FOREST FIRE HISTORY
OF
KOOTENAY NATIONAL PARK, BRITISH COLUMBIA

Alan M. Masters, R.P.F.
Project Forester,
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April, 1989
Canadian Parks Service
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ABSTRACT

This study uses time-since-fire distribution analysis to determine forest fire frequency for 1400 square kilometre Kootenay National Park, located on the West slope of the Rocky Mountains, British Columbia. The time-since-fire distribution is comprised of at least two spatial and two temporal fire regimes. Mean fire return intervals (MFRI) for the Kootenay/Sinclair and Vermilion areas ranged from 92 to 165 years, respectively, and from 75 to 267 years for the Vermilion Valley prior to and after 1768. MFRI for the whole park was 127 years. Elevation, aspect, and proximity to the Great Divide had little direct effect on the distribution of forest ages and could not be linked to fire frequency using the methods employed. A fire suppression policy since park establishment in 1919 has had little effect on the time-since-fire distribution. A period of cool climate may be responsible for the present, bell-shaped age-class distribution of the park's forests. Findings of the study are discussed in relation to fire control and prescribed fire use in the park.

Key Words: forest fire history, national parks, Kootenay.

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Tim Van Egmond should be acknowledged for his work in compiling the individual forest fire report database under the auspices of a Parks Volunteer Project.

"Tell me about the great fire, grandfather." ...

"Ah, the great fire, Impka. Yes, I remember. It was a long time ago ... when we first came into the valley. There was a great storm; the wind was strong; the thunder rolled; the lightning crackled and the darkness was deep except when the great flashes lit the sky. Then the fires started. First here, then there, as lightning hit the trees. All night we watched as the sky grew red with flame and the wind rushed past us like a blast from great fire. I was young then. I stood on a hilltop watching as a great tree limb glowing like a meteor was hurled by the wind across the tops of the trees, dropping live coals as it flew into the dry bush. There was a sudden burst of flame everywhere one dropped. It seemed the whole world burst on fire."

... "But where did you go, to get away from it?"

"There was only one place to go as the fire raced closer. We gathered everything we could together and drove the horses ahead of us or rode them ourselves to the flat island in the river ... Then the rain came and put the fire out but the forests were black, the hills deep with charred trees and the swamps filled with blackened logs."

> - Chief Pierre Kinbasket, to his granddaughter Rosie, in "Tales of the Windermere", by Winnifred Ariel Weir, 1980. Conversation refers to a forest fire in the Columbia Valley in 1886 that also burned most of the Sinclair area of KNP. Used with permission.

1. INTRODUCTION

Since 1979, national park policy has suggested that natural processes, such as forest fires, be allowed to fulfill their ecological role in national parks. Numerous fires have occurred in Kootenay National Park (KNP) since it's establishment in 1919 (Figure 1). Large suppression efforts were organized on some fires in response to the management philosophies prevailing at the time. Although it is known that suppression of some fires since park establishment has been successful, suppression activities on other fires had little effect on the fire's progress and eventual size. Fire history studies conducted near Kootenay in Banff National Park (White, 1985), Jasper Townsite area (Tande, 1977), Kananaskis (Hawkes, 1979; Johnson and Fryer, 1987), and Waterton Lakes National Park (MacKenzie, 1973) have shown fire to be a pervasive element in the landscape of the Rocky Mountains.

An important question in national park management is that of representation. Does the park represent a natural system? The Kootenay National Park Management Plan (Canadian Parks Service, 1988) requires the park to represent the Rocky Mountains natural region. The plan recognizes the importance of natural processes in maintaining this landscape and requires the development of a comprehensive Fire Management Plan. The question remains: Given past interference in natural processes, either by fire suppression or by man-caused forest fires, do the forests of KNP represent a natural environment? Also, what management is required to maintain this landscape?

Partial answers may be provided from the results of a "fire history study". This type of study examines the fire frequency record hidden in tree rings and fire scars and compares the current period of park management to periods before European settlement. It is important to note that fire is not the only natural process for vegetation change, but it is probably the most important in KNP (Achuff et. al., 1984).

The KNP Park Conservation Plan identified the need for a better understanding of the frequency of forest fires. Because fire history is only one aspect of fire management, this study was designed to meet several objectives:

- To document the past history of forest fires;
- To test the distribution of forest fires against gradients such as elevation, aspect, valley location, and proximity to the Great Divide;
- To assemble weather and fire report databases to be used in the development of fire preparedness systems and fire management guidelines;
- To utilize quantitative methods and new technology;
- To make recommendations regarding fire management in KNP.

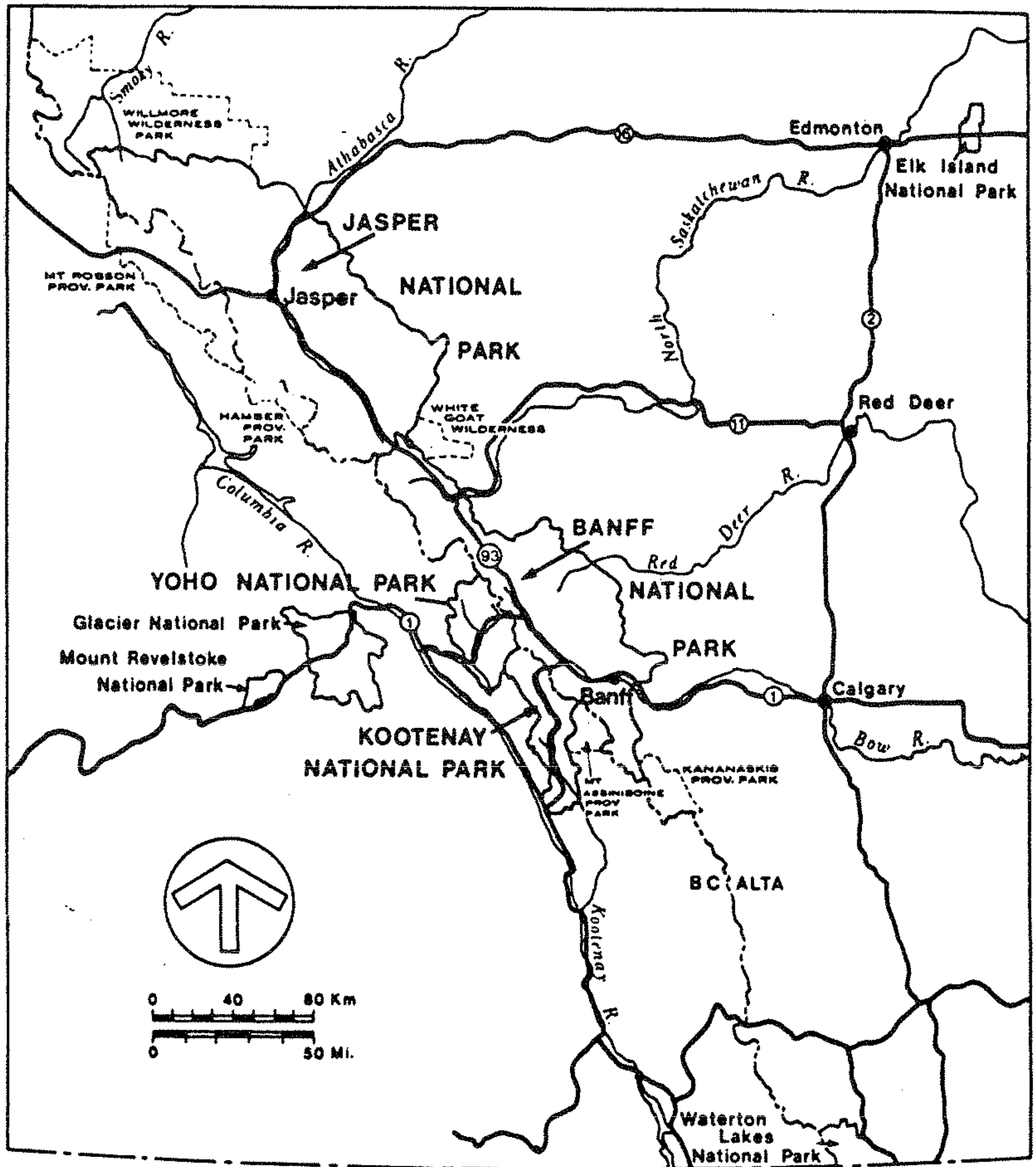

Figure 1. The Western Region national parks, showing location of Kootenay National Park, British Columbia.

Fire weather and report databases were compiled, but lack of time and incomplete data prevented complete analysis. The report presents the findings of the fire history study and progress to date on fire weather and individual fire reports are in separate appendices. For readers unfamiliar with fire history methodology, an introduction to the subject is provided. Results of the study are discussed in relation to current fire management initiatives in KNP and recommendations are made on future action.

In no way is this report intended to be a text on fire ecology or fire management, nor is it the sole information base for a fire management plan.

2. FIRE HISTORY PRIMER

This section is included because there is considerable confusion surrounding the term "fire history" and the methods used to determine it.

Fire history studies are intended to quantify the fire frequency or fire return period of a study area. "Fire history" is thus one element of a multivariate system comprising the "fire regime" of an area or type in an ecosystem. The concept of fire regimes was developed in order to classify fires into categories of similar effects on ecosystems. A fire regime can be characterized by fire history (frequency or return period, measured in years), fire intensity (kW/m), and depth of burn (duff removed, kg/m or percent). Because of the nature of response of fire to fuels, weather, topography, ignition, and control, fire regimes may vary widely, even over short distances and time.

Fire history is usually summarized in a table of frequency descriptors for different land types or areas. The most common terms used are "fire cycle", "average fire interval" (or "mean fire return interval"), "annual percent burned", and "fire frequency" (Johnson and Van Wagner, 1985).

A universe (area of interest) is made up of elements. The values of the fire cycle and average fire interval, and the values of annual percent burned and fire frequency, may be equal in a fire regime but the terms have different spatial reference. The fire cycle is the time required to burn an area equal to the size of the universe. In one fire cycle some elements may not burn at all and others may burn more than once. Average fire interval is the expected return period per element. Annual percent burned is the proportion of the universe that burns per unit time. Fire frequency is the same figure but is the probability of an element burning per unit time.

By definition, frequency is the inverse of the return period. Therefore, fire frequency (and annual percent burned) is the inverse of the fire cycle (and average or mean fire return interval). The term "mean fire return interval" (MFRI) will be used throughout this study.

Previous Parks Studies

Several fire history studies have been conducted in the western national parks; MacKenzie (1972, Waterton Lakes), Tande (1977, Jasper Townsite), White (1985, Banff), Fenton (in-progress, Jasper), Johnson (in-progress, Glacier), and Tymstra (in-progress, Yoho). These studies have utilized a variety of techniques to determine fire history depending upon the size of the study area and the specific goals of each study. For example, White (1985) chose representative points from aerial photographs and measured descriptors such as vegetation or ecosite type, elevation, aspect, drainage class, etc. and occurrence of fire from fire scars and tree ages. Fire history was expressed as a mean fire return interval (MFRI) for each type. This method may be termed the "interval" or "point-sample approach" to determining fire history. There are many other examples of this approach outside the Western Canadian national parks.

Johnson and Fryer (1987) and Johnson (in-progress) followed the "stand origin" or "time-since-fire" approach to determine fire history. The same dendrochronology techniques for determining fire dates were used, but entire homogeneous areas of fire origin ("elements") were drawn onto a stand-origin map. A stand origin map represents recent "fires" and "survivors" of earlier fires. The stand-origin map must be complete for the universe to be usable, though the universe may not necessarily be a single, contiguous land unit. Life-table analysis is then conducted to create a survivorship curve and MFRI (and other parameters) can be inferred from the distribution.

Determining Fire Dates

Arno and Sneck (1975) describe the method for determining fire dates. First, direct evidence of fire is cited such as scarred trees, burned stumps or logs, or charcoal in the duff layer of the soil. The trees in the area are examined for stand characteristics (ie. homogeneity of vegetation, height, diameter, etc.) and an age for the stand is determined through tree cores or cross-sections. If trees regenerated immediately after the fire, trees age would indicate the number of years since the fire and the fire date. However, because of varying regeneration delay, fire scar dates are preferred.

Tree species such as lodgepole pine (Pinus contorta) and Douglas-fir (Pseudotsuga menziessi) can survive many years if scarred by a forest fire, whereas white spruce (Picea glauca), Engelmann spruce (Picea englemanii), and sub-Alpine fir (Abies lasiocarpa) are killed very easily. The best fire history records are usually found in areas where there is a predominance of lodgepole pine and Douglas-fir. These fire dates can be used to identify both stand replacing (crown) and understory (surface) fires. Fire dates in areas dominated by spruce and fir may be less accurate because tree age is usually used to determine fire date. If evidence of fire is present on the site, then the trees are assumed to have resulted from a fire. This assumption is important in lodgepole pine forests where fire is required to open serotinous cones and expose mineral soil for seed germination.

The Stand-Origin Map

Criteria for a stand-origin map may vary; the map may be of stand-replacing or of understory fires, or a map of the last fires (stand-replacing and understory). Analysis and conclusions will depend on the criteria used for mapping and the specific parameter sought. For an area with a regime of crown fires, a stand origin map may be a map of recent stand-replacing fires and the survivors of previous stand-replacing fires.

The usual procedure for producing a stand-origin map of an area with a crown-fire regime is as follows. Homogeneous forest areas are identified from aerial photographs and sketched on a base map. Field surveys are then conducted to determine evidence of fire (ie. whether the stands identified are in fact of fire origin) and to determine the fire date. Polygons of surviving and resulting stands are adjusted on the map as required. At completion, the map of the study area contains many different sized polygons each with a fire date representing a forest area homogeneous in age. An example of a stand-origin map is shown in Figure 2. It must be remembered that criteria for mapping is important because fire intensity (ie. fire effect and resulting vegetation) can vary widely within the same fire. The criteria used in the example in Figure 2 was to map only stand date of origin; not necessarily understory fires, or species, or any other parameter.

A table of stand-origin data taken from the stand-origin map shows the date of origin, area, per-cent of total area, and cumulative per-cent area for each polygon. The date of origin is converted to an age from a reference year (usually the current year). The ages can be used in their raw form or grouped into classes. The age values can be referred to as "age-classes" or as "time-since-fire" classes. From this point, the data can be presented in three ways in order to express three concepts.

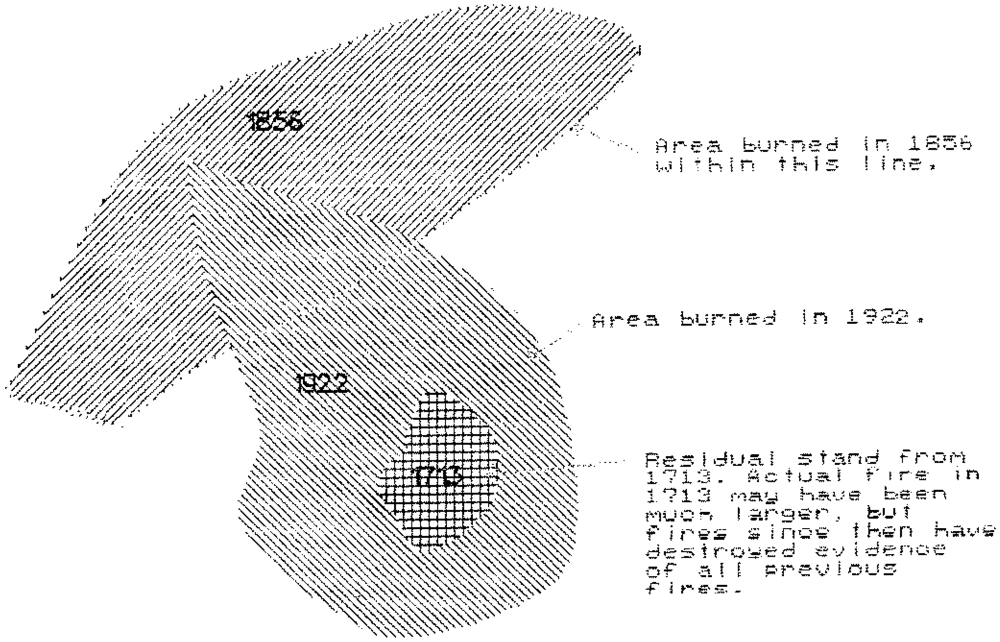

Figure 2. Example stand-origin map. Note the date of origin assigned to each polygon.

Grouping the dates (and by extension, forest ages from a reference year) into equal classes and graphing area (or % area) over age shows the "density age-class distribution" of the forest. The age-class distribution can be interpreted as the proportion of the total universe in different age-classes. The second concept is the "cumulative time-since-fire distribution" which is the cumulative per-cent area in each age, starting at 100% in the reference year.

It is crucial to distinguish between the density and cumulative forms of the age-class or time-since-fire distribution. "Age" is synonymous with "time-since-fire", but only the cumulative form of the distribution shows survivorship and allows for estimating the parameters of the distribution. The density form is most often used by foresters for harvest planning and has been used to explain the impact of fire suppression on the age-class distribution of a forest.

The Negative Exponential Distribution

Van Wagner and Methven (1979) introduced the concept of age-class distributions in national parks fire management literature. Their paper indicates that the natural, density age-class distribution of a boreal-type forest should follow a negative-exponential distribution. Johnson and Van Wagner (1985) describe the negative exponential model as follows. The negative exponential is a "random selection" model with elements in the universe burning independent of their age (ie. no matter the age or time since the last fire in each element, the probability of burning is always the same). This results in a density fire interval distribution which has a monotonically decreasing number of elements in each older time. The greater proportion of young trees compared to older forests is not due to changes in the burning rate, but due to the annual depletion of each cohort in the distribution and it's renewal starting in the youngest age-class. The oldest trees in this distribution have survived by random chance alone; not because they have a lower rate of burning. In reverse, to apply this model using prescribed fire does not mean selecting the oldest trees to burn first. Because it is a random process, each element has an equal probability of being burned, and selection will be made randomly from the element distribution. Numerous computer simulation models have expressed this idea, including one by the author (Masters, 1987).

