FIRE REGIMES IN NAHANNI NATIONAL PARK AND THE MACKENZIE BISON SANCTUARY, NORTHWEST TERRITORIES, CANADA

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ABSTRACT

Nahanni National Park and the Mackenzie Bison Sanctuary are ecologically important areas in the Northwest Territories. Fire history data in Nahanni National Park and the Mackenzie Bison Sanctuary were used for a comparative analysis in order to identify the most influential characteristics of their respective fire regimes. The Mackenzie Bison Sanctuary is located on the Taiga Plains and is surrounded to the east and south by Great Slave Lake. Nahanni National Park is located in the Mackenzie Mountains, approximately 500 km west of the Mackenzie Bison Sanctuary. Elevation relief in the Mackenzie Bison Sanctuary is 160–260 m, and in Nahanni National Park is 180–2,640 m. Fuels are similar in both study areas and are dominated by low-density coniferous forest. Nahanni National Park has a significantly higher mean annual occurrence of very high and extreme classes of Canadian Fire Weather Index System codes and indices. Fire scar data indicate weighted mean fire return intervals (MFRIs) of 28 years and 27 years, respectively, for Nahanni National Park and the Mackenzie Bison Sanctuary. Area burned totals from a national database of fires greater than 200 ha in area suggest a fire cycle of 1,142 years and 199 years, respectively, for Nahanni National Park and the Mackenzie Bison Sanctuary. Differences in average fire size (1,149 ha in Nahanni National Park and 7,806 ha in the Mackenzie Bison Sanctuary) are partially attributed to topographic differences between the two areas.

keywords: boreal, fire frequency, fire history, fire regime, mean fire return interval, Northwest Territories, topography.

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INTRODUCTION

Nahanni National Park and the Mackenzie Bison Sanctuary are two ecologically important areas in northwestern Canada. As in much of the boreal forest, disturbance by fire has historically been a prominent process in defining the ecosystems and their structural distribution in both areas. Resource management objectives are based on policy and science-related guidelines, and a clear understanding of historical fire regimes will contribute to successful management planning in the future. Describing and understanding the fire regime of an area requires defining characteristics such as the fire cycle, fire interval, fire season, and the number, type, and intensity of fires that characterize the given areas (Merrill and Alexander 1987). Fire weather, fuels, topography, and ignition patterns play a prominent role in defining the characteristics associated with the fire regime. A comparative study of the fire history was conducted at these two regional locations in order to estimate these characteristics and the influence of fire weather and fuels.

STUDY AREAS

Nahanni National Park

Nahanni National Park Reserve was established in 1972 to preserve the ecologically significant Nahanni River and Flat River watersheds. The 4,766-km^2 reserve is characterized by mountainous topography, with elevations ranging from 180 m to 2,640 m above sea level (asl). Two major rivers, the Nahanni River

