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UNIVERSITY OF ALBERTA

FIRE HISTORY OF YOHO NATIONAL PARK, BRITISH COLUMBIA AND IMPLICATIONS FOR FIRE MANAGEMENT

by

CORDY TYMSTRA

A THESIS

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ABSTRACT

The fire history of Yoho National Park, British Columbia, was documented and described using fire weather, fire scar and age-class analysis and historical documentation. Area based fire return interval estimates were made using a two-index system to describe both the fire interval and the fire type. Fire cycle estimates were also made.

Since deglaciation began, over 10,000 years ago, fire has had a continued and ecologically significant role in influencing the development and perpetuation of forest communities within and adjacent to Yoho National Park. The unadjusted fire cycle for the whole of Yoho National Park in the last half millennium is 132 years. The western portion of the park has had the greatest incidence of fire and the greatest area burned. The differences in the fire cycles between eastern (FC = 239 years) and western (FC = 105 years) portions of the park are a function of the distance from the Continental Divide.

Prior periods of drought and high surface winds were common factors associated with the large, high intensity fires that occurred during the 1910 - 1988 period.

Within Yoho, different types and sizes of fires have resulted in varying fire effects. The fire regime is however, predominantly characterized by large, high intensity fires.

This fire regime limits the development and implementation of fire management strategies that can operate under the current scope of the National Parks Policy.

The challenge of the Canadian Parks Service is to develop and implement ecologically sound fire management strategies and initiatives to ensure the perpetuation of fire-dependent forests without jeopardizing facility protection and public safety.

ACKNOWLEDGEMENTS

Reconstructing the fire history of Yoho National Park was at times akin to assembling a large "puzzle" without fully knowing what the full picture was or how many pieces to the puzzle were available. Many people contributed to providing pieces to this puzzle. Whether it was a resident from Field providing historic photographs of the park from their personal photograph collection or volunteers assisting in collecting field data, all of the information and assistance that were provided was invaluable in contributing towards obtaining a greater understanding of the fire history of Yoho National Park.

A thanks is extended to the Canadian Parks Service, in particular, Park Superintendent Ian Church and Park Warden Dave Gilbride for providing support during the 1987 and 1988 field seasons.

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1. INTRODUCTION

1.1 Role of fire

Fire is a natural process that plays an important role in the landscape ecology of northern Rocky Mountain forests (Habeck and Mutch 1973, Tande 1977, Hawkes 1979). Many species of plants and animals have adapted to fire and survived in an environment with cyclic occurrences of fire. Numerous authors have identified species adaptations to variations in fire frequency, intensity and severity (Van Wagner 1970, Heinselman 1973, Kozlowski and Ahlgren 1974, Bazzaz 1983). The periodic occurrence of fire acts as the primary regenerating mechanism for fire-dependent ecosystems (Heinselman 1971, Fischer and Clayton 1983). Fuel accumulations are reduced and nutrients in the above-ground biomass are recycled by fire (Heinselman 1971, Wright and Bailey 1983,). Fire also serves to stabilize and maintain ecosystems such as grasslands (Daubenmire 1968, Vogl 1974).

The effects of past and current fire suppression activities within national parks and other protected areas are not well known. Evidence suggests that suppression activities, which began approximately in 1910, have resulted in significant changes in vegetation patterns and fuel accumulations in some vegetation types (Leopold *et al.* 1963, Habeck and Mutch 1973, Wright and Heinselman 1973, Arno and

Peterson 1983). These changes, which are more evident in vegetation types where historically the fire return interval was short, may result in widespread, high intensity fires that may be costly and difficult to control. A loss of species and habitat diversity and an increase in insect and disease hazard may also be associated with fire exclusion (Loucks 1970, Heinselman 1973, Fellin 1979). Various age-class distribution studies in the Canadian Rockies indicate that the "natural" negative-exponential distribution (Van Wagner 1978) has shifted to the right (MacKenzie 1973, Tande 1977, Hawkes 1979, White 1985). The shift or "bell" shape of the age-class distribution reflects the low occurrence of forest stands in the younger age-classes.

The effects of fire on vegetation can be complex and variable. Rarely does a fire exhibit uniform behavior in time and space. As fire behavior varies in response to site-specific variations in topography, fuel characteristics (i.e. loading, type, arrangement) and fuel moisture, the heat output and hence the fire effects on vegetation also vary. Variations in fire behavior and fire effects create various post-fire successional stages and increase the landscape diversity. These successional stages provide a mosaic of habitat for wildlife.

Fire may contribute to either stability[1] or instability in communities in fire-dependent ecosystems. However, the term "fire-dependent" implies that the ecosystems on a whole (i.e. over time [long] and space [large]) are resilient[2] (i.e. able to persist with periodic disturbance of fire).

The term "fire regime" (Heinselman 1973) is used to describe the frequency, intensity and severity of fire in different environments. Sando (1978) identified the following four major types of natural fire regimes in North America:

1. Type one regime - Frequent fires of low to moderate intensity
2. Type two regime - Infrequent high intensity fires generally large in size.
3. Type three regime - Frequent fires of high intensity.
4. Type four regime - Infrequent low intensity fires.

The frequency of fires can be described by calculating fire cycles for stand-replacing fires and mean fire return intervals for stand-damaging and non-damaging fires. The fire cycle is the number of years required for stand

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[1] *Stability in this context, refers to the ability of the system to revert to its original configuration after disturbance.*

[2] *Resilience in this context, refers to the ability of the system to persist with periodic disturbance of fire.*

replacing fires to burn an area equal in size to a designated area. The mean fire return interval is the average number of years between successive fires for a designated area and a designated period of time. All types of fires are generally included in the calculation of fire return intervals. Fire return intervals therefore provide information on the periodicity of fire but not on the area burned.

In the absence of fire, lodgepole pine (*Pinus contorta* Dougl.) usually becomes replaced by Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) or sublpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and white spruce (*Picea glauca* (Moench) Voss) or Engelmann spruce (*Picea engelmannii* Parry). In the Canadian Rockies, lodgepole pine often becomes established on burned sites in the montane ecoregion and the lower portion of the subalpine ecoregion (La Roi 1975, Kuchar 1978, Corns and Achuff 1982). Fire frequently interrupts successional trends by replacing stands of lodgepole pine with new even-aged lodgepole pine or mixed stands of lodgepole pine and spruce. Some sites in the montane ecoregion may be invaded by varying associations of Douglas-fir, white spruce and aspen (*Populus tremuloides* Michx.).

Corns and Achuff (1982) identified four successional vegetation stages (early, intermediate, advanced and mature) in Banff and Jasper National Parks and identified general successional trends. Post-fire stands less than 50 years old (i.e. time-since-fire) were considered as early successional stands. Intermediate successional stands 50 to 100 years old were usually dominated by lodgepole pine. Advanced successional stands (mature stage) 80 to 200 years old were characterized by mixed stands of seral (i.e. lodgepole pine) and climax species (i.e. Engelmann spruce, subalpine fir). The successional trends and relationships are temporally and spatially complex. The climatic conditions after fire, availability of seed, dispersal distance of source trees, wind direction, severity of the burn and site-specific factors (e.g. soil) all influence the type and extent of regeneration on burned sites. Corns and Achuff (1982) suggest that the complexity of successional pathways are simplified by the common occurrence of advanced successional stages. Agee and Smith (1984) suggest that it is not possible to accurately predict trends in post-fire vegetation succession because it is not possible to predict future trends in climate.

Fires of low to moderate intensity may thin lodgepole pine stands and/or stimulate regeneration. Many interrelated factors influence the fire regime in lodgepole pine forests. Little is known about the effects of periodic occurrences of low to moderate intensity fires in changing the forest stand structure in the Canadian Rockies. In the Oregon Cascades, Morrison (1984) found that small, low to moderate intensity fires were more common than previously thought. He concluded that these fires contributed to the composition and age distribution of the forest stands. Hemstrom (1981) also found that a fire regime including fires of low to moderate intensities likely resulted in the uneven-aged structure of the forest stands in Mount Rainier National Park, Washington.

Bergeron and Brisson (1990) documented the fire regime on two islands located in northwestern Quebec. They found that the uneven age structure of the red pine (*Pinus resinosa* Ait.) stands were correlated with a history of low to high intensity fires.

1.2 Fire management in Canada's national parks

Fire management in North America has traditionally been that of fire suppression. The importance of more broadly based effective fire management research, planning and implementation is now widely recognized by land management agencies. In 1968, the United States National Parks Service modified its "10 a. m."[3] fire suppression policy to allow lightning-caused fires to burn within prescription guidelines within wilderness areas. Early fire research in Everglades National Park (1950s) and in Sequoia and Kings Canyon National Parks (1960s) and the Leopold report (Leopold *et al.* 1963) were instrumental in bringing about changes in the policy. Sequoia and Kings Canyon were the first national parks to officially initiate fire management programs under the revised policy. The overall goal of their fire management programs is:

> " To restore or maintain the natural range of fire behavior and effects (i.e. fire regime) to the maximum extent possible so that the natural ecosystems can operate essentially unimpaired by human influence" (United States 1984).

As a result of the 1988 Yellowstone National Park fire season, the policy for fire management in national parks was reviewed. A Fire Management Policy Review Team (FMPRT) concluded that although the objectives of the prescribed natural fire programs in the national parks are sound, the policies need to be refined, strengthened and reaffirmed (United States 1989).

Changes did not occur in the Canadian national parks until the 1979 National Parks Policy (Canada 1979) was

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[3] *The "10 a. m." policy refers to the objective of suppressing a fire after it is reported, by 10 a. m. the following day.*

released. It recognizes fire as a natural process which should be allowed to take its course within the management planning constraints identified for the area under consideration. A simple interpretation of the policy is: fires are acceptable and unless there is a need for suppression, consideration should be given to allow fires to occur. The policy allows managers to use prescribed fires and permit man-caused or lightning-caused fires to burn within a park to attain resource management objectives (Lopoukhine and White 1985).

Within the Canadian national parks, natural resources are given the highest degree of protection to ensure the perpetuation of a natural environment essentially unaltered by human activity. The national parks policy states that:

> " Natural resources within National Parks will be protected with minimal interference to natural processes to ensure the perpetuation of naturally evolving land and water environments and their associated species" (Canada 1979).

The perpetuation and protection of both natural resources and natural processes are therefore primary considerations in managing national parks. Although natural processes are generally allowed to take their course, they may be altered if monitoring shows that:

- there may be serious adverse effects on adjacent lands;

- public health and safety are threatened;
- natural processes have been altered by man;
- major park facilities are threatened;
- a major natural control is absent from the park;
- the continued existence of a plant or animal species, which is rare or endangered or which is critical to the representation of the natural region, is threatened by a natural cause such as insects or disease;
- the population of an animal species or stage of plant which has been prescribed in the objectives for the park cannot be maintained by natural forces (Canada 1979).

The policy further indicates that if any active resource management is required, strategies that duplicate or approximate natural processes should be used. The use of fire as a management tool within national parks is therefore preferred over other active, large-scale management strategies. Fire can also, under certain circumstances, be the most controllable and predictable of all ecologically significant natural processes. Public safety is an important concern in fire management in mountain national parks. The scope of present fire management programs is largely determined by the costs to eliminate or reduce public safety concerns.

The objective of fire management in national parks and other public wilderness lands is usually to restore and maintain the natural role of fire in the environment

(Heinselman 1973, Kilgore 1973). Since fire management is primarily vegetation management, the objective can be further defined from a "structure" (*vs.* "process") viewpoint as the need to restore and maintain the vegetation mosaic which a natural fire regime would have created. Van Wagner and Methven (1980) suggested that we should strive to attain "that vegetation in the best long term equilibrium with the natural regional environment". Since the effects of fire on vegetation are independent of the source of ignition, random or planned ignition prescribed fires may be used if it is determined that it is the most reasonable and feasible strategy to attain the vegetation management objectives. These objectives should be defined in the park vegetation management plan. Within national parks, resource management concerns, objectives and strategies are identified and assigned priorities through the application of the natural resource management process (NRMP) (Figure 1). Vegetation management issues are identified in the Park Conservation Plan (PCP), a product of the NRMP. Within the United States national park system, the goal is to allow fire to operate to the fullest extent possible, as a process. The 1988 wildland fires in Yellowstone National Park showed that although the wilderness fire management policy in the United States national parks was sound, there were problems in applying the policy at the park or operational level (Hackett 1989). In the Canadian national parks, the fire

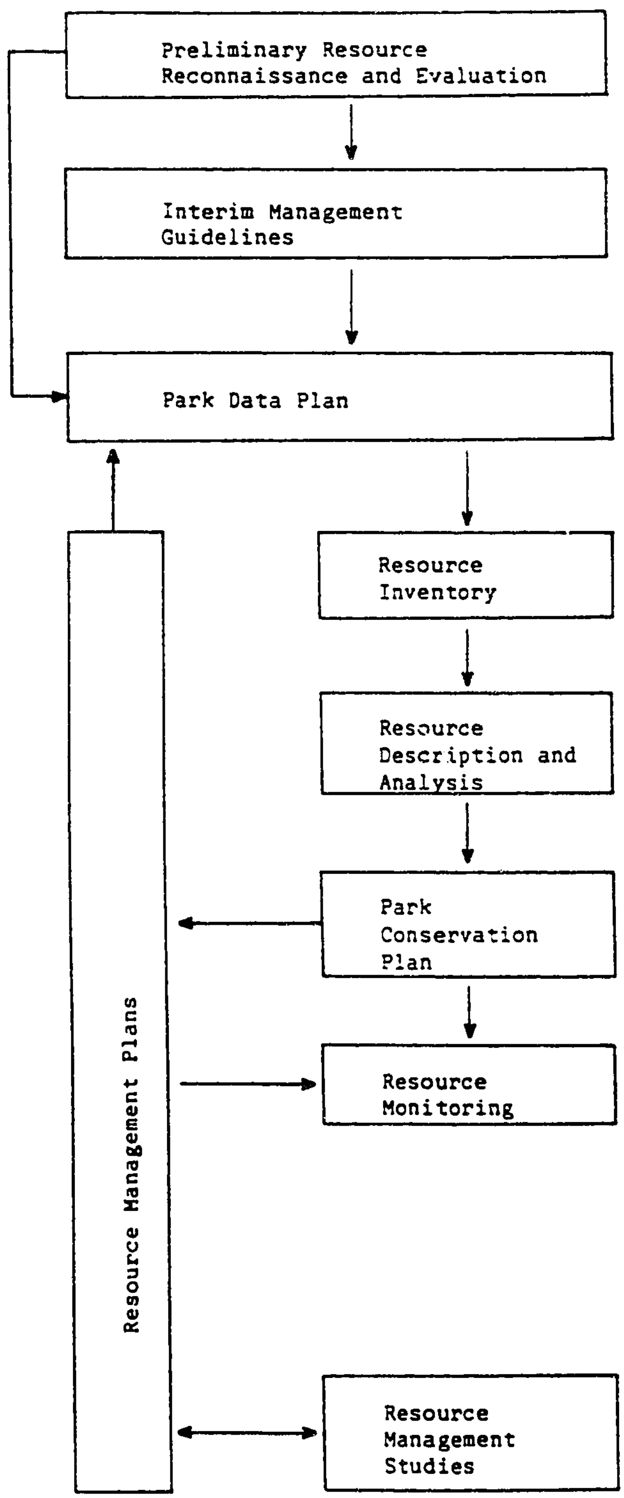

Figure 1 Natural resource management process for the Canadian National Parks (modified from Parks Canada 1980)

management programs are guided more by the resource (e.g. vegetation) management objectives and less by the goal of perpetuating the process *per se*. The management of the age-class distribution of forest stands to fit the negative exponential model described by Van Wagner (1978) is one approach that can be used to approximate a natural vegetation condition within fire dependent ecosystems. This approach also allows for the consideration of the effects of other processes affecting vegetation (e.g. herbivores, insects, macro and meso-climate).

Some of the northern national parks in Canada such as Wood Buffalo and Nahanni are large and remote. With fewer constraints (e.g. neighboring land conflicts) and values at risk (e.g. capital investments), wildland fires can be permitted to play a more natural role. Within these parks, fire can operate as a process with minimal interference by man.

From an ecological perspective, it is not possible to attain the goals of restoring and maintaining a fire regime and vegetation defined as "natural". It can be argued that there are few ecosystems that essentially operate without the influence of man. We can at best, recreate what we perceive as a "reasonable illusion" of natural fire and natural vegetation (Kilgore 1985). Kilgore (1985) defined a "natural" fire for any ecosystem as one that burns within the range and frequency distributions of fire intensities, seasons and sizes found in that ecosystem (i.e. pre-European), and yields the range of fire effects found in that ecosystem (i.e. pre-European).

Basic research is therefore required to determine pre-European conditions before a fire management program can be implemented for any national park. Fire history and fire behavior studies are essential components in the development of a fire management program (Hawkes 1979, Fischer 1984, Parsons *et al.* 1985).

It is also important to assess the ecological significance of the effects of man-caused fires and fire suppression activities on ecosystems. The investigation of historical events within national parks, will assist managers in developing resource management strategies. Christensen (1989) suggested that historical events not only initiate change but continue to play a significant role in regulating the structure of most forest ecosystems.

1.3 Review of fire history investigations and techniques

Since Clements (1910) pioneered fire history methods using fire scarred trees, fire history studies have become an important component in fire management planning within parks and wilderness areas. Fire history investigations have been conducted in western Canada (MacKenzie 1973, Tande 1977, Hawkes 1979, White 1985, Heathcott and Johnson 1987, Parminter 1987, Masters 1989) and western United States (Habeck and Mutch 1973, Kilgore 1973, Loope and Gruell 1973, Hemstrom 1979, Arno and Davis 1980, Davis 1980, Romme 1980), to document the fire history and describe the ecological role of fire in different ecosystems. Arno (1980) provided a good summary of documented forest fire history from recent fire scar studies in the northern Rocky Mountains.

Various fire history and fire weather studies have been compi for all seven mountain national parks in western Canada. ass studies have been completed or are near complet all parks. These studies will provide information to aid park resource managers in developing park specific vegetation and fire management plans. Fire history investigations for each park avoid the need to try to extrapolate fire history information from one physiographic region to another.

In the Canadian Rockies, forest fire danger is usually the greatest during the months of July and August (Tande 1977, Hawkes 1979). Evidence from fire history studies in the Canadian Rockies, suggest that climate may be the predominant environmental factor that ultimately controls the extent of burned areas. Prolonged periods of drought, and high surface wind speeds are common factors influencing the behavior and size of stand-replacing fires. These studies also show that low to moderate intensity fires were more frequent before 1880 (i.e. period before European occupation), particularly in low elevation forests. Mean fire return intervals (MFRI) ranged from approximately 20 - 30 years in dry montane Douglas-fir and lodgepole pine stands (Tande 1977, White 1985). At higher elevations, fires were less frequent with mean fire return intervals of 300+ years in upper subalpine stands of Engelmann spruce and subalpine fir (Hawkes 1979, White 1985).

In a fire history and ecology study of the forest ecosystem in Kluane National Park, Hawkes (1982) found that lightning was a very infrequent ignition source. He concluded that man-caused fires (i.e. early Europeans and Indians) have significantly influenced the development of present vegetation patterns within the park.

Using provincial forest age-class data, Murphy (1985) showed a change (decrease) in the annual rate of burn for the 1909 to 1969 period. A similar decrease in fire activity in the national parks since 1910, coincides with the development of increasingly effective fire suppression programs. An often argued cause and effect relationship may exist, however other factors require investigation. Heinselman (1973) contended that it is not the direct efforts of man but changes in fuel and weather that inevitably control major fires.

Tande (1977) found that 70 % of the fires and 92 % of the total area burned as a result of fires that occurred during a drought year. Hawkes (1979) also found a correlation between climate (i.e. precipitation) and fire activity.

The analysis of tree rings and basal fire scars, interpretation of aerial photographs and historical photographs, and use of historical records and accounts, have generally been used to document the fire history of an area. Reconstructing the fire history for the time period extending beyond 500 BP requires the use of alternate techniques such as the analysis of sediment cores from lake bottoms (Cwynar 1978). The presence of charcoal, pollen and fossils, can provide paleoecological evidence of the occurrence of fire after glaciation. Stratigraphic studies of bogs (Mehringer *et al.* 1977) and the analysis of glacial deposits (Heinselman and Roe 1963) have also been used.

Hawkes (1979) used fire records, age-class and fire scar data to document the fire history of Kananaskis Provincial Park. He found that most fires in the lower elevation areas of the park were large in size and of moderate to high intensity. Major fires occurred during 1858, 1890 and 1920. Tande (1977) found that most of the vegetation patterns within his 43,200 ha study area around Jasper townsite in Jasper National Park, originated after fires in 1758, 1847 and 1889. MacKenzie (1973) used only age-class data to develop a generalized stand origin map for Waterton Lakes National Park, Alberta.

Stand origin analysis is an indirect approach to obtaining fire history data, especially for stand-destroying fires. It is often used in conjunction with fire scar analysis. The use of the increment core is the common, non-destructive technique for obtaining age-class data. Increment cores can be obtained from live trees, standing dead trees, stumps and downed logs. Analysis of dead material (e.g. snags) using cross-dating techniques can provide valuable data to enhance fire chronologies and extend them backwards in time (Alexander 1978, Hawkes 1979, Baisan and Swetnam 1990).

The age of the dominant trees, or the oldest fire cohorts in a stand, provides an estimate of the year of origin for the stand. It is assumed that the dominant trees sampled reached dominance because they established sooner after the fire. Physical evidence of fire (i.e. presence of charcoal in soil, scarred trees) are used to determine whether a stand established as a result of a fire.

In Kananaskis Provincial Park, Johnson and Fryer (1987) showed that lodgepole pine and spruce had a large peak in regeneration in the first five years after fire. In northern Colorado, Clements (1910) found that effective lodgepole pine seeding took place during the first two years after the fire. In Montana and Wyoming, Mason (1915) found that approximately 70 % of the lodgepole pine seeding occurred during the first five years and 91 % during the first ten years.

The age of the species regenerating after fire therefore provides an approximate date of the year of the disturbance. The following equation can be used:

$$A = E - (B + C + D) \qquad [1]$$

where A = estimated year of the fire

B = number of annual rings counted from the sample

C = number of years added to adjust for the height where the increment core was obtained

D = regeneration lag

E = year the sample was obtained

Trees are generally cored at a height of 30 cm above the point of germination. An age correction is made to adjust for the height where the increment core was obtained. The number of years to add can be determined from a site-specific series of age-height cross-sections or basal cross-sections of small trees, assuming similar site and growing conditions. Tree ring counts can also be made from full or partial cross sections. These data can be used to augment age-class data obtained from increment cores.

Annual ring counts, cross-referenced with a master chronology, provide estimates of the years during which fire occurred. Cross-dating, or matching of tree rings from one specimen to another, is a common dendrochronological procedure used to minimize discrepancies in regeneration and fire scar dates. Inaccuracies can occur as a result of missing, discontinuous and false rings. Drought and defoliation by insects or fire can cause missing or discontinuous rings. Climatic patterns, lightning and defoliation by insects can cause false rings.