Figure 3 shows the negative exponential distribution in it's cumulative form. Figure 4 the same cumulative form, time-since-fire distribution but drawn on a semi-log scale. It follows that a set of numbers with values from a negative exponential distribution will form a straight line when graphed on a semi-log scale. This line represents the "survivorship" curve of this population, or the chance of not being killed by fire up to age t. The inverse of this line is "mortality", or the chance of being killed by fire up to age t.

Parameter Estimation

The shape of the negative exponential distribution is described by a parameter "b" (Johnson and Van Wagner 1985). This parameter is termed the "hazard function" of the distribution.

The inverse of the slope of the survivorship (or mortality) curve gives the fire cycle of the distribution. If all the points on the graph can be described by this straight line, then the line and the slope represent a homogeneous fire history. Because the time-since-fire distribution shows the cumulative survivorship (or mortality) of the study universe, an instantaneous MFRI can be inferred from this graph. The MFRI in this case is the constant rate of burning or "hazard function" referred to above.

It is this instantaneous MFRI that is the object of the previously mentioned "interval approach" to fire history studies. An instantaneous MFRI is calculated for each different forest or vegetation type from fire scar interval information or differences between stand ages on the same vegetation type.

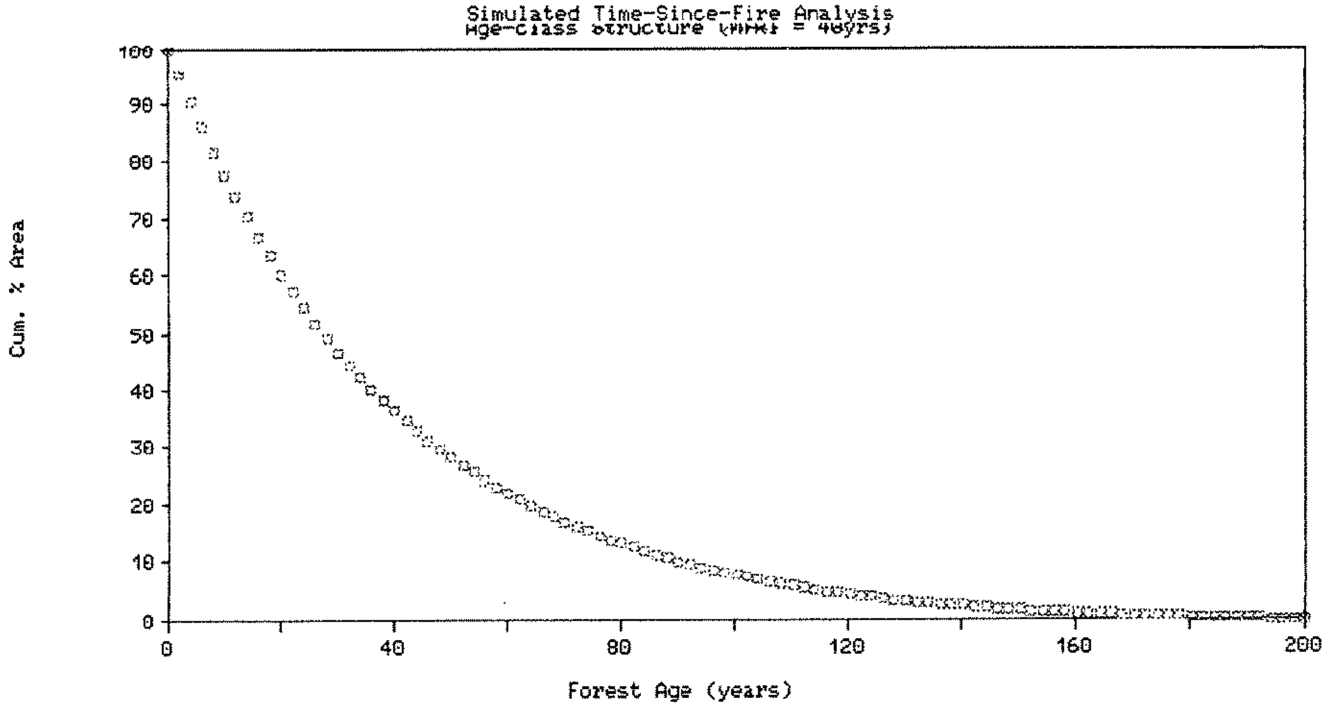

Figure 3. Example negative exponential age-class distribution, cumulative form. Y-axis values indicate % area older than age t (<u>eg.</u> approx. 30% greater than 42 years).

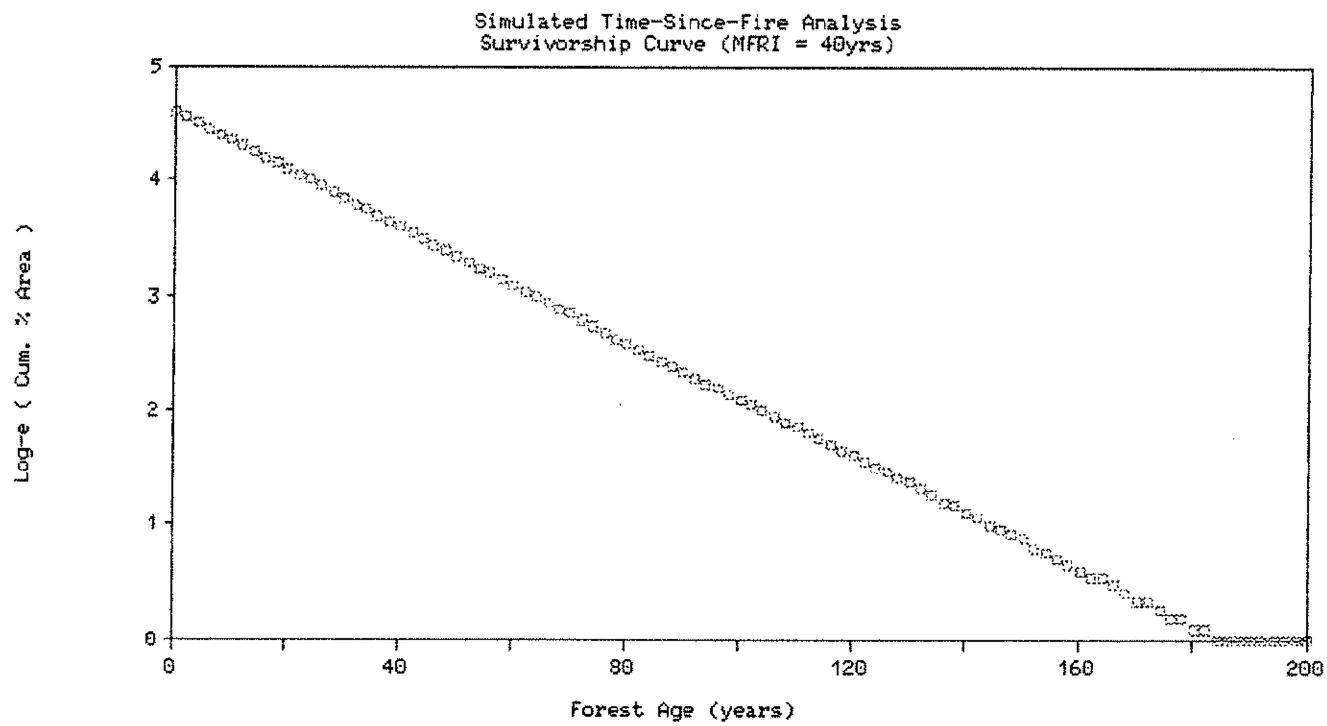

Figure 4. Example negative-exponential distribution, cumulative form, drawn on semi-log scale (survivorship curve). The straight line indicates a constant rate of burning (example shows MFRI = 40 years).

Because of natural variation and sample design, each estimate of MFRI has a sample and a natural (inherent) variance which can blur the distinction between the labeled fire history groups. Complex statistical procedures such as cluster analysis are required to separate these types (see White, 1985).

Calculation of an arithmetic mean to estimate MFRI is presumed to be a measure of central tendency (ie. a normal distribution of fire intervals is assumed). However, actual recurrence of fire on a point may not be normally distributed but according to some other model. If the distribution is not normal (eg. negative exponential) the use of a mean as a measure of central tendency may not be accurate. An arithmetic mean taken from a distribution other than normal may be used as a complex "x/n" calculating device for some other purpose (such as calculating an expected value in the distribution). Another difficulty is the assumption that the interval data represents a point over a long period. Few fire history studies discover more than few trees with greater than three fire scars; additional intervals are lumped with points from similar types. Because fires in forests with a crown-fire regime tend to destroy evidence of previous fires, and fire scarred trees are often found on microsites that do not represent the type that has burned, use of the fire interval data can be questioned.

There is a split among fire history researchers: those who feel the point sample "interval approach" is flawed because the points are not true interval samples, and those who feel the interval approach is sound and accurately represents the fire regimes of differing vegetation types. The results of the two methodologies may be similar (ie. comparisons of the MFRI for the whole universe may be similar) but the "interval approach" usually suggests a greater number of individual fire regimes. The time-since-fire ("stand origin") approach can detect spatial and temporal changes in the fire regime where the "interval approach" usually shows only spatial differences (ie. differences between vegetation types over spatial areas, as opposed to changes in the frequency of fire over time). Spatial and temporal breaks in the fire regime can be determined by examining and recalculating certain portions of the time-since-fire distribution and comparing the slopes of the new sub-sets of the distribution (explained in section 4.2).

3. METHODS

The Park

KNP covers over 1400 square kilometers of the west slope of the Rocky Mountains. It stretches from the Great Divide in the north-east, almost to the valley floor of the Rocky Mountain Trench in

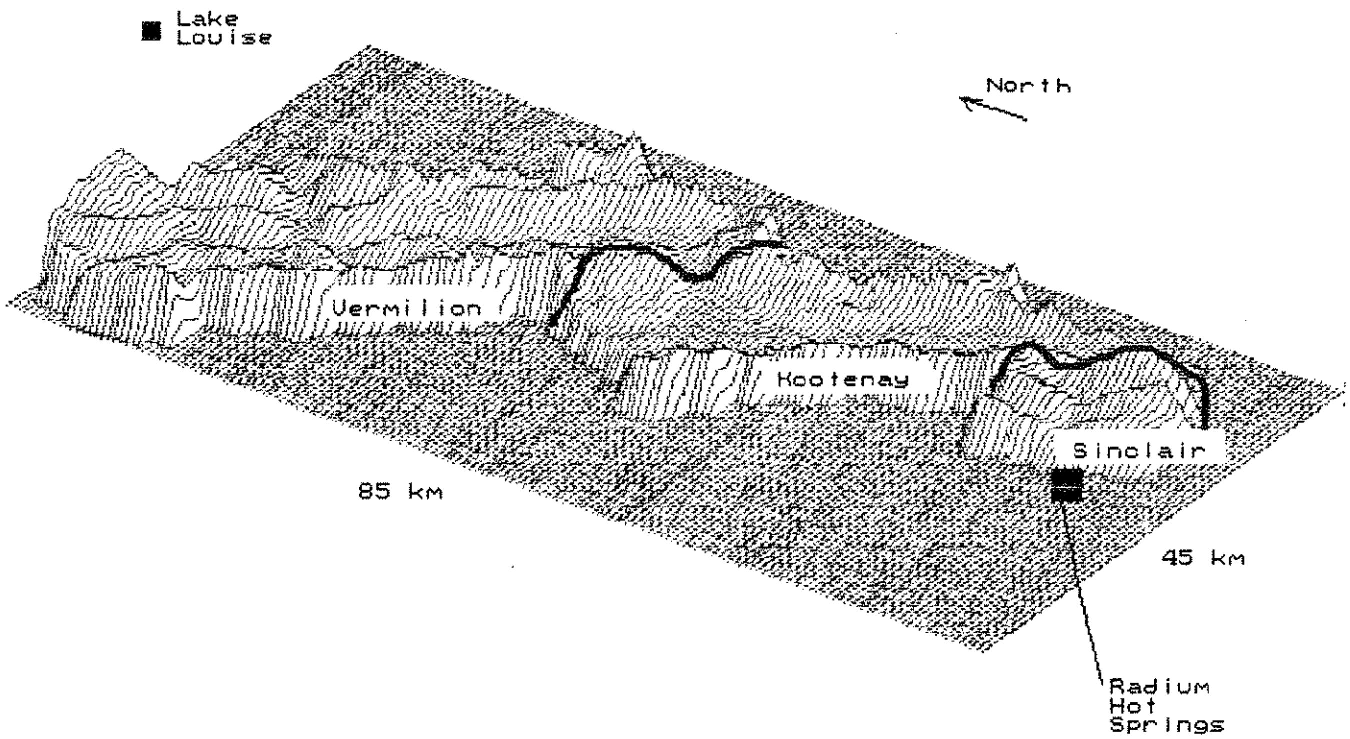

Figure 5. Orthographic view of KNP. Elevation ranges from 800 - 3400 metres. Note location of the 3 main valleys; Vermilion, Kootenay, and Sinclair. Generated by ORTHO routine in Idrisi GIS software using SPANS elevation data.

the south-west. Most of the park is oriented along the strike of two main valleys; the Vermilion and the Kootenay (Figure 5). The Sinclair Pass area of the park is transitional between the Kootenay Valley and the Rocky Mountain Trench. Elevation ranges from approximately 800 - 3400 metres over an area roughly 45 kilometers in width and 85 kilometers in length. Numerous hanging valleys are present along the length of each of the main valleys. Vegetation consists primarily of lodgepole pine, Douglas-fir, Englemann spruce, and sub-Alpine fir forests, with alpine meadows at upper elevations and riparian vegetation along the floor of the Kootenay Valley. Climate is cordilleran with occasional outbreaks of cold, continental air in winter.

The land was ceded to the federal crown in 1919 and the Windermere Highway completed in 1923. No major changes in the park boundary have occurred since that time, with exception of small parcel exchanges in the extreme south-west portion of the park near the town of Radium Hot Springs.

The time-since-fire approach to fire history was chosen because KNP contained sufficient road and trail access and lodgepole pine and spruce/fir forests with predominantly crown fire regimes.

Field work was conducted by the author with assistance from members of the KNP Warden Service. Funding was provided through a KNP special project which permitted some helicopter access to remote areas.

3.1 STAND ORIGIN MAP

Base Map

Two 1:50,000 scale base maps (north and south sheets) from the park ecological land classification (Achuff, et al., 1984) were fixed to a drafting table and covered with transparent mylar. The base map and aerial photographs of KNP were examined to delineate the park boundary and non-forest areas such as rock outcrops and alpine meadows. The aerial photographs were made up of five series: 1952 black and white 1:25,000; 1952 black and white 1:5,000 (highway only); 1978 1:25,000 black and white and colour infrared; and 1979 1:50,000 black and white. No one series was best for all locations in the park due to shadow and species composition.

Identifying Stand Polygons

Initial position of polygon boundaries was derived as follows. Stands were identified originally from homogeneity of species and uniformity of height (texture on the photo). Stand boundaries were often distinct on airphotos and from the ground, and at other times more subtle. Areas with complex forest ages and heterogeneous species, height, and other characteristics were grouped and lines drawn using a visual best-fit approximation to encompass one age. Different investigators may draw polygon lines in different places. The extreme ends of the Kootenay Valley are places where polygon delineation was quite easy; the central area of the Kootenay Valley near McLeod Meadows and Daer Mountain were much more difficult.

Collecting Fire History Information

Potential fire history plots were located from airphotos and coordinates marked on a field map. Each day of field work was planned to minimize travel and to focus on small areas in a systematic pattern from south to north. Plot locations were modified in the field to locate fire scarred trees or trees that represented various stands. Fire scarred trees were usually found near the edge of two types, but were frequently found on surviving trees within burn polygons. Not all of the information collected was used in the analysis. Following is a description of the information collected at each site:

Tree Number: A unique identifier for each sample tree composed of the UTM location of the site and the order in which the samples were taken. Thus ###-1 was the first tree taken at ### site, ###-2 the second, etc.

Observer: Initials of the observer.

Date: Day and month (year coded on top of form; all 1988).

UTM: Universal Transverse Mercator grid designation. KNP is located within UTM zone 11U and grid square NG. Easting and northing were taken to 100m accuracy.

Location: A place name, usually a local place name, creek, or mountain. Used for quick cross-referencing of information.

Ecosite: The 3-letter code from the ecological land classification map.

Aspect: Compass direction of the slope, to the nearest 15 degrees, as estimated from a topographic map.

Elevation: Height above sea level in feet from the base map, and converted to metres using a table.

Species: Species of the sample tree. Pl - lodgepole pine, Df- Douglas-fir, Sw - White spruce, Se - Englemann spruce, Fs- sub-Alpine fir, Ls - sub-Alpine larch.

Age: Age of the tree, as of 1988. Age was determined from cross-section or increment core (see text).

Year of Origin: 1988 minus age.

# of Scars: Number of fire scars on tree. Care was taken to differentiate between scars from insect attack, tree damage, porcupines, and black bears.

Year Fire 1: Year of the most recent fire scar on the cross section (see text).

Year Fire 2: "

Year Fire 3: "

Year Fire 4: "

Map #: Intended to be the unique polygon number (not used).

Fire Evidence: Direct evidence of fire is noted such as burned stumps or logs, fire scars, or charcoal in the duff.

Notes: Suspicion of other disturbance, etc.

Cross-sections and increment cores were taken as close to germination point as possible in order to accurately determine tree age. Ages from increment cores were rounded up to the nearest 5 years; a standard regeneration delay or height adjustment was not used. Calculations of ages and dates were most often made in the field. Some cross-sections and cores were sanded and examined using a 10-50 power binocular microscope. Most of these samples were later discarded; a few were retained at the KNP Warden Office for demonstration purposes.

Field plot locations and fire dates were then plotted on the mylar overlay. Polygon boundaries were re-drawn to suit findings of the field survey (ie. polygons of homogeneous age), and final polygon origin dates were also computed at this time. Accurate fire dates from fire scars were used when available. When multiple dates were found the modal date was chosen (ie. the date occurring most frequently).

In total 256 sample trees were either sectioned or cored (Figure 6). Tree sections were taken in most locations except in visible tourist areas (eg. along a popular hiking trail or within a campground) and places where fire scars were not available. Some tree dates taken from the 450+ vegetation plots of the ecological land classification were used in inaccessible areas. However, these dates were taken not for stand origin but for vegetation releve purposes and were generally of little use in this study.

