Changes in forest fire frequency in Kootenay National Park, Canadian Rockies

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Time-since-fire distribution analysis is used to estimate forest fire frequency for the 1400 km^2 Kootenay National Park, British Columbia, located on the west slope of the Rocky Mountains. The time-since-fire distribution indicates three periods of different fire frequency: 1988 to 1928, 1928 to 1788, and before 1788. The fire cycle for the park was >2700 years for 1988 to 1928, 130 years between 1928 and 1788, and 60 years between 1778 and 1508. Longer fire cycles after 1788 and 1928 may be due, respectively, to cool climate associated with the Little Ice Age and a recent period of higher precipitation. Contrary to some fire history investigations in the region, neither a fire suppression policy since park establishment in 1919, nor the completion of the Windermere Highway through the park in 1923 appear to have changed the fire frequency from levels during pre-European occupation. Spatial partitioning of the time-since-fire distribution was unsuccessful. No relationship was found between elevation or aspect and fire frequency.

Key words: fire cycle, Rocky Mountains, climate change.

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L'analyse temporelle de la distribution des feux est utilisée pour évaluer la fréquence des incendies de forêt sur les 1400 km^2 du Parc national de Kootenay en Colombie-Britannique, situé sur la pente ouest des Montagnes Rocheuses. La distribution des incendies dans le temps indique trois périodes de fréquences de feux différentes : 1988 à 1928, 1928 à 1788 et avant 1788. Le cycle des incendies pour le parc a été > 2700 ans pour la période de 1988 à 1928, 130 ans pour la période de 1928 à 1788 et 60 ans pour la période de 1788 à 1508. Les cycles longs survenus après 1788 et 1928 pourraient être dus respectivement aux climats frais associés au Petit Âge Glaciaire et à une récente période de fortes précipitations. Contrairement à d'autres études conduites dans la région sur les feux, il ne semble pas que la politique d'élimination des feux dans le parc depuis sa création en 1919 ni la construction de l'autoroute Windermere à travers le parc en 1923 aient changé la fréquence des feux par rapport à ce qui existait avant l'arrivée des européens. La distribution dans l'espace des données de distribution temporelle a été impossible. Aucune relation n'est apparue entre l'élévation ou l'aspect et la fréquence des feux.

Mots clés : cycles des incendies, Montagnes Rocheuses, changement climatique.

[Traduit par la revue]

Introduction

Fire history is one element of a multivariate system comprising the fire regime of a landscape. The concept of fire regimes was developed to classify fires into categories of similar effects on ecosystems (Van Wagner 1983). A fire regime can be characterized by fire history (frequency or return period, measured in years), fire intensity (kW/m), and depth of burn (duff removed, kg/m or percent). Fire frequency is particularly useful in initial studies of fire behaviour in a region because it allows the empirical determination of causes of spatial and temporal differences in fire recurrence. Fire frequency can be estimated from a stand-origin map (i.e., a map of forest ages since the last fire). The areas in each forest age are used to estimate a survivorship distribution that can be called the time-since-fire distribution. The time-since-fire distribution can be described by a negative exponential (Johnson and Van Wagner 1985). This distribution will give a straight line on semilog graph paper. Survivorship can be estimated from the cumulative form of the negative exponential as

$$[1] \quad A(t) = \exp(-t/b)$$

where $A(t)$ is the frequency or probability of not having a fire up to age t, t is the time in years since the last fire, and b is fire cycle in years that will be exceeded 36.79% of the time.

In the Canadian Rockies, some investigations have concluded that fire frequency differs between vegetation and landform types (Tande 1979; Hawkes 1980), or that temporal changes are due to European man's influence either increasing the amount of fire through increased ignitions, or reducing fire recurrence through fire prevention and suppression (Nelson and Byrne 1966; Tande 1979; White 1985). However, Johnson *et al.* (1990) and Johnson and Larsen (1990) concluded that changes in fire frequency may be due to climate. The objective of this paper is to demonstrate that the estimated time-since-fire distribution of Kootenay National Park can be divided to reveal temporal changes in its fire history (differences between time periods). To demonstrate this, the time-since-fire distribution or $A(t)$ for Kootenay National Park was constructed from a stand-origin map and the distribution was partitioned using various dates. The reasons for the changes in fire frequency are discussed.