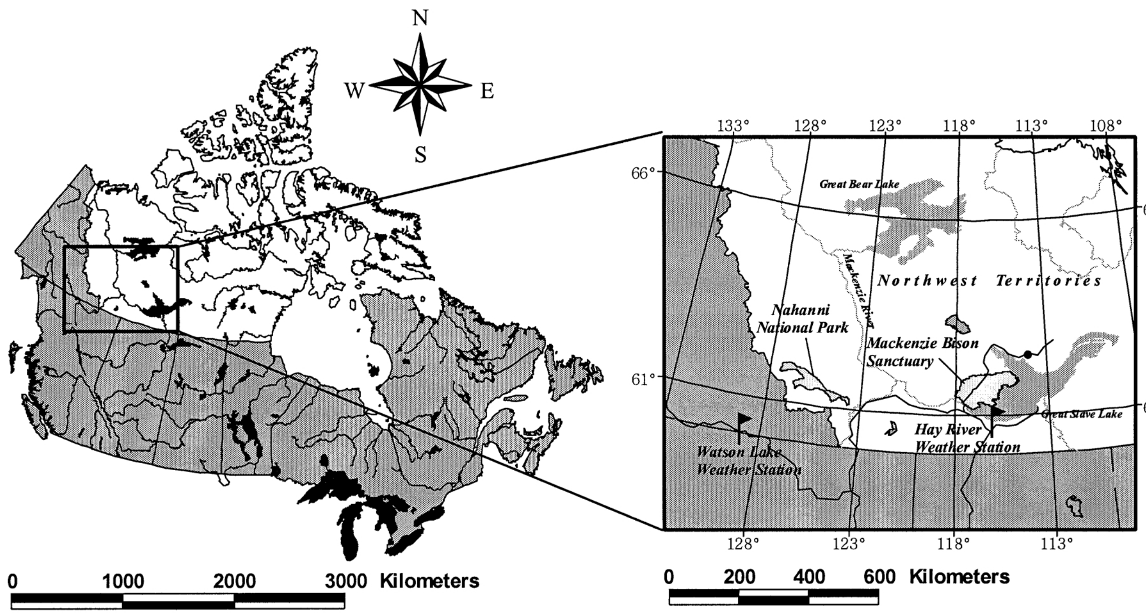

Figure 1. Study area locations in Nahanni National Park and the Mackenzie Bison Sanctuary, Northwest Territories.

and the Flat River, flow through the valleys of the reserve and were used by aboriginal peoples as access to the region for the past 10,000 years. Recent European settlement initiated exploitation of valuable fur resources and promoted further occupation of the remote area (Parks Canada 2001).

Nahanni National Park is located in the southwestern corner of the Northwest Territories (62°00′N, 127°30′W to 61°05′N, 123°45′W) (Figure 1) and occupies the Alpine Forest–Tundra forest section of the Boreal Forest Region (Rowe 1972). This section is characterized by low-density stands of coniferous forest, predominantly black spruce (*Picea mariana*) and white spruce (*Picea glauca*), as well as smaller proportions of deciduous forest including aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), and birch varieties (*Betula* spp.). Stands of tamarack (*Larix laricina*) and subalpine fir (*Abies lasiocarpa*) are found on the lowlands and higher elevations, respectively. Scotter (1974) reported extensive stands of lodgepole pine (*Pinus contorta* var. *latifolia*) throughout the southern portion of the park boundary, particularly along the Flat River. The distribution of jack pine (*Pinus banksiana*) is limited to the eastern boundary of the park, with lodgepole–jack pine hybrids common where the species' distributions overlap.

The region's climate can be summarized as cold continental, with large fluctuations resulting from the mountainous terrain. The long-term weather station nearest to Nahanni National Park is located about 225 km southwest at Watson Lake, Yukon (689 m asl) (Figure 1). The average maximum July temperature at Watson Lake is 21.1 °C, while the average minimum January temperature is –30.0 °C. Average annual precipitation as rainfall is 256.7 mm and as snowfall is 218.9 mm (water equivalent). The region experiences an average of 12 thunderstorms annually, primarily during June and July (Environment Canada 1993).

Mackenzie Bison Sanctuary

The Mackenzie Bison Sanctuary was established to meet the objectives of wood bison (*Bison bison athabascae*) management in the Mackenzie Region of the Northwest Territories. The area used for this study (61°00′N, 114°00′W to 63°00′N, 118°00′W) extends beyond the defined boundaries of the Mackenzie Bison Sanctuary and encompasses about 11,150 km^2. Elevation relief in the Mackenzie Bison Sanctuary is minimal, ranging from 160 to 260 m asl.

Rowe (1972) classifies this area as part of the Northwestern Transition Section of the Boreal Forest Region. This transition area joins the higher-density coniferous forest in the south to the tundra in the north and is primarily composed of low-density coniferous forest, bog, muskeg, and barren rock. Harsh climatic conditions and frequent fire events result in limited vegetation success, distribution, and dwarfed growth patterns. The most common tree species include black spruce, white spruce, paper birch (*Betula papyrifera* var. *papyrifera*), tamarack, jack pine, aspen, and balsam poplar.

The climate in this area is strongly influenced by Great Slave Lake and seasonal averages are similar to those in Nahanni National Park. The nearest long-term

Table 1. Relative classes for various Fire Weather Index System codes and indices used in the fire weather analysis for Nahanni National Park and the Mackenzie Bison Sanctuary, Northwest Territories.