Completion of the Map

Once the stand origin map was complete for the entire park, dates were rechecked and some polygon boundaries re-drawn. The map was comprised of over 130 polygons with 57 dates of origin ranging from 1332 to 1984. Five months from June to October was required to complete the stand-origin map.

3.2 TIME-SINCE-FIRE ANALYSIS

SPANS (Spatial Analysis System, from Tydac Technologies of Ottawa) geographic information system software was used on an IBM PC 80386 compatible microcomputer to calculate areas of the stand origin polygons and to do the map overlay analysis. The 1:50,000 stand-origin map was digitized in several sections and joined to produce a single stand-origin map in the GIS. An example of this map, using 50 year age-classes, is shown in Figure 7. The uncensored stand-origin map was used in the other analyses.

First Approximation of Fire History Units

Using a 1:200,000 scale map of the park, an initial approximation of spatial fire regime units was made using the three main valleys of the park; Vermilion, Kootenay, and Sinclair. These were termed as possible fire management units, based on an intuitive difference in fire regimes from the differing vegetation types and ecoregions in the 3 valleys (the Vermilion is predominantly spruce/fir and upper sub-Alpine, the Kootenay pine and lower sub-Alpine/Montane, and the Sinclair Douglas-fir Montane/lower sub-Alpine).

Area Analysis

The stand-origin map and fire management units map were overlaid and the total area by date of origin for each unit was calculated using SPANS. Forest age was calculated by subtracting the stand origin date from 1988, the % of total area for each age group was calculated, and the cumulative % of total area tabulated for each valley and the park.

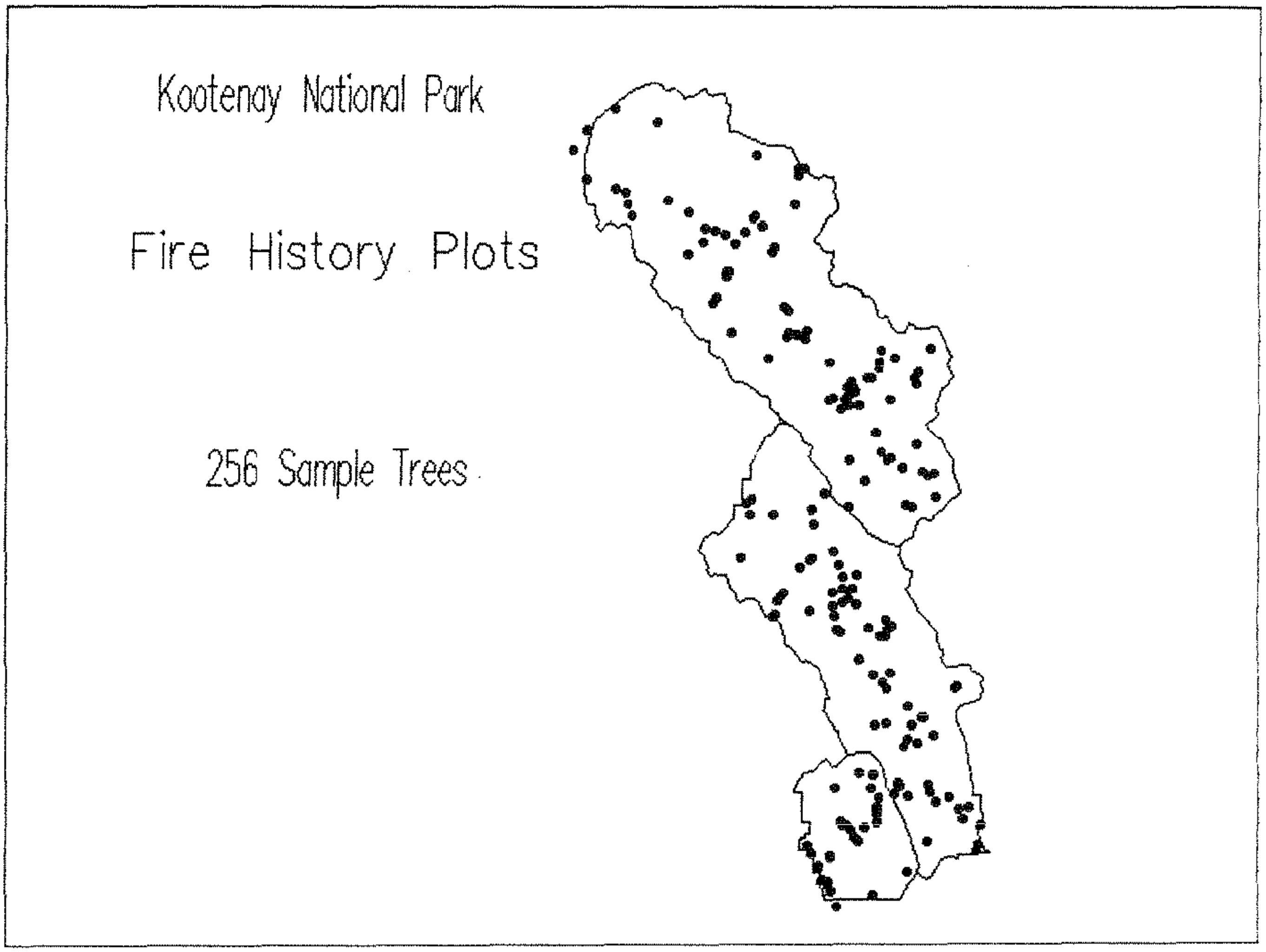

Figure 6. Location of fire history sample trees.

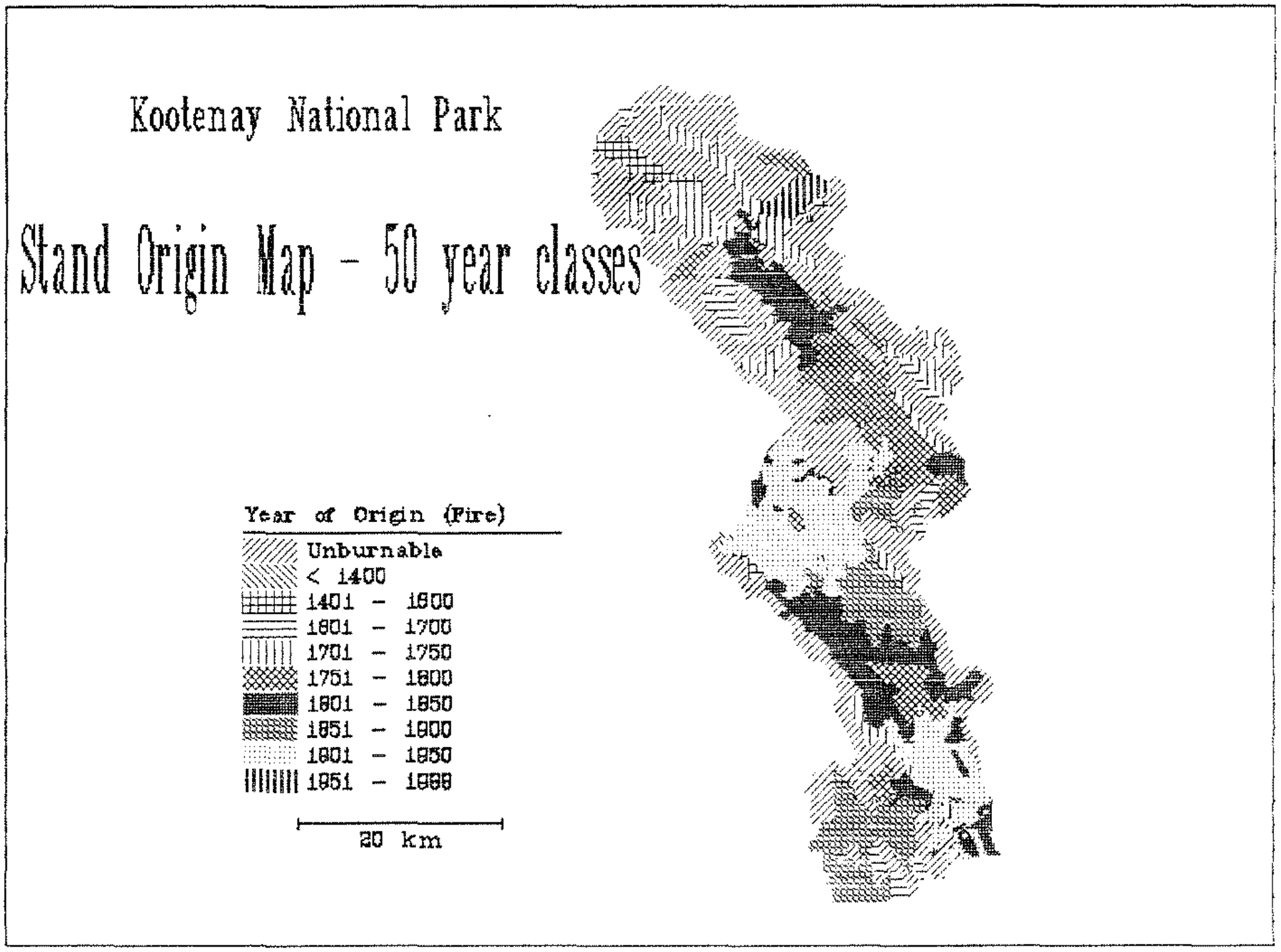

Figure 7. Stand-origin map of KNP. Unburnable represents rock, alpine meadows, glaciers, etc. Uncensored map contains over 130 polygons and 57 dates of origin from 1332 to 1984. Classified data is shown here for presentation purposes. Note 50 year class width except for first two and the last age class.

3.3 PHYSIOGRAPHIC INFLUENCE

Elevation and Aspect

Elevation and aspect maps were created by contouring 3200 elevation points within SPANS (200m contour information, Figure 8). Due to the north-west, south-east strike of the main valleys, aspects were reclassified across three gradients; South to North, West to East, and South-West to North-East. See legend on Figure 9 for classification of the aspects. For the South to North gradient, the cosine of the aspect could have been used (White, 1985). Sine and tangent of the aspects could have been used for other gradients.

Proximity to the Great Divide

The Great Divide represents the height-of-land along the spine of the Rocky Mountains. With weather systems moving primarily South-West to North-East, it was felt proximity to the Great Divide would show an inverse relationship with forest age, due to greater precipitation at higher elevations. Figure 10 shows KNP in 5 Km classes from the Great Divide.

A general hypothesis was developed that the oldest forests in the park would be found at higher elevations, on north-easterly aspects, and close to the Great Divide. All of these conditions should result in cooler temperatures and greater precipitation which would protect the forests from forest fires. Data was collected from the variable maps in two ways: a point sample, and an attribute mean overlay.

Point Sample and Class Means

1402 point samples were taken on a systematic grid of one point per square kilometre. Each point included the values of stand-origin date, valley, elevation, aspect (4 maps), and proximity to the Great Divide. The second method of extracting the area information was to conduct a class means procedure for each map using the stand-origin map as an overlay. In this way the values derived can be considered a parameter, rather than a statistic, because the figures do not represent samples. For example, a report from this procedure might show the mean date of origin for each class of elevation. Information from each of these reports was then transferred to a statistics package.

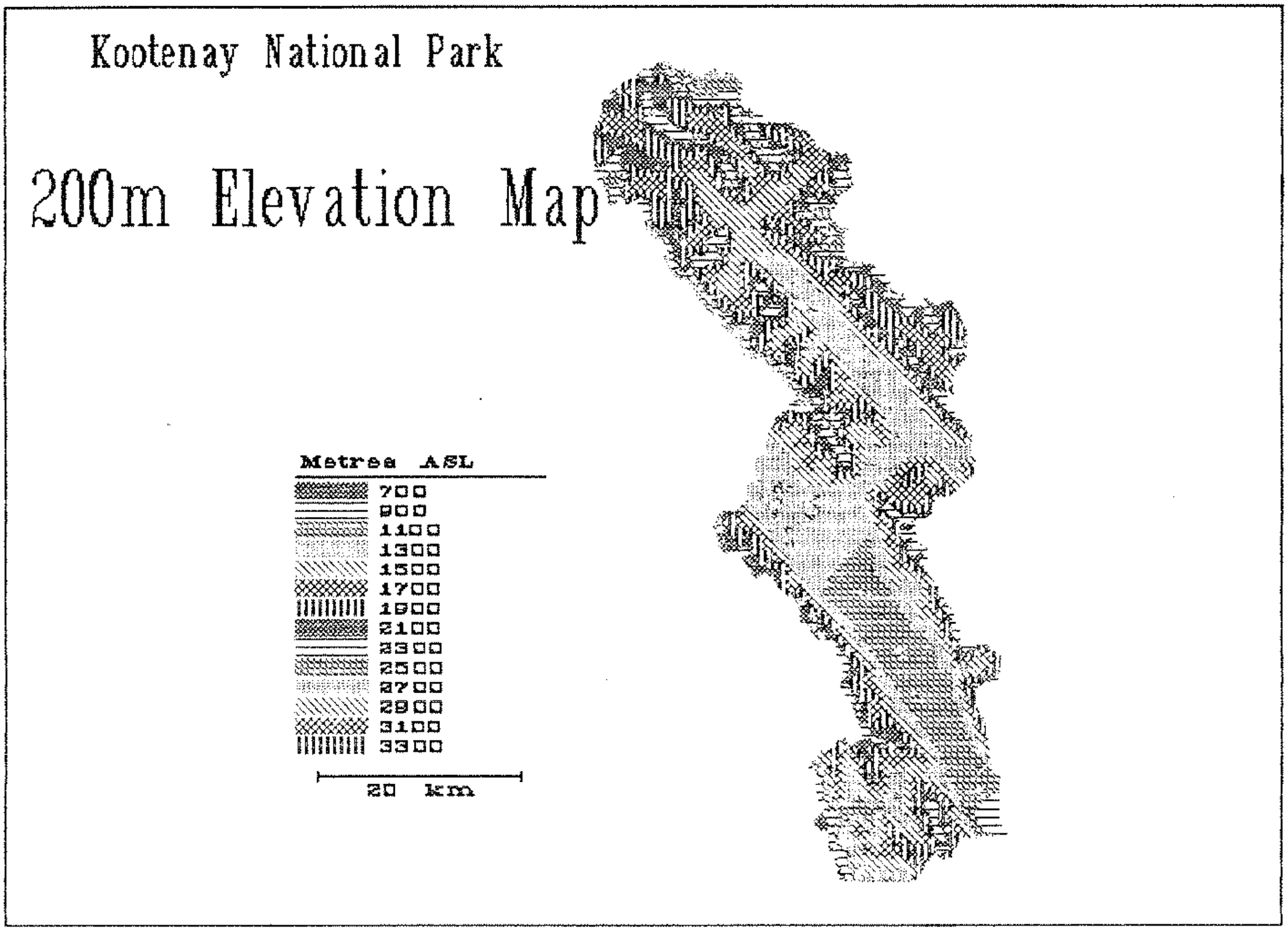

Figure 8. 200m elevation map of KNP. Map was created from 3200 elevation points using the contour module in SPANS. Note generally higher elevation in the Vermilion Valley (top half of map).

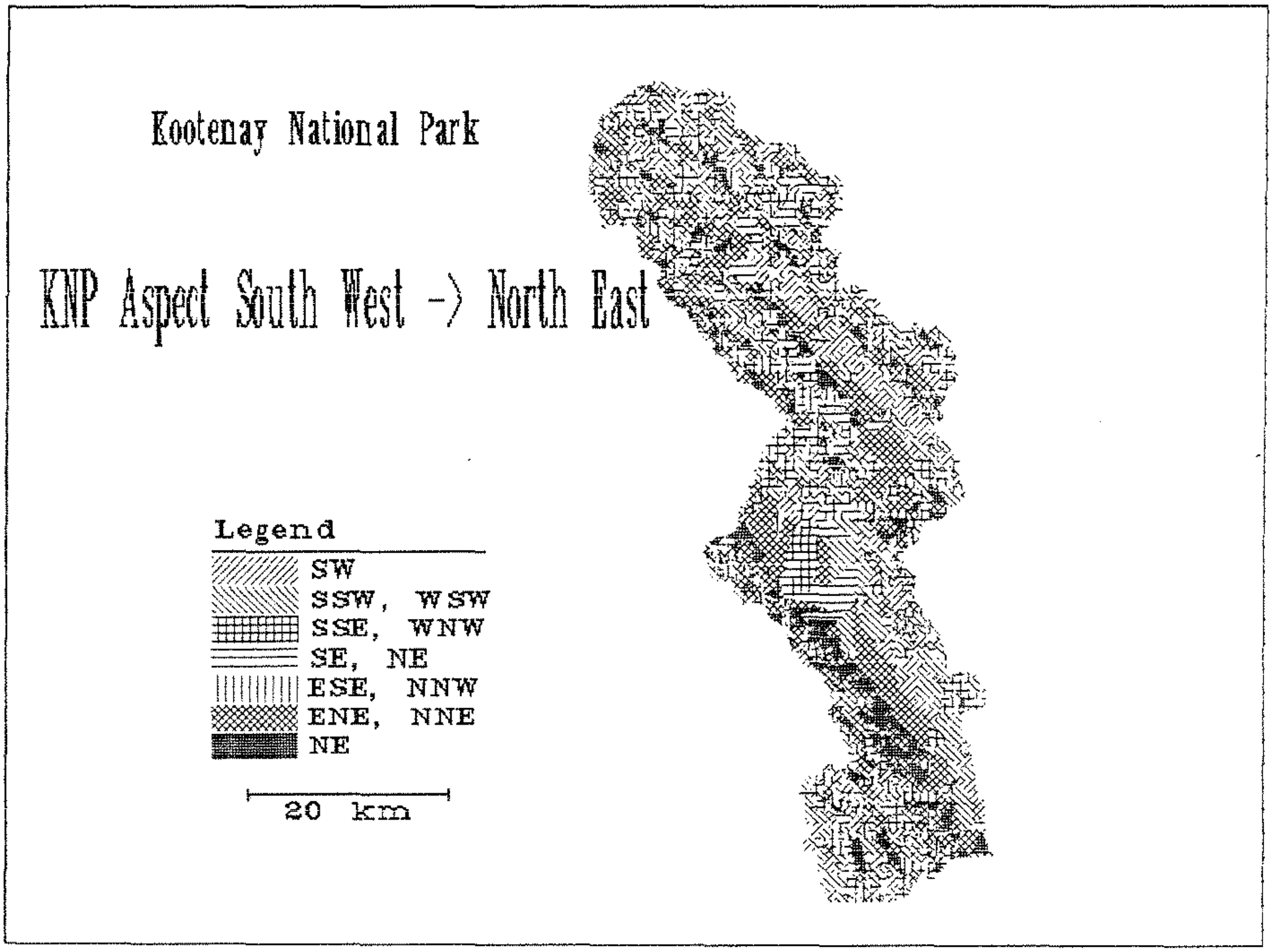

Figure 9. Example aspect map, showing compass direction of slope in 30 degree classes. Each of the 30 degree classes in this example was grouped across a South-West to North-East gradient.