Kootenay National Park covers 1400 km^2 of the west slope of the Rocky Mountains and is located approximately 40 km west of Banff, Alberta. The park was established in 1919 and a highway was completed through the park in 1923. No major changes in the park boundary have occurred since 1919. The park stretches from the Continental Divide in the northeast, almost to the valley floor of the Rocky Mountain Trench in the southwest. Most of the park is oriented along the strike of two main valleys, the Vermilion and the Kootenay (Fig. 1). The Sinclair Pass area of the park is transitional between the Kootenay Valley and the Rocky Mountain Trench. Elevation ranges from approximately 800 to 3400 m over an area 45 km in width and 85 km in length. Numerous hanging valleys are present along the length of each of the main valleys. Vegetation consists primarily of lodgepole pine (*Pinus contorta*

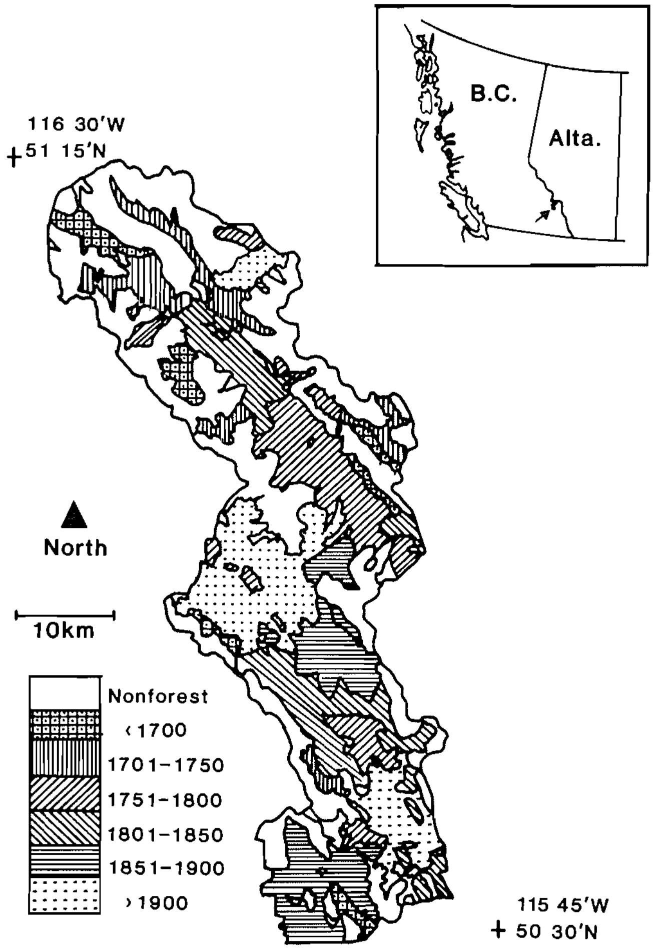

FIG. 1. Stand-origin map of Kootenay National Park showing 50-year age-classes. Fifty-year age-classes are used in this map for reproduction purposes; 20-year age-classes are used for the fire frequency analysis.

Loudon var. *latifolia* Engelm.), Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco), Englemann spruce (*Picea engelmannii* Parry), white spruce (*Picea glauca* (Moench) Voss), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), with alpine meadows at upper elevations. The forest fire season lasts from May to September, with peak lightning activity in July and August. Large, high intensity, stand-replacing fires are infrequent in the Park but contribute to most of the area burned. Small, lower intensity, surface fires are frequent but do not spread to cover large areas. Winters are cold, with snowfall accumulations ranging from 20 to 200 cm.

Methods

Construction of the stand-origin map followed methods used by Johnson and Fryer (1987). Initial positions of fire boundaries were identified from changes in tree height and species from 1 : 25 000 scale aerial photographs. Time since the last fire was determined in the field from fire scars or age of oldest trees on either side of the fire boundary, or from fire records (McBride 1983). Final fire boundaries were drawn on two 1 : 50 000 scale base maps. Nonforest and forest areas without evidence of fire (e.g., burned stumps, charcoal in soil, fire-scarred trees) were excluded. These excluded areas were usually small, isolated clumps of high subalpine forest near the tree line with poor continuity of fuel with adjacent, previously burned stands. The final map had over 130 polygons with dates of fire origin ranging from 1508 to 1984.