	Fire Weather Index System component			
Class	Fine Fuel Moisture Code	Buildup Index	Initial Spread Index	Fire Weather Index
Low	0–79	0–24	0–2	0–4
Moderate	80–84	25–40	3–4	5–10
High	85–87	41–60	5–9	11–18
Very High	88–89	61–89	10–16	19–29
Extreme	90–101	90+	17+	30+

weather station is located about 50 km south at Hay River (164 m asl) (Figure 1) and reports an average maximum July temperature of 20.9 °C and an average minimum January temperature of –29.3 °C. Precipitation as rainfall averages 194.2 mm and as snowfall averages 158.5 mm annually (water equivalent). The region experiences an average of 8 thunderstorms annually, primarily during June, July, and August (Environment Canada 1993).

METHODS

Fire Weather

Fire weather parameters were collected from the nearest representative Atmospheric Environment Service weather stations (Environment Canada) and used to derive parameters of the Canadian Fire Weather Index (FWI) System (Van Wagner 1987). Fire Weather Index System values for the Fine Fuel Moisture Code (FFMC), Initial Spread Index (ISI), Buildup Index (BUI), and the Fire Weather Index were categorized into five relative classes (Table 1) and the relative frequency of occurrence was determined.

The Watson Lake station was used for Nahanni National Park because of its long-term records (1953–1992) and mountainous topography. Long-term (1953–1995) weather data from the Hay River station was used for the Mackenzie Bison Sanctuary. The FWI System codes and indices were used to compare fire weather severity between the two weather stations. Paired *t*-tests and Friedman Two-Way Analysis of Variance tests (SYSTAT 2000) were performed on each FWI System parameter in order to determine if the annual average number of days in the very high and extreme classes were significantly different between the two weather stations. In order to accommodate the statistical tests it was necessary to standardize the data by setting the seasonal start date of each year at 25 May and the end date at 30 September. Weather data from 1953 to 1992 were used for this analysis.

Data from the Watson Lake and Hay River weather stations were also used to document the fire weather events that occurred during the days and years known to have fire activity from the Large Fire Database (Stocks et al. 2002). Nahanni National Park and the Mackenzie Bison Sanctuary were analyzed separately using a two-sample *t*-test to determine if years with fire activity had a higher mean Seasonal Severity Rating (SSR) (Van Wagner 1970) than years without fire activity.

Fuels

A vegetation inventory was not readily available to derive fuel classifications for either area. Instead, fuel type classifications were derived using data collected by the National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer. This satellite collects data at a 1-km resolution. Data were interpreted using the Normalized Difference Vegetation Index to derive a land cover classification of Canada for 1995 (Beaubien et al. 1997). This spatial database of land cover was then used to estimate the area of various fuel types as described by the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992).

Fire History Sampling

Field sampling for fire history data was performed in both Nahanni National Park and the Mackenzie Bison Sanctuary. Tree discs were collected; fire scars and stand origins were dated from numerous sample sites. Disc preparation and tree-ring analysis methods were similar to those described by Arno and Sneck (1977).

Sample collection for fire scar and stand origin data in Nahanni National Park occurred during the summers of 1977 and 1978, and in the Mackenzie Bison Sanctuary throughout 1991 to 1993. Sample sites were selected based on numerous conditions including vegetation type, topography, aspect, evidence of fire occurrence, and access considerations. A total of 62 sites were sampled in Nahanni National Park equaling a sampling intensity of 1 site per 51.6 km^2 (5,160 ha). A total of 216 sites were sampled in the Mackenzie Bison Sanctuary equaling a sampling intensity of 1 site per 34.8 km^2 (3,480 ha). Sample intensities were calculated based on forested area.

