterns on the landscape. It will take some time to accept and digest information to the contrary. It will also take time to accept the new management ideas that will evolve. Calling landscape management ideas part of a new "paradigm" is a bit strong, but the fact that it is being called this by some reflects how different some of the ideas really are. Perhaps the first step to management through approximation is to instill respect for fire as an ecological process.

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GLOSSARY OF TERMS

The following is a list of terms used in this document that are either uncommonly technical, or have ambiguous definitions. *As used in this document*, the list is as follows:

Age dependence
- susceptibility to fire changes (usually increases) with age.

Age invariance
- forests of all ages are equally susceptible to fire.

Approximation
- landscape management strategy whereby patterns and processes of natural landscapes are quantified and used as templates or targets for forest planning. Sometimes referred to as "mimicry", although mimicking natural disturbance patterns is out of the question in the strict sense.

Biodiversity
- a qualitative feature of natural systems describing the numbers and types of different elements. Not the same thing as diversity.

Crown fire
- fire actively or passively reaches into the crowns of trees. Crown fires are virtually always associated with surface fires, but mortality can vary widely.

Disturbance
- any abrupt event that results in the destruction or damage of any part of the biota. Disturbances can occur at any scale.

Disturbance frequency
- the probability that a specific area is disturbed in a given time period. Reciprocal of return interval.

Disturbance rate
- the percentage of area affected by disturbance over a given period. In this case, the period was 20 years. Sometimes the reciprocal of fire cycle when expressed on an annual basis.

Disturbance regime
- types, frequencies, periodicity, severity, and sizes of disturbances.

Diversity
- the number (and sometimes the relative amounts) of different types of elements. Diversity is *one* element of biodiversity.

Fire behaviour

- how, how fast, where, and what an individual fire burns. Contrast with Landscape fire behaviour below.

Fire cycle

- the average number of years required to burn an area equivalent in size to the study area / landscape.

Fire intensity

- the actual temperature at which a fire burns, as opposed to fire severity.

Fire refugia

- a small-scale area which survived at least the last fire event, and therefore tend to be older than surrounding areas of forest.

Fire return interval

- the average return time of fire at a specific location. North-facing slopes may have longer fire return intervals than south-facing slopes.

Fire severity

- the amount of damage or mortality caused by a fire. Not necessarily related to fire intensity.

Landscape

- a mosaic of stands large enough to have identifiable large-scale (fire) behaviour emerge. The two larger areas (JNP and the FMA) were referred to as landscapes, as were the natural sub-regions within them.

Landscape fire behaviour

- how, how often, where, and what hundreds of fires burn over decades or centuries.

Meso-scale

- between stand and landscape scales.

Non-forested

- anything other than merchantable forest, including water, meadow, brush, rock outcrop, swamp, and understocked forest.

Patch

- a contiguous area of the same type (defined by age, composition, structure, or other feature). Usually 20-year age-classes were used to define a patch. Patches are not necessarily fires, since fires skip and overlap each other.

Pattern

- any behaviour (spatial or temporal) that is not random.

Surface Fire

- fires that burn along the ground, only occasionally "torching" individual trees. Tree crowns are usually unaffected.

Stand Origin Map

- map showing the year of stand origin. Also referred to as a "fire map"