The area of each stand-origin polygon was calculated using a digitizing table and a microcomputer geographic information system. These areas were then grouped into 20-year age-classes and their cumulative percent area was plotted on semilog graph paper to estimate the time-since-fire distribution (cf. Johnson and Van Wagner 1985). Twenty-year age-classes were used to smooth the effect of individual large fires and inaccurate tree dates.

First, the time-since-fire distribution was estimated for the whole park and the distribution partitioned when sharp breaks occurred in its slope. Known dates of park establishment (i.e., beginning of fire suppression era) and suspected change in climate from the literature (e.g., Johnson and Fryer 1987) were also tested as temporal divisions.

Second, the fire cycle (i.e., the number of years required to burn an area of equivalent size or parameter *b* in eq. 1) for each partition was determined from the slope coefficient of a least-squares linear regression. The data used for the regression included all the points between and including the start and end dates of the period in question. The age and frequency data used in the regressions were taken from the time-since-fire distribution plotted for the entire period (i.e., from 1988 to the earliest date). The regression for each distribution was forced through the most recent age and frequency point of each period. Differences between regression slope coefficient were tested with a Student's *t*-test (Zar 1984).

Daily precipitation values from 1915 to 1981 were obtained from Environment Canada for Lake Louise, Alberta. Lake Louise is located in the main range of the Rocky Mountains, approximately 10 km east of the Great Divide just north of Kootenay National Park, at 1500 m (AMSL). The daily records covered the summer season from the start of the Canadian Forest Fire Weather Index System calculations (cf., Canadian Forestry Service 1984), usually late April to October 31 of each year. This period represents the fire season. Total fire season precipitation (mm) was plotted for each year and then smoothed using a 10-year moving mean.

Results

Area and percent area by 20-year age-classes for stands in Kootenay National Park are shown in Table 1. The time-since-fire distribution for the Park (Fig. 2) indicates three periods of different fire frequency: 1988 to 1928, 1928 to 1788, and before 1788. The time-since-fire distribution for 1988 to 1927 is too short to allow regression estimation of its fire cycle (parameter *b* in eq. 1), but fire records indicate only 2.2% of the Park area burned during this period (i.e., fire cycle >2700 years). Using 1788 as a temporal division for the rest of the distribution, the fire cycles were calculated for each period and tested for significant differences. Fire cycles were 130 years between 1928 and 1788 and 60 years between 1788 and 1508. The two fire cycles were significantly different at $p < 0.05$.

Discussion

The small area burned in Kootenay National Park in the 60 years between 1988 and 1928 may be due to a period of moist weather as seen in the precipitation record for Lake Louise (Fig. 3). No large fires (>500 ha) occurred in the park between 1927 and 1968; however, a few large fires were reported in adjacent areas from 1941 to the late 1960s. Fire prevention and suppression during the entire history of the park (i.e., since 1919) may also have contributed to this decline in burned area, but examination of fire reports from major lightning-caused fires in 1926 (13 000 ha) and 1968 (1700 ha) indicate little success in suppressing these fires. Only since the early 1980s have helicopters and initial attack crews been used

TABLE 1. Area (ha) and percent area of forest cover by 20-year age-classes for Kootenay National Park, as of 1988

Age (years)	Area (ha)	% area	Cumulative % area
0	0	0.0	100
20	1 823	2.1	97.9
40	25	0.03	97.9
60	44	0.1	97.8
80	19 939	22.7	75.1
100	169	0.2	74.9
120	12 988	14.8	60.1
140	1 421	1.6	58.5
160	12 972	14.7	43.8
180	4 729	5.4	38.4
200	5 914	6.7	31.7
220	9 694	11.0	20.7
240	5 576	6.3	14.4
260	363	0.4	14.0
280	5 768	6.6	7.4
300	240	0.3	7.1
320	1 480	1.7	5.4
340	1 110	1.3	4.1
360	1 260	1.4	2.7
380	0	0.0	2.7
400	0	0.0	2.7
420	391	0.4	2.3
440	1 876	2.1	0.2
460	0	0.0	0.2
480	182	0.2	0.0
	87 964	100.0	

to fight forest fires, and this period is too short to evaluate suppression effectiveness. Conversely, man-caused fires during construction of the Windermere Highway through the park in 1919 and increased tourist travel after that time have burned less than 0.5% of the park. Few native indians have resided in the main valleys of the park since before the first Europeans arrived in 1841 (Choquette 1987), so it is unlikely that their absence has had any effect on fire frequency.