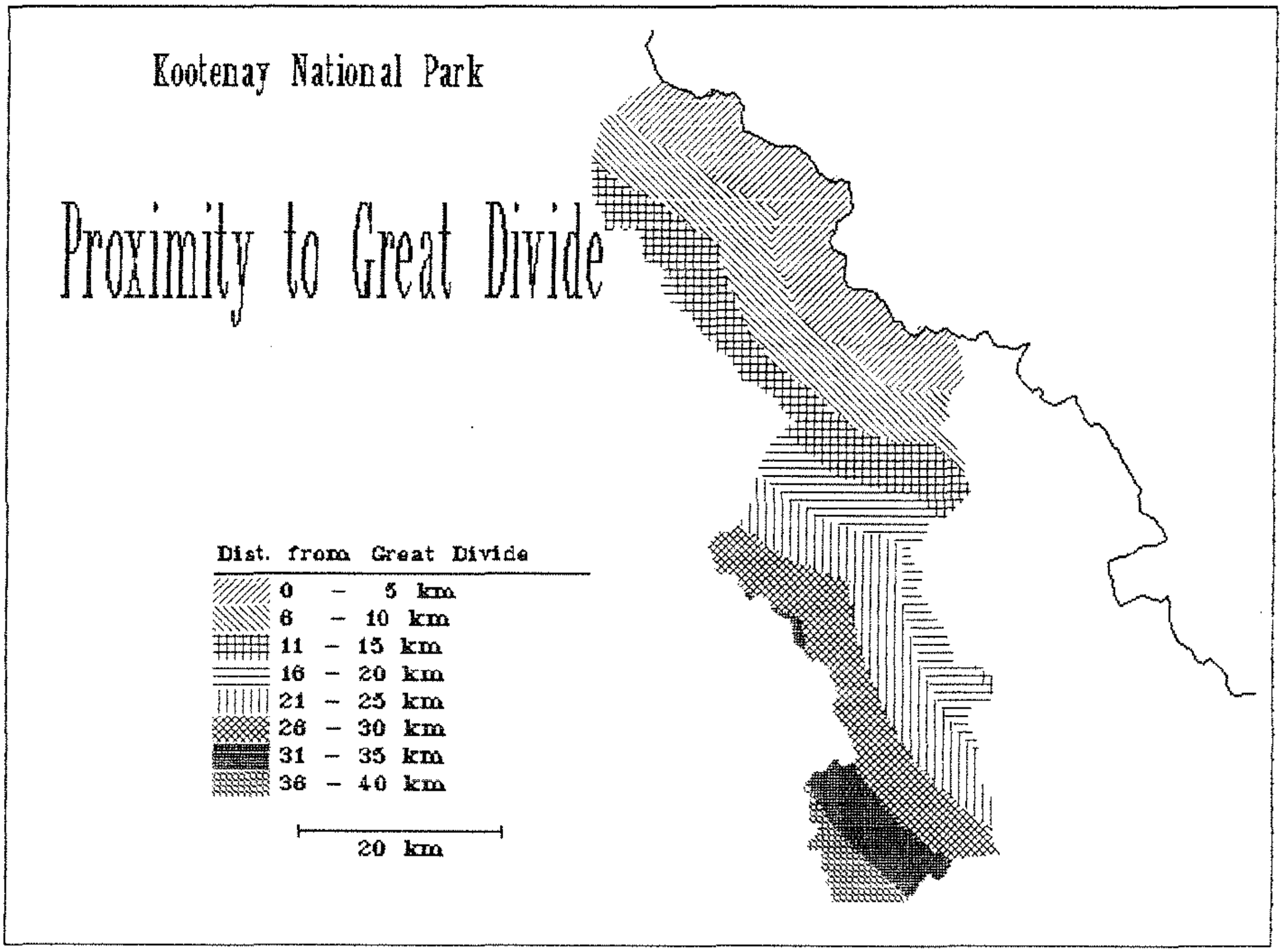

Figure 10. Proximity to the Great Divide. Each class on the represents a 5 km corridor. The map was created by generating corridors along a vector (the Great Divide) using SPANS.

4. RESULTS

4.1 AGE-CLASS AND TIME-SINCE-FIRE DISTRIBUTION

Age-Class Distribution

Figure 11 shows the proportion of the park in each age class. As mentioned in section 2, the density age-class distribution of a natural boreal forest should approximate a negative exponential distribution. Figure 11 shows the present density age-class distribution of KNP with a negative-exponential overlay. The two distributions were compared with a Chi-squared Goodness of Fit test and were found to be different; the present age-class distribution of KNP's forest does not approximate the negative exponential ($p<.05$). Age-class distributions for each of the 3 valleys in the park shows the characteristic bell-shape but the degree of distortion is greater in the Vermilion Valley.

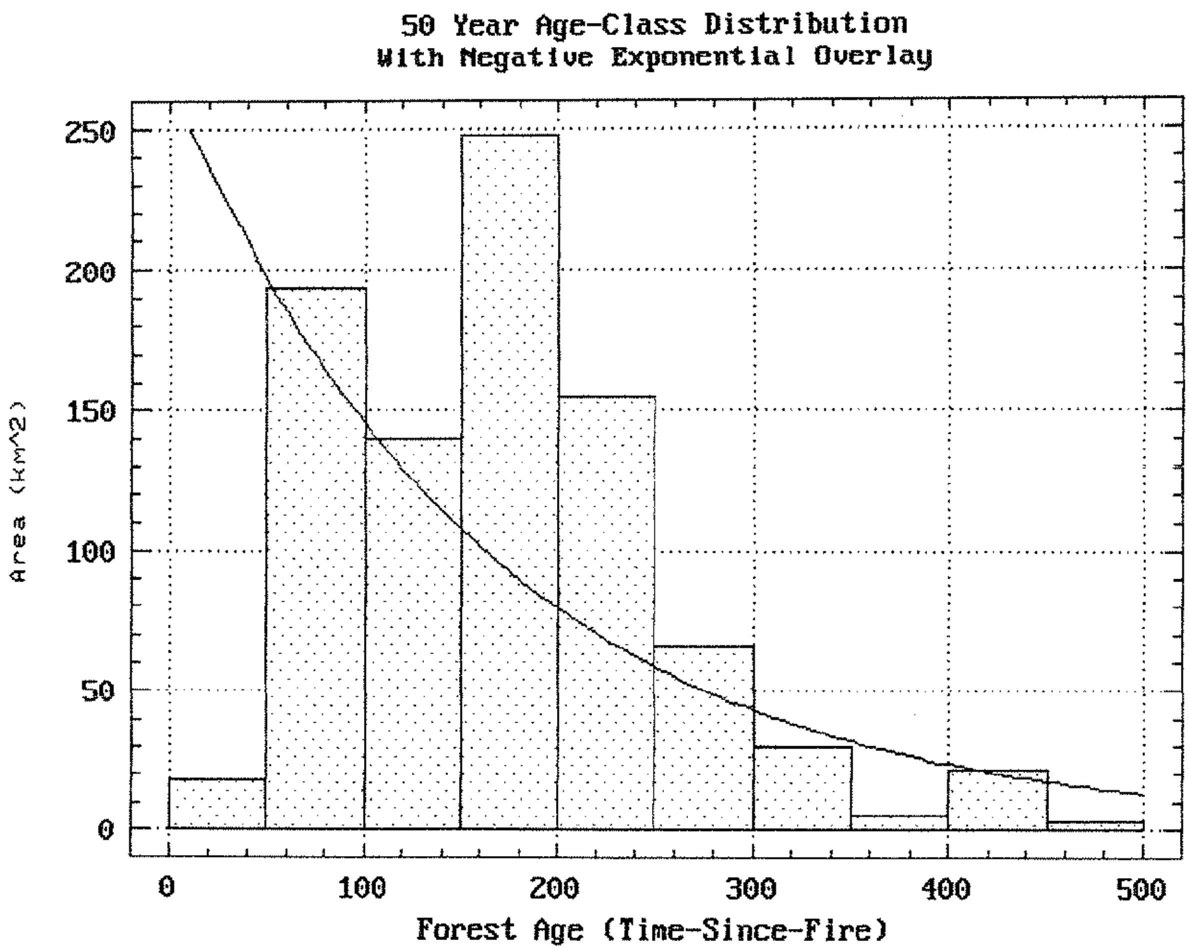

Figure 11. 50 year density age-class distribution for KNP. Note the scarcity of trees <50 years old. Present distribution and negative exponential (overlay) differ to $p<0.05$ (Chi-squared goodness of fit test).

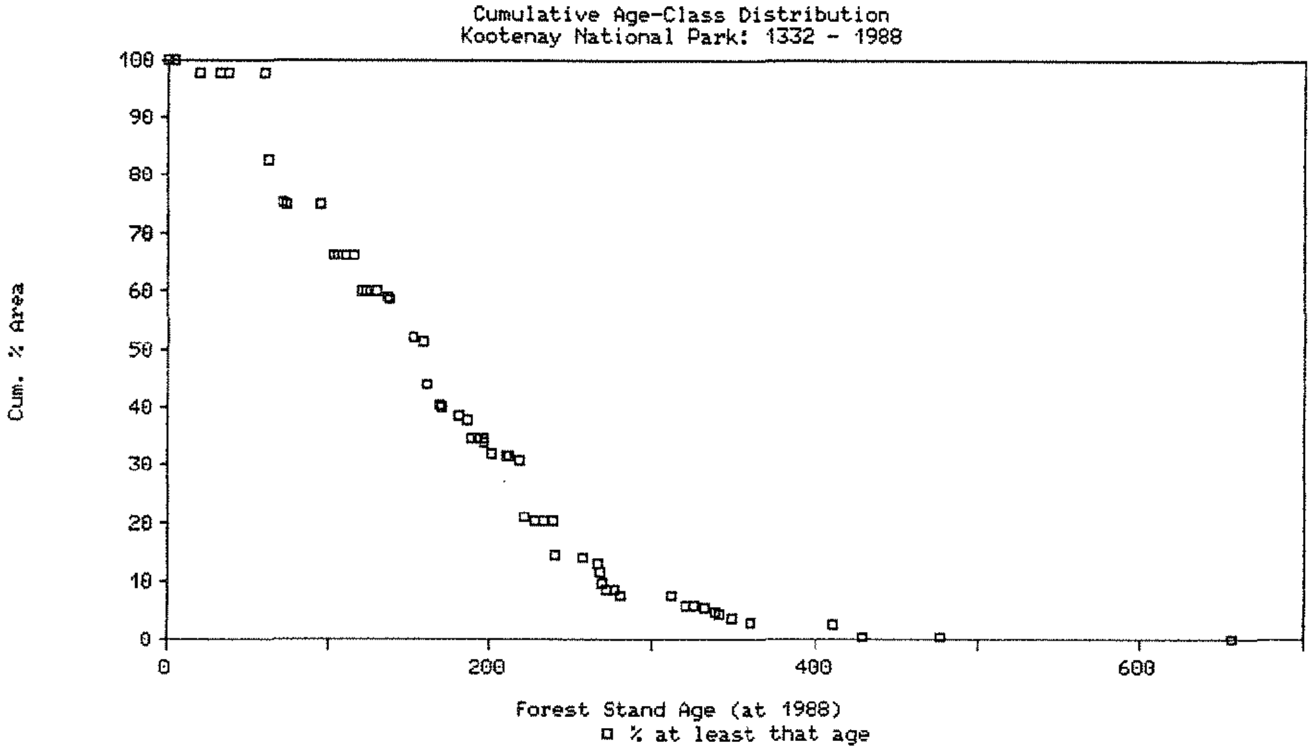

Figure 12. Cumulative time-since-fire distribution, KNP.

Time-Since-Fire Analysis

The most important results from this study come from analysis of the cumulative age-class or time-since-fire distributions, following the methodology used by Johnson and Fryer (1987). Figure 12 shows the cumulative time-since-fire distribution for KNP. Figure 13 shows this same distribution but with a semi-log scale (survivorship). According to the negative-exponential fire history model, the points on this graph should form a straight line. The line fitted through these points was forced through the point 0 years, 100% (or 4.605 on a log-scale) using the mortality curve. The regression is significant ($p<0.05$), although there is some pattern in the residuals. From the discussion in Section 2, this line represents a constant fire return interval. The inverse of the slope of the line in Figure 13 indicates a mean fire return interval of approximately 127 years.

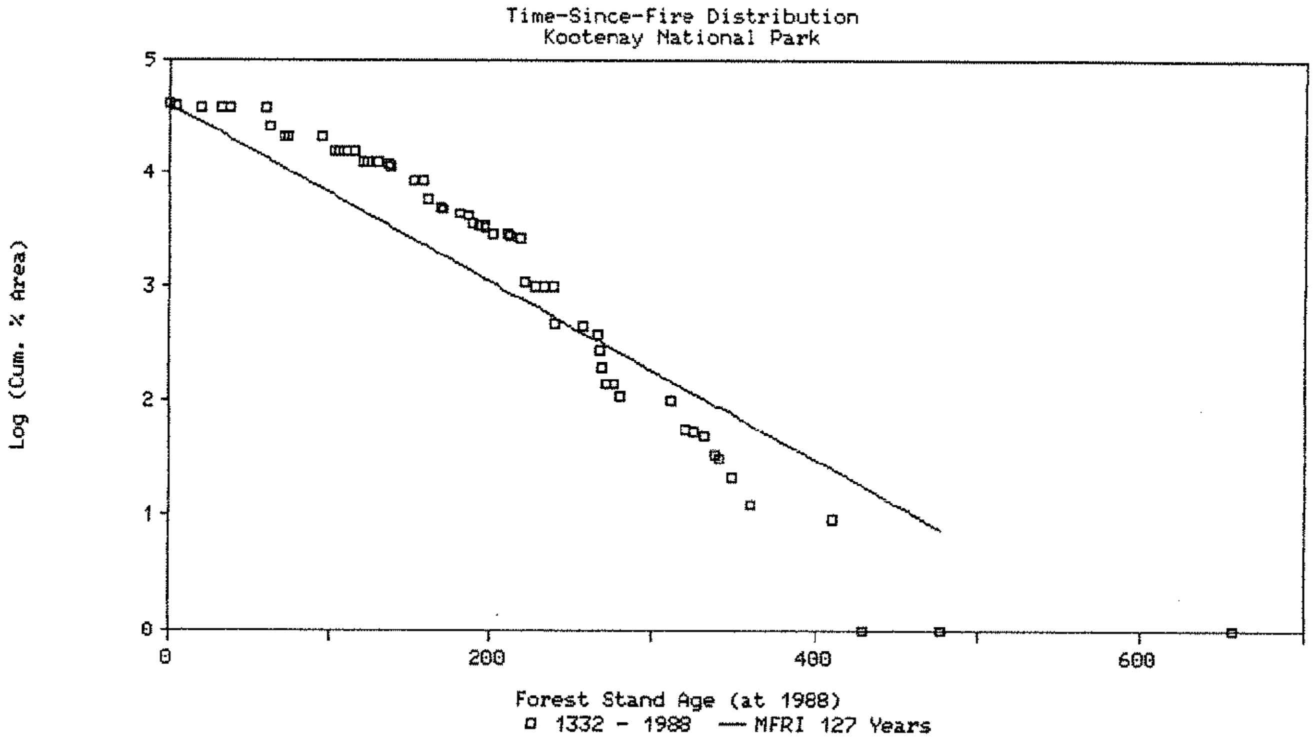

Figure 13. Time-since-fire distribution, KNP, drawn on semi-log scale (survivorship curve). Line indicates MFRI of 127 years for whole park.

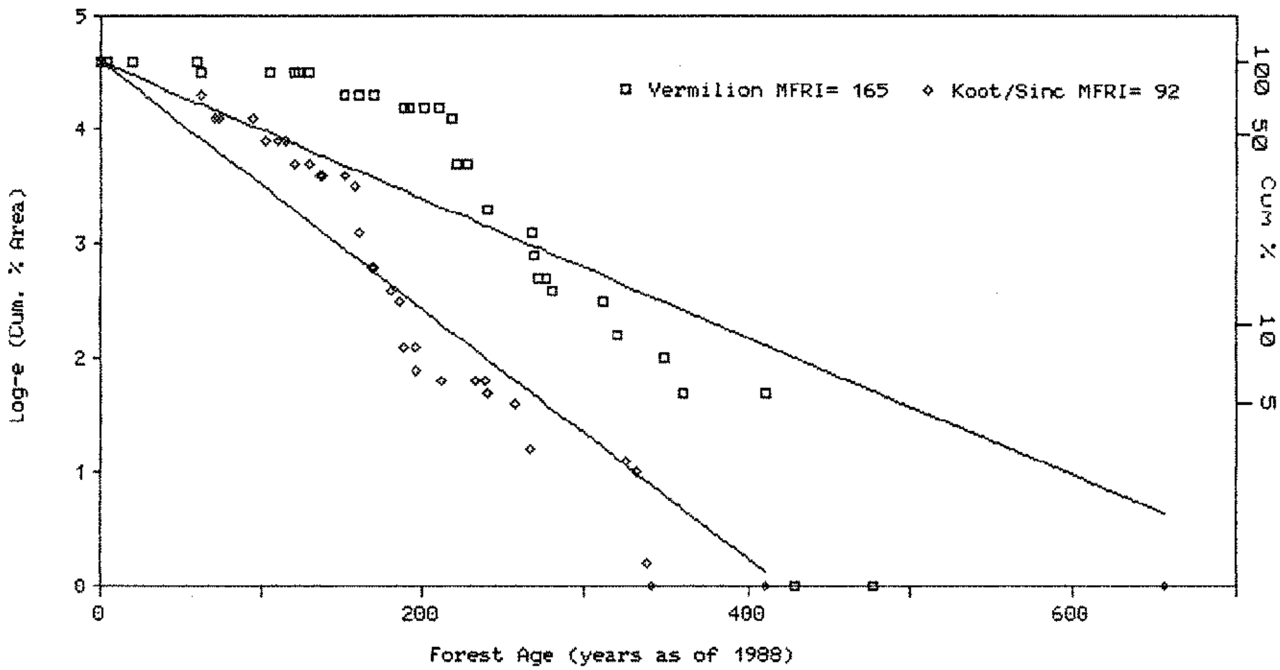

Figure 14. Time-since-fire (survivorship) distributions: Vermilion and Kootenay/Sinclair Valleys, showing MFRI of 165 and 92 years, respectively.