Computer technology applications for cross-dating now facilitate the use of cross-dating to more accurately age increment cores and sections. Cross-dating is a time-demanding procedure that generally relies on the use of clean samples (e.g. no rot or distortions) and species with clear ring patterns.

Synchronizing individual fire scar dates to produce a master fire chronology is an alternative approach that is relatively simple and quick (Arno and Sneck 1977). A shift of scar dates (usually ± 1 year) is justified on the basis of missing or false rings. If it is assumed that annual fires did not likely occur within the study area, and if only single scarred trees are evident, then it is concluded that the difference in dates (± 1 year) from different individual trees, do not represent two or more separate fires at the same site. Unfortunately, this assumption cannot be independently verified unless accurate fire report information is available. Madany *et al.* (1982) compared these two approaches (synchronization of raw dates *vs* cross-dated dates with no synchronization) for accuracy in determining fire dates from tree scars on Ponderosa pine (*Pinus ponderosa* Laws.). The agreement of fire dates between the two approaches was only 26 %. Although inaccuracies occur, they are considered insignificant for the purposes of developing fire return intervals, time since fire distributions and fire management recommendations for the national parks in western Canada. The accuracy of dating fires is more important in ecosystems where annual or consecutive fires occur. McBride (1983) provided a thorough review of the problems associated with fire history study methodologies based on fire scar and tree ring analysis.

Fire scar analysis is a common, direct approach to reconstruct the fire history of an area from the present to 300 - 500 BP. Recognition of the limitations of fire history information obtained from fire scar analysis is important. It is first important to distinguish fire scars from scars that have formed from other causes. In the Canadian Rockies, the identification of fire scars is usually not a problem. The following characteristics are used;

1. Fire scars are elongated or triangular in shape with the widest part of the scar at the base.
2. Occurrence of charred bark or exposed charred sapwood (scar wood). Char on the face of a scar normally represents a second fire.
3. Occurrence of snags and charred stumps and logs.
4. Increase in growth after the fire, observed in the ring width pattern in a cross section.
5. Location of the scar on the tree in relation to probable fire behavior (i.e. topography, prevailing winds).
6. Occurrence of charcoal mixed in the duff or a layer of charcoal on the mineral soil at or near the base of the tree.

7. Number of scars and the species and age of the trees scarred.

8. Black crust on scar margins observed in cross sections.

Scars due to other causes are usually irregular in shape. Often the evidence from mechanical injuries (e.g. fallen boulder or tree) can be seen at or near the base of the tree. Injuries from avalanche debris were determined by the site conditions, and the height, size, shape and consistency of the scar formations. Injuries from bears (from claw and teeth markings), ungulates (from antlers) and porcupines can be easily distinguished by observing associated non-scar markings on the trunk, irregular shaped scar formations and other indicators.

In the Canadian Rockies, some problems may occur in distinguishing fire scars from scars caused by strip attacks of mountain pine beetle on lodgepole pine trees, particularly if the beetles attack only one side of the stem. These scars can be differentiated from fire scars by the following indicators (Mitchell *et al.* 1983, Gara *et al.* 1986):

1. Bark often remains on beetle scars but exfoliates from fire scars.

2. Blue fungal stain is often associated with beetle scars but is absent from fire scars.

3. Fire scars date to the same year whereas beetle scars can occur over a 5 - 10 year period.

4. Charcoal is usually evident in the duff or on the mineral soil at the base of fire scarred trees.

5. Beetle scars are often on the north and east sides of the stem whereas the location of fire scars depends on the site and fire behavior characteristics.

6. The mountain pine beetle mainly attacks lodgepole pine whereas fire scars trees other than lodgepole pine.

The amount of fire scar data collected depends on the sampling design and intensity, and the size of the area under investigation. The quantity and quality of data (i.e. accurate fire year information) are also a function of the fire regime (i.e. fire intensity, fire frequency) and the tree species and age. The effects of fire on trees are variable. Their ability to survive and record a fire may vary temporally and spatially. There are many influencing factors. Heat avoidance is one of the most important factors related to plant survivability to fire. Bark is a good example. This physical barrier insulates the cambium from the high temperatures of a fire. Temperatures above 60°C are lethal to the cambium (Hare 1961). Madanay and West (1980) found that the age range from 10 to 80 years was the most susceptible period for Ponderosa pine to scar initially (i.e. first burn). The majority of trees under 10 years of age died, and trees over 80 years old had thick enough bark to insulate the cambium. For a scar to form on old trees, fire must consume the bark. Fuel accumulations at the base of a tree may locally increase the intensity of a fire. A moderate to high intensity fire that burns the bark will eliminate fire-susceptible species. As tree diameter increases, bark thickness and resistance to cambial damage increases. Some species such as Douglas-fir and Ponderosa pine have thick protective, resin free bark. Other species such as aspen and subalpine fir have thin bark and are easily killed by fire.

Once a fire has initially scarred a less susceptible species such as Douglas-fir, the tree becomes more susceptible to further scarring from fires that would not have previously have wounded the tree. A portion of the cambium at the scar margin becomes less insulated, and a buildup of resin along the scar margin intensifies the heat output. When a tree is scarred, callous tissue forms around the edge of the dead cambium. Eventually, the bark falls off, exposing the sapwood. Annual growth rings continue to form and slowly close off the wound from each side. In some cases, the scar can be completely closed resulting in the formation of a hidden or internal scar.

Although high intensity, stand-destroying fires leave little evidence of their occurrence, individual trees and small islands of trees often escape mortality. Scars can occur on these trees and on trees along the edge or boundary of a fire. Later successive fires tend to destroy evidence from earlier fires. It therefore becomes difficult to find evidence as the fire chronology extends backward in time.

Fire scarred stumps and/or trees can be selected along a transect or from systematically or randomly located points or plots. The study area is usually stratified to allow for the correlation of site characteristics with fire history data. Sample fire scarred stumps and/or trees are selected on the basis of the number of scars and the least amount of evident rot and/or insect damage. Old trees with multiple scars are preferred.

2. OBJECTIVES AND HYPOTHESES

The aim of the study was to document and describe the fire history of Yoho National Park and investigate the role of fire in the development of present day vegetation patterns.

The primary objectives, which are predominantly descriptive, were as follows:

2.1 Develop historical fire weather databases by reconstructing the Canadian Forest Fire Weather Index (CFFWI) indices (fuel moisture codes and fire behavior indices) and compare yearly fire danger with fire seasons in which major fire activity occurred adjacent to or within Yoho National Park, using the following parameters:

i) maximum daily Buildup Index (BUI)
ii) June - August and overwinter precipitation
iii) Fire Weather Index (FWI) and Seasonal Severity Rating (SSR)

2.2 Reconstruct the natural fire regime by using stand origin and fire scar analysis to estimate fire return intervals for high intensity stand-replacing fires and fires of low to moderate intensity.

2.2.1 Develop a two-index system an on area basis to describe the fire return intervals for high intensity stand-replacing fires and fires of low to moderate intensity.

2.3 Develop and compare time-since-fire distributions for the whole park and the western and eastern regions of the park.

2.4 Determine the effect of the known man-caused fires on the time-since-fire distribution for the whole park

2.5 Determine if the construction of the Canadian Pacific Railway and associated man-caused disturbances significantly altered the vegetation within the Kicking Horse Corridor.

2.6 Determine if any temporal breaks or partitions occur in the time-since-fire distributions.

2.7 Describe the role of fire in Yoho National Park and discuss the implications for fire management.

Objective 2.3 was achieved by testing the following hypothesis:

Ho_1 The time-since-fire distribution for the eastern region of the park is not significantly different than the time-since-fire distribution for the western region of the park.

Objective 2.4 was achieved by testing the following hypothesis:

Ho_2 The unadjusted fire cycle for the whole of Yoho National Park is not significantly different from the adjusted fire cycle for the whole of Yoho National Park.

Objective 2.5 was achieved by testing the following hypothesis:

Ho_3 The adjusted fire cycle for the period 1740 - 1879 is not significantly different from the adjusted fire cycle for the period 1520 - 1739.

3. DESCRIPTION OF THE STUDY AREA

3.1 Location

Yoho National Park is located in the Canadian Rocky Mountains along and west of the Continental Divide and east of the Columbia valley in British Columbia, between 116° 48' and 116° 20' W longitude and 51° 08' and 51° 50' N latitude (Figures 2 and 3). The park is approximately 1300 km^2 in area and is one of four adjoining national parks that together comprise the "Four Mountain Park Block". Banff National Park lies east and Kootenay National Park lies south-east of Yoho. British Columbia Crown forest land abuts the park on the west side. The Trans-Canada Highway and the Canadian Pacific Railway traverse northeast to southwest and divide the park in half.

3.2 Climate

Yoho National Park lies within the Cordilleran climatic region (Hare and Thomas 1974). The climate is strongly influenced by the topography and the park's geographic location immediately west of the Continental Divide.

The main air masses that influence the regional climate

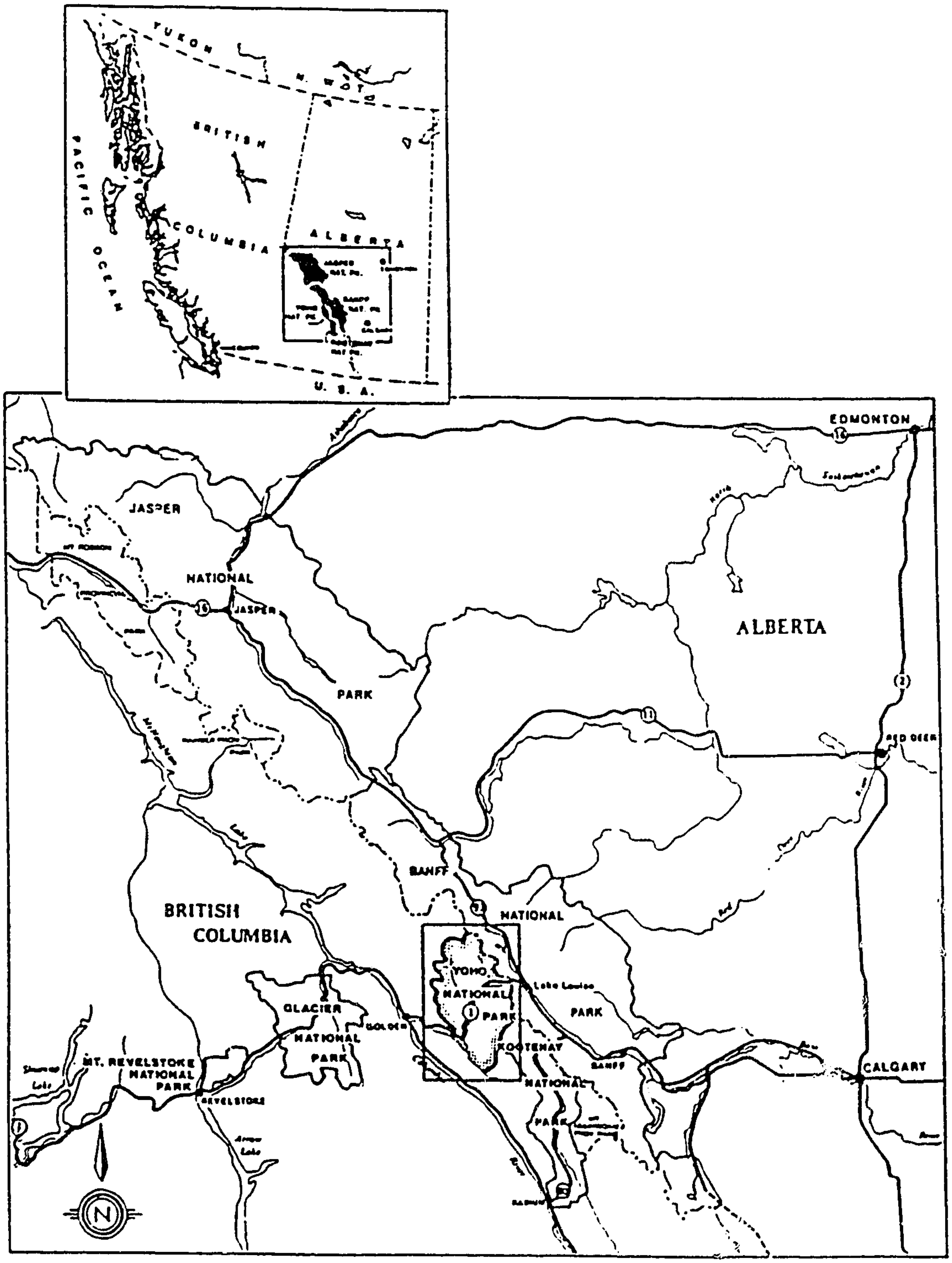

Figure 2 Regional setting - Yoho National Park

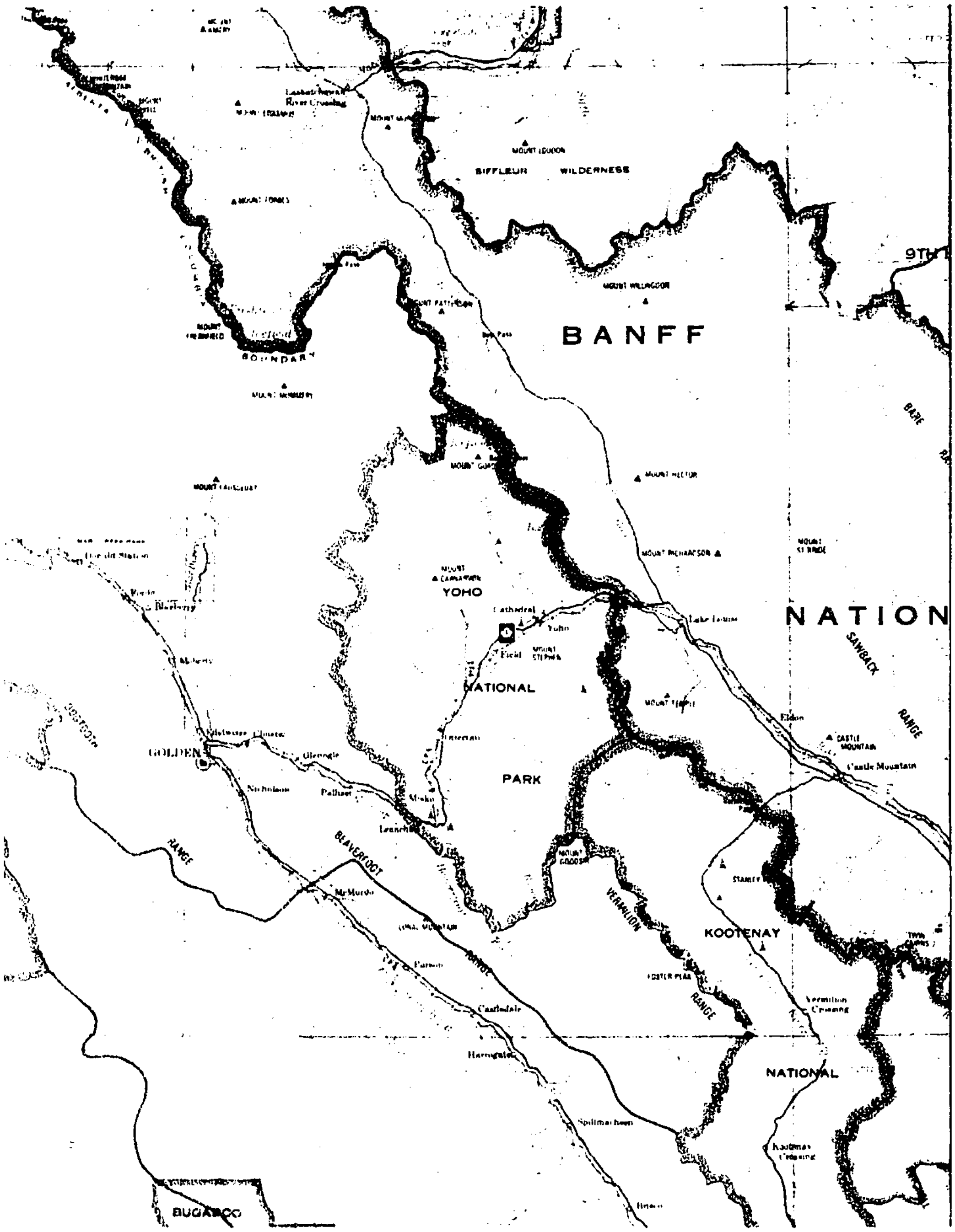

Figure 3 Geographic setting and location of place names

are the Continental air masses originating in Yukon and Alaska, and the Maritime air masses originating in the Pacific (Janz and Storr 1977). As Pacific disturbances move eastwards, they ascend on the windward side and descend on the leeward side of the northwest-southeast mountain ranges. As a result of orographic precipitation, the air masses become progressively cooler and drier. Maritime air masses have a moderating affect on the climate in Yoho National Park. The -35° C extreme minimum temperature and 68° C extreme temperature range are indicative of the Pacific influence (Janz and Storr 1977). As well, compared to areas east of the divide, the park experiences a lower frequency of cold arctic air penetrating from the east. The extreme minimum temperature at Banff is, in comparison, -51° C (Janz and Storr 1977). Areas east of the divide also experience higher extreme maximum temperatures.

Hot and dry weather generally occur in the summer and often into the fall. The warmest months are July and August with mean daily temperatures of 15° C and 12° C respectively (Coen and Kuchar 1982). The north and east areas of Yoho National Park are cooler and receive greater summer precipitation than the south and west areas. Windward slopes or areas west of the Continental Divide receive more precipitation than leeward slopes or areas east of the Continental Divide.

The average yearly precipitation is about 557 mm with snowfall accounting for approximately 45% of this total. The highest monthly precipitation occurs in June (6.8 cm) and January (6.4 cm). The driest months are March (3.0 cm) and April (2.8 cm).

3.3 Geology and soils

The rugged northwest-southeast trending mountains in Yoho National Park lie within the Eastern and Western Main Range Subprovinces of the Cordilleran Orogen geological region (Coen and Kuchar 1982). The Main Ranges include the highest mountains that form the Continental Divide. The flat and gently dipping strata and broad, open folds characteristic of the Main Ranges, result in mountains that are rounded and "castellate" in appearance. Shale, dolomite, quartz sandstone and limestone are the most common types of rock. The hard dolomite, quartz sandstone and limestone formations are more resistant to erosion than the shales. They also form the spectacular cliffs and walls down which the many waterfalls cascade. The laminated shale beds are softer and less resistant to erosion. The clay and silt that formed these rocks are also apparent in many of the soils. Unsorted surficial sediments that are non-calcareous and medium textured, generally overlie bedrock characterized by non-calcareous, medium and fine grained and clastic lithology (Coen and Kuchar 1982).

Brunisolic soils are commonly found on sorted and unsorted tills in the montane and lower subalpine ecoregions. Immature and weakly developed Regosols generally occur on unstable sites whereas the more well developed Podzols occur on stable sites usually associated with moist, cool environments (Coen and Kuchar, 1982).

3.4 Vegetation

The vegetation of Yoho National Park was described by Kuchar (1978). Detailed vegetation maps at a scale of 1:25000 were prepared from aerial photographs and field inspections. The basic unit of vegetation identified by Kuchar is "vegetation type", which stresses growth form in the dominant layer together with site conditions, especially soil moisture. Vegetation types were named by the dominant species in the uppermost layer. Fifty two vegetation types were designated. The vegetation groups, sub-groups and vegetation types identified by Kuchar (1978) are listed in Table 1.

Three ecoregions (zones) have been defined on the basis

Table 1 Vegetation classification for Yoho National Park (modified from Kuchar 1978)

Major Vegetation Group and Sub-Groups	Vegetation Type
1. Upland Forest	
a. Moist Montane	white spruce-Douglas fir-western red cedar (- western hemlock)
	white spruce-subalpine fir-Douglas fir-western yew
b. Intermediate Montane	white spruce-Douglas fir
	Douglas fir-white spruce
	white birch-Douglas fir-white spruce
	aspen-balsam poplar-white spruce
c. Dry Montane	white birch-aspen
	aspen-Douglas fir
	lodgepole pine-balsam poplar
	lodgepole pine-Douglas fir
	Douglas fir-lodgepole pine
	Douglas fir
	Douglas fir-limber pine
d. Montane-Subalpine	lodgepole pine
	lodgepole pine-spruce
	spruce-lodgepole pine
e. Low-mid Subalpine (mostly closed canopy)	Engellmann spruce-subalpine fir
	lodgepole pine-spruce-fir
f. High Subalpine (mostly open canopy, often numerous glades)	whitebark pine
	subalpine fir
	subalpine larch
2. Fluvial Forest	
	white spruce-Douglas fir-lodgepole pine on old alluvial fans
	white spruce-western red cedar on damp alluvial fans
	white spruce on permanently water-logged soil
	lodgepole pine-white spruce on flood-plain
	white and hybrid spruce (-lodgepole pine) on coarse dry alluvium
	white and hybrid spruce on moist to fairly dry alluvium
	white spruce-balsam poplar on moist alluvium
	aspen-balsam poplar on moist alluvium

of vegetation within the park; montane, subalpine and alpine ecoregions (Kuchar 1978). These zones reflect macroclimate.

Approximately 50 % of the park is coniferous forest. The other 50 % is comprised of bare rock, primarily above timberline (30 %), glaciers, ice and snow (10 %) and non-forest vegetation (10 %). The coniferous forest is dominated by lodgepole pine, Engelmann spruce, white spruce, subalpine fir and Douglas-fir. Other species such as whitebark pine (*Pinus albicaulis* Engelm.), subalpine larch (*Larix lyalli* Parl.) and Pacific species near the eastern limit of their range such as western red cedar (*Thuja plicata* Donn), western white pine (*Pinus monticola* (Dougl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western yew (*Taxus brevifolia* Nutt.) are present but less common.

4. CULTURAL USE

4.1 Pre-settlement period

Early natives knew that fire could be harmful or beneficial. Barrett and Arno (1982) found that widespread and generally unsystematic Indian burning occurred in Montana before 1860. "Opportunistic" burning served many purposes such as;

1. opening forest stands to facilitate travel;
2. increasing productivity (wildlife habitat enhancement);
3. improving range conditions for horse grazing;
4. tribal communication.

Evidence suggests that the Indians of the Northern Rockies were knowledgeable about fire and its effects, and skilled in the application of prescribed fire.

In northern Alberta, natives generally selected the time and the place for burning to create the effects they desired. These conditions were elaborated upon by Lewis (1977, 1982) in his thorough review and analysis of Indian burning in Northern Alberta.