The longer fire cycle in the Park after the mid 1700s may be due to a change in climate associated with the cooler, wetter weather during the Little Ice Age. Concurrent with this period, Osborn (1982) and Osborn and Luckman (1988) reported advances in glaciers in the Rocky Mountains; Johnson and Fryer (1987) and Johnson and Larsen (1990) cited longer fire cycles in the Kananaskis Valley of Alberta; and Johnson *et al.* (1990) described longer fire cycles in Glacier National Park, British Columbia. Evidence of warming after the Little Ice Age ended in the mid 1800s is not clearly visible in the time-since-fire distributions.

Attempts to partition the time-since-fire distribution spatially were unsuccessful. Plots of the cumulative percent area for each of the two main valleys of the park (i.e., Vermilion and Kootenay/Sinclair) showed poor fit to the negative exponential. Examination of the fire record shows that 18 000 ha of the Kootenay/Sinclair Valley were burned in 1917 and 1926. The effect of these two large fires (40% of the Kootenay/Sinclair Valley) suggests that the Kootenay/Sinclair Valley is too small to evaluate fire frequency from a stand-origin map (cf. Johnson and Van Wagner 1985). In the Vermilion Valley, fire cycle estimates for the period 1928 to 1788 were 405 years. Using these methods, spatial partitioning could not be substantiated statistically or logically.

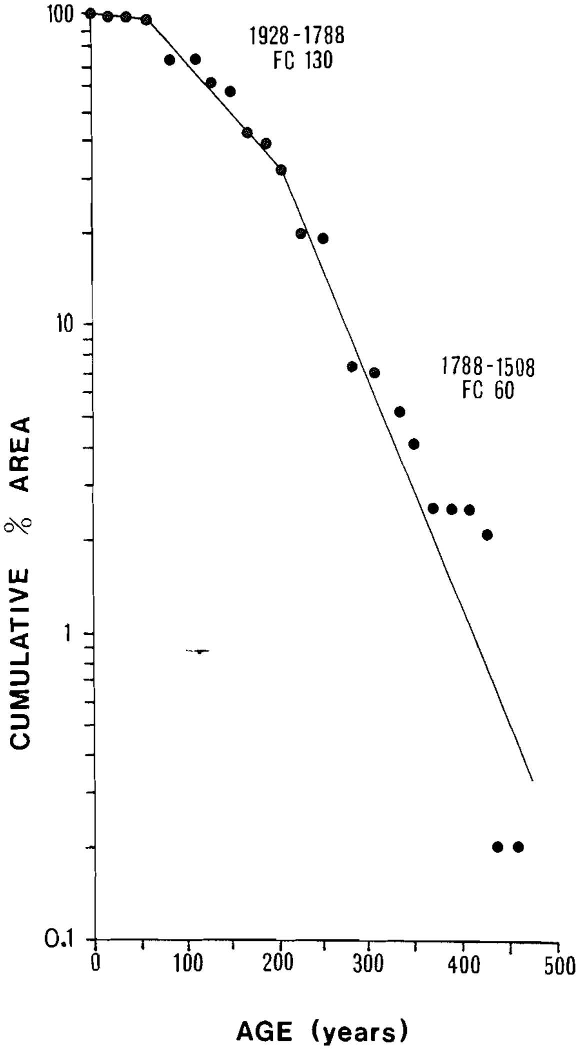

FIG. 2. Time-since-fire distribution for Kootenay National Park from 1508 to 1988. Data points below 0.1% cumulative frequency are not shown.