4.2 SPATIAL BREAKS

Vermilion versus Kootenay/Sinclair

The pattern in the residuals around the regression line in Figure 13 may indicate a spatial or temporal change in the fire regime. Figure 14 shows the recalculated time-since-fire distribution for the Vermilion versus the Kootenay/Sinclair area. The Kootenay and Sinclair areas were grouped together after age-class distribution and time-since-fire calculations showed that the Sinclair area was probably too small to be examined separately (most of the area burned in one fire in 1886).

The distributions and the regression lines in Figure 14 indicate that the two main valleys have different fire regimes (the regressions are significant and the slopes differ to $p<0.05$). The area and date of origin information for the two areas was separated and each distribution was recalculated to represent 100% of their respective areas. The slopes indicate the Kootenay/Sinclair area has a MFRI of 92 years and the Vermilion Valley a MFRI of 165 years.

Forest Age versus Elevation, Aspect, and Proximity to the Great Divide

A multiple linear regression from the point sample extracted using SPANS revealed only elevation and valley as significant variables in predicting forest age. Figure 15 is a plot of the mean forest age for each elevation class with 95% confidence limits (ANOVA significant difference between some classes to $p<0.05$). A similar plot of age over aspect does not show significant difference between ages on various aspects ($p<0.05$). Results of the regression and ANOVA tests are questionable, because important assumptions were not met.

Regression analysis requires independent data points (Zar, 1984). In this case, the elevation of one point is partially dependent upon the elevation of the next nearest point, regardless whether the points are chosen systematically or at random. The elevation points are said to be "spatially autocorrelated". Points taken to test aspect and proximity to the Great Divide are also dependent on the values of neighboring points. ANOVA demands equal variances between levels of the analysis (eg. elevations, aspects, etc.); a Bartlett's test of homogeneity of variances failed in each case.

The result of a multiple linear regression to predict forest age from the mean values of elevation, aspect (4 maps), valley, and proximity to the Great Divide reported for each forest stand origin date shows that all but the raw aspect data were significant variables to predict forest age. Results included a low r-squared value of 46% and individual coefficients that do

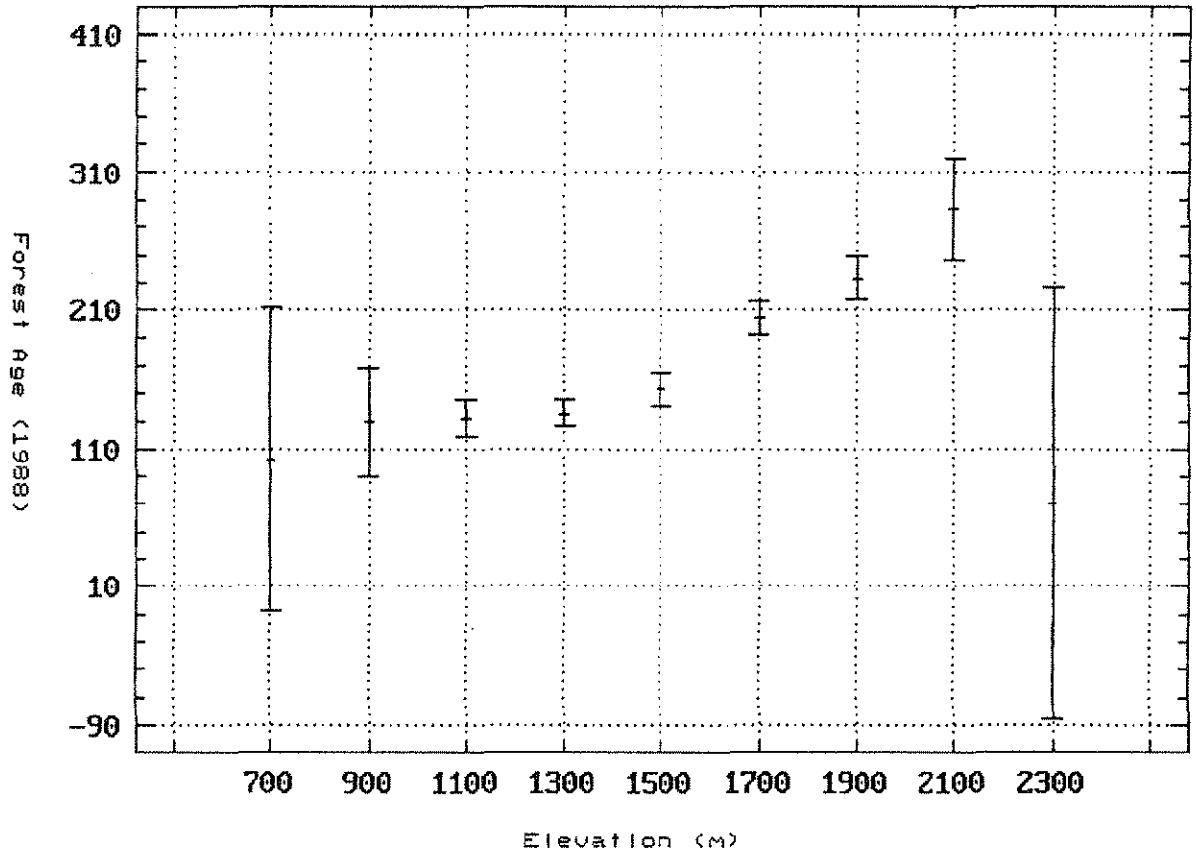

Figure 15. Forest age versus elevation from point sample for KNP. Bars represent 95% confidence limits. Sample sizes at 700 and 2300 metres were very small.

not support the hypothesis. A more significant problem is interpreting the meaning of the regression to fire history (see Discussion).

Individual regressions and plots of mean ages for each variable reveal some patterns in the data. Forest age versus proximity to the Great Divide data points are clumped, with no observations about the mean. Closer examination of this data, and the valley map, shows the transition between the Vermilion and the Kootenay/Sinclair areas to occur at the point the two clumps are separated; indicating not that proximity to the Great Divide has influence, but that perhaps the influence on forest age is due mainly to unquantified valley differences. Similarly, the mean elevation taken from the point sample for each valley is also different, indicating that differences in forest age may not be due to elevation <u>per se</u>, but to other differences between the valleys.

<u>Rationale for Spatial Partitioning</u>

Why can't the time-since-fire analysis be conducted using elevation and aspect as spatial breaks? The reason this was not attempted is because the breaks should follow an identifiable barrier. Elevation and aspect classes of arbitrary designation do not necessarily form any "barrier" that a fire can detect. The Vermilion and Kootenay/Sinclair areas were partitioned because only a very narrow strip of forest connects the two valleys through Hector Gorge. Though fire history information indicates recent fires have proceeded through this gap, it was considered enough of a barrier to permit partioning.

4.3 TEMPORAL BREAKS

Temporal breaks are identified in the same manner as spatial breaks. A pattern to the residuals around the regression line fitted to the survivorship curve may also indicate a change in fire frequency over time. Temporal breaks are identified and tested using the same procedure of partitioning the distribution at suspected points and recalculating each section as a new distribution starting at 100% area in the reference year.

Figure 16 shows the only clearly identifiable temporal break in the fire regimes of KNP. This figure is a plot of the Vermilion fire regime shown in Figure 14, but broken into two periods; 1512 to 1767 and 1768 to 1988. The two regression lines are significantly different to $p<0.05$. The date of the break corresponds roughly with the time of the "Little Ice Age"; a time when the climate cooled and glaciers of the Rocky Mountains showed dramatic advances (Heusser, 1956). Johnson and Fryer (1987) identified a similar break around 1730 in the Kananaskis which may have been due to the same change in climate. Attempts to break the Kootenay/Sinclair and the whole-park distribution at the same and other years were unsuccessful. Figure 17 shows no difference in the fire regime for the Kootenay/Sinclair area for the pre and post 1768 periods. For the Vermilion Valley, this break represents a change in the MFRI from 75 years prior to 1768 to a MFRI of 267 years after 1768. Breaking the distribution around 1830 (when the Little Ice Age is reported to have ended) and at 1917 (park establishment) did not produce any distinct distributions.

5. DISCUSSION

5.1 DATA COLLECTION

Stand-Origin Map

The stand-origin map varies in accuracy of the positioning of the polygons and the dates of origin. Investigators using the map for other purposes or trying to recreate the polygons may develop a different looking map in certain areas. Deviations in area or dates must be consistently large in one direction to cause

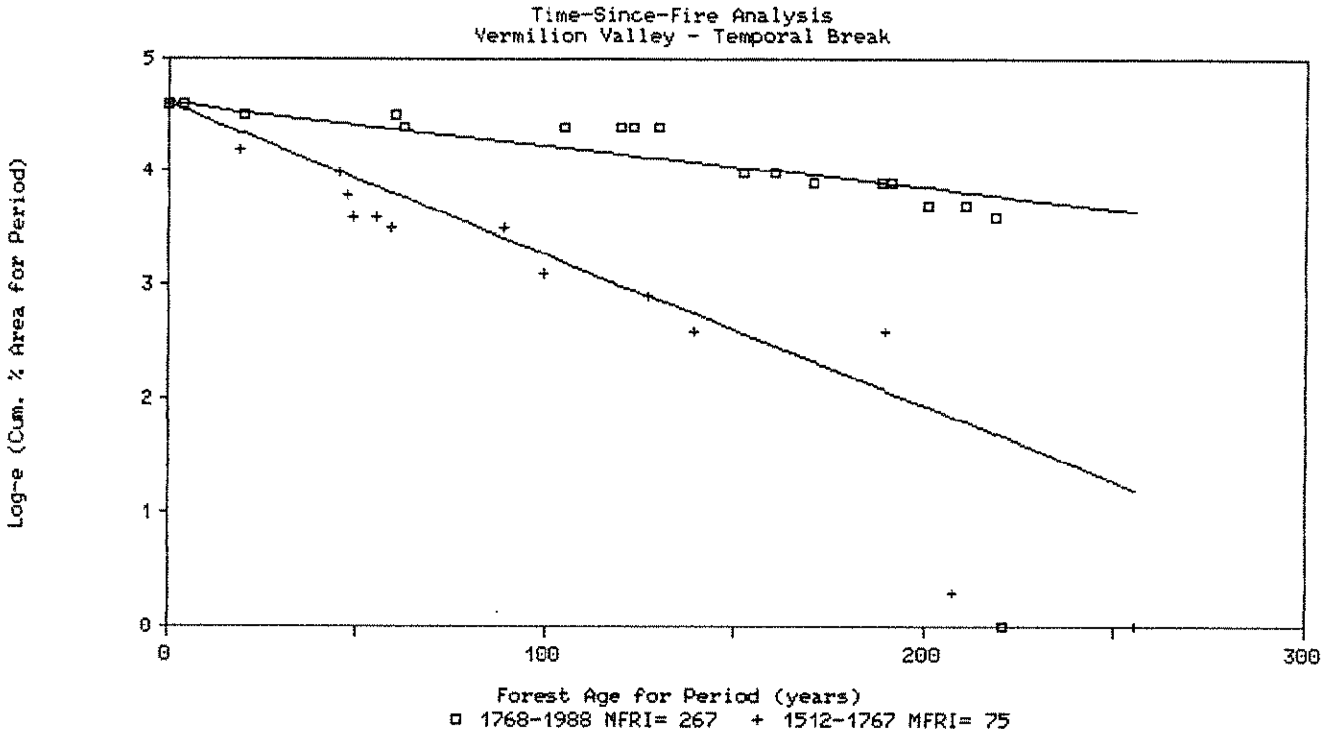

Figure 16. Time-since-fire (survivorship) distributions for Vermilion Valley, prior to and after 1768. Change in MFRI from 75 to 267 years may be due to a change in climate.

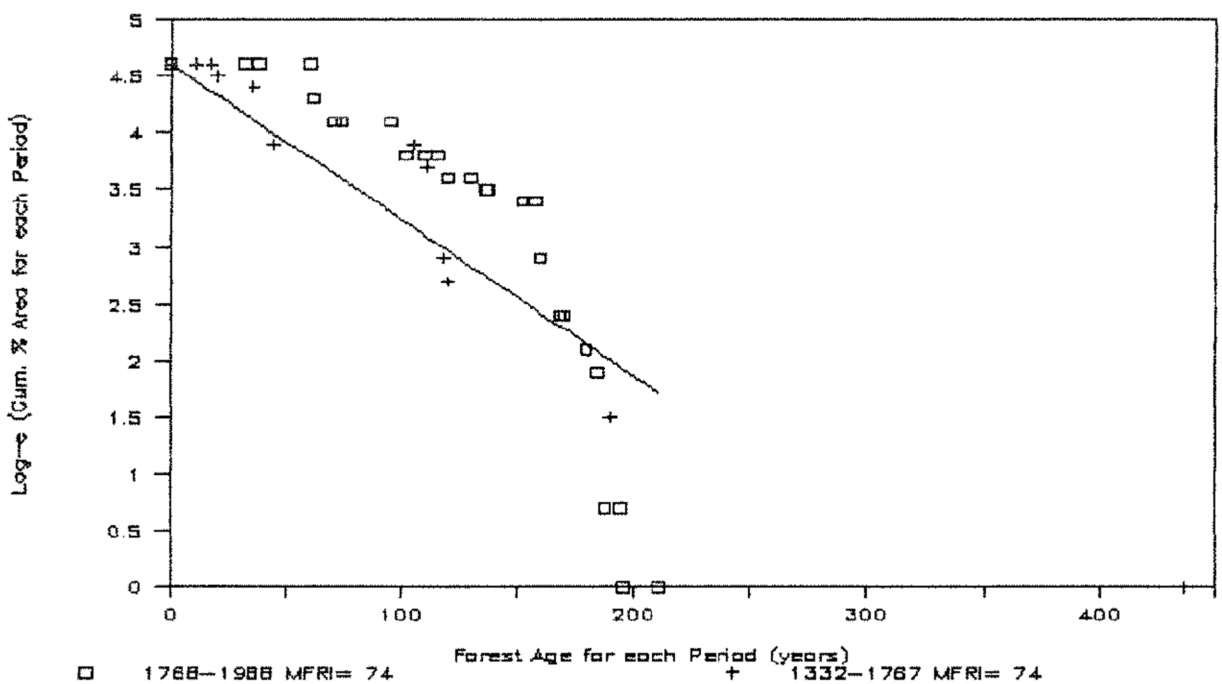

Figure 17. Time-since-fire (survivorship) distribution for Kootenay/Sinclair Valleys prior to and after 1768 (no difference in the distributions).

significant shifts in the time-since-fire distributions.

Sample Trees

The elevation, aspect, and ecosite variables collected with each sample tree were not analyzed because selection of the sample trees was not designed to control site differences. For example, this study focussed on finding trees that survived from major forest fires. Surviving trees were often found on microsites that did not represent the area burned or a particular aspect, elevation, or ecosite. To assert that all of these trees were an unbiased sample of these conditions would be incorrect.

Elevation Data

The elevation and aspect maps derived from 200m contour points may be inadequate for other purposes. One solution to greater accuracy will be to digitize more points or acquire the data from other sources.

5.2 TIME-SINCE-FIRE ANALYSIS

Changes in Fire Frequency

Fire is pervasive in KNP. Virtually all forests in the park have burned at some time; charcoal was even found at 2400 metres elevation less than 750 metres from a glacier. The survivorship curve for the whole park shows some pattern that is not fully described by a straight line. Partitioning the distribution spatially into the Vermilion and Kootenay/Sinclair areas accounts for some of this variation.

A temporal change in the fire regime should affect the different spatial entities in a similar way. This does not seem the case in KNP. It appears as though the temporal change in the fire regime (ie. a cooling in climate and lengthening of mean fire return intervals after 1768) affected only the Vermilion Valley; the Kootenay/Sinclair area shows little or no response to this change. A possible explanation may be that at time of the change in climate the Vermilion Valley was already near a fuel moisture threshold that would severely restrict fire growth. This change then was significant for the Vermilion but not the Kootenay/Sinclair area, presumably because the latter area was not as close to this moisture threshold. This may not be perpetuated because the crowning threshold for spruce/fir forests is lower than that for pine forests (Alexander, et. al., 1984), and we have no way to be certain of the vegetation composition of the park or weather patterns prior to the change. Another possible explanation for the difference between the two valleys may be that the shift in climate somehow altered the pattern of lightning occurrence, though the distance between the two valleys is slight.

The change in fire frequency from 75 to 267 years in the Vermilion Valley after 1768, and the difference in MFRI from 92 to 165 between the Kootenay/Sinclair and Vermilion areas are significant to forest ecology. The longer MFRI since 1768 is probably responsible for the relatively older forests found in the Vermilion Valley. Fire control personnel in KNP cite greater mop-up problems with fires in this valley which may be due to greater biomass accumulations because of reduced burning. MFRI in each of the main valleys is longer than the period required for lodgepole pine to reach sexual maturity (about 20 years). Lodgepole pine, as the dominant pioneer tree species in the park, would then be allowed to reproduce after each fire, as opposed to fire regimes with MFRI of less than 20 years. Long periods between fires may allow understory spruce species to reach greater height, thus dominating the composition of some forests.