There is little evidence, either historical or archaeological, of early native settlement within the area that is now Yoho National Park. This suggests that the park area was not considered an important hunting or settlement area. Areas to the west (i.e. Beaverfoot, Columbia valleys) and to the east (i.e. Bow valley, eastern slopes) offered more opportunities for year-round settlement (Loy 1972). East-west travel was hindered by the difficulty of traversing the divide. Topography, vegetation, climate and low numbers of wildlife, particularly the ungulates, may have accounted for the low level of native use within the park. The little native use the park did receive was limited to the western portion. Many of the valleys within the park (e.g. Yoho, Little Yoho, Otterhead, Porcupine, O'Hara) received no or very little native use.

Among early European explorers, David Thompson first discovered Howse Pass in 1807. Thompson and his group constructed a Trading House near what is now Invermere, B. C., to trade with the Kootenay Indians. With Howse Pass established as the fur trade route, the eastern area of the park was essentially by-passed by regional native and European traders. When the Blaeberry valley burned (1880s), the Amiskwi valley became the preferred route to reach Howse Pass (Stutfield and Collie 1903). The use of Howse Pass declined when Athabasca Pass became established as the new route through the Rockies.

Travel through the Kicking Horse Corridor (i.e. Upper Canyon) was hindered by the difficulty of traversing the divide. The narrow, rugged canyons deterred early travellers from using the park area. The natives themselves, apparently did not use the Kicking Horse Pass since it was too difficult for horses to travel.

Early surveyors did however make several accounts of native use within the park. Otto Klotz, a Dominion land surveyor, reported that during his survey work in 1886 along the Canadian Pacific Railway from Laggan [Lake Louise] to Golden City, he did not encounter many Indians except "wandering Kootenays or Shushwaps, principally the former" (Klotz 1887).

In his 1887 report entitled "Topographical survey of the Rocky Mountains", J. McArthur, also a Dominion surveyor, noted the presence of native encampments while climbing a peak on the east side of the Beaverfoot Valley (McArthur 1887). From McArthur's description it appears that he climbed Clawson Peak and was looking down to the upper Ice river valley in Yoho National Park. The meadows above the warden patrol cabin match his description of the "long narrow meadows". This further substantiates the evidence indicating that the areas to the west of the park (i.e. Beaverfoot, Columbia valleys) provided more favourable conditions for pre-contact native settlement.

McArthur's survey party followed a native trail up the Beaverfoot valley and reported that the trail was in very good condition as a "large band of Stony Indians" preceded them up the Beaverfoot. Other "old Indian trails" were also used. The survey party used an Indian trail to follow the Amiskwi Valley to Amiskwi Pass. After exploring and surveying the Emerald Lake area, McArthur returned to Field by an old Indian trail. He described the return trip as:

> " the greater part of the way leads through a beautiful park-like forest of small pines without understory, and which affords excellent pasturage" (McArthur 1887).

4.2 Railroad construction and park boundary changes

James Hector and his crew, while exporing the Rockies in 1857 as part of the Palliser Expedition, travelled down the Beaverfoot and up the Kicking Horse valleys. During the journey, Hector was kicked by his horse. This event led to the naming of the Kicking Horse Pass and river. Despite the arrival of early Europeans in western Canada during the 1790's and the early 1880's, the park area received relatively little use. This continued until construction of the Canadian Pacific Railway began. In 1882, Kicking

Horse Pass was chosen as the C.P.R. route through the Rocky Mountains. The following year, the town of Field was established as a C.P.R. switchyard and repair depot. By the fall of 1883, track-laying was completed several kilometres east of the summit. In 1884, thousands of laborers were hired to complete construction of the railway across the divide and through Yoho National Park. Considerable activity (logging, mining, construction) occurred in the Kicking Horse valley. Major fire activity also occurred during this period. Sparks from early locomotives and activities associated with the construction and maintenance of the railway started many fires during the 1883 - 1915 period.

Yoho Park Reserve (16 km^2 area around Mount Stephen) was established by Order-In-Council on Oct. 10, 1886. In 1901, the reserve was named "Yoho" and enlarged to 2,144 km^2 in area. In 1911, the Dominion Forest Reserves and Parks Act was passed. This resulted in the park's administration being separated and distinguished from the Dominion Forestry Branch. The park area was also reduced in area to 1,450 km^2.

The boundary of the park changed considerably in 1920. The park acquired an area on its northern boundary from the provincial Forestry Branch in exchange for a portion of the park that lay west of the Beaverfoot river. While this eliminated several timber berths from the park, the park area was subsequently reduced in size to 1,233 km^2.

4.3 Fire suppression period

Tymstra (1988) provided a review and account of fire activity, and development of fire control since 1900 in Yoho National Park. White (1985) provided a good account of the changes in fire management practices over the past 100 years in the Canadian national parks. Murphy (1985) also provided an excellent review of the history of forest and prairie fire control policy in Alberta.

Fire suppression in Yoho National Park evolved as a result of concern over the number of fires and area burned within the Railway Belt[4]. In 1906, forest protection programs were addressed at the first Canadian Forestry Convention. The Commission on Conservation was also formed in 1909 to address national problems in forest protection and forest conservation. It became clear that if the forests were to be protected, an improved fire protection system was required. This meant an increase in staff. In

[4] *A 66 km strip of land along the Canadian Pacific Railway right-of-way*

1909, a system of game and fire protection was inaugurated with the appointment of permanent game and fire wardens. Fire protection was concentrated along the Railway Belt. Fire guardians patrolled the Railway Belt for the sole purpose of extinguishing fires caused by sparks from the Canadian Pacific Railway (C.P.R.) locomotives. Areas outside the Railway Belt received no forest protection. Access was the limiting factor. Without a system of fire roads, trails and lookout towers, forest protection was not possible.

In 1912, there were one Dominion forest ranger stationed at Palliser and two park rangers in Yoho National Park. An amendment to the Railways Act in 1912 gave authority to the Railway Commission to ensure that the railway companies complied with the requirements of employing fire rangers to patrol the railway lines. This legislation made the companies liable for damages and costs resulting from fires started by locomotives.

In 1913, an inspector of fire-ranging reported that the C.P.R. was negligent in meeting the requirements of the Railway Commission Board. Inspections revealed that there were still instances of defective screens being used on the locomotives. The requirement for a connection between the overflow pipe and the ash-pan was in some cases, neglected.

The inspector noted that it was common practice a few years previous for the engineer or fireman to purposely destroy a screen to create a greater draft. Although lignite coal was prohibited by the Board for use in railway engines, inspections indicated that in some cases it was still being used. Despite the use of spark-arrestors, fires still occurred. This was blamed on the use of low-grade or finely powdered coal. Until construction of the two spiral tunnels was completed in 1909, railway engineers had to contend with the "Big Hill", a dreaded section of the route that crossed the divide and descended into the town of Field at a grade of 4.5 %. Obtaining suffucient power was a constant problem. Three locomotives were required to pull eight wooden cars over the divide.

In 1914, it was reported that the conversion of coal-burning locomotives to oil-burning locomotives was completed. However, in 1916, the district inspector of forest reserves for British Columbia noted that of the 33 railway caused fires during 1916, about 80 % were set by coal-burning engines that were still being used. No fires were reportedly caused by oil-burning locomotives.

The development of a portable, six horse-power gasoline pumping engine by the park service in 1915, was an important and successful accomplishment that began to revolutionize forest fire-fighting that began in 1910.

In 1919, the superintendent reported that Yoho National Park was acquiring a "power speeder"[5] to assist in fighting fires along the railway. The same year, motor vehicles were allowed to use certain park roads for the first time. In1920, aircraft begant to be used for forest fire detection.

With cabins, forestry telephone lines, portable fire units, chemical extinguishers and speeders available to wardens, forest fire fighting began to enter a new era of technology. In his 1934 annual report, the Superintendent reported that railway fires were becoming very rare. He felt that there was very little chance of a railway fire assuming very large proportions.

Continued developments and progress were made in the forest protection program. Training continued, new fire roads constructed and maintained, new and improved equipment purchased, additional support facilities constructed and fire plans and agreements prepared. Fire science research and development also started to influence the forest protection program.

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[5] A small two-manned motorized vehicle that operated on the railway line

5. METHODS

5.1 Historical documentation

Historical fire documents were reviewed and summarized by Tymstra (1988). Historical records and accounts were analyzed to obtain information on fires within the park. Historical photographs were collected and compared with present photographs and vegetation maps to assist in recording the influence of fire and changes in vegetation.

5.2 Fire weather analysis

The Canadian Forest Fire Weather Index (CFFWI) system is a sub-system of the Canadian Forest Fire Danger Rating System (CFFDRS) (Van Wagner 1974). The CFFWI is a continuous accounting system of probable fire danger that uses daily surface weather observations taken at 1200 h (noon) local standard time or 1300 h daylight saving time. Temperature (° C), 10 metre height open wind speed (km/h), total 24 hour precipitation (mm) and relative humidity (%) are used to calculate a series of numerical ratings representing three fuel moisture codes (Drought Code, Duff Moisture Code, Fine Fuel Moisture Code) and three fire behavior indices (Buildup Index, Initial Spread Index, Fire

Weather Index) (Figure 4).

The Fire Weather Index (FWI) is a numerical rating of fire intensity. It represents the energy output rate per unit length of fire front. The FWI is not suitable for averaging (Van Wagner and Pickett 1985). The Maximum Daily BUI and the Daily Severity Rating (DSR) averaged over the fire season were therefore used to compare fire weather over time and assess wildland fire potential. The DSR is a function of the FWI:

[2] $$DSR = 0.0272\ (FWI)^{1.77}$$

The Buildup Index (BUI) is a numerical rating of the total amount of fuel available for combustion.

The CFFWI fuel moisture codes and fire behavior indicies were calculated from 1941 to 1988. Historical fire weather observations for the periods 1941-54 and 1956-65 were obtained from the Petawawa National Forestry Institute in Chalk River, Ontario. Digitally archived climatological data for the period 1966-69 were obtained from the Atmospheric Environment Service Canadian Climate Centre in Downsview, Ontario. Fire weather data for the period 1970-88 were available from the Warden Service in Yoho National Park.

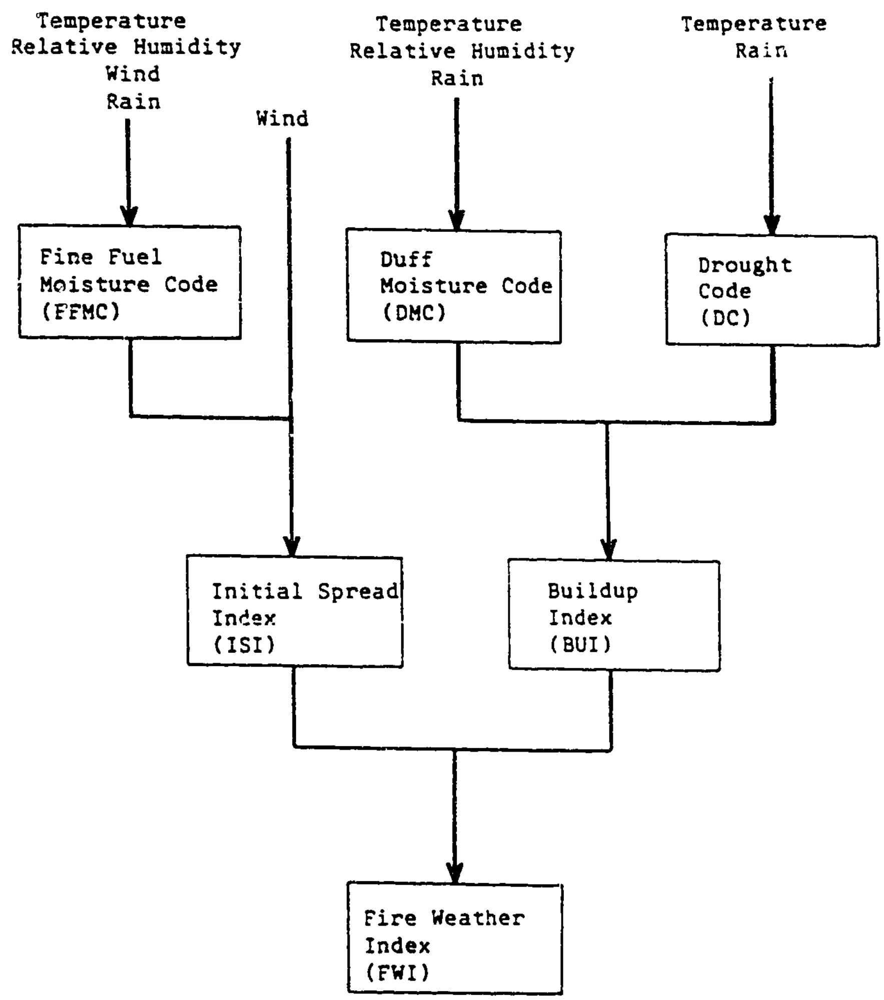

Figure 4 Canadian Forest Fire Weather Index System (modified from Environment Canada 1984)

Presently, there are two weather stations in operation; Boulder Creek and Wapta Lake. The Boulder Creek station represents valley bottom climatic conditions. The Wapta Lake station, situated approximately 230 metres higher in elevation, represents climatic conditions influenced by the proximity to the Continental Divide. The Boulder Creek station experiences higher mean and extreme maximum temperatures. Three precipitation gauges are also located within the park. Two Sacramento precipitation storage gauges are in the Ottertail valley, one at Float creek and the other at McArthur creek. Another Sacramento gauge is also located in the Amiskwi valley at Fire Creek.

The Ottertail weather station was installed in 1941 with an anemometer, rain gauge, wet and dry bulb hygrometer and maximum, minimum thermometers. No readings were taken in 1955. In June 1956, the station was moved to Field and readings resumed. Two years later, the Ottertail station was moved 0.8 km east near the junction of the Ottertail fire road and the Trans Canada Highway.

From 1941-45, weather observations were recorded four times a day (0900 h, 1500 h, 1700 h and 1900 h LST). Adjustments were required to enable the calculation of the components of the CFFWI. It was assumed that the 1500 h dry bulb temperature would approximate the maximum temperature for that day. The 1500 h temperature was then adjusted to a noon temperature. For the years 1979, 1981, 1983 and 1985 the daily maximum temperatures during the fire season were compared with the daily noon temperatures. The mean monthly difference was used to determine the required adjustment for each month. This resulted in a subtraction from the daily maximum temperature of 3.0° C for May, 3.5° C for June and September and 4.0° C for July and August. The 1500 h adjusted (i.e. noon) dry bulb temperature and the 1500 h wet bulb temperature were used to recalculate relative humidity. The equations and procedures used are described by Alexander (1983b). A psychrometric constant for non-ventilated thermometers was used since the wet bulb thermometer was not ventilated. The 1500 h wind speed and direction observations were used as noon observations.

The 24 hour precipitation was estimated by adjusting the 0900 h and 1900 h depths of rain based on the recorded times when rain began and ended.

The weather observing times changed in 1946 to 0800 h, 1200 h and occasionally, "other" afternoon readings (usually 1400 h). The noon observations were used to calculate the Canadian Forest Fire Weather Index (CFFWI) codes and indices. Since the wet bulb thermometer was not ventilated, the dry and wet bulb temperatures were again used to recalculate relative humidity.

In 1947, the weather observing times changed again as a result of the use of daylight saving time in the Pacific time zone. Daylight saving time was officially adopted in British Columbia in 1919. However, from 1919 to 1941 the use of daylight saving time was controlled by each municipality. From 1942 to 1946, the control of the use of daylight saving time was transferred to the federal government. In 1947 the B. C. provincial government resumed control. Time zone boundaries have since changed. Yoho National Park now lies within the Mountain standard time zone. The 1245 - 1300 h weather observations were used to calculate CFFWI system codes and indices. Other than the absence of weather observations in 1955, the 0900 h, 1200 h and "other" readings continued until 1965.

Weather records from Yoho National Park for the 1966-69 period could not be found. Archived climatological data from Atmospheric Environment Service (AES) in Downsview, Ontario were therefore used. Since wind and relative humidity observations were not archived, only drought codes could be calculated for this period. The AES Ottertail station data are based on 0800 h and 1600 h MST observations. The maximum temperature therefore represents the same day assuming that a maximum temperature did not occur after 1600 h. The daily maximum temperature was adjusted to estimate a noon temperature. The total precipitation was based on a 0800 - 0800 24 hour period. The majority of the recorded precipitation therefore represents that for the previous day. The 0800 h precipitation was used as the noon precipitation for that day.

The precipitation, noon temperature and month (i.e. drying factor) are the input variables required to calculate drought codes (Figure 4). The drought code is a numerical rating of the average moisture content of deep (i.e. 10 - 25 cm), compact, organic layers and large diameter fuels. The drought code is a good indicator of seasonal drought conditions. Overwinter moisture effectiveness affects the spring moisture content of deep, organic layers. The spring drought code starting values may need to be adjusted to account for any overwinter moisture deficiency. If there is no deficiency, the standard spring starting value of 15 should be used. Overwinter adjustments of spring drought code (DC) starting values were made for the Yoho historic weather data. The procedure described by Alexander (1983a) was used. A carry-over fraction of fall moisture of 1.00 and a precipitation effectiveness fraction of 0.75 were used.

The daily maximum BUI values from 1941 - 1987 were compared with years of major fire activity (i.e. > 200 ha) and with the maximum daily BUI for the 1988 Yellowstone fire season (Old Faithful weather station[6]).

Simple moment parameter estimates for the Weibull distribution (three parameter) were calculated and used to estimate the probability and return period for extreme BUI values. This procedure was used to estimate the likelihood of attaining a maximum daily BUI similar to that for the 1988 Yellowstone fire season.

Precipitation data were also obtained for Lake Louise, Alta. (1915 - 1988), Field, B. C. (1924 - 1987), and Golden/Donald, B. C. (1895 - 1940). The precipitation data were plotted against the average precipitation and the years in which major fire activity occurred adjacent to or within Yoho National Park.

5.3 Stand delineation

Forest stands were delineated using Kuchar's (1978) vegetation classification of vegetation types, mapped at a

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[6] The 1988 Yellowstone CFFDRS codes and indices were provided by D. Quintilio, Director, Forest Technology School, Hinton, Alberta.

scale of 1:25000. Field investigations, interpretation of 1952 aerial photographs at a 1:25000 scale, historical photographs, and a 1952 forest cover map completed by park staff were also used to assist in identifying and delineating stand boundaries. A forest stand acetate overlay map at a scale of 1:50000 was prepared and used to record fire scar and age dates. As the study progressed, this map evolved into the stand origin map.

5.4 Sampling procedure

During the first year (1987) of the study, 24 fire history plots were established thoughout the park (Figure 5). The plots were located in subjectively chosen homogeneous areas of selected forest stands. A 30M X 30M X 30M triangle plot with three point-centered quadrant sub-plots was used (Figure 6). The start or corner point of the plot was selected using a random compass bearing.

The number and location of the plots were based on the representativeness of vegetation subgroups from Kuchar's (1978) vegetation classification, accessability, drainage representation and logistical constraints (i.e. time and manpower requirements). Since the fire history study was only one component of the fire management program, the plots

Figure 5 Location of fire history plots and age-class data sampling sites in Yoho National Park

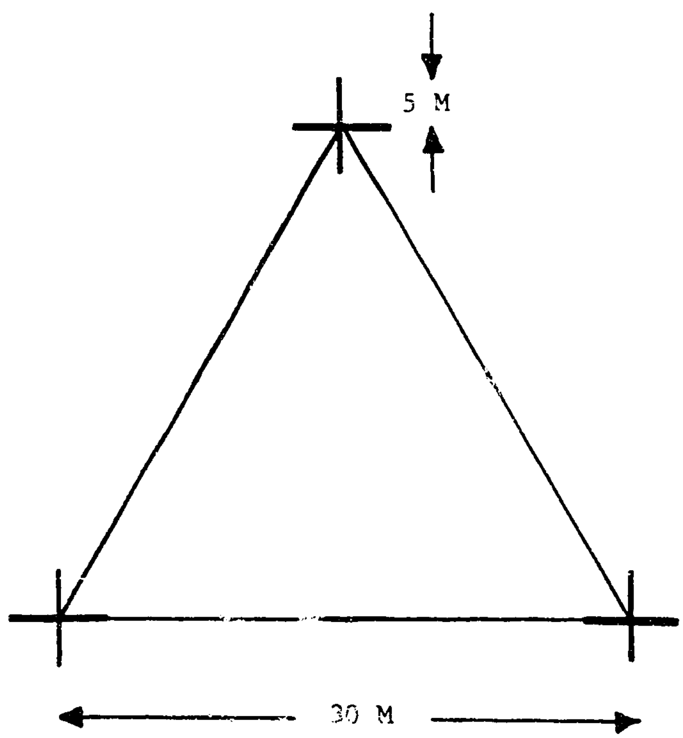

Figure 6 Triangle plot and three point-centered quadrant sub-plots (modified from McCrae *et al.* 1979). The field data collection form used to record the plot data is included in Appendix I

were established in consideration of obtaining additional information (i.e. forest fuel data).

An area of approximately 200 m radius from the centre of the plot was searched for fire scarred trees. The oldest trees with the greatest number of externally visible individual fire scars, and with no or little apparent rot, were sampled for fire scar analysis. A minimum of three fire scarred trees with the same fire scar dates per sampling site was used as a guideline to minimize errors in establishing a fire chronology.

Using the point-centered quadrant sub-plots, a total of 12 dominant trees was cored for stand origin analysis. The ages of the oldest fire cohorts were plotted on the stand origin map. Trees were cored at a height of approximately 1.3 m to avoid basal decay. A standard table age correction factor based on site conditions was used to adjust the core count to total age (Univ. of B. C., 1983). Annual ring counts from cross-sections of felled trees were compared with adjusted increment core ages to determine if large errors occurred in the adjustment. In the montane ecoregion, the error deviation was generally low ($\pm$ 1 - 2 years). The age data from cross-sections of dominants were considered more reliable and therefore used rather than the ages from the increment cores. Although there may be some inaccuracies, the adjusted ages were considered adequate for the purpose of stand age and time-since-fire distribution analysis.

The age-class data and fire scar data were used to delineate stand origin boundaries and to develop a two fire return interval index for the area sampled. This index is represented by the following equation:

[3] $$A = B/C$$

where A = index consisting of two fire return intervals

B = fire return interval for high-intensity stand-replacing fires

C = fire return interval for low to moderate intensity fires

A preliminary analysis of the stand age data collected during the first year of field work showed that many of the montane forest stands did not have a single distinct age-class or origin date. Instead, many of these stands were uneven-aged. As a result, age-class distributions were calculated and graphed for these stands to determine the age breaks. It was assumed that the lodgepole pine age breaks represented regeneration pulses. The magnitude of the pulse is a function of the disturbance intensity. This technique was used to assist in assigning stand origin dates and to correlate these dates with fire scar dates.

During the second year of the study, further stand age data were obtained to fill "gaps" in the stand origin map and to resolve interpretation of areas with complex fire histories. Additional fire scarred trees were also sampled from stand boundaries and residual stands. The sampling procedure in the second year was neither true random nor systematic. Forest stands were sampled by walking though selected stands, usually following a straight line transect though the centre of the stand and subjectively sampling approximately eight dominant trees. The objective was to confirm burn boundaries and stand ages. The largest trees (DBH and height) were selected for coring. One of the objectives of the second year of the study was to complete the age-class analysis for the whole park. Small, isolated and high elevation stands of spruce-fir and larch were not sampled.