The stand-origin map also shows that many recent fires (e.g., 1830, 1917, 1926, 1968, 1984) burned over a wide range of elevations and aspects. Plots of forest age over elevation and aspect for the whole park showed no pattern. No relationship between forest age and elevation or aspect may be because stand-replacing fires burn during very dry periods where there is little difference in fuel moisture between different elevations and aspects (Anderson 1968; Fryer and Johnson 1988).

Conclusion

Partitioning the time-since-fire distribution of Kootenay National Park shows different fire cycles between the periods 1988 to 1928 (>2700 years), 1928 to 1788 (130 years), and before 1778 (60 years). Changes in climate rather than the influence of European man (either from increased fire ignitions or fire prevention or suppression) appear to be responsible for the longer fire cycles in the park after 1788 and 1928. This conclusion is contrary to a prevailing attitude about man's (both European and Native) effect on the landscape of the Rocky Mountains (i.e., Nelson and Byrne 1966; Tande 1979; Hawkes 1980; White 1985). Early settlement of the region in the late

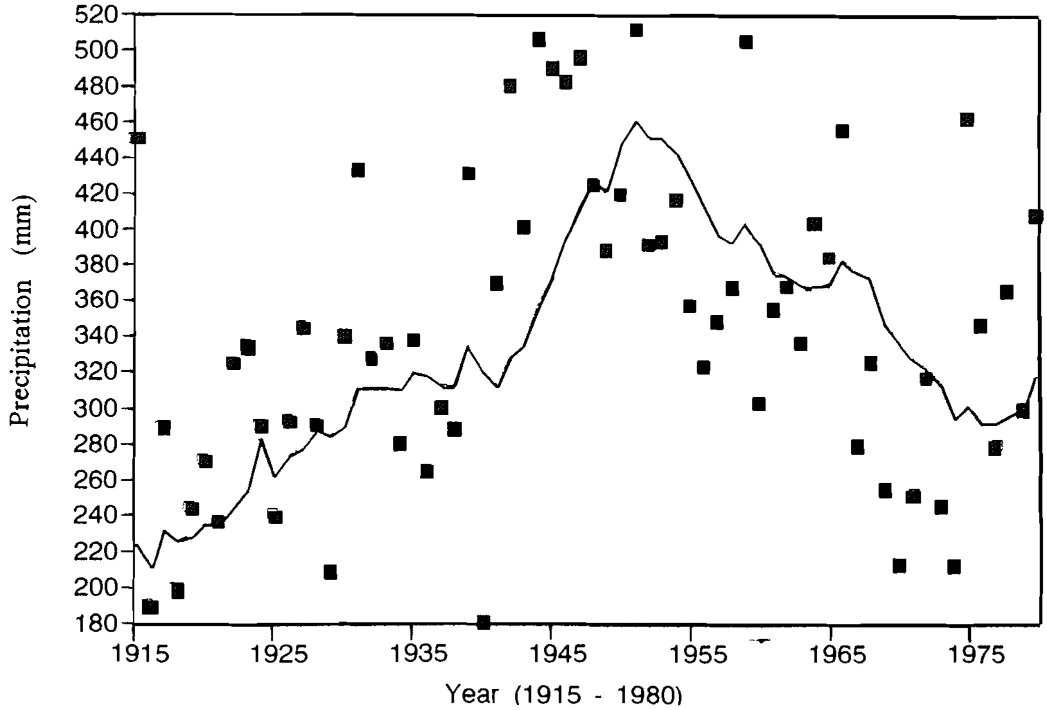

FIG. 3. Total summer precipitation for Lake Louise, Alberta, 1915–1980. Line indicates the 10-year moving mean.

1800s corresponded with a known period of very dry climate and high natural fire activity. Some areas, where native and European man's activities were intense, were undoubtedly affected by increased man-caused ignitions. In Kootenay National Park, however, intensive use by European man after 1919 and numerous man-caused fires due to road construction, careless smoking, and cooking fires were not sufficient to overcome the overall effect of cool, moist conditions in impeding the spread of forest fires. Evidence from the stand-origin map that fires burned without influence of elevation or aspect is also contrary to existing literature (i.e., Tande 1979; Hawkes 1980; White 1985). Valley orientation to prevailing wind direction and resulting fire spread direction is not well understood and may provide more information about the spatial patterns of fire recurrence in the Rocky Mountains.

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