If these MFRI values are accepted, the annual average burn area for the Kootenay/Sinclair would be 539 hectares and 144 hectares for the Vermilion, for a total of 683 hectares for the whole park (Table 1). Annual burn areas cited are long-term averages which may include re-burning.

Area	Burnable Area (ha)	MFRI (years)	Annual Average Burn Area (ha)
Whole Park	88,066	127	693
Vermilion	38,522	165	233
- Pre 1768	38,522	75	514
- Post 1768	38,522	267	144
Kootenay/Sinclair	49,544	92	539

Table 1. Mean fire return intervals and annual average burn areas for KNP. Annual average burn area is the burnable area divided by the MFRI.

Fire Size

The stand-origin map shows that very large fires have occurred in KNP (eg. 1926 fire near Kootenay Crossing burned 13,325 hectares or 13% of the forested area of KNP). Some of the fires remained within the present boundaries of the park and others have crossed the park boundary, in both directions, between neighboring national and provincial parks and commercial forest land (eg. Vermilion Pass, Simpson River, Kootenay Crossing, Daer Creek, Settlers Road, Radium Hot Springs). Because the stand-origin map is not a map of all fires, fire size distribution could not be inferred for the entire record.

Influence of Man

Fire cause analysis was not conducted. Records from KNP archives cover only 60 years of the 600+ years in the tree record. Many fires could have been caused by native indians though lightning is assumed to be the cause responsible for most of the area burned. This is a reasonable assumption, given the knowledge about lightning fire ignition and lightning activity detected by sensor networks.

Have man-caused fires after park establishment had much effect on the time-since-fire distribution (eg. during construction of the highway)? Examination of the stand-origin map and the fire dates will show only a very small area burned since park establishment where the cause of the fire was known to be other than lightning. Major fires since 1919 (park establishment) such as in 1926 and 1968 were known to be lightning caused.

What about the effect of fire suppression? Fire control policy in KNP has been full suppression since park establishment. The time-since-fire distribution shows park status as a brief period in the tree record. Study of fire reports from 1926, 1935, 1950, and 1968 show that fire suppression had little effect on the progress of these fires. Though costly efforts were mounted, rain was listed as bringing most fires under control, after which they could be extinguished by fire crews. Only since the early 1980s has KNP effectively used helicopters and rappel trained initial attack crews to perform rapid initial attack. In 1985, this system was tested and at least ten fires were successfully suppressed that would have burned more area had it not been for the suppression effort. This is not to belittle the valiant efforts of many who followed the policy of the day, or to over-rate the successes of a few years since the early 1980's. Many small fires under marginal burning conditions were suppressed; all of the extreme fires were not. Over 17% of the park surface burned in 72 years since park establishment, 15% in one lightning-caused fire in 1926. The relatively fire free interval on the cumulative time-since-fire distribution in recent years could be a response to a period of cool climate, but is too short to evaluate. Partitioning the time-since-fire distribution starting at park establishment did not reveal any convincing breaks.

5.3 PHYSIOGRAPHY

Difficult to Test

The use of GIS allowed the investigation of various physiographic influences on forest age. If the noted problems such as autocorrelation between sample points and unequal variances can be overcome, a difficulty remains in how to interpret the results in relation to fire history. Because a stand-origin map is primarily a map of survivors, how can forest age as a function of elevation and aspect be interpreted? To break the cumulative time-since-fire distribution between elevation and aspect classes assumes the fire can "tell the difference". There are a few examples of fires in KNP where the stand-origin map is a good representation of the extent of the fire (eg. 1968 fire at Vermilion Pass, 1926 fire near Kootenay Crossing, 1917 fire in south end of Kootenay Valley, 1886 fire in Sinclair area, etc.). Examination of the extent of these fires shows burning on all aspects and over all ranges in elevation; from tree-line on one side of the valley, across the valley floor a thousand metres below, and up to tree-line on the other side of the valley. Clearly, these fires showed little preference for elevation or aspect, and to break the distribution along these lines of convenience would likely not yield convincing results.

The stand-origin map represents survivors of the most severe, stand replacing fires in KNP. These fires probably occurred during the heat of the summer in July or August, a time when all aspects and elevations are dry enough to carry crown or stand replacing fires. Experience in wildfire and prescribed fire control under marginal burning conditions in the spring shows a pronounced aspect and elevation effect: when northerly and upper elevation slopes are still covered in snow, lower more southerly slopes are engaged in a full crown fire. In this regard, the stand-origin map fails to separate spring from summer fires because burning month cannot be determined. A map of understory fires, or a sequence of stand-origin maps over a long period, may provide answers.

Valley Geometry

Relationships shown previously between age and elevation and age and proximity to the Great Divide may be inconclusive because of the distribution of the data points and the clustering due to unquantifiable valley differences. This is not to say that the difference in age between the valleys is not quantifiable, it is that the reason for the difference is poorly understood. For example, the Vermilion valley is bordered with numerous hanging valleys that rise in elevation to the south-west. Old forests are found in these valleys. Are the differences in age due to simply elevation and precipitation, or because fires in the main valley would have to back into the side valleys against the prevailing wind in order to progress south-westward? Clearly, there are phenomenon related to the complex geometry of the valleys that we do not yet fully understand and cannot yet describe with an equation; even with GIS.

6. CONCLUSIONS AND RECOMMENDATIONS

Fire Frequencies

Table 1 shows the MFRI values for KNP. These frequencies are accurate for forests with crown fire or stand-replacing regimes; the greatest proportion of the park. Sites with understory fire may require further study (ie. Douglas-fir forests along the East Kootenay fire road and in the Sinclair/Radium area, and aspen/grassland environments near Daer Mountain fire lookout). An interval approach may be necessary for this understory fire investigation. The difference in the fire regime between the Kootenay/Sinclair and the Vermilion Valley may be easiest to reconcile; division of the park into two fire management units on the basis of fire history is sound, though other criteria (such as fire control priorities, etc.) will likely be included. What natural fire regime will be chosen for the Vermilion; MFRI of 267 or 75 years? The climatic event that caused the dramatic change in the fire regime may be defined as "natural". In that case, a valid choice may be to accept the most recent MFRI for the Vermilion Valley of 267 years.

Park Period

The period of park management is too short to state whether suppression has affected the age-class distribution of the park. Current evidence shows that the present age-class distribution could have been caused by cool climate and only minimally affected by fire suppression. Johnson and Fryer (1987) found a similar situation in the Kananaskis Valley, stating that in 1972 natural processes such as site differences and fire occurrence still dominated the changes in the vegetation composition and age.

Physiographic Variables

Elevation, aspect, and proximity to the Great Divide do not appear to affect fire frequency *per se*. These variables may contribute to overall geometry of the surface on which forests grow and die, but were not found to be causal factors in the distribution of forest fires.

Natural and Prescribed Fire

Unchecked fires in KNP would likely cause loss of life, property damage, high costs, legal liability for the crown, public concern, and the most accurate window of representation on the Rocky Mountain landscape. Four persons were killed in KNP in 1926 when their car was trapped by a forest fire near Hector Gorge; two women and their two children aged 8 and 10. Capital developments and public facilities such as bungalow camps and campgrounds placed in hazardous fuels since park establishment could easily be damaged by fire.

One way of permitting some of the desirable effects of fire while minimizing the undesirable effects is to use prescribed fires (planned ignition). A simulated natural fire regime of less than 700 hectares would be burned annually on average, and may involve reburning areas several times. A fundamental question arises as to whether KNP will be a window or a microcosm of the landscape (R/EMS, 1988).

Consider the following scenario. 700 hectares are burned annually for 10 years according to mean annual burn statistics; microcosm approach. An event such as 1917 or 1926 occurs and burns 14% of the forests of the park, or 20 years worth of prescribed burning. The park is now a window on the landscape with an age-class distribution highly biased by young stands. To continue burning 700 hectares annually for the next 20 years would shorten the MFRI by half and double the annual area burned, resulting in a KNP that is neither a microcosm or window on a representative Rocky Mountain landscape. To cease prescribed burning for 20 years would cause the loss of expertise and organizational effectiveness through atrophy and attrition. Prescribed fire and wildfire control expertise would be lacking in wildfire years when it is needed and would have to be recreated over again.

Allocating the order in which areas are burned is also important (assuming perfect fire control). In order to replicate the natural process as shown in this study, fires should be located and timed at random. Random does not mean "haphazard"; it means designing prescribed burn units and igniting those units such that the forests of a fire management unit have an equal probability of being burned over time. Equal probability of burning regardless of age is essential to the negative-exponential fire history model, and therefore essential to "duplicate natural processes as closely as possible" (Parks Canada, 1979). Individual unit burn probabilities will be a function of the assigned MFRI and the size of the unit; other factors may be added as required or for experimental (<u>ie.</u> learning) purposes. Using natural fire breaks to confine both natural (wild) fires and prescribed fires, minimizing the amount of mechanical line construction, and utilizing indirect control techniques (<u>eg.</u> convection burning, "Boreal black-line", etc.), prescribed burn units of designed sizes and shapes could be developed. An example of this approach can be found in Lopoukhine and White (1985) for the lower Bow Valley in Banff National Park.

Fire Management Plan

Specific fire control and fire use guidelines may be motivated by other resource management goals and plans, but coordination of all fire management activities must be in the park fire management plan (Parks Management Directive 2.4.4). KNP's Preliminary Fire Management Plan (Irons, 1989) will be used to develop a comprehensive fire management plan.

Elements of this study to include in KNP's future fire management plan are as follows:

- Fire is pervasive. Virtually all forests in the park have burned at some time.

- Fire history has changed since the mid 1700s and is different between the Vermilion and Kootenay/Sinclair areas of the park.

- Very large fires have occurred which if repeated, could cause significant threat to public safety and could have very high control costs. Three fires (1917, 1926, 1968) have occurred this century which burned over 25% of the park, caused safety and damage concerns, and in one case, loss of life for four persons. Fires have crossed the park boundary in both directions.

- Current initial attack strength is sufficient to suppress most fires, but only those fires burning under marginal conditions. The current system of helicopter-borne initial attack has not been tested under the most severe conditions that have occurred in KNP.

- Neither fire suppression or increased man-caused fires in KNP since park establishment appear to have altered the fire history from previous times. The present bell-shaped density age-class structure of KNP may be due to other factors, such as a temporary cooling in climate.

If these facts are accepted, the following recommendations should be included as guidelines in KNP's fire management plan:

- All wildfires should receive rapid and aggressive initial attack. If a fire escapes initial attack and is not anticipated to be under control by 10 a.m. the following day, an escaped wildfire analysis should be conducted which will evaluate alternatives for suppressing the fire. These alternatives should include options for full suppression, indirect attack (burning out), and observation. This is the status-quo in KNP and should be continued.

- Greater emphasis should be made on monitoring fire danger and predicting fire behaviour. Improvements should be made to the number and location of weather stations. Observations of fire behaviour in and outside KNP should be analysed in relation to fire weather parameters. Experience from this exercise should culminate in an accurate fire preparedness system which would better prepare KNP for adapting to changing fire danger conditions. Current initiatives to acquire remote automatic weather stations and telemetry equipment should be encouraged (see Appendix A).

- Under extreme fire danger conditions, KNP can offer only limited protection to public and private property owners. Fire hazards around facilities should be evaluated and fuel modification conducted where necessary. During the 1926 fire, furniture and equipment was removed from residences at Kootenay Crossing and special protection was required at Storm Mountain Lodge during the 1968 fire. Fuel modification done today will certainly lessen concerns for fire personnel and facility owners in the future. Examples of fuel modification in national parks are available from Jasper, Banff, and Waterton Lakes National Parks. Criteria must be developed for each site to determine the nature of the hazard, the most likely threatening scenario, and the most helpful tactic for fire control and fuel modification. KNP already has evacuation plans for major campgrounds. These documents should be updated an circulated to other parks.

- The public should be informed about the uncertainty of fire control in extreme circumstances and made aware of the adaptive policies of the Canadian Parks Service to deal with natural region representation, hazardous fuels around facilities, escaped wildfires, etc. Specifically, the public should be made aware of the history of forest fires in KNP, financial and technological limits of fire control and fire use, the consequences of large forest fires, and the decision systems (ie. plans) in place to aid managers at the time of forest fires. It is important that KNP inform the public that not all wildfires can be controlled.

- The most difficult question is whether or not to regulate the age-class structure of the forests of KNP through prescribed burning. Risks and costs associated with planned ignition fires may be unacceptable when added to the risk and costs associated with hazard reduction, initial attack, and evacuation during the most extreme fire years. Either scenario of planned ignition or unplanned ignition fires may achieve a similar result on the landscape because of large, uncontrollable wildfires in the worst fire years. The KNP fire management plan must specify a temporal scale for management (ie. whether we view age-class structures and fire cycles in a short or long time, specified by a certain number of years). Spatial scale (ie. microcosm or window) may be dictated by the overriding force of timing between the major fire events, regardless of our plans for the landscape. Our choice of temporal scale will make the difference between whether a bell-shaped density age-class distribution (as is today in KNP) is considered undesirable (ie. not conforming to a negative-exponential) or considered a temporary aberration totally within the bounds of natural climate variation.

- Concerns for wildlife habitat, hazard reduction and maintenance of understory fire regimes may require a prescribed burn programme in KNP. This programme will require experienced personnel. Much will be learned about fire control, fuel modification, fire behaviour, etc. during development and execution of the programme. Experience gained will improve fire control decisions made during wildfires. Extending the programme to include stand-replacing fires for landscape maintenance involves greater risk and cost. Uncontrollable wildfires during infrequent, severe fire years may force a reduction in prescribed burn quotas because total area burned by wild and prescribed fires may be too large for natural landscape maintenance. Complexity and controversy about fire effects, ambiguity of microcosm versus window landscape management objectives, uncertainty about severe fire years, consequence of errors, and organizational and financial constraints, qualify fire management in KNP as a "wicked problem" (McNamee, et. al., 1986).

- Efforts should be made to understand and to predict the effect of various prescribed burning and major wildfire scenarios on park natural features, budget requirements, and human resources. It is difficult to make progress and to secure management support on complex issues with imperfect knowledge and ill-defined goals. One way to explore the relationships between variables such as fire frequency, major fire events, prescribed burn programmes, wildlife habitat, resource management objectives, etc. would be to conduct a computer simulation modelling workshop utilizing the expertise of foresters, park managers, wildlife biologists, and modelers. Using the process outlined by Walters (1987) as an example, various managers would be invited to structured workshops to articulate and assemble their concepts of system dynamics into a common set of rules (ie. the computer program). This process could result in a higher common basis of understanding among the participants, a priorized list of knowledge gaps, innovative solutions to problems, and identification of new problems. The computer model is not a product but a process for exploring fire management problems and solutions in KNP.

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APPENDICES

The following appendices do not relate directly to the fire history study but were components of the project that should not go undocumented. They are included here for reference and to document the work that has been completed thus far.

List of Figures and Tables

APPENDIX A: FIRE WEATHER DATABASE

One of the objectives of the KNP fire study was to assemble a weather record that could be compared with fire report information and used to develop a preparedness system. The results are incomplete and the following is provided as a brief progress report.

Lack of Data

Accurate fire danger readings (from the Fire Weather Index system of the Canadian Forest Fire Danger Rating System) are necessary in fire management. KNP instituted consistent fire weather observation in 1984 with the purchase of two remote, automatic weather stations from Forest Technology Systems of Victoria, B.C. These are located at McLeod Meadows and Vermilion Crossing. Weather readings prior to this time were inconsistent and unusable in the CFFDRS.

Unfortunately, a five-year database does not provide enough data to fully appreciate the variability of fire danger conditions. The nearest weather stations to KNP with readings for a longer period are Banff, Lake Louise, Boulder Creek Compound (Yoho National Park), Golden, and Invermere. All stations far enough away to not be representative of all of the codes and indices of the FWI in KNP. Remote stations operated by the B.C. Ministry of Forests, such as the Beaverfoot and Ravenhead, were installed between 1985 and 1987.

FWI Requirements

The FWI requires daily readings at solar noon (local standard time) of temperature (celsius), relative humidity (%), wind speed (km/hr), and 24 hour precipitation (mm). If only the date, temperature, and precipitation are known, the Drought Code (a measurement of fuel moisture in deep, compacted layers of duff) can be calculated. High DC values indicate hold-over fire problems and heavy fuel involvement which can persist between seasons.

Daily maximum and minimum temperature and 24 hour rainfall at 0800 were taken at Kootenay Crossing and Radium/East Gate since 1963 and 1954, respectively. It was decided that these observations could provide at least the Drought Code of the FWI system. The daily weather observations could be used in a less refined but quantitative sense with fire report data gathered for the same period. Because precipitation measurements were conducted through each winter an accurate over-winter adjustment could be carried out for several decades.

Data Manipulation

The data taken at Kootenay Crossing and Radium/East Gate are compiled by the Atmospheric Environment Service and were provided on IBM PC diskette free of charge. The format consisted of an ASCII file in a matrix of months by days, with the 3 readings in each cell of the matrix (Table A1). A Pascal computer program was written to decode the matrix and write the data to another file in a list format, with the date and readings for each day on one line. The files for Kootenay Crossing (1964-1987) were concatenated with the files for Radium/East Gate (1954-1963) and comprised a daily weather record of almost 13,000 records.

This file was read into a dBASE III+ database. A short program was written to adjust the 24 hour precipitation recorded at 0800 hours to reflect 24 hour precipitation recorded at 1200 hours using the 2/3 + 1/3 rule; 2/3 of yesterday's precipitation plus 1/3 of tomorrow's precipitation equals today's 1200 hour precipitation.

Fire weather observations from McLeod Meadows weather station (15 km south of Kootenay Crossing in the same valley at the same elevation) from 1984 to 1988 were imported to another database. The Kootenay Crossing and McLeod Meadows databases were linked on common dates and paired observations were written to a third database. This database was then read into the StatGraphics statistical analysis package and a regression developed to predict McLeod Meadows noon temperature from the maximum, minimum, and precipitation values from Kootenay Crossing (r^2 = 92%). ANOVA finds the mean temperature difference between the two stations to be not significantly different for the summer months. Another regression equation to predict RH was developed with r^2 < 50%. A wind regression was not successful.