5.5 Preparation and analysis of stand origin and fire scar data

A variable power binocular microscope and 10X magnifying hand lens were used to count the annual tree rings from increment cores and cross sections. Increment cores were glue-mounted onto grooved core boards and labelled. The cores were oriented and mounted to provide a transverse section view. The cores were sanded and, if required, sliced with a sharp knife to make the rings more distinct. Saliva, coffee or white chalk were sometimes applied to further enhance the rings. If the pith was missing, the number of years added was estimated from the curvature and width of the innermost rings.

Sections of basal fire scarred trees were obtained using a chainsaw. All sections were labelled, recorded and brought to the lab for analysis. The slope direction and the magnetic north direction were marked on the sections in the field. Sections were sanded with a belt sander using coarse (no. 80) and then medium grit (no. 150) sandpaper. If required, portions of the sections were sanded by hand using medium to fine grit sandpaper. Two radii or pith to bark line counts were made of each section. If discrepancies in the counts occurred, partitioned recounts were made to identify any discontinuous rings. If discrepancies still occurred, a third line was sometimes counted to reach a consensus of two lines. If fungal and insect damage was present in the cross section, often only one line could be counted.

Identifying the correct "fire annulus" (annual ring whose growth was disrupted by fire) was sometimes difficult. The reliability of the fire scar date was therefore identified as definite or approximate. This facilitated the shifting of fire scar dates if required. Individual fire scar dates were not synchonized unless they occurred close together within the same stand.

One hundred and fifty basal fire scar sections were utilized from a total of 49 sampling sites. The fire scar dates were plotted on the stand origin map and, with the age-class data, used to develop a fire chonology and fire return interval index for different areas within the park.

A total of 281 age-class sampling sites was utilized including 120 data points that were replotted from Kuchar's (1978) field investigations. In total, approximately 1,200 individual tree ages from increment cores and sections were used to delineate and age the forest stands within the Yoho National Park.

5.6 Time-since-fire distribution

The stand origin map was digitized and the cumulative 20 year age-classes and time-since-fire distribution were analyzed using a micro-computer based geographic information system. The distribution of time-since-fire classes was used to estimate fire cycles for the whole park and for the western and eastern regions of the park (Figure 7). The

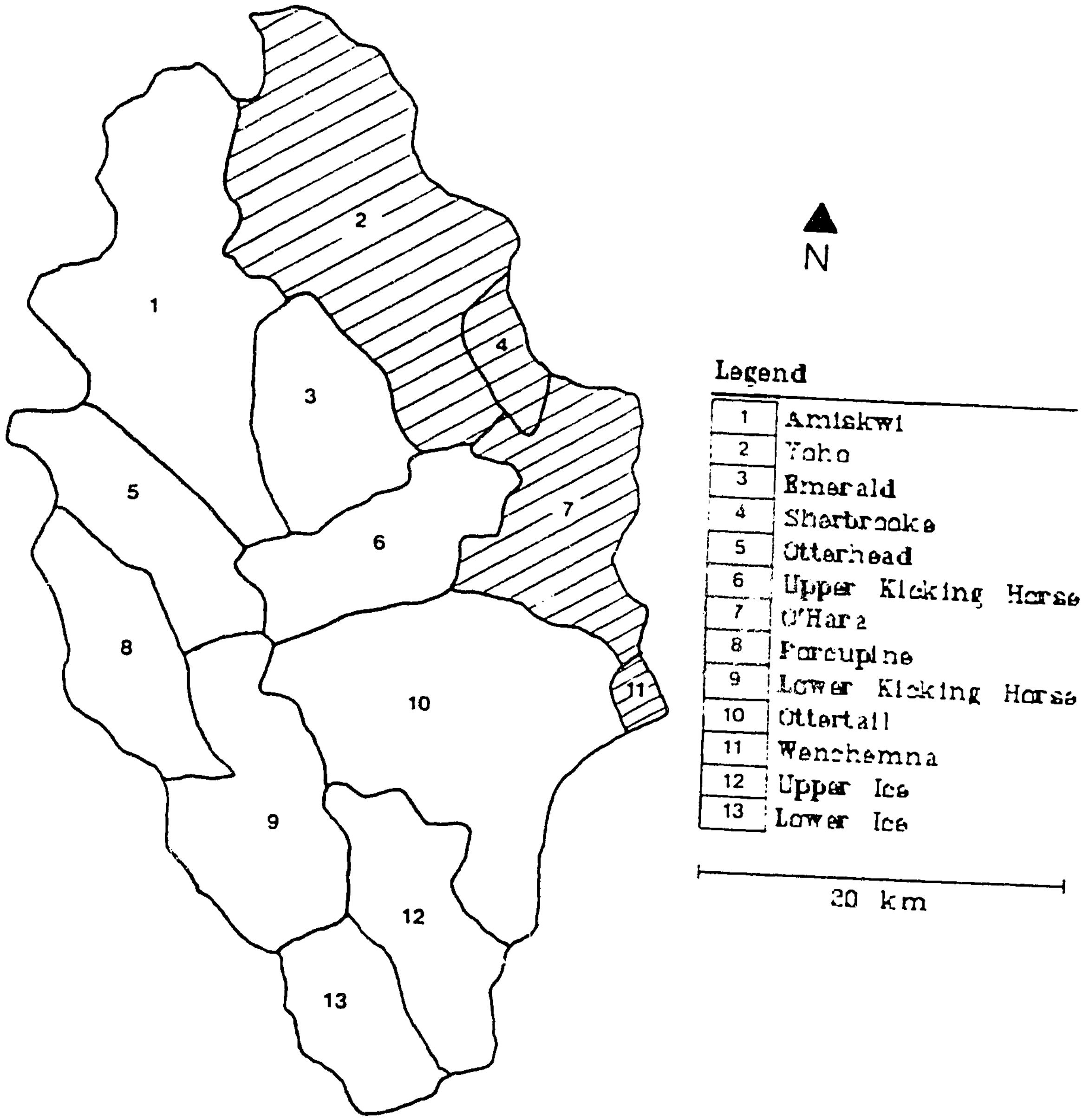

Figure 7 Watersheds within Yoho National Park (eastern region of the park adjacent to the Continental Divide is represented by the hatched area)

eastern region which includes the Yoho, Sherbrooke, O'Hara and Wenchemna drainages, lies immediately west of the Continental Divide. The cumulative time-since-fire distributions were plotted on semi-log graphs, and the slope coefficients of a least-squares linear regression used to estimate the fire cycles. The *y* intercept of all the regressions were forced to be zero. This represents the most recent age-class point within the data set. The difference between the fire cycle for the eastern region of the park and the fire cycle for the western region of the park was tested with a Student's t-test (Steele and Torrie 1980). The time-since-fire distributions for the eastern and western regions of the park were also tested for equality using the Kolmogorov-Smirnov test (Steele and Torrie 1980).

The fire cycles for the 1520 - 1739 and 1740 - 1879 periods were estimated by re-plotting the cumulative time-since-fire distributions (using 20 year age-classes) for each period. The difference between the two fire cycles were tested with a Student's t-test (Steele and Torrie 1980).

The time-since-fire distribution fit to a negative exponential curve (Van Wagner 1978) assumes the following:

1. Uniform flammability regardless of age (i.e.

constant rate of mortality independent of age).

2. Random ignition.

3. Large area (the negative exponential model is not applicable to small areas).

4. Relatively constant climate from year to year.

The negative exponential model implies that a forest with a stand renewing fire regime would consist of ages approximately one-third older and two-thirds younger than the mean stand age or fire cycle. Approximately 37 % of the forest stands will be older than the mean stand age and would escape mortality from fire for a period of time greater than the mean stand age or fire cycle.

The time-since-fire distribution is represented in its cumulative form by the equation:

[4] $$At = \exp(-t/b)$$

where

At = frequency or probability of not having a fire up to age t

t = time in years since the last fire

b = fire cycle in years which will be exceeded 37 % of the time

5.7 Analysis of man-caused fires

The areas burned by man-caused fires were reclassified to estimates of ages of the stands before they burned. The prior stand age was estimated from the ages of residual trees and small stands or patches of trees that survived the fire. The areas by 20 year age-classes were then recalculated. The cumulative time-since-fire distribution was again plotted on semi-log graph paper and the regression slope coefficient used to estimate the fire cycle. The difference between the adjusted fire cycle and the unadjusted fire cycle was tested with a Student's t-test (Steel and Torrie 1980).

Fire reports were also analyzed to determine the characteristics of man-caused fires since 1915. This included a review of cause, size, location and time (i.e. month) of the fires and a review of the weather conditions during the fires.

5.8 Fire return intervals

The fire scar data and age-class data were analyzed and used to develop area specific mean fire return intervals. The following fire types were used in describing the fire regime of Yoho National Park:

1. Stand-replacing fires - These are generally large, high intensity, high severity stand destroying fires that occur in both montane and subalpine vegetation types.

2. Stand-damaging fires - These are generally moderate to high intensity fires that do not completely destroy the stand (i.e. overstory vegetation). Fires were considered to be stand-damaging if 50% or less of the canopy was destroyed.

3. Stand-non-damaging (ephemeral) fires - These are generally small, low to moderate intensity surface fires that usually result in no canopy destruction.

The negative exponential fire cycle model considers only stand-replacing fires. It does not take into account the effects of fires of low to moderate intensity. A two fire return interval index system was developed to not only describe the frequency of fire but the type of fire. For example, if an area had a return interval for stand-replacing fires of 200-250 years and a return interval of 30-40 years for fires of low to moderate intensity, the fire regime can be summarized using the two index system, as 200-250/30-40.

6. RESULTS

6.1 Fire weather index analysis

During the 1941 - 1988 period, 68 % of the total number of days that had very high or extreme fire danger (FWI $\geq$ 19), occurred during July and August (Figure 8). This is the main fire danger period. The month of June has the second highest monthly average precipitation (68 mm) and an average of 16 % of the total number of very high or extreme fire danger days. The month of June has an average of twice the number of very high or extreme fire danger days as the month of September. The fire danger is generally greater in the spring than in the fall. The month of September has the least incidence of very high to extreme fire danger.

The five years from 1941 to 1988 that had the highest fire danger based on the calculation of the Seasonal Severity Rating (SSR) are listed in Table 2. Included in Table 2, are the five years that had the highest maximum daily BUI and the five years that had the greatest fire activity (i.e. area burned). There is no relationship between the five years with the greatest fire activity (i.e. area burned) and the five years with the greatest fire danger. Major fire activity usually occurs during periods of high fire danger but not necessarily during years with the highest fire danger. If

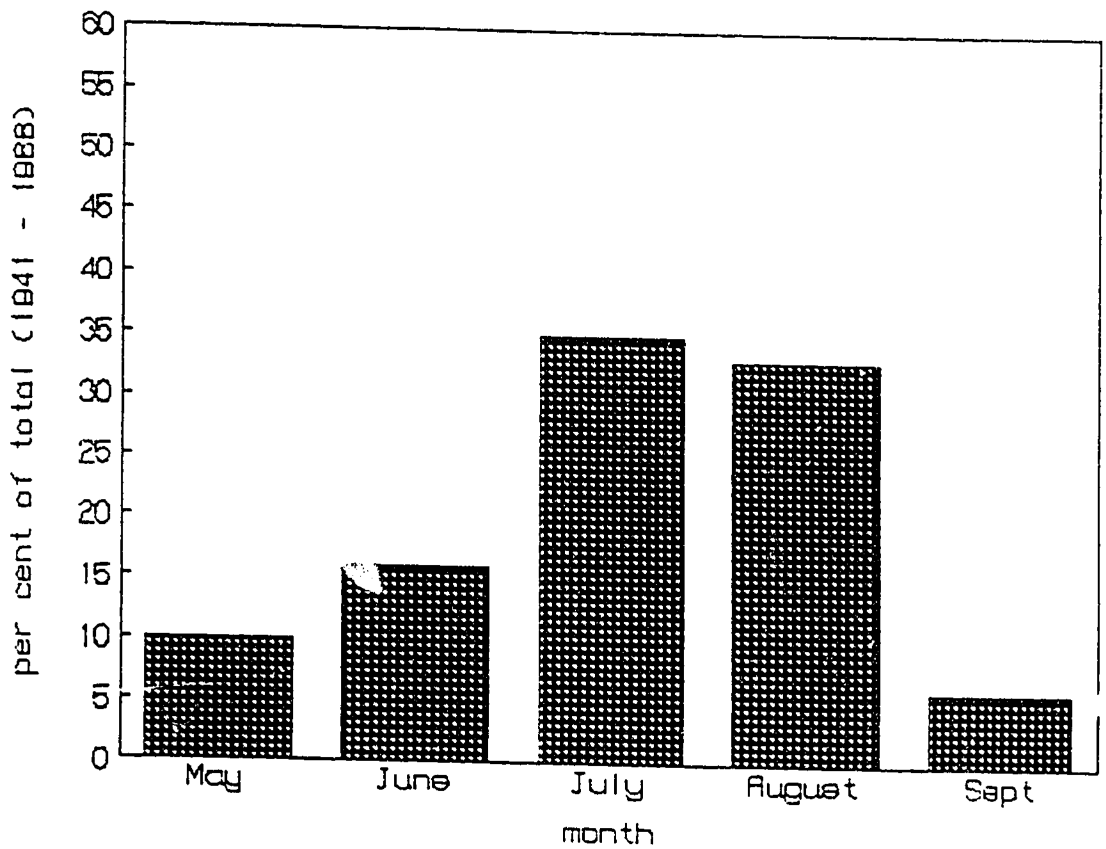

Figure 8 Incidence of fire danger (FWI $\geq$ 19) in Yoho National Park from 1941 to 1988

Table 2 Comparison of years with the greatest fire danger from 1941 to 1988 within and adjacent to Yoho National Park

Rank	Seasonal Severity Rating	Maximum Daily BUI	Area Burned
1	1960	1960	1971
2	1961	1959	1960
3	1958	1958	1955
4	1951	1951	1984
5	1956	1972	1941

there is no ignition source (i.e. at the right time and location) not all years with high fire danger have major fire activity.

6.2 Buildup index analysis

The highest daily maximum BUI value for the 1941 - 1988 period is 152, occurring on August 1, 1960. The fire seasons in which major fire activity occurred adjacent to or within Yoho National Park during the 1941 - 1988 period all had above average daily maximum BUI values (Figures 9 and 10).

The daily maximum BUI calculated for the 1988 Yellowstone national park fire season (Old Faithful weather station) was, in comparison, 259 (and occurred on July 28). Using extreme value statistics (Figure 11), it is estimated that there is a 99.5 % confidence that the overall maximum BUI for Yoho National Park will not be greater than 212 for a 200 year return period.

6.3 Precipitation regime analysis

Warm, moist Pacific air masses increasingly lose moisture as they move towards the Continental Divide. For example, the

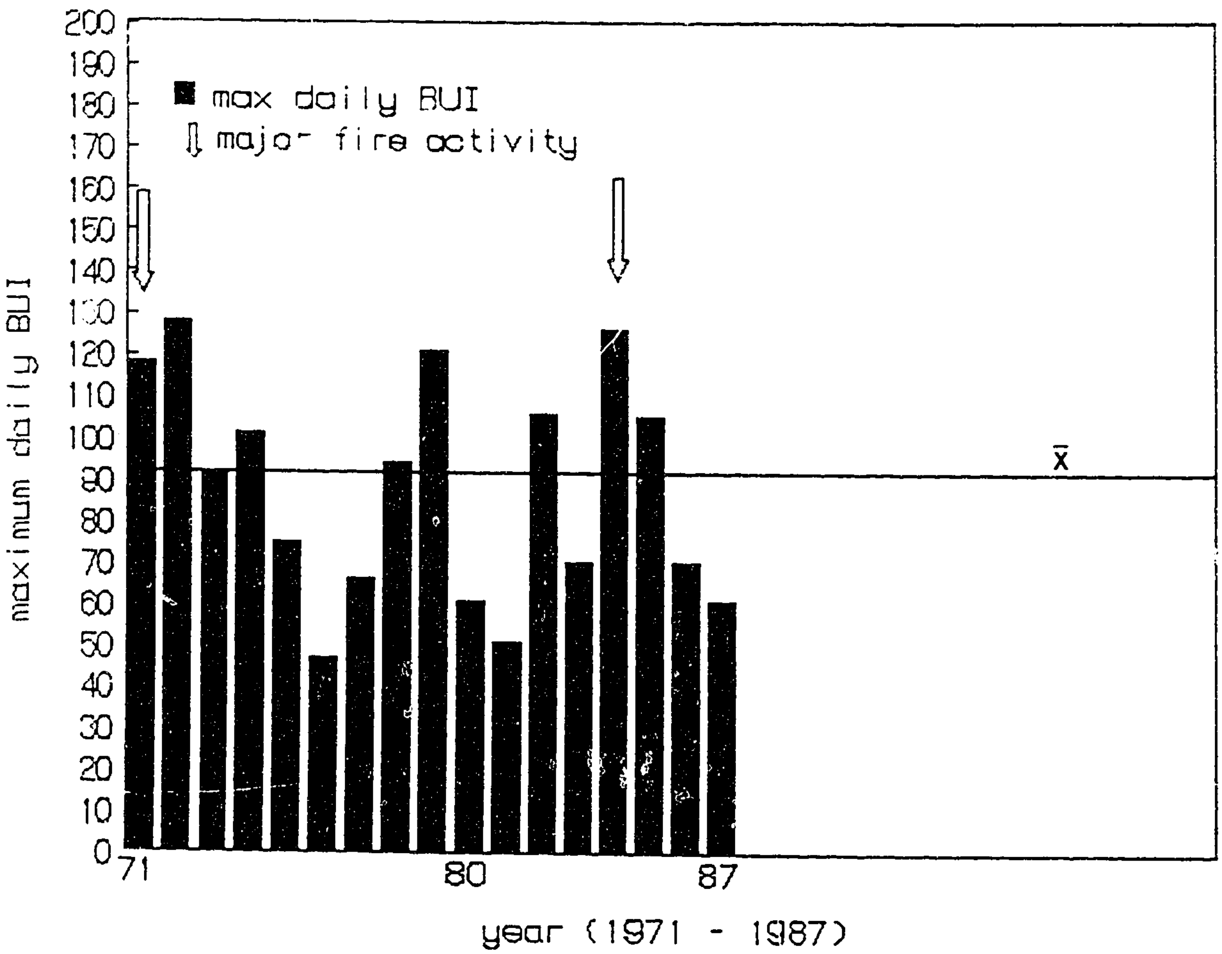

Figure 9 Maximum daily BUI for Field, B. C. (1971 - 1987)

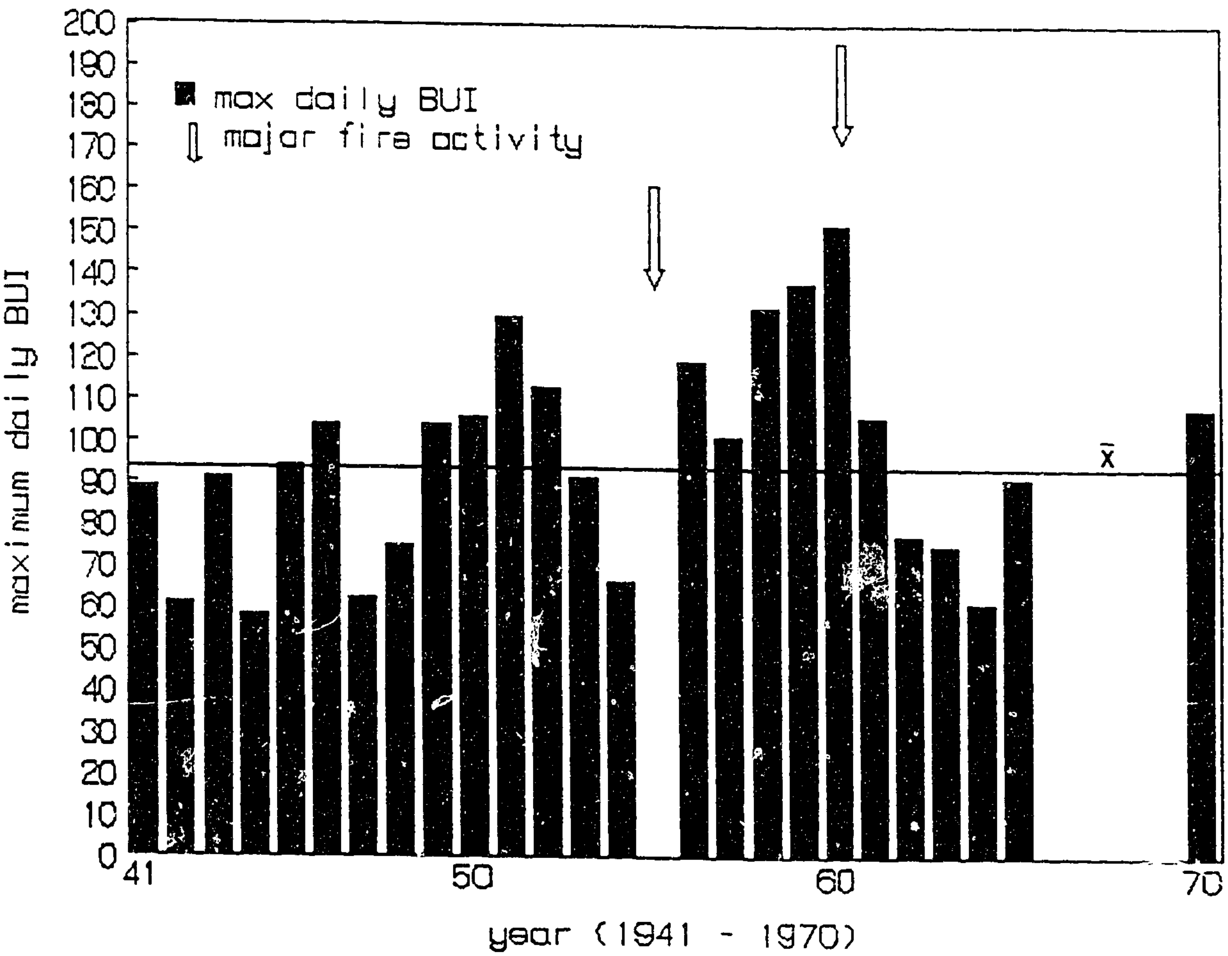

Figure 10 Maximum daily BUI for Field, B. C. (1941 - 1970)
Data not available for 1955 and 1966 - 1969.

```
x[i] ...................... maximum daily BUI
x[i] - (upper BUI limit)
ln(x[i]) .................. natural logarithm
                            transformation

N = 42
x = 5.322 ................. location parameter
s = 0.132 ................. scale parameter


Moment estimates      a = s ( 6 /π)
                        π = 3.1415927
                      a = 0.1824

                      u = x - aγ
                        γ = Euler's constant = 0.5772156649
                      u = 5.2167


Weibull scale parameter = EXP (extreme value location
                                 parameter)
                        = 184.32

Weibull shape parameter = 1.0 / (extreme value scale
                                   parameter)
                        = 5.48


 Return period = T = 1 / (1 - Prob)
 Prob = 1 - 1 / T
 Y = -ln (-ln(Prob))
 IF Prob = 0.995  THEN Y = 5.296

 X = u + aY
 X = 212 .................. (Max BUI)
```

Figure 11 Maximum daily BUI calculations for Yoho National Park, B. C. using the three parameter Weibull estimation procedure described by Kinnison (1985) mean June - August quarterly precipitation for Golden/Donald, B. C., for the 1895 - 1981 period is 114 mm (n = 76), and for Field, B. C., for the 1924 - 1987 period it is 186 mm (n = 38). The mean June - August quarterly precipitation for Lake Louise, Alberta, for the 1915 - 1988 period is 162 mm (n = 72). This trend is also evident in the spatial precipitation pattern within the park (Figure 12). The eastern area of the park receives the greatest precipitation. The driest areas of the park are on the southwest side of the park. These are low elevation areas that are the furthest distance from the divide.

During the forty year period from 1948 to 1988, only one year, 1950, required an adjustment of the spring Drought Code starting value from 15 to 61. The Oct. 1 - April 30 overwinter precipitation during 1949/50 was 54 % of the average (x = 288 mm, n = 50). Although the Drought Codes were not reconstructed for the 1923 - 1936 period because fire weather data were not recorded, the 1936/37 overwinter precipitation (Oct. 1 - April 30) was 44 % of the average (x = 288). The overwinter precipitation for the 1923 - 1936 and 1948 - 1988 periods represent the total water equivalent in mm of snowfall and rainfall.

Of the seven years in which major fire activity (> 200 ha) occurred adjacent to or within Yoho National Park during the

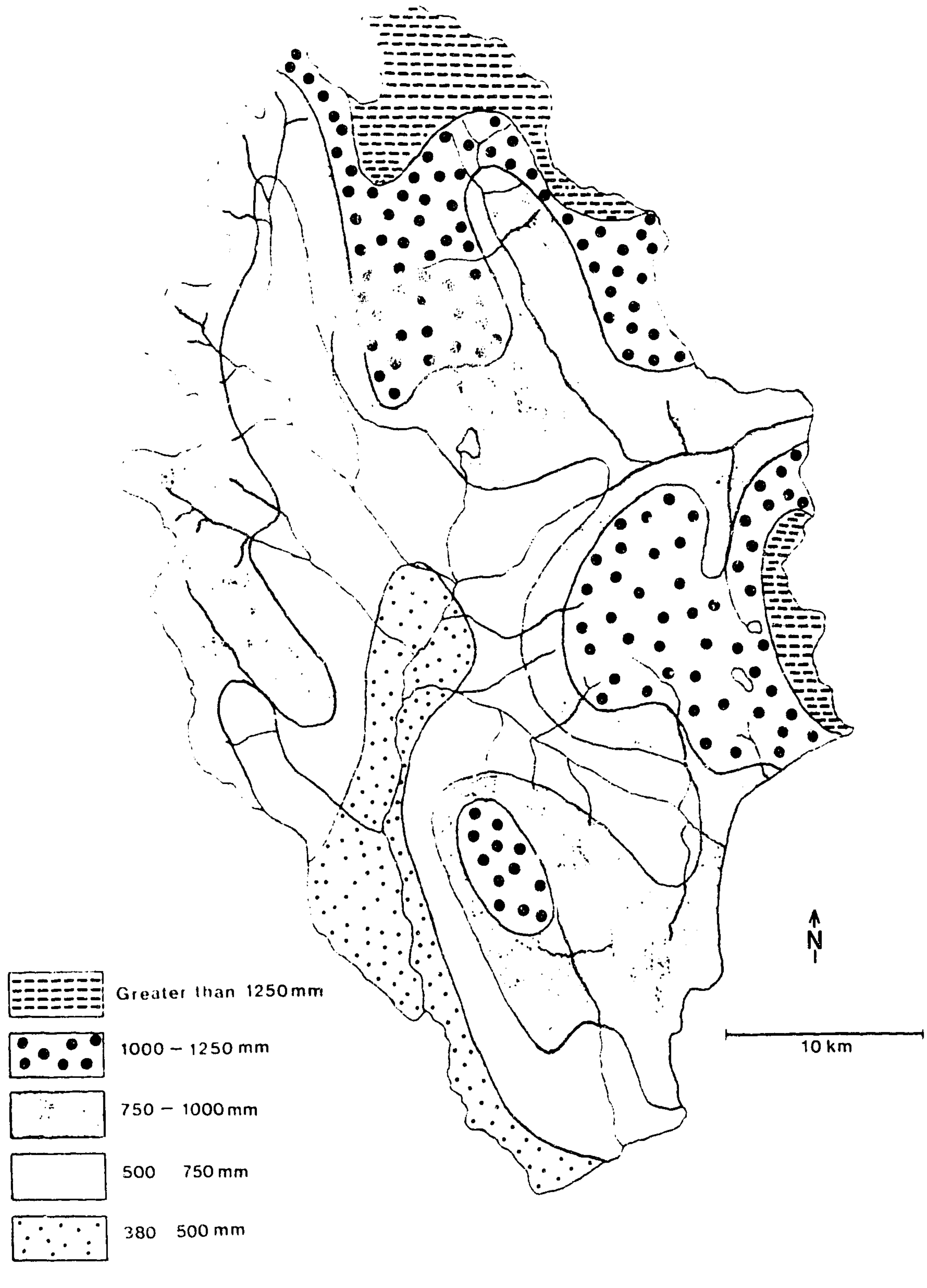

Figure 12 Total annual precipitation within Yoho National Park (modified from Janz and Storr)

1923 - 1936 and 1948 - 1987 periods, six of the fire seasons were preceded by winters with below average precipitation. No overwinter precipitation data were available for Field for the 1937 - 1947 period. Below average precipitation during the June - August quarter also occurred during the nine years in which major fire activity occurred from 1915 - 1988. The relationship between the fire seasons with major fire activity and the June - August precipitation totals for Lake Louise, Alberta, and Field, B. C. is shown in Figures 13 and 14. Though there is a relationship, not all fire seasons with below average precipitation experience major fire activity.

6.4 Fire characteristics (1900 - 1988)

An analysis of fire occurrence, area burned, fire cause and fire behavior, from historical documentation was completed by Tymstra (1988, 1989). Little historical documentation (i.e. fire reports) was available on fires that occurred during the 1900 - 1919 period.

Approximately 241 wildland fires were reported within Yoho National Park from 1910 to 1988. From 1900 to 1971, major fire activity (area burned ≥ 200 ha) occurred adjacent to or within Yoho National Park on an average of every 7 years (Table 2). Fires that burned over 1,000 ha occurred on

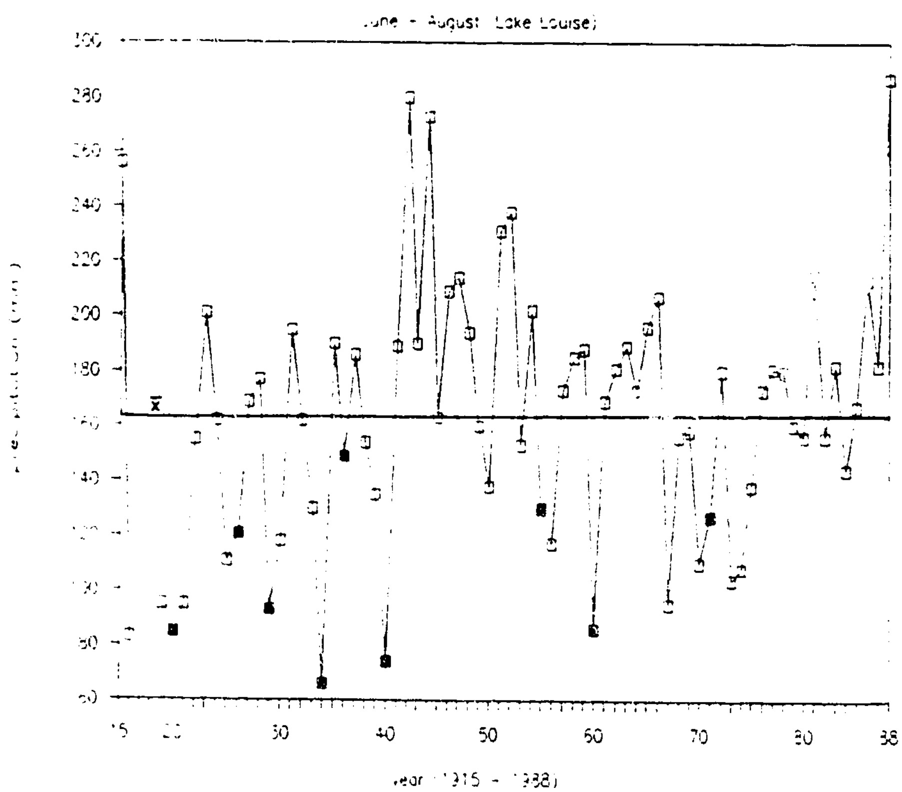

Figure 13 Total June - August precipitation for Lake Louise Alta. (1915 - 1988). The solid squares represent years in which major fire activity occurred within or adjacent to Yoho National Park.

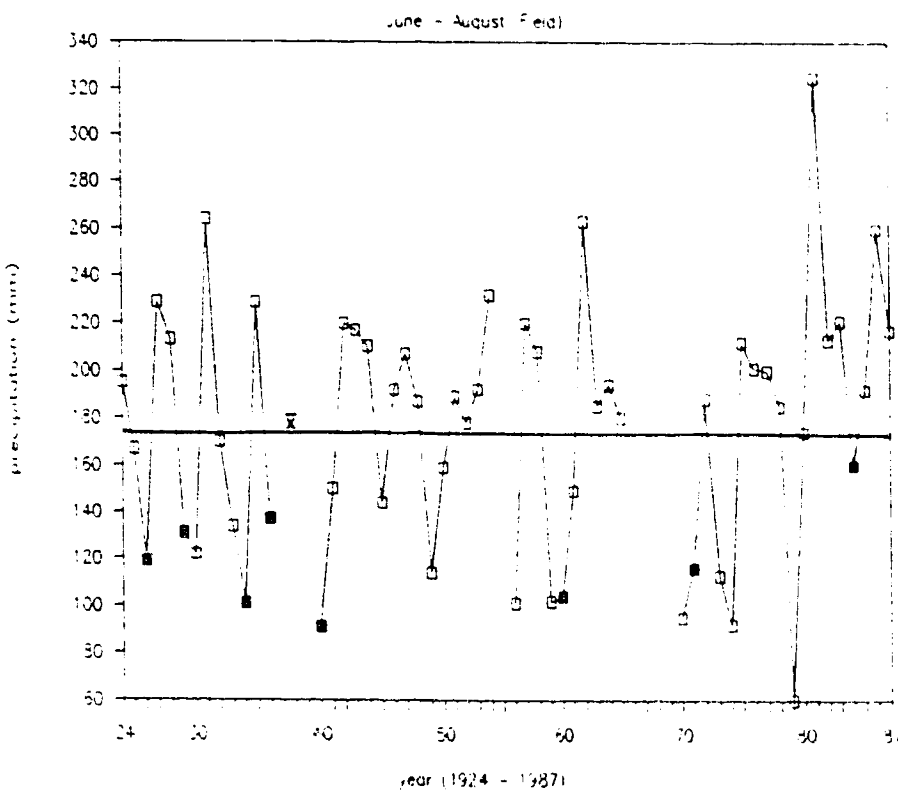

Figure 14 Total June - August precipitation for Field, B. C. (1924 - 1987). The solid squares represent years in which major fire activity occurred within or adjacent to Yoho National Park. No data were available from 1966 to 1969.

Table 3 Years in which major fire activity occurred within or adjacent to Yoho national park during the 1910 - 1988 period. Fire cause is either man-caused (M) or lightning caused (L). The area adjacent to Yoho national park refers to B. C. provincial lands west of the park and includes Glenogle, Ensign, Martin and Split Creeks, the Beaverfoot Range and the Blaeberry valley.

Year	Fire Name	Fire Size ≥ 200 HA	Fire Size ≥1000 HA	Fire Cause
1910	Mount O'Daray	X		L
1912	Timber Berth No. 29	X		L
1914	Wapta ┐		X	M
	Mount Owen ┘			L
1920	Frenchman's Creek	X		M
1926	Otto Creek ┐		X	L
	Porcupine Valley ┘			L
1929	Mount Fulmen	X		M
1934	Kapristo Mountain (Beaverfoot Range)	X		L
1936	Horse Creek (Beaverfoot Range)		X	L
1940	Beaverfoot		X	L
1955	Otterhead	X		L
1960	Burnt Hill		X	M
1971	Amiskwi ┐		X	L
	Mount Hurd ┘			L
1984	Glenogle Creek	X		L

average of once every 12 years. Since the 1971 Amiskwi Valley fire, no major fires have occurred within Yoho National Park or within the four mountain park block.

Of the total number of fires reported to have occurred within Yoho National Park, approximately 41 % were man-caused. Approximately 24 % were of unknown or "other" (e.g. spontaneous combustion) cause. Except for the 1914 Wapta fire, 1920 Frenchman's Creek fire and the 1960 Otto Creek fire, the man-caused fires during the 1910 - 1988 period were small in size and restricted to the valley bottoms. These fires were generally in close proximity to trails, roads and the railway right-of-way.

The majority of the forest stands in the Kicking Horse Corridor originated from fires during the 1883 - 1915 period. In 1912, the Superintendent of Yoho National Park in a letter addressed to Dominion Parks Commissioner Howard Douglas, described the extent of the burned area throughout the Kicking Horse Corridor. His account indicated that there was very little merchantable timber left in the Kicking Horse Corridor. The only remaining large stands of mature forest were located on the slopes of Mount Burgess.

From 1883 to 1910, railway-caused fires were common. Railway-caused fires continued to occur after 1910, but were generally suppressed quickly and kept small in size. During the construction and early operation of the railway, many large fires occurred. Although the causes of these fires were difficult to determine and substantiate, the historical documentation and age- class and fire scar data suggest that many fires were caused directly or indirectly by the construction and operation of the railway. The construction of the railway and the beginning years of its operation were also coincident with very dry summers that occurred during the 1880s.

Approximately 35 % of the total number of fires of known cause were lightning-caused. Class D (10.1 - 100.0 ha), E (100.1 - 1,000.0 ha) and E1 (1,000.1 - 100,000.0 ha) lightning fires only occurred during the month of August. Class C (1.1 - 10.0 ha) fires occurred during June, July and August. No lightning-caused fires larger than Class A (< 0.11 ha) occurred during the fire season after August. The majority of lightning fires started between 1400 - 2100 h. While lightning was responsible for 35 % of the total incidence of fires in the park, it accounted for approximately 85 % of the total area burned during the 1910 - 1988 period.

From 1931 to 1988, lightning accounted for 85 % of the total incidence and 93 % of the total area burned for provincial forest fires adjacent to the park and greater than

16 ha in size. Approximately 50 % of the lightning-caused fires adjacent to the park started between 1400 - 2100 h.

Very few lightning-caused fires greater than Class A have occurred on the east side of the park. The location of lightning-caused fires indicate that some areas have received a higher incidence of fires than other areas. The Mount Hunter, Mount Hurd and Emerald Lake/Yoho Pass areas have in total, received almost half of the known number of lightning-caused fires (Figure 15).

6.5 Time-since-fire distribution

The regression estimate of the unadjusted fire cycle (parameter b in equation [4]) for the whole of Yoho National Park is 132 years ($r^2 = 0.847$). The time-since-fire distribution did not show any statistically significant sharp breaks in the slope even though the plotted points suggest a change in rate may have occurred about 150 years ago (Figure16). The adjusted fire cycle (i.e age adjustment of stands originating from man-caused fires) for the whole of Yoho National Park is 138 years ($r^2 = 0.786$) (Figure 17). There is no significant difference between the adjusted fire cycle and the unadjusted fire cycle (for $b_1 = b_2$ at $p = 0.05$).

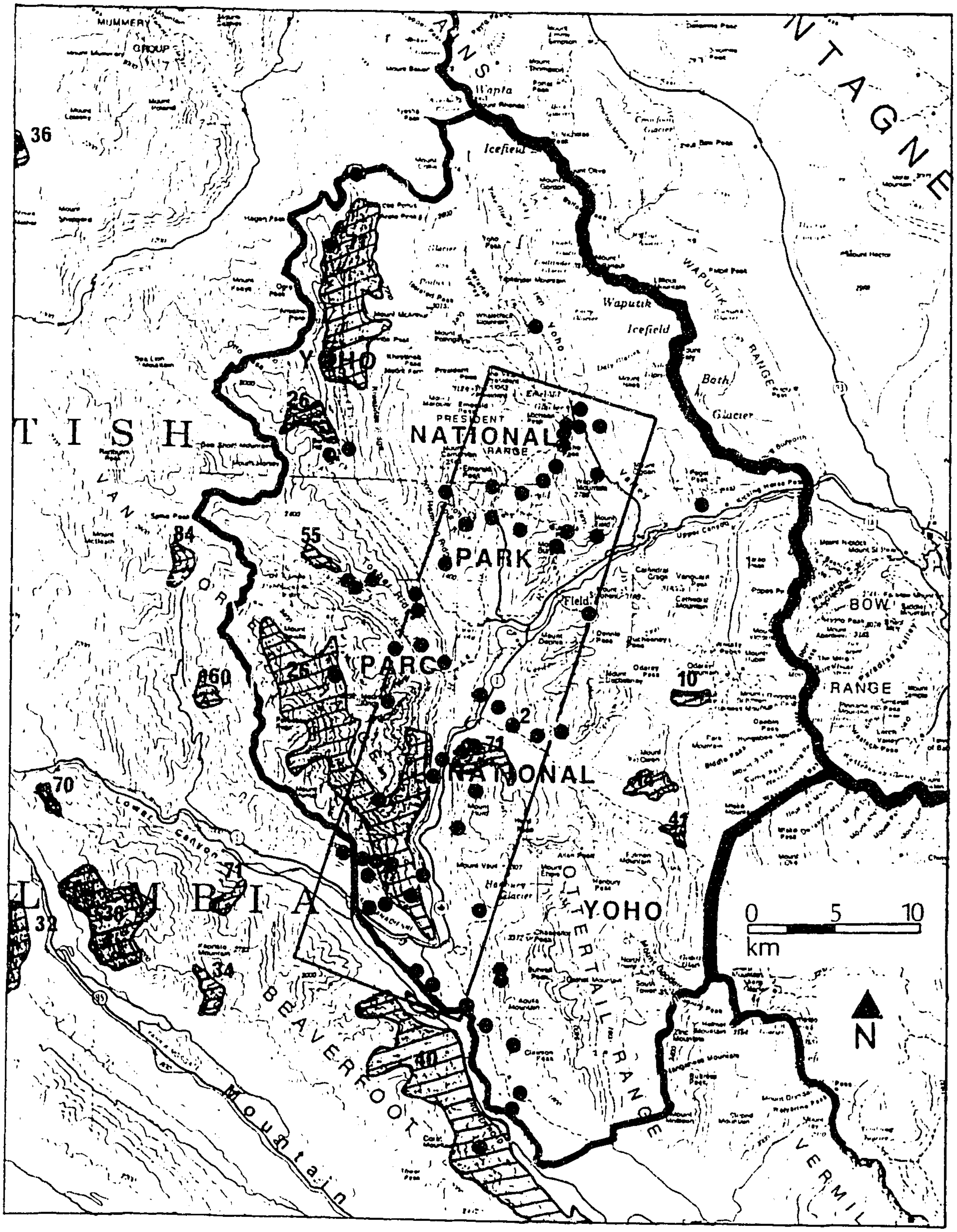

Figure 15 Known location of lightning-caused fires within or adjacent to Yoho National Park. For the larger fires, the year is given (e.g. 36 = 1936). Approximately 65 % of the fires occur within the area delineated by the rectangle.

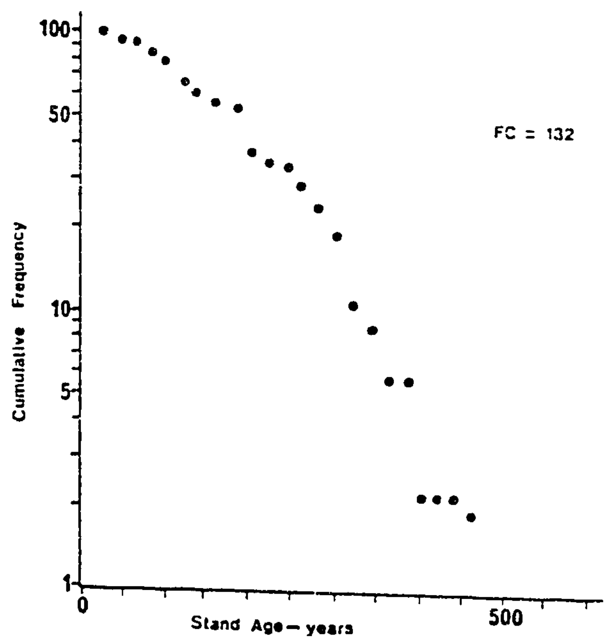

Figure 16 Unadjusted time-since-fire distribution for the whole of Yoho National Park ($r^2 = 0.847$)

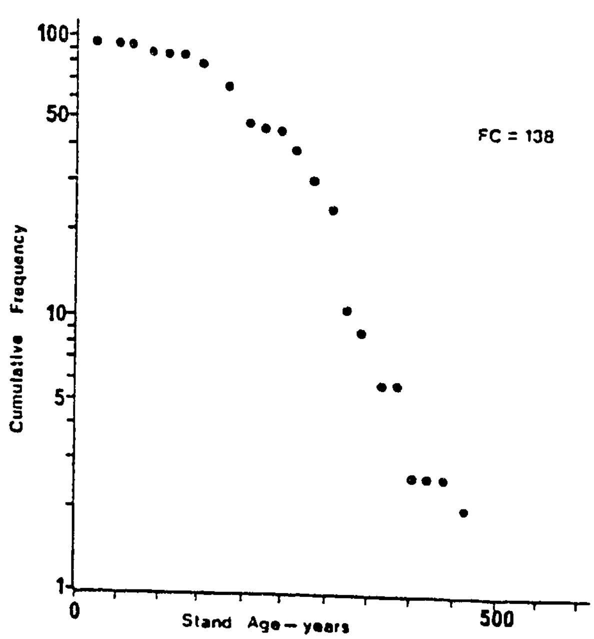

Figure 17 Adjusted time-since-fire distribution for the whole of Yoho National Park ($r^2 = 0.786$)

The time-since-fire distribution was recalculated for the eastern region of the park that includes the Yoho, Sherbrooke, O'Hara and Wenchemna drainages (Figure 7). The unadjusted fire cycle is 239 years ($r^2 = 0.797$) and the adjusted fire cycle is 254 years ($r^2 = 0.689$).