The temperature and RH regressions were then used to estimate noon temperature for 1953 - 1987 for the Kootenay Crossing-Radium/East Gate database. Only the temperature for 1964 - 1987 (and thus the DC) for Kootenay Crossing should be considered accurate; RH and the Radium/East Gate data were included for experimental purposes.

Over-Winter Precipitation

Another computer program was written to read the >13,000 record database, sum the precipitation from November 1 to the first day of the start of the next fire season, write that figure to a file, and then write the readings from the start of the fire season to October 31 to a separate ASCII file. The start of the fire season is defined as the third consecutive day in April that the temperature is greater than or equal to 12 degrees celsius.

DAY/MONTH MATRIX OF SELECTED DAILY DATA

FROM 1154400 KOOTENAY NP KTNY CRSG BC 1966
TIME ZONE : P

DAY	ELEM	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01	001		3.9	-3.9	11.1	15.0	17.8	18.3	28.3	18.3	8.9	.6	M
	002		-2.8	-20.6	-6.7	-5.6	5.6	1.7	1.1	-1.1	2.8	-10.6	M
	012		.0	.0		.0	7.6	4.1	.0	.0	4.3	.0	M
02	001		.0	-5.6	8.3	M	22.8	13.9	30.0	20.6	10.0	7.2	M
	002		-9.4	-18.9	-3.9	-3.3	.6	1.7	2.2	.0	-2.2	-7.2	M
	012		.0	.0		.0	.0	39.6	.0	.0	.0	.0	M
03	001		-1.7	-1.1	10.6	22.8	17.8	11.7	30.6	M	9.4	6.1	M
	002		-17.2	-27.8	-8.3	-3.9	5.0	5.0	2.8	.0	-5.0	-10.0	M
	012		.0	.0		.0	2.5	14.2	2.8	.0	.0	.0	M
04	001		-.6	-.6	8.9	23.9	17.8	M	23.9	25.6	17.2	3.9	M
	002		-15.0	-28.9	-8.3	-3.3	-4.4	4.4	8.9	-1.1	2.2	-10.6	M
	012		.0	.0		.0	21.8	.0	9.4	.0	.0	1.5	M
05	001		4.4	-.6	8.3	26.1	M	18.9	17.2	27.8	16.7	3.3	M
	002		-8.9	-18.9	-6.7	-1.7	3.3	M	9.4	-1.1	-3.9	.0	M
	012		.0	.0		.0	.0	.5	5.3	.0	.0	.0	M
06	001		.6	-1.7	16.1	28.3	M	25.6	22.2	27.8	21.1	-3.9	M
	002		-10.6	-19.4	-6.7	-1.7	M	5.0	4.4	11.1	-3.3	M	M
	012		.0	2.0		77.7	.0	.0	.0	.0	2.5	2.0	M
07	001		2.2	5.6	13.3	13.3	22.2	28.3	M	17.8	17.2	-1.7	M
	002		-15.0	-5.6	-2.8	3.3	M	3.9	3.3	3.3	7.2	-11.7	M
	012		.0	.0		2.0	.0	.0	.0	.0	9.1	.3	M
08	001		.6	4.4	15.0	21.7	21.1	25.6	24.4	M	8.9	-2.2	M
	002		-13.3	-6.1	-4.4	.0	-1.1	3.3	4.4	.0	-1.7	-9.4	M
	012		.0	.0		.0	.0	.0	.5	.0	2.0	1.5	M
09	001		-.6	7.8	11.7	22.2	15.6	27.2	M	M	10.6	-2.2	M
	002		-9.4	-.6	-1.1	-1.1	3.9	3.9	6.1	M	-6.7	-9.4	M
	012		.0	.5		27.4	10.2	.3	.0	.0	.0	6.1	M
10	001		-2.2	6.1	7.8	M	16.7	23.3	23.9	23.9	5.6	.6	M
	002		-23.3	-7.2	-.6	-1.7	7.2	7.8	3.3	-2.2	-6.1	-14.4	M
	012		.0	.0		.0	.8	1.5	3.6	.0	.0	5.1	M
11	001		-2.8	7.2	11.1	17.2	15.0	20.0	15.6	23.3	10.0	-1.1	M
	002		-9.4	-5.6	.0	-1.7	5.0	5.6	1.1	2.2	-2.2	-5.6	M
	012		4.6	.0		.0	.0	.0	.0	.0	1.3	11.7	M
12	001		.0	7.8	13.3	17.2	16.7	23.3	16.7	22.2	3.3	1.1	M
	002		-23.3	-13.9	-1.7	-2.8	2.8	6.7	-2.2	5.0	-2.8	-1.1	M
	012		.0	.0		18.0	.8	.0	1.8	.0	5.1	.5	M

Table A1. Example AES climate record, Kootenay Crossing, KNP. Each year is presented as a matrix with three elements for each day. Element 001 = maximum temperature (c), 002 = minimum temperature (c), and 012 = precipitation (mm). All readings taken at 0800 local time.

FWI Calculation

Using FWI calculation software purchased by the Canadian Parks Service from R/EMS Research Ltd., FWI values were calculated. Two programs were used; FWAP and ASC2FWAP. The first year DC was started at 15. The ASCII file for the first year was processed using ASC2FWAP and the fall DC value noted. FWAP was then used to calculate the overwinter fraction of the DC using options 1 and 2 in the calculation menu (calculations made up to Nov. 1, and frost occurs late in fall, if at all). In the second and subsequent years, the adjusted DC starting value was used to calculate that year's codes. All wind speeds and directions were coded -99 for missing.

The result was a 34 year fire weather database usable in the FWAP program for fire weather analysis. The usable observations, codes, and indices include: date, temperature, precipitation, RH, and DC. RH, DMC, and BUI could be used, but have not been tested. FFMC, ISI, FWI and DSR should not be used because wind data was not available.

Potential Uses of the Data

These readings were then transported back to a dBASE database and linked with 72 years of fire report data collected using the Parks Fire Data Recording System (Appendix B). Figure A1 shows the spring and fall DC values for 34 years in KNP. These figures could be compared with annual burn statistics. Daily readings could be compared with fire occurrence and area burned. Without all the codes and indices of the FWI system analysis will be limited, but simple calculations of temperature and days without rain could be used as a substitute. For example, a comparison of the number of days without rain before and after the occurrence of lightning fires might reveal something about the pattern of lightning fire ignition and rainfall.

Copies of the data and the computer programs used in this analysis (except FWAP and ASC2FWAP) can be acquired from the author.

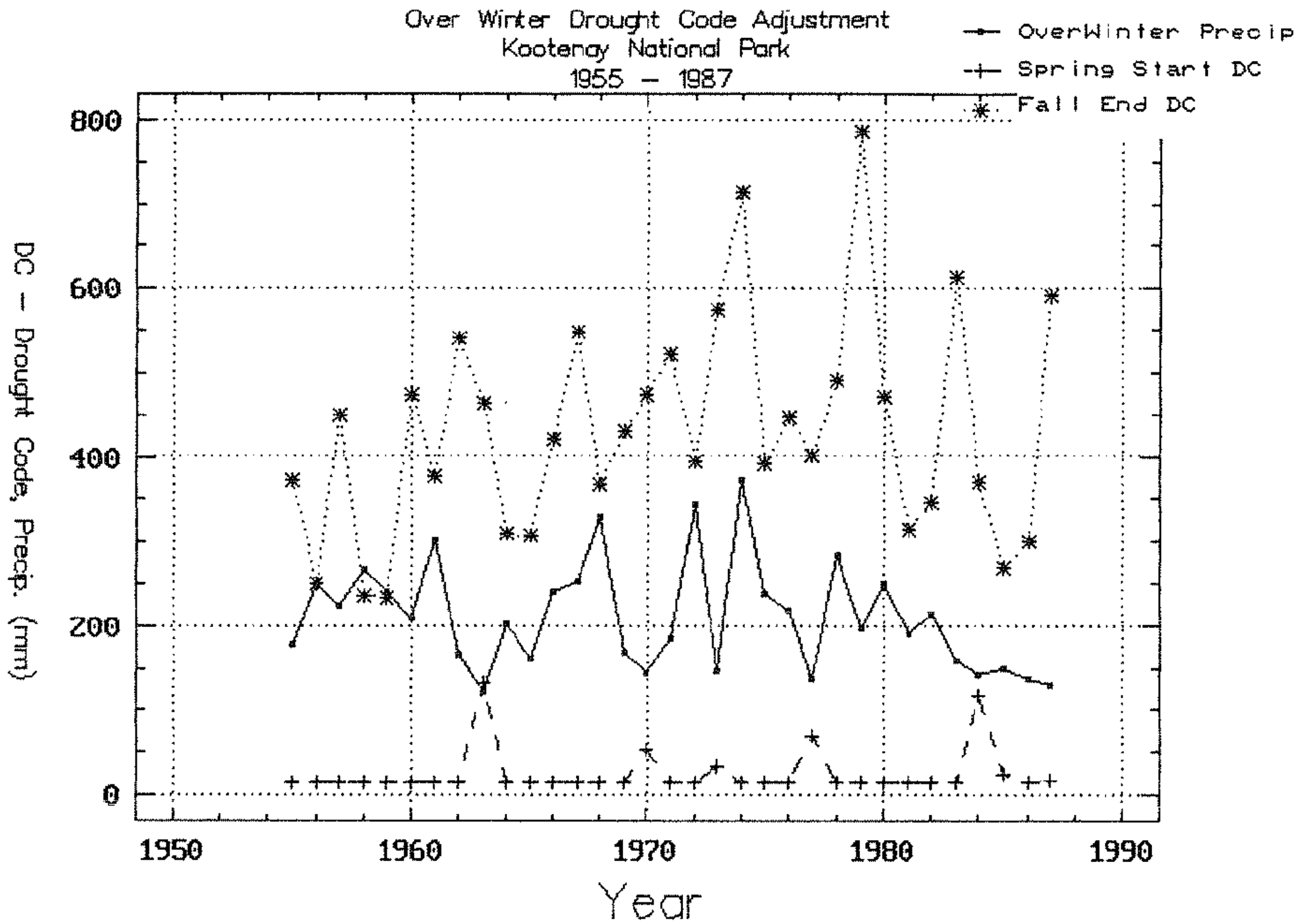

Figure A1. Over-winter drought code adjustment, Kootenay Crossing, KNP.

APPENDIX B: HISTORIC FIRE REPORTS

Individual fire reports can provide useful information; weather observations, fire behaviour observations, dates, times, fire cause, area burned, fire location, suppression forces used, travel times, fuel types, etc. This information was intended to be used with fire weather data in the formation of a preparedness system for the park, and various summaries useful to fire management (ie. fire cause analysis, etc.). A search was conducted of KNP, federal, provincial, municipal, and private archives for all available fire reports for KNP. This search was conducted and a report prepared by Mr. Tim Van Egmond, M.Sc. student at Manitoba Natural Resources Institute and University of Calgary, under a Parks Volunteer Agreement. All reports were coded onto the most recent Parks Fire Report Form (1987 version) and entered into dBASE III+ files using the Parks Fire Data Recording System. These reports have been amalgamated into one set of three dBASE files covering the period since park establishment. No analysis has been conducted to date.

The following report, prepared by Mr. Van Egmond on October 31, 1988, details data collection and the format of the data.

KNP Fire History Database

The KNP fire history database, has been put together from various archival files. The majority of the fire occurrence reports, and correspondence, were obtained from the KNP administration archival files. Gaps in the record were filled from a combination of archives including the "Archives of Rocky Mountains" in Banff, "The Glenbow Museum" in Calgary, "Parks Central Registry Files" in Western Regional Office in Calgary, and the "National Archives" in Ottawa.

Occurrence reports, annual reports, monthly reports, and important correspondence were photocopied and filed. All data is filed by decade with the file code representing the span of years for that decade, for example 20-9 for the years 1920-1929. The following divisions are made in the file for each decade: fire reports and correspondence; fire reports and correspondence larger than class A; and annual reports/monthly reports.

All data was computerized using the National Fire Reporting Form developed in 1987. For 54 years out of 68, complete record using individual reports was input into the computer database. For 14 years out of 68, individual reports were missing or not complete for the entire year. In the case of missing occurrence reports the fire data was entered from the monthly or annual record. Often, the only available data in this case was that of cause, total size for year, and total cost for year. In this situation the data was averaged for each fire from the entire year's record. For example, if ten fires occurred, and the total years cost was $10,000.00 then each fire was assigned a value of $1000.00. In the same manner, if one fire was severe and the cost was noted, then that proportion of the total year's cost was used to derive the size, and the remainder was divided between the other fires.

The computer database was compiled according to the instructions for data entry in the National Fire Reporting Form. Two deviations exist from this format. Number one, all cigarette fires are listed as incendiary (7), there are no other incendiary fires occurring throughout the historical record so this serves as a useful way to isolate these fires from those caused by recreational activities. Number two, all costs listed under O&M are in present day costs; manpower and department vehicles at $20.00/hr, equipment destroyed or lost at replacement cost (based on personal communication with A. Masters). Vote 120 costs are in the dollar value of the year of occurrence. Exceptions take place to these rules in a certain occasions.

Exceptions are as follows: 1920-1929 costs are as noted in years of occurrence, no data was available for upgrade to present day costs or to differ between O & M and Vote 120; the same representation is used for 1936, 1940, and 1956. All costs for the 1980's are in up to date figures for both O & M and Vote 120; $500/hr was used for helicopters. Whenever was interpreted or calculated in a different manner from the norm that change is noted in the remarks; if space was available the normal method of calculation is often noted.

The following list summarizes the database. The use of the word "incomplete" signifies that individual reports were missing for all or part of the year indicated. All data available was then input from annual or monthly record, inferences made are noted in the remarks.

Kootenay National Park

Fire History Record-Present Database as of October 29/88

Fire Record--1920-1929.

No. of Fires in 1920-- 1.
Individual Record-- No. INCOMPLETE
Computerized.

No. of Fires in 1921-- 2.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1922-- 1.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1923-- 0. COMPLETE
Computerized

No. of Fires in 1924-- 4.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1925-- 10.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1926-- 10.
Individual Record-- Only the Big One. INCOMPLETE
Computerized

No. of Fires in 1927-- 0. COMPLETE
Computerized

No. of Fires in 1928-- 12.
Individual Record-- No. INCOMPLETE
Computerized

No of Fires in 1929-- 9.
Individual Record-- 9. COMPLETE
Computerized

Fire Record 1930-1939.

No. of Fires in 1930-- 4.
Individual Record-- 2. INCOMPLETE
Computerized
No. of Fires in 1931-- 3.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1932-- 2.
Individual Record-- 2. COMPLETE
Computerized

No. of Fires in 1933-- 4.
Individual Record-- 4. COMPLETE
Computerized

No. of Fires in 1934-- 6.
Individual Record-- 6. COMPLETE
Computerized

No. of Fires in 1935-- 5.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1936-- 1.
Individual Record-- No. (Monthly Record, Available). INCOMPLETE
Computerized

No. of Fires in 1937-- 0. COMPLETE
Computerized

No. of Fires in 1938-- 0. COMPLETE
Computerized

No. of Fires in 1939-- 4.
Individual Record-- 4. COMPLETE
Computerized

Fire Record 1940-1949

No. of Fires in 1940-- 3.
Individual Record-- 3. COMPLETE
Computerized

No. of Fires in 1941-- 0.
Computerized COMPLETE

No. of Fires in 1942-- 0.
Computerized COMPLETE

No. of Fires in 1943-- 0.
Computerized COMPLETE

No. of Fires in 1944-- 0.
Computerized COMPLETE

No. of Fires in 1945-- 3.
Individual Record-- 3. COMPLETE
Computerized

No. of Fires in 1946-- 3.
Individual record-- 3. COMPLETE
Computerized

No. of Fires in 1947-- 0.
Computerized COMPLETE

No. of Fires in 1948-- 0.
Computerized COMPLETE

No. of Fires in 1949-- 6.
Individual Record-- 6. COMPLETE
Computerized

Fire Record 1950-1959

No. of Fires in 1950-- 1.
Individual Record-- 1. COMPLETE
Computerized

No. of Fires in 1951-- 1.
Individual Record-- 1. COMPLETE
Computerized

No. of Fires in 1952-- 0. COMPLETE
Computerized

No. of Fires in 1953-- 3.
Individual Record-- 3.
Computerized COMPLETE

No. of Fires in 1954-- 1.
Individual Record-- 1. COMPLETE

No. of Fires in 1955-- 0.
Individual Record-- 0. COMPLETE

No. of Fires in 1956-- 3.
Individual Record-- 3. COMPLETE
Computerized

No. of Fires in 1957-- 0.
Computerized COMPLETE

No. of Fires in 1958-- 2.
Individual Record-- 2. COMPLETE
Computerized

No. of Fires in 1959-- 3.
Individual Record-- 3. COMPLETE

Fire Record 1960-1969

No. of Fires in 1960-- 3.
Individual Record-- 3. COMPLETE
Computerized

No. of Fires in 1961-- 1.
Individual Record-- 1. COMPLETE
Computerized

No. of Fires in 1962-- 2.
Individual Record-- 2. COMPLETE
Computerized

No. of Fires in 1963-- 1.
Individual Record-- 1. COMPLETE
Computerized

No. of Fires in 1964-- 0. COMPLETE
Computerized

No. of Fires in 1965-- 1.
Individual Record-- 1. COMPLETE
Computerized

No. of Fires in 1966-- 0. COMPLETE
Computerized

No. of Fires in 1967-- 8.
Individual Record-- 8. COMPLETE
Computerized

No. of Fires in 1968-- 1.
Computerized COMPLETE

No. of Fires in 1969-- 1.
Individual Record-- 1. COMPLETE
Computerized

Fire Record 1970-1979

No. of Fires in 1970-- 5.
Individual Report-- 5. COMPLETE
Computerized

No.of Fires in 1971-- 0. COMPLETE
Computerized

No. of Fires in 1972-- 1.
Individual Record-- 1. COMPLETE
Computerized

No. of Fires in 1973-- 0. COMPLETE
Computerized

No of Fires in 1974-- 2.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1975-- 1.
Individual Record-- 1. COMPLETE
Computerized

No. of Fires in 1976-- 0.
Individual Record-- 0. COMPLETE
Computerized

No. of Fires in 1977-- 0.
Individual Record-- 0. COMPLETE
Computerized

No. of Fires in 1978-- 5.
Individual Record-- No. INCOMPLETE
Computerized

No. of Fires in 1979-- 6.
Individual Report-- 6. COMPLETE
Computerized

Fire Record 1980-1987

No. of Fires in 1980-- 1.
Individual Report-- No. INCOMPLETE
Computerized

No. of Fires in 1981-- 0. COMPLETE
Computerized

No. of Fires in 1982-- 0.
Individual Record-- 0. COMPLETE
Computerized

No. of Fires in 1983-- 0. COMPLETE
Computerized

No. of Fires in 1984-- 4.
Individual Record-- 4. COMPLETE
Computerized

No. of Fires in 1985-- 9.
Individual Record-- 9. COMPLETE
Computerized

No. of Fires in 1986-- 2.
Individual Record-- 2. COMPLETE
Computerized

No. of Fires in 1987-- 3.
Individual Record-- 3. COMPLETE
Computerized

Total # of years record-- 68.