For the remainder of the park (i.e. western area that includes the Amiskwi, Emerald, Otterhead, Upper and Lower Kicking Horse, Porcupine, Ottertail, Lower and Upper Ice River drainages), the unadjusted fire cycle is 105 years (r^2 = 0.656). The adjusted fire cycle is 115 years ($r^2 = 0.588$). There is a significant difference between the regression coefficients between the eastern region of the park and the western region of the park (Student's t-test of homogeneity of regression at $p = 0.05$). The age-class distribution data for the eastern and western regions of the park also do not support the hypothesis that the distributions are identical using the Kolmogorov-Smirnov test (D = 8/12, critical value at $p = 0.01$ is 7/12).

The temporal partition of the time-since-fire distribution for the whole park resulted in unadjusted fire cycle estimates of 207 years ($r^2 = 0.461$) for the 1520 - 1739 period and 178 years ($r^2 = 0.428$) for the 1740 - 1879 period. The adjusted fire cycles are 183 years ($r^2 = 0.475$) for the 1520 - 1739 period and 176 years ($r^2 = 0.462$) for the 1740 - 1879 period.

Approximately 54 % of the total park area was classified as unburnable. These non-forested areas were comprised predominantly of rock. Small, high elevation stands that were difficult to access and sample accounted for approximately 3.6 % of the total park area. Areas classified as water accounted for less than 1 % of the total park area.

As shown in the time-since-fire distribution (Figures 18 and 19) a relatively small percentage (8.58 %) of the total forested area in Yoho National Park is comprised of stands less than 51 years old. The amount of area burned during this time period (1939 - 1989) equates to an annual burn rate over the fifty year period (i.e. in per cent of the total forested area) of 0.170 % and a fire cycle of 582 years. The majority of the area burned did however, occur during one year (i.e. 1971).

A fire cycle of 132 years (Figure 16) equates to an annual burn rate of 0.75 %. During the 1900 - 1989 period (i.e. fire suppression period) the annual burn rate was 0.228 %. The annual burn rate during the 1800 - 1900 period was approximately twice (0.426 %) this rate.

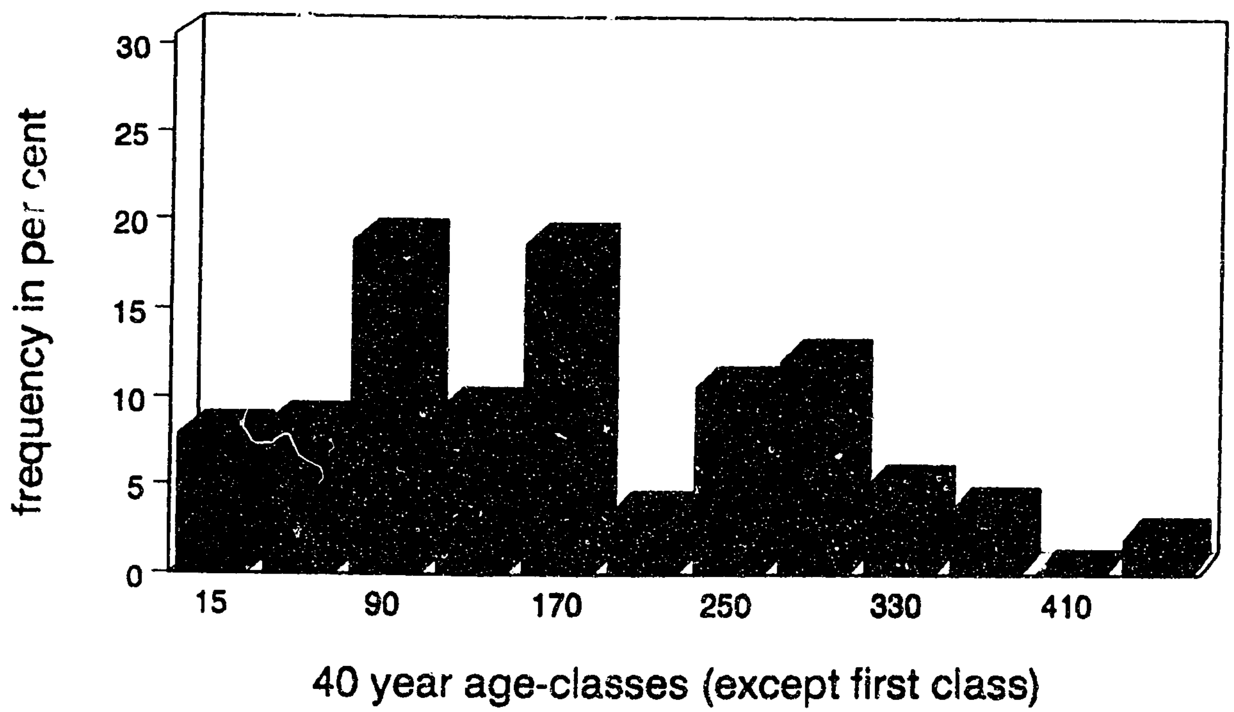

Figure 18 Age-class distribution for Yoho National Park

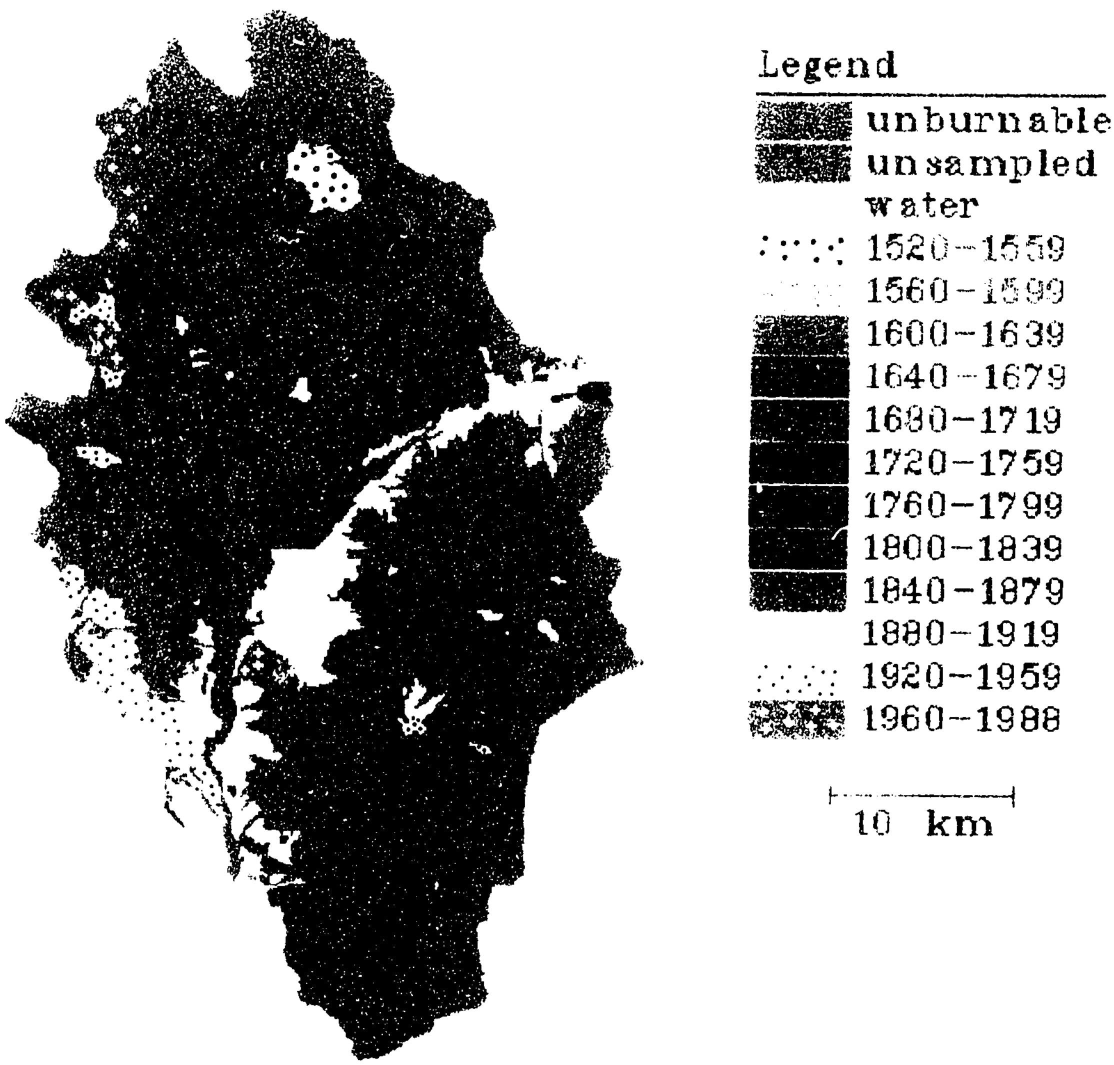

Figure 19 Time-since-fire distribution for Yoho National Park

6.6 Fire return intervals

Fire return intervals were estimated on an area-specific basis (Figure 20) from age-class and fire scar analysis (Table 4). These estimates were made initially for each drainage (i.e. watershed) and then for selected sub-units or specific areas within the drainages. The sub-units were delineated by assessing the vegetation type(s), aspect, topography and the amount and extent of fire history evidence within the drainage.

The differences in fire return interval estimates reflect differences in climate and, in some areas, varying influences from man-caused disturbances. In mountainous terrain, fuel availability, weather and topography can vary considerably, thereby affecting fire behavior. Though Yoho National Park is relatively small in area, the fire regime is not spatially uniform. Nor has the fire regime been temporally uniform.

A two (a/b) index system is used to describe the type and frequency of fires. The first interval (a) represents the mean fire return interval for large, moderate to high intensity fires. These fires are primarily stand-replacing fires. The second interval (b) represents the mean fire return interval for small to large, low to moderate intensity fires which essentially leave scars on living trees, but do

Table 4 Fire return interval estimates from age-class and fire scar analysis (major fire years are underlined, lack of data is indicated by a dash "-", a = interval for stand-replacing fires and b = interval for low to moderate intensity fires). Refer to Figure 20 for location of areas.

Drainage/ Area	Mean Fire Return Intervals (a/b)	Fire Years
Ice River		
Upper Ice	150+/-	¯<u>1834</u>, 1871
Lower Ice	120/30	¯<u>1834</u>, 1841, <u>1854</u>, 1871
Lower Kicking Horse	60/15	¯1854, ¯1872, <u>1883</u>, <u>1887</u>, 1891, <u>1914</u>, <u>1926</u>
Porcupine	250/-	¯<u>1676</u>, <u>1926</u>
Otterhead		
Tocher Ridge	90/30	¯1583, <u>1720</u>, ¯1801 1955
Upper Otterhead	250+/-	¯<u>1720</u>
Amiskwi		
Upper	120/-	¯<u>1647</u>, <u>1971</u>
Lower	70/-	¯<u>1647</u>, 1818, 1834, 1840 <u>1926</u>, <u>1960</u>
Kiwetinok	200/35	¯<u>16[illegible]0</u>, 1883
Emerald		
Emerald River/ Hamilton Ridge	90/20	¯<u>1696</u>, ¯<u>1795</u>, 1854, 1840, 1834, 1817, 1801
Emerald Lake	300+/30	¯<u>1625</u>, ¯<u>1652</u>, ¯1730, 1795, 1823, 1840, 1851
Upper Kicking Horse	80/20	¯<u>1676</u>, ¯<u>1795</u>, ¯1817, 1803, 1852, ¯1879, <u>1887,</u> 1904
Ottertail		
Lower	90/15	¯1825, 1854, <u>1887</u>, 1971
Silverslope	90/20	<u>1796</u>, 1841, ¯18[illegible]5, 1920 1929
Upper	150/20	¯1525, <u>1696</u>, 1825, <u>1828</u>, ¯1705, 1720, 1906, 1941, 1914
McArthur Creek	300+/-	¯<u>1696</u>
Float Creek	300+/-	¯<u>1696</u>
Fulmen	300+/-	¯<u>1696</u>
Yoho	320+/150	¯1595, ¯<u>1670</u>, ¯<u>1740</u>
O'Hara		
Kicking Horse Canyon	170/20	¯<u>1672</u>, ¯1720, ¯1745, 1758, ¯1775, ¯1805, 1825, 1851 1871, <u>1889</u>, 1920, 1940
Cataract Creek	300+/-	¯<u>1696</u>
Sherbrooke	280+/-	¯1720, <u>1889</u>

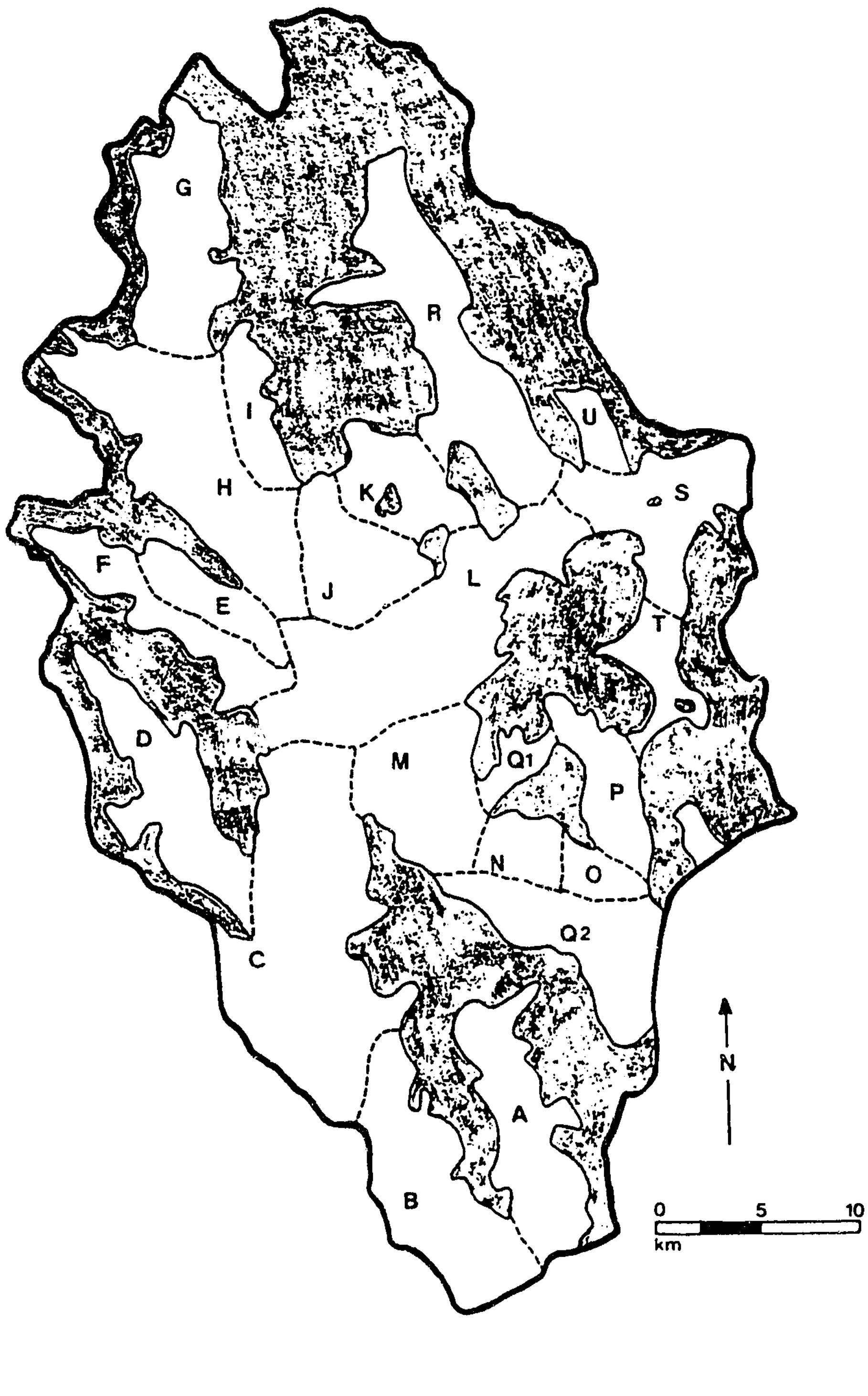

Figure 20 Location of fire return interval areas in Yoho National Park. Refer to Table 4 for listing of drainages and areas.

not cause widespread mortality.

6.6.1 Upper Kicking Horse drainage

The upper Kicking Horse drainage has a two-index fire return interval of 80/20. Large, moderate to high intensity fires have occurred an average of once every 80 years. Low to moderate intensity fires have occurred an average of once every 20 years. Other than the small, high elevation stands of whitebark pine and spruce-fir, the only old forest stands in this drainage are the Douglas-fir and spruce/Douglas-fir stands on the slopes of Mount Burgess. Douglas-fir/lodgepole pine, lodgepole pine, and lodgepole pine/spruce stands 100 - 150 years old occur throughout the montane and lower to middle subalpine zones. Major fires occurred in ~1795, 1852, 1887 and 1904. The oldest fire dated from fire scars, occurred in ~1676.

6.6.2 Emerald drainage

Extensive, uneven-aged stands of lodgepole pine/spruce occur in the Emerald drainage. A large, high intensity fire occurred in ~1795. Low to moderate intensity fires in ~1801, 1817, 1834, 1840 and 1854, have resulted in an uneven age-class structure of these stands. This drainage, excluding the Emerald Lake area, has a two index fire return interval of 90/20. The area along the Emerald river was once described as "a beautiful park-like forest of small pines" (McArthur 1887). Periodic fires of low to moderate intensity likely created this condition.

The Emerald lake area has old, mixed stands of white spruce and Douglas-fir. These moist montane forest stands also have old, scattered lodgepole pine trees. The oldest lodgepole pine tree sampled in this area was 335 years old. Lodgepole pine occurs on the north and west sides of Emerald lake but not on the east side. The open stand of lodgepole pine on the alluvial fan located north of Emerald lake is of interest because it is all-aged and regenerating in the absence of fire.

The fire return interval for high intensity fires in the Emerald lake area is 300 - 350 years. High intensity fires occurred in this area in ~1625 and ~1650. The fire scar evidence suggests that small, low to moderate intensity fires occurred in 1795, 1823, 1840 and 1851.

6.6.3 O'Hara drainage

The O'Hara drainage includes the upper Kicking Horse Canyon. The 1889 Kicking Horse Canyon fire was a large, high intensity fire that burned from Monarch creek on Mount Stephen, across the Continental Divide and into the Bow valley. This fire also burned approximately 3.5 km up the Cataract valley. Large stands of residual spruce/fir approximately 270 years old, occur near the divide (Figure 21).

No evidence of fire was found in the upper subalpine stands of alpine larch and subalpine fir in the Lake O'Hara region, other than a few individual trees that appeared to have been struck by lightning. The upper Kicking Horse Canyon has a two index fire return interval of 170/20. Fires occurred within this drainage in ~1672, ~1720, ~1745, 1758, ~1775, ~1805, 1825, 1851, 1871, 1889, 1920 and 1940. The 1672 and 1889 fires were large, high intensity fires. Only one lightning caused fire was reported in this drainage during the 1910 - 1988 period. The upper Cataract valley has a fire return interval of 300+ years.

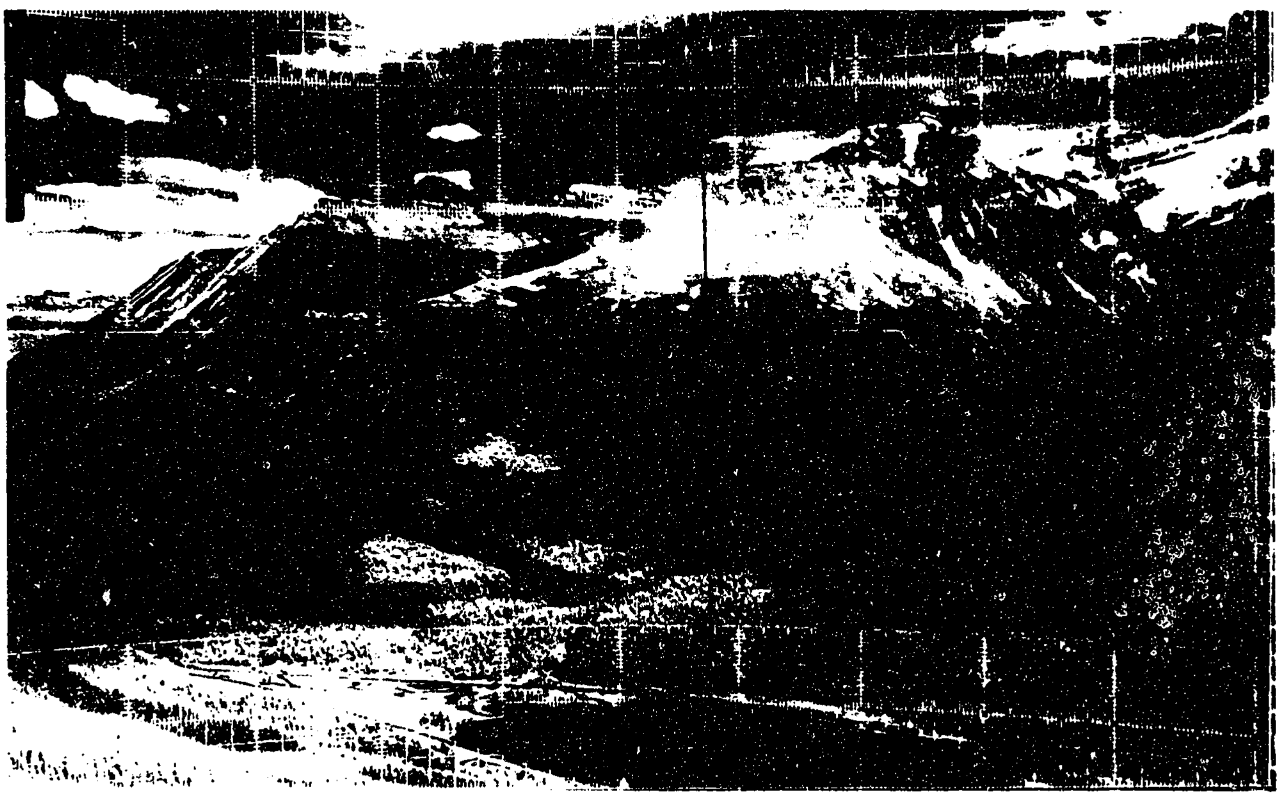

Figure 21 Kicking Horse Canyon post-fire lodgepole pine stand (Wapta lake in the foreground and residual spruce-fir stands to the left) (photo was taken in 1963 - photographer unknown)

6.6.4 Amiskwi drainage

In 1971, lightning started the Amiskwi fire, a large, high intensity fire that first burned in a stand of mature spruce approximately 275 years old, and then entered slash fuels from the lower block of timber berth #406. The Amiskwi fire burned the entire upper valley. This fire destroyed any evidence of earlier fires.

The upper Amiskwi valley has a fire return interval of 250 years. The lower Amiskwi valley has a fire return interval of 70 years. Fires occurred in the lower Amiskwi valley in 1818, 1834, 1840, 1926 and 1960. During the 1910 - 1988 period, nine small lightning fires were reported to have occurred in the Amiskwi drainage.

6.6.5 Sherbrooke drainage

The forests within this small drainage are predominantly 250 year old spruce/fir stands. The 1889 Kicking Horse Canyon fire burned the lower slopes of Paget Peak and Mount Ogden, in the lower portion of this drainage. Lodgepole pine has regenerated on these slopes. At higher elevations, a mixture of lodgepole pine and whitebark pine have seeded in. During the 1910 - 1988 period only one small lightning caused fire occurred within this drainage. The fire return interval for this unit, is 250+ years.

6.6.6 Otterhead drainage

Lodgepole pine/spruce/fir stands occur on the north side of Otterhead creek in the lower Otterhead valley. The lower Otterhead (Tocher Ridge) unit has a two index fire return interval of 90/30. The remainder of the valley is comprised of spruce/fir forest stands and has a fire return interval of 250+ years. During the 1910 - 1988 period, six lightning caused fires were reported to have occurred within the Otterhead drainage. The only major fire during this period occurred on Tocher Ridge in 1955. Before this period, major fires occurred in ~1720 and ~1801.

6.6.7 Yoho drainage

Extensive and very old spruce/fir stands occur in the upper Yoho valley north of Lake Duchesnay. These ancient forest stands are 400 - 450 years old. No evidence of fire was found in these stands.

The forest stands in the little Yoho valley are predominantly 200 - 250 year old fir stands. Spruce/fir stands occur from Lake Duchesnay south to Takakkaw falls. These stands are approximately 300 years old. Spruce/fir stands approximately 250 years old occur from Takakkaw falls south down the valley for about 4.5 km. Spruce/Douglas-fir stands approximately 250 - 300 years old occur along the east side of the lower Yoho valley. Spruce/fir stands approximately 175 years old occur along the west side of the lower Yoho valley.

The fire return interval for the upper Yoho valley is very long (400+ years). A two index fire return interval of 250+/150 is estimated for the middle and lower portions of the Yoho valley.

A small stand of self-regenerating lodgepole pine surrounded by spruce/fir forests occurs on an alluvial fan near Takakkaw falls. The oldest lodgepole pine tree in this stand is 393 years old.

Six small lightning caused fires were reported in the vicinity of Yoho Pass during the 1910 - 1988 period. Only one other small lightning caused fire was reported in this drainage.

6.6.8 Ottertail drainage

The Float creek, McArthur and Goodsir drainages are included in this unit. The forest stands in these secondary valleys are predominantly spruce/fir. Stands of whitebark pine and subalpine fir occur in the upper subalpine zone. The spruce/fir forest stands ranged in age from 250 - 350 years. There is little evidence of fire in these valleys. Only one lightning caused fire was recorded in these secondary valleys during the 1910 - 1988 period. It occurred on the upper slope of Mount Odaray in 1910.

Extensive evidence of fire was found throughout the remainder of the Ottertail drainage, excluding the spruce/fir stands bounded by Silverslope creek, Fulmen mountain and Goodsir creek. In the upper Ottertail valley, fire evidence was found north of the Ottertail river. No fire evidence was found in the upper Ottertail valley, south of the Ottertail river. A 150/20 two index fire return interval was calculated for the upper Ottertail valley. Old lodgepole pine trees with multiple fire scars were found scattered throughout mid-elevation Douglas-fir/spruce stands. The age obtained from the section of one of these trees was 461 years. This is the oldest documented age of a lodgepole pine tree in North America. Major fires occurred in the upper Ottertail in ~1525, ~1705 and 1828.

During the 1910 - 1988 period, fires greater than 50 ha in size occurred in the Ottertail drainage in 1914, 1920, 1929, 1941 and 1971. In total, ten lightning-caused fires have been recorded to have occurred in this drainage during the 1910 - 1988 period.

6.6.9 Lower Kicking Horse drainage

Major fires occurred within the lower Kicking Horse drainage in ~1854, ~1872, 1883, 1887, 1891, 1914 and 1926. Forest stands of lodgepole pine and mixed stands of lodgepole pine and spruce and lodegpole pine and Douglas-fir are common in the montane and subalpine zones within this drainage. Small residual stands of Douglas-fir and Douglas-fir/spruce occur along the Van Horne and Ottertail Ranges. These older stands are approximately 300 years old.

Fourteen lightning caused fires were recorded to have occurred within this drainage. The majority of these fires occurred on the southeast ridge of Mount Hunter. The lower Kicking Horse drainage has a two index fire return interval of 60/15. This index indicates that high intensity fires occur an average of once every 60 years and low to moderate intensity fires have occurred an average of once every 15 years.

4.6.10 Porcupine drainage

In 1926, a high intensity fire burned through the entire Porcupine drainage and along the slope of Mount Hunter and the Van Horne range. The spruce/fir forests that burned in the Porcupine valley were described as being thickly timbered. The age of the forest stands that burned is estimated to have been approximately 300 years old. During a two-day period, the crown fire travelled approximately 13 km down the valley. This fire destroyed any evidence from previous fires. No evidence of fire other than the 1926 fire, was found in the Porcupine valley. High elevation stands of spruce/fir that were not burned, occur along the southwest (i.e. northeast aspect) side of the valley.

Evidence of the 1926 fire was found throughout the narrow V-shaped valley, including the avalanche paths. Very few trees in the valley bottom survived the fire. The largest component of deciduous and mixed forest stands in the park, occur in the lower Porcupine valley.

The fire return interval in this drainage is estimated to be 250 -300 years. During the 1910 - 1988 period, a total of three small lightning caused fires were recorded to have occurred in this drainage.

6.6.11 Ice river drainage

The age-class and fire scar data suggest that the upper Ice river valley was subjected to two fires of moderate to high intensity. The first fire occurred around 1834 and the second fire around 1871. The subalpine forest stands throughout this valley are predominantly post-fire spruce stands. A few lodgepole pine trees were sampled. Their ages correspond to the first disturbance.

Fire scar evidence from a low to moderate intensity fire in ~1862 was found in the north end of the valley. A few isolated trees with fire scars were found in the south end of the valley suggesting the occurrence of small local fires in the valley bottom in 1898 and 1929. There is no evidence suggesting the occurrence of frequent, low - moderate intensity fires in this valley. No lightning caused fires have been recorded to have occurred in the upper Ice river valley during the 1910 - 1988 period. A fire return interval of 150+ is estimated for this valley. The fire history evidence obtained from this valley was insufficient to develop a two index fire return interval.

In the lower Ice river valley (i.e. Beaverfoot) fires occurred in ~1834, 1841, 1854 and 1871. Seven small lightning caused fires were recorded in this valley during the 1910 -

1988 period. Post fire stands of Douglas-fir/lodgepole pine, lodgepole pine/Douglas-fir, White spruce/Douglas-fir and White spruce/Douglas-fir/Lodgepole pine are common in this valley. Some of these middle elevation stands form a mosaic with smaller residual (i.e. older) stands of White spruce/Douglas-fir, Douglas-fir and Douglas-fir/Spruce that escaped the fires. Considerably more fire scar evidence was found in the lower Ice river valley than in the upper Ice river valley. A two index fire return interval of 120/30 is estimated for the lower Ice river valley.

6.7 Influence of man-caused fires in the Kicking Horse corridor

A review of the historical documentation and analysis of the fire scar and stand age data indicate that the majority of the Kicking Horse Corridor burned during the 1883 - 1915 period. This period coincides with the construction and early operation of the Canadian Pacific Railway and logging and mining activities within the park. Large areas throughout the Kicking Horse valley burned as a result of fires in 1883, 1884, 1887, 1889, 1904, 1914 and 1915. Though not all of the evidence can be substantiated, the historical documentation suggests that most of the fires were man-caused. The 1887 and 1914 fires were determined to have been man-caused. The 1883, 1884, 1889, 1904 and 1915 fires were determined to have been specifically railway-caused.

The adjusted fire cycle (parameter b in equation [4]) for the whole of Yoho National Park, using an age reclassification for areas burned by man-caused fires, is 138 years. The age reclassification removes the effect of known man-caused fires on the time-since-fire distribution. There is no significant difference (at P = 0.05) between the unadjusted fire cycle (FC = 132) and the adjusted fire cycle (FC = 138). This suggests that human influences (i.e. man-caused fires) in the "large picture" have not been significant. However, the impact of man-caused fires within the Kicking Horse Corridor has been significant. Approximately 80 % (12/15) of the reclassified polygons on the stand origin map that represented areas burned by man-caused fires were located within the Kicking Horse Corridor.

7. DISCUSSION

7.1 Climate and fire weather

Long term changes (i.e on a time scale of thousands of years) in the development of vegetation are predominantly a function of climate which over the long term is characterized by change. The palaeoclimatic reconstruction of the upper Cataract creek valley in Yoho National Park suggests that climatic fluctuations strongly controlled the vegetation development following deglaciation 10,000 years ago (Reasoner 1988). From 8,500 to 7,000 B. P., the treeline advanced to a higher elevation (Figure 22). A small gradual retreat in the treeline occurred during the 7,000 - 3,000 year period. Glacial activity was renewed during the period starting 3,000 years ago. As the climate became warmer and drier, lodgepole pine invaded new areas. Douglas-fir also established itself and increased in dominance.

Dendroclimatic reconstruction (Luckman *et al.* 1985) and reconstruction of glacial activity during the "Little Ice Age" (Luckman 1986, Osborn and Luckman 1988) in the Canadian Rockies, suggest that a change in climate occurred around 1700 A. D. A warm, dry climate and treeline re-advance were prevalent from ~1500 to ~1700 A. D. From 1700 to present, the climate was relatively cooler and wetter. The cooling period

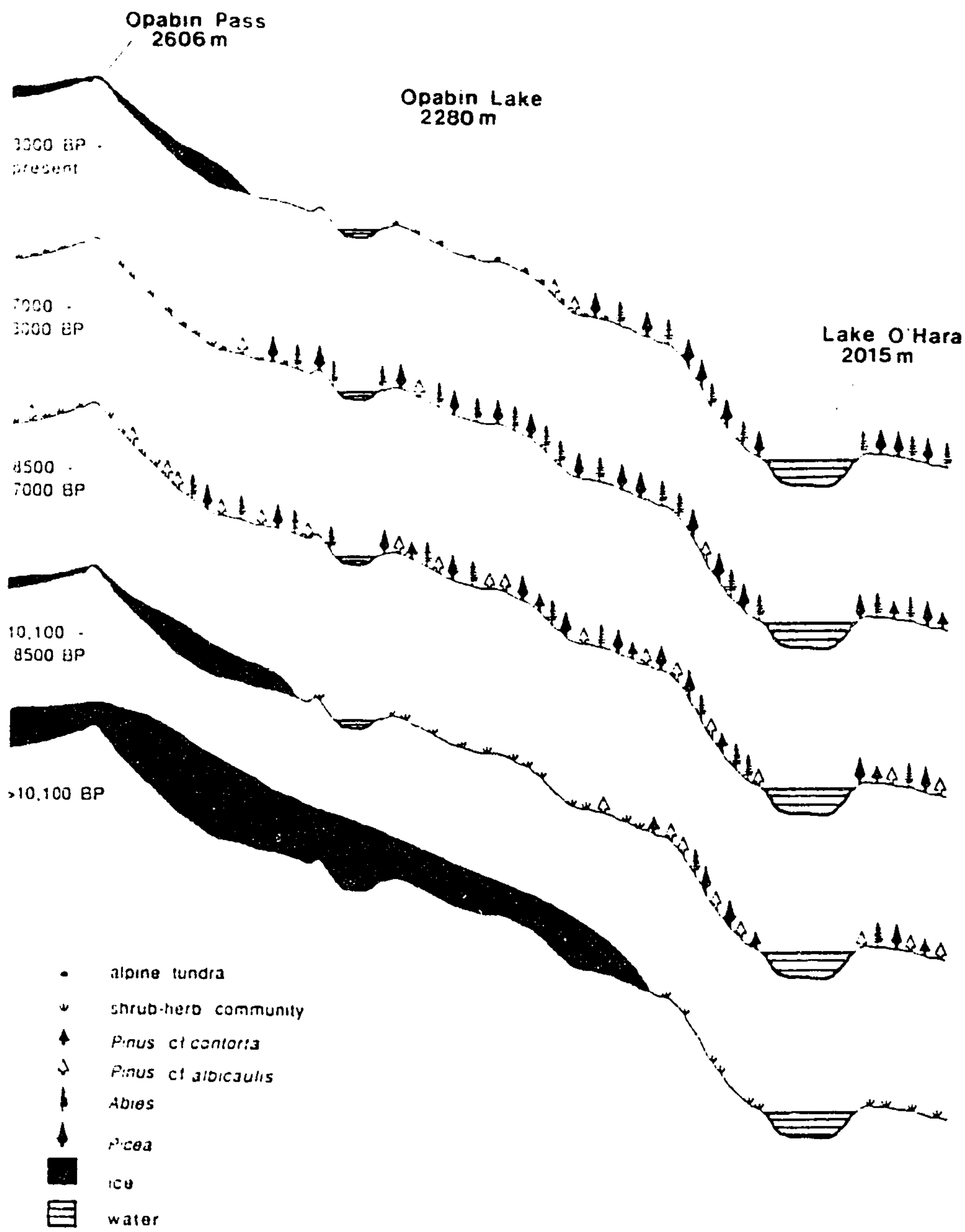

Figure 22 Vegetation development following deglaciation in the upper Catarack creek valley (modified from Reasoner 1988)

known as the "Little Ice Age" began after 1100 A. D. and ended in the mid 1800s. A short,high treeline period occurred from 700 - 1100 A. D., prior to the "Little Ice Age".

The change in climate that is suggested to have occurred around 1700 A. D. is not reflected in a significant difference between the fire cycle estimates for Yoho National Park for the 1520 - 1739 and 1740 - 1889 periods.

With relatively constant climatic conditions, short term changes (i.e. on a time scale of 10 - 300+ years) in the development of vegetation are a function of one or a combination of insects, disease, fire, wind (i.e. blowdown), snow (i.e. avalanches) and wildlife. Of these biotic and abiotic disturbances, fire is the most predominant natural process that affects the vegetation structure and mosaic within Yoho National Park. In the Yoho and Little Yoho valleys, precipitation (i.e. snowfall) and avalanche activity may be the predominant short term processes that affect the development of vegetation. Further investigation is required to determine the significance of these processes and their role in the development of vegetation.

A climate reconstruction from X-ray densitometric analysis of Douglas-fir tree rings at Banff (Robertson and Jozsa 1988) suggest that extreme drought years (i.e. 50% or less of mean

June and July precipitation) occurred an average of once every 35 years from 1800 to 1980. The Banff June and July precipitation reconstruction suggests that from 1800 to 1900, drought during June and July occurred in 1814, 1817, 1841, 1861, 1881 and 1883. The fire scar and stand age analysis in Yoho National Park indicate that major fires occurred in ~1817, 1841, ~1861 and 1883.

Dendrochronology studies may be useful to correlate reconstructed climate variables with fire occurrence. Unfortunately, there has been very little research to investigate the possible correlation of ring-width, or maximum latewood density chronologies with the occurrence of fires or the correlation of the frequency of drought years with estimated fire return intervals. Hawkes (1979) found that years of major fire activity (> 1000 ha) in Kananaskis Provincial Park correlated with the maximum latewood density chronology for Engelmann spruce at Peyto Lake, Alberta (Parker and Henoch 1971).

As changes in climate occur over time, the fire regime for a particular area will also change. The fire environment, and hence the fire regime, are not static. Resource managers are challenged with managing resources that are in affect, "moving targets". This challenge is further complicated if global climate changes (i.e. warming) and corresponding sudden shifts in climate (i.e droughts and floods) occur and alter fire environments (United States 1990).

In Yoho National Park, the greatest fire danger and the majority of the fires and area burned since 1900, have occurred during the month of August. Large fires can occur during normal climatic conditions if drought conditions persist for a relatively short period (e.g. two weeks) and high winds occur resulting in high rates of spread. Drought conditions, lightning activity and high surface winds are the common variables that when combined, usually result in large fires.

During periods of extended drought, extreme fire behavior can occur as the amount of fuel available for consumption increases. The Buildup Index (BUI) is a good indicator of the relative amount of fuel available for consumption by a fire. The extreme value statistic analysis of BUI values for Yoho National Park suggests that within a 200 year return period, there is a 95 % probability that conditions similar to the 1988 Yellowstone National Park fire season (i.e. BUI = 212) will occur. BUI values over 200 are representative of extremely explosive fire behavior conditions. Extreme drought conditions are probable events and if an ignition source is available (at the right time and place) large high intensity fires will occur. High intensity fires are however also possible within shorter return periods.

7.2 Fire return intervals

Wildland fires have been a pervasive force and renewing agent in the landscape that is now protected as Yoho National Park, since the last period of deglaciation, over 10,000 years ago. Area based fire return interval estimates using age class and fire scar analysis indicate that a range of fire return intervals occur in Yoho National Park. This range in fire return intervals is, in part, a result of the range in the incidence and distribution of precipitation and lightning. Different types and sizes of fires have also occurred historically within Yoho National Park. These include stand replacing (high intensity), stand damaging (low to moderate intensity) and stand non-damaging fires (low intensity). Within the montane zone where lodgepole pine/spruce (Engelmann and White) forests are common, the fire behavior is typically characterized by two extremes, either high or low intensity.

Stand-replacing fires are generally large, high intensity, high severity stand destroying fires that occur in both montane and lower subalpine vegetation types. The location and extent of historic stand replacing fires in the Kicking Horse Corridor in Yoho National Park, suggest that during extreme fire behavior, aspect and elevation have little or no affect on the fire behavior (i.e. spread). Large, high intensity fires occur during the months of July and August and are associated with periods of prolonged drought. In some of the secondary valleys (i.e. Ottertail, Otterhead, Cataract and Kiwetinok), the location and distribution of lodgepole pine trees and fire scar evidence, suggest that aspect may affect the extent and distribution of fire. This trend was particularly evident in the upper Ottertail and Otterhead valleys. Fire scar evidence was found only on the east and north sides of the Ottertail and Otterhead rivers. This relationship requires further study since the location of fire history plots and stand age data sites was not stratified to assess the effects of aspect or elevation. In Kananaskis Provincial Park, Hawkes (1979) found that high elevations and north aspects had significantly longer mean fire return intervals.

S[illegible]-damaging fires have generally not exhibited extreme fire [illegible] or attained large size. Variable fire behavior and fi[illegible]s are common. These moderate to high intensity fires do [illegible] completely destroy the stand (i.e. overstory vegetation). In Yoho National Park, this fire behavior and fire effects have commonly occurred at the edges of high intensity fires. This is particularly evident in the middle to upper elevation sites in the lower Ice river and Ottertail valleys where the fuel and topographic conditions result in lower fire intensities.

Fire evidence from all types of fire are usually aggregated to estimate fire return intervals. Fire intervals however have limited significance from an ecological perspective if the intervals are not area based. It is relatively easy to estimate areas burned by high intensity fires but much more difficult to evaluate the area burned by low to moderate intensity fires within mountainous terrain. This study utilized a two index fire return interval system to describe both the mean interval of fires and the type of fires. The system is also applied on an area basis.

The majority of the area burned by lightning-caused fires from 1910 to 1988 within and adjacent to Yoho National Park occurred on the west side. This side also receives the least amount of total precipitation.

Very few lightning-caused fires occur in the eastern portion of the park. Preliminary analysis of the B. C. lightning location system data suggests that the west side of the park receives a greater incidence of lightning strikes than the east side. Lightning strikes have occurred and caused fires in the eastern portion of the park, but these fires are not common. They generally become self-extinguished and burn very little area.

The location of fire lookout towers in the Kicking Horse corridor prevented the detection of lightning fires in the Upper Ice river, McArthur, Upper Amiskwi, Little Yoho and Upper Yoho valleys. The location of known lightning-caused class A fires is therefore biased by the location of the fire lookout towers. Nevertheless, since 1900, only one lightning-caused fire larger than class C has occurred on the east side of the park.

7.3 Time-since-fire distribution

The time-since-fire distribution for Yoho National Park indicates that fire has created a mosaic of age-classes. Other than the 60 ha Amiskwi fire in 1985, there has been no significant area burned since 1971. As a result, there is little area in the 0 - 20 year age-class. The low percentage of forest stands in the young age-class was also found in other studies in the Rocky Mountains where a fire control capability had been developed (MacKenzie 1973, Tande 1977, White 1985).

The time-since-fire distribution for Yoho National Park does not follow the typical pattern of some of the other time-since-fire distribution studies that have a relatively high percentage (i.e. 50 % or more) of the forest stands in a single age-class (Mackenzie 1973, Tande 1977). The pattern however is very similar to the time-since-fire distribution for Kootenay National Park (Masters 1990). Approximately 54 % of the forest stands in Kootenay National Park are in the 60 - 179 year age-class compared to 47 % for Yoho in the 70 - 189 year age-class.

The time-since-fire distribution and fire scar data suggest that fire activity within Yoho National Park was greater before the fire suppression period which began formally in 1910.

7.4 Effects of man-caused fires

The comparison of adjusted and unadjusted time-since-fire distributions for the whole park suggest that man-caused fires have not had a significant effect on the forest age-class structure in Yoho National Park. However, when the data are analyzed for the park as a whole, the influence of man-caused fires in the Corridor is masked. The majority of the man-caused fires have occurred within the Kicking Horse Corridor (in the montane and lower subalpine zones). Man-caused fires during the 1883 - 1919 peri d have contributed to altering the age-class structure of the forests within the Kicking Horse Corridor.

Since the Kicking Horse Corridor includes portions of nine of the thirteen watersheds within the park, it was not possible to quantitatively assesss the effect of man-caused fires by analyzing the data on a drainage basis.

Further, the significance of change (i.e. adjusted vs unadjusted time-since-fire distribution) is measured by comparing the present age-class of the forests to what the age-class structure would have been if the man-caused fires had not occurred. This assessment of change does not consider the probable ecological effect of man-caused fires that were suppressed (i.e. what would have been the area burned if these fires were not suppressed). The majority of the 241 fires reported in Yoho National Park from 1910-1988 were small fires (ie. class A fires) that were suppressed using park fire fighting resources. Some of these fires became extingushed without the requirement of any suppression action. Other fires may have later developed into large, high intensity fires if they had not been suppressed.