# of years lacking complete individual record-- 14.

# of years complete individual record-- 54.

Record of 164 individual fires.

APPENDIX C: OBSERVATIONS

This appendix contains incidental observations about fire management related topics noted during the 1988/89 field season. Because observations such as these may provide ideas for further study they are recorded here.

The topics covered include:

- Regeneration Delay
- Stem Analysis
- Air Temperature Profiles
- Elk Winter Use by Forest Age

Regeneration Delay

Regeneration delay after forest fires was noticed when germination dates of trees (from accurate, near-to ground cross-sections) were compared with reliable fire dates from accurate fire scars or known dates from written reports. The delay seemed to vary from a mode of around 7 years in the bottom of the Kootenay Valley, 3-10 years in the Sinclair Area, to over 60 years at high-elevations near tree line in all areas of the park. Regeneration delay of lodgepole-pine after the Vermilion Pass fire at one site was only 3 years.

Delay may be a function of tree species, site conditions, vegetation cover before the fire, and intensity of burn. A siliviculturalist with the B.C. Ministry of Forests noted long regeneration delays near tree line possibly due to consumption of available nutrient in the thin A-h soil horizon on these sites. This phenomenon was observed in high elevation areas where fire dates corresponded with well stocked valley bottom sites, such as the headwaters of Silt, Minnow, and Lachine Creeks, and near Spar Mountain and the Vermilion Pass.

This phenomenon is important because vegetation managers should not be surprised by short or long regeneration delay; the phenomenon should be understood so that implications can be assessed before a prescribed fire (or after a wildfire) occurs. Obvious implications might be remarks from tourists as to why trees are not growing back on a certain site, or the desire of a wildlife habitat manager to remove trees from a site for many years following a fire. Long regeneration delays appear to be natural events and we should be prepared to understand them.

A study of regeneration delay would probably have to control for variation in site conditions, and may be hampered by not always knowing the condition of the vegetation before the fire or the fire's behaviour (ie. intensity, fuel removed, etc.). Regeneration delay could have an effect on age-class distribution and the overall effects could be modeled using computer simulation. Some information may be available from the fire history sample tree database used in this study, but the sample design may not be adequate for controlling variation due to site and other conditions.

Stem Analysis

Figure C1 shows the results of stem analysis performed on three lodgepole pine trees at different locations in KNP. Stem analysis is performed by sectioning a felled tree at certain height intervals and counting annual rings at each section. The number of rings on each cross section is subtracted from the total age of the tree (taken as close to germination point as possible) to compute the age of the tree near each height.

Foresters use stem analysis for many purposes, including derivation of site-index curves which indicate the expected height growth of a tree over a set time for a certain site. The curves for KNP overlap in two instances, for the first approximately 20 years, and a third curve shows a very different rate of growth. Different growth rates and patterns are likely due to site differences, temporal change in climate or other conditions, damage, etc.

Tree height growth curves may be useful for KNP for a number of reasons. Similar to the regeneration delay problem, vegetation managers should not be surprised with lack of or astounding height growth of new trees after fire or other disturbance, and should be able to react to public or other concerns with accurate information. Wildlife habitat includes a cover component of which concealment may be important in some circumstances. Knowing the length of time required for trees to reach the equivalent or necessary concealment height of elk cows with calves on certain sites may influence habitat protection or enhancement decisions.

Air Temperature Profiles

Smoke management is a major issue in prescribed fire management in national parks and wilderness areas in the U.S.A. and in commercial forestry areas in many provinces. Some complaints have been received by residents of Canadian national parks during prescribed fire operations.

Smoke dispersal is strongly influenced by atmospheric stability; a condition easily assessed from a vertical air temperature profile. Figure C2 shows temperature profiles for two locations in KNP taken in July of 1988. These traces show the temperature at various elevations read from temperature and altimeter instruments inside a Bell 206 Jet Ranger helicopter. Also shown

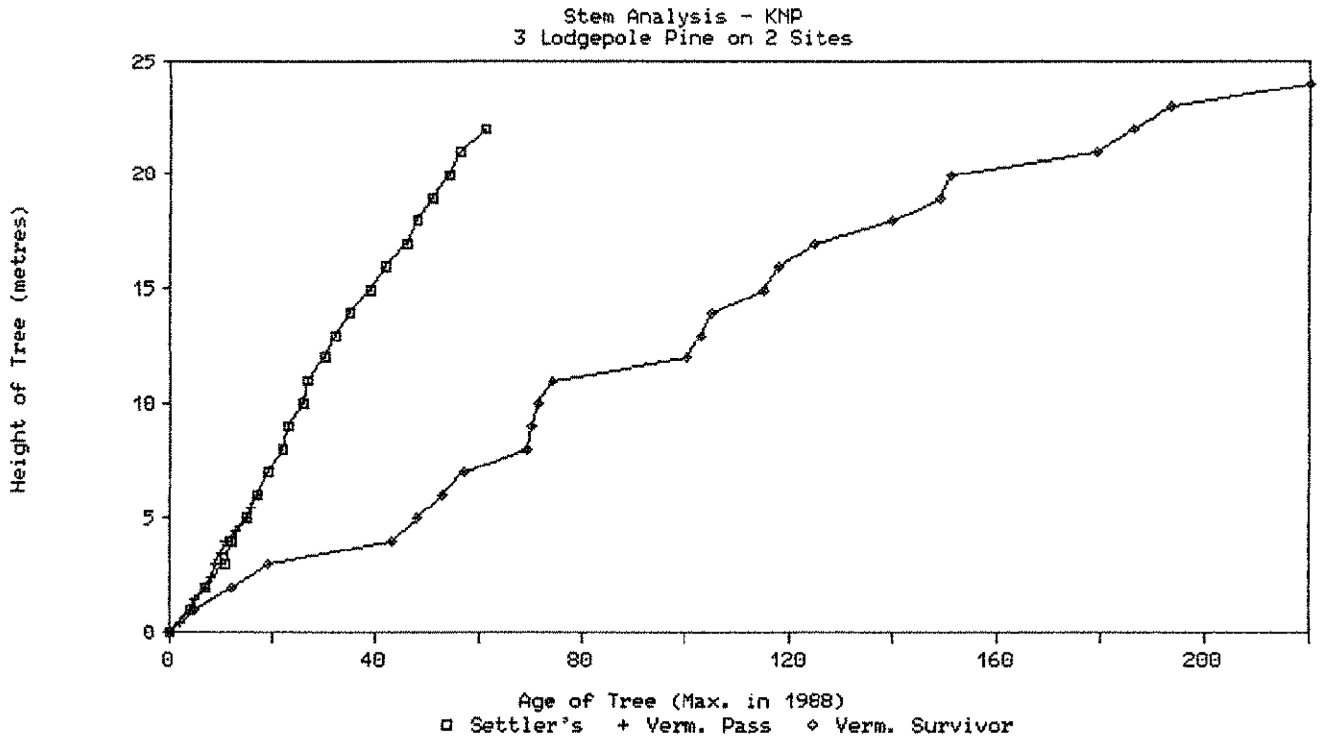

Figure C1. Stem analysis of 3 lodgepole pine on 3 sites in KNP.

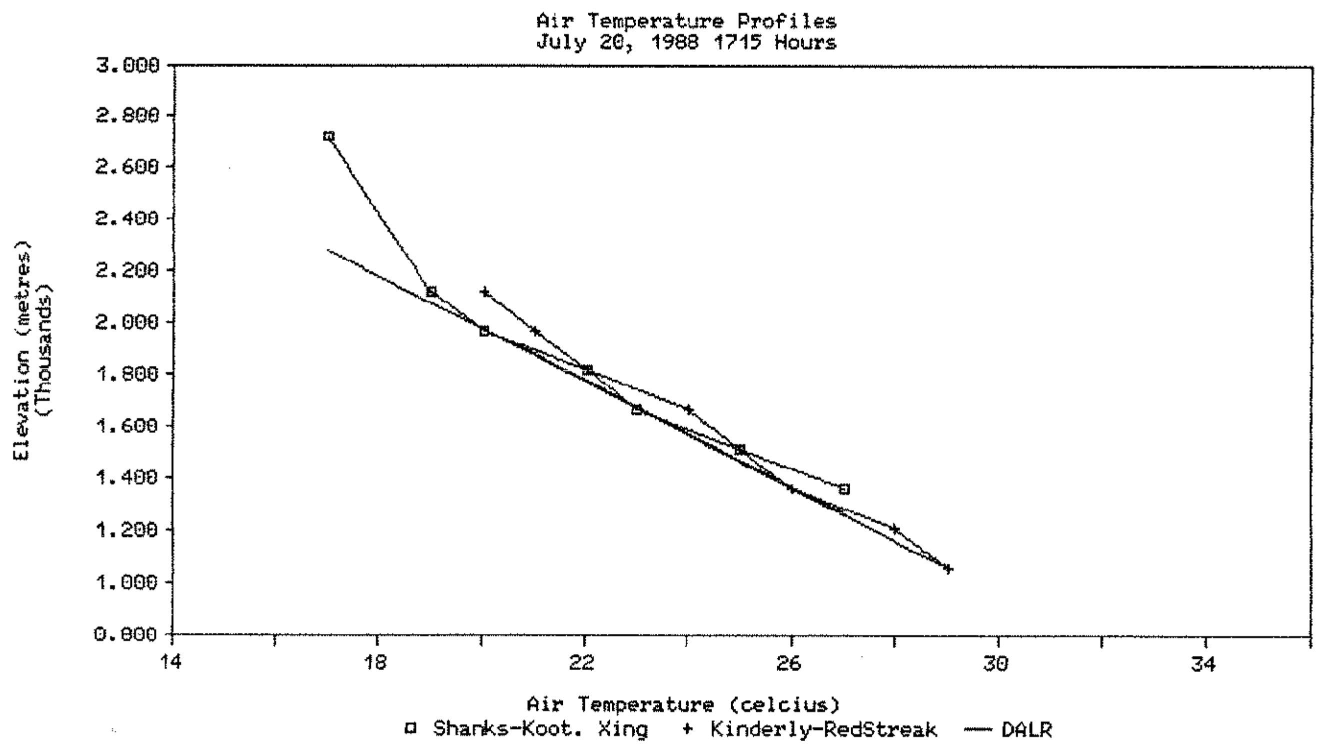

Figure C2. Air temperature profiles, KNP. Straight line is DALR (dry adiabatic lapse rate).

on the graph is the dry adiabatic lapse rate of 0.98 degrees celsius per 100 metres. DALR is the rate at which an un-saturated parcel of air cools or warms as it is raised or lowered through the atmosphere, due to friction and change in pressure. The actual temperature profiles can be referred to as the environmental lapse rate (ELR).

If the ELR is less than the DALR (ie. ELR curve is steeper than the DALR) then the atmosphere is said to be stable, and smoke will not disperse vertically above the point where the curves cross. The reverse is also true: if ELR > DALR the atmosphere is unstable and smoke will continue to rise, unless there is a stable layer at another height (Oke, 1978).

The KNP situation on this particular day is neutral stability up to about 2100 metres elevation, above which a stable situation exists. Depending on the placement of the DALR line due to initial parcel temperature, one could expect slow vertical movement of smoke up to about 2100 metres. At this height the smoke may stop, unable to proceed higher because the surrounding temperature is already higher (cooler air is more dense and will not rise through warmer air). Depending on other factors such as the initial temperature of cooled smoke at its' release height and upper level winds, such conditions could lead to a problem if the venting height is not sufficient. In this case, smoke may obscure sunlight and the surrounding mountain peaks, causing unpleasant sight-seeing conditions for some tourists and impatience from local business owners sensitive to tourist revenue.

Better understanding of this situation and avoidance of more severe situations can be achieved through measuring temperature profiles in advance of prescribed fires using a helicopter, driving a high-mountain road, or checking upper-level wind and temperature information available through Atmospheric Environment Service, the nearest Transport Canada Flight Service Station, or commercial on-line weather services. The information will not allow managers to change the ELR, but may better prepare them for decisions taken later in the day. Smoke management information and guidelines have been developed by provincial and federal fire management agencies in both Canada and the U.S.A.

Elk Winter Use by Forest Age

Use statistics for many wildlife species were collected with the KNP ecological land classification and are described in Achuff (et. al., 1984). Use of ecosites by elk during winter were derived primarily from pellet group counts and are listed as Nil, Low, Medium, High, and Very High. A classification scheme using these indicators as numbers 1-5 was developed for use in SPANS. A map of elk winter use was produced and overlaid with the stand origin map and a class-means report generated.

Figure C3 shows the average use statistic for each class of forest age shown on the stand origin map, using 50 year age-classes. Also shown is the average use statistic for non forested areas in the park, according to the stand origin map. The graph shows a bimodal distribution but some problems are evident.

The stand origin map was not sensitive to open, riparian habitat along the Kootenay and other rivers that are known to be important elk habitat. Even though a data point for the 0-50 year age-class is shown, there are very few forests in the park less than 60-70 years old. Therefore, the use statistic for the 0-50 year age-class may not be representative. Also, 50 year age-classes may not be an appropriate class-width. The peaks observed near 100 and 500 years may be due to natural thinning of pine and spruce stands. The sharp peak in use around 350 years may be an artifact of the data; there may be a preponderance of 350 year old forests near microhabitat (such as riparian areas or small meadows not detected on the stand origin map) with very high use values.

This graph is presented because use of ELC data was one of the primary justifications for Parks to purchase GIS. Use curves, such as the one presented here, may be invaluable for use in habitat modelling exercises. If this curve is to be accepted for a moment, consider the effect of changing the age-class distribution of the forests of KNP (Figure 11) either by fire exclusion, fire management according to ecosystem goals, excessive area burned, mountain pine beetle, or other disturbance. Use curves and other relationships will have to be thoroughly scrutinized by various resource experts before put into use as a table or function.

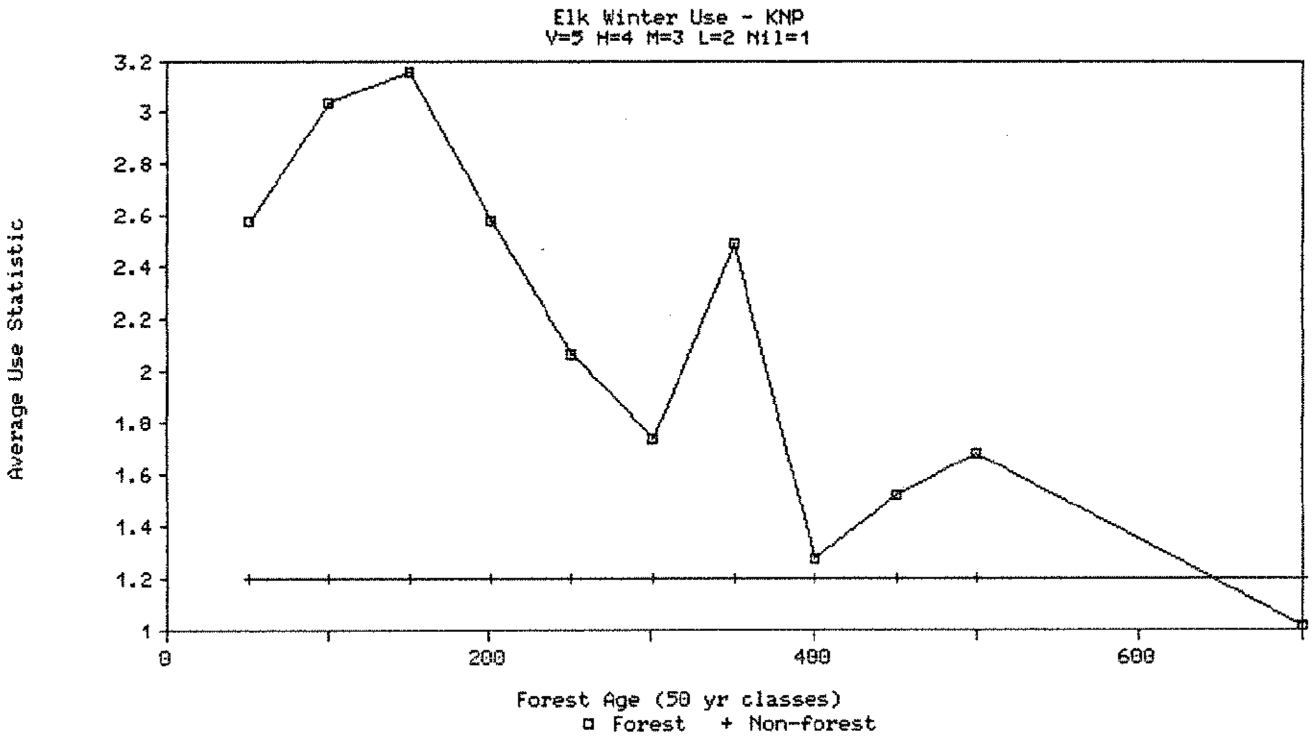

Figure C3. Elk winter use from KNP ELC as a function of forest age from stand-origin map.