7.5 Limitations of study

a) As the fire chronology is extended back in time, it becomes increasingly difficult to find evidence (ie. fire scars) in the field. Later fires tend to destroy the evidence from earlier fires. Because the fire scar evidence is weighted (ie. to more recent fires) it is difficult to estimate fire years and fire return intervals for the period before 1700.

b) When the pathological longevity of trees is reached, decay prevents the accurate ageing of trees. The maximum longevity of trees also limits the length of fire chronologies.

c) The dominant trees were cored at DBH and a site/species age-correction factor added to determine the age. A comparison of these ages with ages obtained from basal cross-sections indicated that in the montane zone there was little or no deviation. However, in the subalpine zone two factors have an influence. Longer regeneration lags increase the time interval between the burn and tree age. Slower growth may also result in errors in age estimates if cores are not taken at the base. It is more accurate to obtain increment cores as close as possible to the base (ie. point of germination) to minimize errors in ageing.

d) In other studies, fire history sample units are generally stratified to allow estimation of fire return intervals between different elevation sites and vegetation or habitat types. The lack of fire scar evidence (ie. sample trees) in Yoho national park, size of the study area, and the time constraints of the study did not allow for detailed stratified sampling.

e) Reconstructing the fire history of large areas is difficult. Arno & Peterson (1983) suggest that estimates of fire intervals become shortened as the number of sample points (ie. fire scarred trees) used to create a master fire chronology, increase. Also, larger areas have shorter fire return intervals because more fires may be included within it. The constraints and limitations (financial, manpower, time and logistical factors) of fire history studies often determine the level of sampling that is carried out.

Fire evidence from small fires (ie. spot fires) causes problems if it is included in the fire return interval calculations. It is therefore important to use common fire scar evidence from two or more sample trees. During this study, effort (i.e. field investigation) were made to estimate the areal extent of fires. The use of age-class data (i.e. regeneration pulses) provided additional information to assist in estimating the size of fires. To prevent the "lumping" of evidence from all types of fires, it is useful to use a two-index or even a three-index system to describe both fire type and fire return interval.

It is relatively easy to determine the boundaries and size of high intensity stand replacing fires. It is the low to moderate intensity fires that are more difficult to reconstruct and map.

f) This study did not investigate the relationships between fire and insects and disease, and fire and logging. It is interesting to note, however, that the majority of the logged forest stands cut within the designated timber limits within Yoho National Park were later subjected to fire.

It is known that recurrent outbreaks of Mountain Pine Beetle have occurred in Yoho National Park. These infestations and subsequent sanitation and salvage cutting in the 1930's and 1940's changed the composition of the stands in the Leanchoil area by removing the lodgepole pine component.

g) This study was not able to determine in detail, the qualitative or quantitative role of native-caused fires in the historic fire regime within and adjacent to Yoho National Park. The historical and archaeological evidence does however suggest that the area that is now Yoho national park was not a good settlement area for early natives. The topography, vegetation, climate and lack of abundant wildlife deterred early natives from establishing permanent encampments. Areas to the west of the park (i. e. Beaverfoot, Columbia valleys) provided more favourable conditions for early native settlement. The evidence that is available indicates that the west side of the park was used as a seasonal travel corridor by the Kootenai Indians. Evidence of three native campsites near the confluence of the Emerald, Amiskwi and Kicking Horse rivers suggest that Kootenai Indians used temporary campsites around 1792 to 1802 (Loy 1972). The Kootenai Indians used the Beaverfoot, Kicking Horse and Amiskwi valleys as routes to reach Howse Pass and onwards to the "Kootenai Plains".

The high intensity fire behavior that is typical of the pine and spruce forests in Yoho National Park provides a strong argument that intentional burning by natives would not have been purposeful in clearing and facilitating travel, particularly if horses were used. Barrett (1981) found that frequent native-caused fires were an important ecological influence on the forests in western Montana, before 1860. These fires however, were often in low elevation ponderosa pine/Douglas-fir forests or grasslands which do not occur in Yoho National Park.

Despite the lack of evidence suggesting that native-caused fires ecologically influenced the forests in Yoho National Park, the possibility that some of the fires that occurred in the Lower Kicking Horse, Ottertail, Emerald and Amiskwi drainages before 1880, could have been caused by natives during their travels through the park, cannot be completely dicounted.

8. SUMMARY AND CONCLUSIONS

8.1 Fire's influence on vegetation in Yoho National Park

Fire has played an important role in influencing the development of vegetation in Yoho National Park. The long fire return intervals (250+ years) on the east side of Yoho National Park have allowed the spruce-fir forests to evolve for many years in the absence of fire. These stands have many of the attributes characteristic of old growth forests in the Pacific northwest. Large, high intensity fires can occur in these stands during extreme drought years. The eastern portion of the park receives the greatest amount of precipitation.

Although the fire return intervals for the western portion of the park vary depending on the watershed, they are on the whole, considerably lower than the eastern portion of the park.

Hypothesis number one (Ho_1) was rejected. The time-since-fire distribution for the eastern region of the park is significantly different than the time-since-fire distribution for the western region of the park.

Hypothesis number two (Ho_2) was accepted. There is no significant difference between the unadjusted cycle fire and the adjusted fire cycle for the whole of Yoho National Park.

Hypothesis number three (Ho_3) was accepted. There is no significant difference between the fire cycles for the 1740 - 1879 and 1520 - 1739 periods.

The fire evidence from the western portion of Yoho National Park indicates that the fire regime consists of stand-replacing, stand-damaging and stand non-damaging fires. Fires have also occurred that exhibit fire behavior and fire effects that are characteristic of all these types of fires. Since 1910, with the exception of the 1929 man-caused fire in the Ottertail valley, low to moderate intensity fires have not been large in size. The fire scar and age-class analysis suggest that low to moderate intensity fires that spread over large areas (i.e. $\geq$ 200 ha) did occur prior to 1910. Fire suppression efforts have been relatively successful in controlling these fires and hence the total area burned by these types of fires has been ecologically insignificant at the landscape level. Before 1910, these fires burned more frequently and burned over larger areas.

Fire is the single most important natural disturbance that affects the development of vegetation. However, while fire initiates the process of vegetative succession, other site factors (i.e. effective moisture conditions of the site, seed source availability) are also important. Most fire effects studies have focused on describing post-fire communities resulting from single fire events. Little is known about the long term successional response and development of forest stands resulting from different fire regimes and the short term and long term cumulative effects of different fire regimes.

8.2 Implications for fire management

Within the national parks, all fire management activities are detailed in approved fire management plans. The present fire management program in the Canadian Parks Service consists of a combination of effective fire control and the use of planned ignition (i.e. prescribed) and random ignition (i.e. lightning) fires to attain specific resource management objectives. Although the Canadian Parks Service has adopted a fire management program that emphasizes vegetation management through the use of planned ignition fires, the ability to model and predict vegetation response, particularly from cumulative fire effects, is limited. It is difficult to predict the long term effect of different fire regimes on the vegetational succession. If the Canadian Parks Service focuses on fire effects (i.e. "structure") rather than fire cause (i.e. "process"), fire effects research is required to develop a greater knowledge and understanding of fire effects and to develop short and long term fire succession models. Further study is required to provide fire effects information that can be used in succession modelling. In Yoho National Park, a variety of sites are relatively accessible to study vegetation succession (i. e. composition and stucture) resulting from a range of fire regimes.

If global warming occurs and temperatures increase, changes in the fire environment and the fire regime will occur. The frequency of larger and more intense fires will likely increase if these changes in climate occur along with decreased precipitation. The values at risk within and adjacent to national parks therefore need to be re-assessed. Fire history studies are useful because major fire activity years (i.e. large, high intensity fires) can be identified and correlated with climate (i.e. drought years). These studies are useful because they identify what may be considered as the "worst case scenario". If very large, high intensity fires occurred in the past, they will likely occur again if similar conditions in the fire environment occur. With global warming, the probability of catastrophic fires will increase.

The Canadian Parks Service should recognize that global warming will affect the fire and vegetation management programs in the national parks. Further study is required to develop strategies that will address this problem. The following fire management recommendations should also be considered:

1. Maintaining an effective fire control capability will continue to be of paramount importance to the success of a fire management program. Considerable progress has been made in the last three years as part of a national initiative to upgrade fire management expertise and capabilities in the national parks. A commitment for further funding and training is required to ensure the long term success of fire and vegetation management in the national parks. Continued fiscal constraint will require parks to share resources, develop cooperative studies, programs and partnerships, and develop creative and innovative solutions to overcome the obstacles to effective fire management.

2. If there are no or minimal public safety concerns and values at risk within a fire management unit, preference

should be given to allowing lightning-caused fires to occur withou any interference except for the monitoring of these fires. In some units pre-defined prescriptions based on the CFFDRS, site conditions and fire history may need to be applied. The use of random ignition fires is cheaper and ensures minimal interference with fire and its natural role within the ecosystem. Within Yoho National Park, opportunities (i.e. sites) occur for allowing the use of random ignition fires in the secondary valleys.

3. One of the major obstacles to the Canadian Parks Service fire management program is that fire history studies in the Canadian Rockies have shown that large, high intensity fires are the main component of the fire regime. The constraints and limitations of using large, high intensity prescribed fires within many areas, are presently too severe. A comitment to provide the necessary resources to adequately implement prescribed burning programs is also required. A number of options to resolve this problem should be considered:

3.1 Allow the use of high intensity prescribed fires that are smaller in area (i.e. divide or block a unit). By burning yearly or over a short period of time, the total cumulative area burned and effects of the fires may approximate the area burned and the fire effects associated with a large fire. The burned areas can be used as fuel breaks for future prescribed burns.

Further study is required to determine whether smaller, moderate to high intensity fires produce the same or similar ecological effects as large high-intensity fires.

3.2 It is inevitable that some fires will escape initial attack and continue to burn out of control regardless of the suppression resources available. It is therefore important that values-at-risk be considered or protected in anticipation of a worst case scenario occurring. Strategies to eliminate or minimize the loss or damage to values at risk may not be necessary if a cost effectiveness analysis demonstrates that the loss or damage is acceptable. For example, indirect attack on a wildland fire may be more effective and safer than direct attack. Although a backcountry cabin or facility may be destroyed, it may be cost effective to replace it rather than suppress a fire directly and expend resources to protect the facility. At the same time, an assessment of the values-at-risk and the potential for having an uncontrollable fire may warrant consideration of the removal and/or relocation of the values at risk. Many facilities were built without an awareness or knowledge of the fire environment that surrounds them or of the park's fire management policy.

If some fires are going to escape initial atttack and develop into campaign fires, having a good evacuation plan and effectively executing the evacuation operations, are a priority. During the 1988 Yellowstone fire season, considerable expenditures were made in effort to suppress the wildland fires. Considerable discussion and debate occurred after the fires, of the ineffectiveness of these massive expenditures and the need to initiate strategies to minimize the loss and damage of facilities and investments within the park before large fires occur.

3.3 Fuel management strategies such as fuel removal (i.e. fire breaks) and fuel reduction (i.e. stand thinning) have been initiated near townsites and facilities but little has been completed compared to what is required. Fuel management practices should be based on fire science principles (i.e. predicted thresholds for sustained crowning). It is also important to know the limitations of implementing fuel management strategies.

3.4 The principles of fire containment and fire confinement allow for a relaxation of fire control standards and should be included when developing fire management strategies for each fire management unit.

3.5 There is some urgency to implement a comprehensive fire management program in Yoho National Park. Conducting planned ignition (i. e. prescribed) fires will provide invaluable experience and training to park staff that will also be beneficial for fire control. The results of this study suggest that if the Canadian Parks Service plans to restore the ecological role of fire in Yoho National Park to that of pre 1880 conditions, an annual rate of burn (based on the age-class distribution for the 1800 - 1900 period)of approximately 0.43 % is required. During the 1900 - 1989 period (i.e. fire suppression period) the annual burn rate was 0.23 %.

The unadjusted fire cycle of 132 years (Figure 16) equates to an annual burn rate of 0.75 % (= 363 ha/yr). The western portion of the park however has lower fire return intervals than the eastern portion of the park.

Based on the age-class and fire scar data, it is recommended that a fire cycle of approximately 100 years for the western portion of the park be used as an approximate average estimate to guide the fire management program. This equates to an annual rate of burn of 1.0 %. The fire cycle in the eastern portion of the park is approximately 240 years. This equates to an annual rate of burn of 0.416 %. These rates of burn should be used as a guide to assist managers to develop fire management objectives and strategies that are specific for each drainage or fire management unit.

All types of fire that have occurred historically should be integrated into the fire management program. At the landscape level, extensive, high intensity fires have been the predominant type of fire that has ecologically influenced the montane and subalpine forests. The results of this study and the development of a two-index fire return interval system provide useful information for resource managers to consider and integrate the effects of other types of fires in the fire and vegetation management programs. Historically, fires of low to moderate intensities were more common before the fire suppression efforts began. All types and sizes of fires need to be integrated into the fire management program.

In their review of fire management policy and practices in Savanna parks, Mentis and Bailey (1990) suggest that a regimented application of fire under relatively uniform and restricted conditions, limits the range of fire behavior and fire effects. An appropriate range of fire regime parameters is therefore recommended to ensure landscape and biotic diversity.

3.6 The Canadian Parks Service [Parks Canada] recognizes fire as a natural process that will, to the extent possible (i.e. within the constraints and limitations), be allowed to occur with no or minimal interference. In Yoho National Park, fire is an important ecological process that, if not allowed to continue, will over the long term, result in landscape and vegetation mosaic changes that are not natural.

3.7 The Canadian Parks Service should not limit itself to only use planned ignition fires to implement its fire and vegetation management programs. The circumstances associated with some sites or units may warrant the implementation of other strategies or a mix of strategies (e.g. low impact modified cutting and prescribed fire). The challenge of the Canadian Parks Service is to develop and implement innovative strategies to meet its resource management objectives.

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APPENDIX I

FIELD DATA COLLECTION FORM

ATA FORM - YOHO NATIONAL PARK

Drainage OTTERHEAD

Plot No. 19

Date SEPT 27/87

UTM NG 255740

Vegetation Type SPRUCE - FIR SF

Ecosite Type OG-SF

Elevation 1850 M Aspect S Slope 66 % (33°)

Moisture Regime MESIC

Soil

ORTHIC HUMO - FERRIC PODZOLS AND

ELUVIATED EUTRIC BRUNISOLS

Topography (macro) 1 - Ridge 2 - Upper Slope (3) - Middle Slope 4 - Lower Slope

5 - Valley Bottom 6 - Plain

(micro)

UNDERSTORY - S. FIR. MEN

Evidence of Fire

Obvious recent fire X

Charred snags/stumps

Species

Fire evidence - trees ✓

Species BASAL SCARS - L. PINE. E. SPRUCE S. FIR.

Fire evidence - soil/duff

Charcoal in soil EVIDENCE OF LIGHT FIRE.

mixed in duff SMALL PIECES OF CHARCOAL ON

on mineral soil MINERAL SOIL.

Fire Behavior 1 - no survival of trees 2 - 5-50% of trees survived (3) - 51-95% of trees survived 4 - trees only scarred

PLOT NO. 19-1

QUARTER NO.	SPECIES	DBH	HEIGHT	HEIGHT TO LIVE CROWN	CROWN CLASS	CONDITION	AGE	DISTANCE
1	E SPRUCE	36.0	100	20	Do	L203=17	+186	3.1
1	—							
2	E. SPRUCE	44.5	80	20	Do	L194=17	+177	3.05
2	—							
3	E. SPRUCE	33.7	80	12	Co	L193=17	+176	6.2
3	S. FIR				S	L		2.5
4	E. SPRUCE	40.6	86	14	Do	L205=17	+188	2.9
4	—							

PLOT NO. 9-3 [illegible] R-1413) L.Pine

25 F

QUARTER NO.	SPECIES	DBH	HEIGHT	HEIGHT TO LIVE CROWN	CROWN CLASS	CONDITION	AGE	DISTANCE
1	E. SPRUCE	46.0	94	13	Do	L206=17	+189	4.35
1	S FIR				S	L		3.3
2	E. SPRUCE	47.3	83	18	Do	L198=17	+181	5.8
2	S. FIR				S	L		4.6
3	E. SPRUCE	25.1	68	21	Co	L198=17	+181	3.2
3	S. FIR				S	L		3.2
4	E. SPRUCE	36.5	75	20	Co	L217=17	+200	5.3
4	E. SPRUCE				I	L		2.1

PLOT NO. 19-5

QUARTER NO.	SPECIES	DBH	HEIGHT	HEIGHT TO LIVE CROWN	CROWN CLASS	CONDITION	AGE	DISTANCE
1	D. FIR	41.5	58	-	Co	D		2.0
1	E SPRUCE				I	D		3.4
2	E. SPRUCE	29.8	72	12	Co	L241=17	+224	3.55
2	E. SPRUCE				I	D		4.5
3	E. SPRUCE	45.0	88	15	Do	L240=17	+223	4.3
3	E. SPRUCE				S	L		4.6
4	E. SPRUCE	41.0	92	32	Do	L231=17	+214	5.1
4	S. FIR				S	L		5.0

REGENERATION TALLY/DUFF & LITTER DEPTH

PLOT NO.	SPECIES	NUMBER	TOTAL	DUFF DEPTH	LITTER DEPTH
1	CONIFEROUS DECIDUOUS	3 REGEN. - S. FIR		6.0	2.0
2	CONIFEROUS DECIDUOUS	4 REGEN. S. FIR		4 0	1.0
3	CONIFEROUS DECIDUOUS	2 REGEN. S. FIR		6.0	1.0
4	CONIFEROUS DECIDUOUS	3 - REGEN S. FIR		11.0	4.0
5	CONIFEROUS DECIDUOUS	2. REGEN - S. FIR		5 0	2.0
6	CONIFEROUS DECIDUOUS	NO REGEN		4.0	1.0

APPENDIX II

GLOSSARY OF FIRE HISTORY, FIRE ECOLOGY AND FIRE MANAGEMENT TERMS

The definitions of the terms were taken from the following four sources:

A - Merrill, D. F., and M. E. Alexander, eds. 1987. Glossary of forest fire management terms. Fourth edition. National Research Council of Canada, Canadian Committee on Forest Fire Management, Ottawa, Ont. Pub. NRCC No. 26516. 91 pp.

B - Parks Canada. 1988. Western region fire management directive. WRD 70, Natural Resource Conservation, Western Region, Parks Canada. 56 pp.

C - Romme, W. Committee chairman. Fire history: Report of the ad hoc committee. pp 153 - 137 *In* M. A. Stokes and J. H. Dieterich (tech. coords.), Proceedings of the Fire History Workshop, Tuscon, AZ, USDA For. Serv. Gen. Tech. Rep. RM-81, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colorado. 142 pp.

D - Author's definition.

Buildup Index **(A)** - A numerical rating of the total amount of fuel available for combustion that combines DMC (Duff Moisture Code) and DC (Drought Code).

Canadian Forest Fire Weather Index (FWI) System **(A)** - A subsystem of the Canadian Forest Fire Danger Rating System. The components of the FWI System provide numerical ratings of relative fire potential in a standard fuel type based on consecutive surface weather observations measured daily at noon (1200 h local standard time or 1300 h daylight saving time). The fire weather elements include dry-bulb temperature, relative humidity, wind speed and precipitation. The system provides a uniform method of rating fire danger across Canada.

Drought Code **(A)** - A numerical rating of the average moisture content of deep, compact, organic layers. This code indicates seasonal drought effects on forest fuels, and the amount of smouldering in deep duf layers and large logs.

Extreme Fire Behavior **(A)** - A level of fire behavior that often precludes any fire suppression action. It usually involves one or more of the following characteristics: high rate of spread and frontal fire intensity, crowning, prolific spotting, presence of large fire whirls, and a well established convection column.

Fine Fuel Moisture Code (FFMC) **(A)** - A numerical rating of the moisture content of litter and other cured fine fuels. This code indicates the relative ease of ignition and flammability of fine fuel.

Fire Cycle **(A)** - The number of years required to burn over an area equal to the entire area of interest.

Fire Effects **(A)** - Any change(s) on an area attributable to a fire, whether immediate or long term, and on-site or off-site. May be detrimental, beneficial, or benign from the standpoint of forest management and other land use objectives

Fire Environment **(A)** - The surrounding conditions, influences, and modifying forces of topography, fuel and fire weather that determine fire behavior.

Fire Frequency **(A)** - The average number of fires that occur per unit time at a given point.

Fire History **(A)** - The study and/or compilation of evidence (e.g. historical documents, fire reports, fire scars, tree growth rings, charcoal deposits) that records the occurrence and effects of past wildfires for an area.

Fire Interval **(C)** - The number of years between two successive fires documented in a designated area.

Fire Management **(B)** - The deliberate integration of knowledge on fire control, effects and behavior into the decision making process pertaining to natural resource management. Normally, fire management is comprised of "fire control" phase (which may consist of less than full-force control) and a "fire use" phase.

Fire Regime **(B)** - Pattern of fires over time in a vegetation which is characteristic of an era. Important elements of the pattern are intensity of fire, depth of burn and return intervals or cycle.

Fire Return Interval = Fire Interval

Fire Scar **(A)** - An injury or wound on a tree caused or accentuated by fire

Fire Weather Index (FWI) **(A)** - A numerical rating of fire intensity that combines ISI (Initial Spread Index) and BUI (Buildup Index). It is suitable as a general index of fire danger throughout the forested areas of Canada.

Fuel Management **(A)** - The planned manipulation and/or reduction of living or dead forest fuels for forest management and other land use objectives (e.g. hazard reduction, silvicultural purposes, wildlife habitat improvement) by: prescribed fire; mechanical, chemical, or biological means; and/or changing stand structure and species composition.

Hazard Reduction **(A)** - Treatment of living or dead forest fuels to diminish the likelihood of a fire starting, and to lessen the potential rate of spread and resistance to control.

Initial Spread Index (ISI) **(A)** - A numerical rating of the expected rate of fire spread. It combines the effects of wind and FFMC (Fine Fuel Moisture Code) on rate of spread but excludes the influence of variable quantities of fuel.

Lightning-Caused Fire **(A)** - A wildfire caused directly or indirectly by lightning.

Man-Caused Fire **(A)** - A forest fire or wildfire caused by human carelessness or malicious use of fire.

Mean Fire Interval **(C)** - The arithmetic average of all fire intervals determined in a designated area during a designated time period.

Planned Ignition Fire **(B)** - A fire ignited at a preplanned location and time by authorized personnel.

Prescribed Fire **(B)** - A random or planned ignition fire contributing to the attainment of the management objectives of a park by adhering to predetermined criteria and prescriptions defined in detail in a resource management plan.

Random (Unplanned) Ignition Fire **(B)** - A fire ignited at a random time and location by natural or accidental human sources.

Time-Since-Fire-Distribution **(D)** - The time in years that has lapsed since a designated area has been burned. This term refers to the survivorship of a stand.

Two-Index Fire Return Interval **(D)** - A two index figure written as "a/b" in which "a" represents the fire interval for stand replacing fires and "b" represents the fire interval for fires of low to moderate intensity.