At each site, between 1 and 16 trees were sampled in order to collect fire-year data. The age and species of each tree were determined and recorded. Ground vegetation, fuel loading, and other stand characteristic data were also recorded at each site. A fire master chronology (Wagener 1961, Arno and Sneck 1977, Johnson and Gutsell 1994) was developed from the tree disc samples after lab analysis. Fire scar data were used to estimate composite mean fire return intervals (MFRI) (Tande 1979, Romme 1980) at each sample site according to the following equation:

$$\text{MFRI} = \left[\sum \left(T_{i+1} - T_i\right)\right] / N, \tag{1}$$

where $(T_{i+1} - T_i)$ = interval between any 2 consecutive fire years at a sample site, and N = number of intervals identified for a site.

The MFRI was calculated two ways. First, MFRIs were calculated using fire scar data only and therefore a site required at least two different fire scars to calculate an interval. This method caused sites with fewer than two scars to be omitted. The second method used jack pine and lodgepole pine origin data to increase the number of intervals used in the calculation by deriving an origin to first scar (OS) interval. This method resulted in fewer sites being omitted. The interval from the most recent fire scar date to the sampling date (time-since-fire) was not included due to its open-ended nature. A weighted MFRI (Baker and Ehle 2001) was calculated for the entire study area using site MFRIs from each study area according to the following equation:

Weighted MFRI =

$$\sum \left[\left(\text{MFRI}_1 \times N_1\right) \ldots \left(\text{MFRI}_n \times N_n\right)\right] / \sum N, \tag{2}$$

where $\text{MFRI}_1 \ldots \text{MFRI}_n$ = the MFRIs from each sample site, and $N_1 \ldots N_n$ = the number of intervals at each study site.

Large Fire Database

The Canadian Forest Service Large Fire Database (LFDB) (Stocks et al. 2002) was used to provide additional and more recent fire history information for this study. The LFDB point data used for this study consists of fires >200 ha that have been reported in Canada from 1959 to 1999. A point indicating the starting location can be spatially displayed for each fire. The LFDB includes information on fire size, start date, location, cause, and other fire-related characteristics. The average annual area burned (AAB) for each study area for the period 1959 to 1999 was determined. The percent AAB and fire cycles were calculated according to the following equations:

$$\text{Percent AAB} = \text{AAB/forested area} \times 100, \tag{3}$$
$$\text{Fire Cycle} = \text{forested area/average AAB}. \tag{4}$$

RESULTS

Fire Weather

We compared the mean annual frequencies of occurrence for the FWI System parameters and relative classes for Watson Lake and Hay River weather stations (Figure 2). Overall, Nahanni National Park had a larger proportion of days occurring in the very high and extreme classes of the FFMC, ISI, and the FWI than the Mackenzie Bison Sanctuary. Analysis of FWI System values using a paired *t*-test showed that Nahanni National Park had a significantly greater mean annual occurrence of values in the very high and extreme classes of the FFMC (P = 0.001), ISI (P = 0.001), and FWI (P = 0.001) than in the Mackenzie Bison Sanctuary for the study period. Annual occurrence of values in the very high and extreme classes of the BUI, respectively, were not significantly different between the study areas (P = 0.751 and P = 0.784). The Friedman Two-Way Analysis of Variance produced the same results as the paired *t*-test.

Years with fire activity according to the LFDB did not have significantly higher SSRs than the years without fire activity in Nahanni National Park (P = 0.876) or the Mackenzie Bison Sanctuary (P = 0.964). Fire Weather Index System codes and indices showed that 100% of the fire start days (according to the LFDB) were in the very high to extreme classes in Nahanni National Park, and approximately 70% of the fire start days were in the very high to extreme classes for the Mackenzie Bison Sanctuary.

Fuels

The forest cover type in Nahanni National Park is primarily low-density coniferous forest that is most similar to the Spruce–Lichen Woodland (C1) fuel type of the FBP System. High-density coniferous forest cover type that is most similar to the Boreal Spruce (C2), Mature Jack or Lodgepole Pine (C3), and Immature Jack or Lodgepole Pine (C4) FBP System fuel types are also dominant across the landscape. Smaller portions of deciduous (D1 fuel type—Leafless Aspen) and mixed coniferous–deciduous (M1 fuel type—Boreal Mixedwood) forest cover types occur at lower

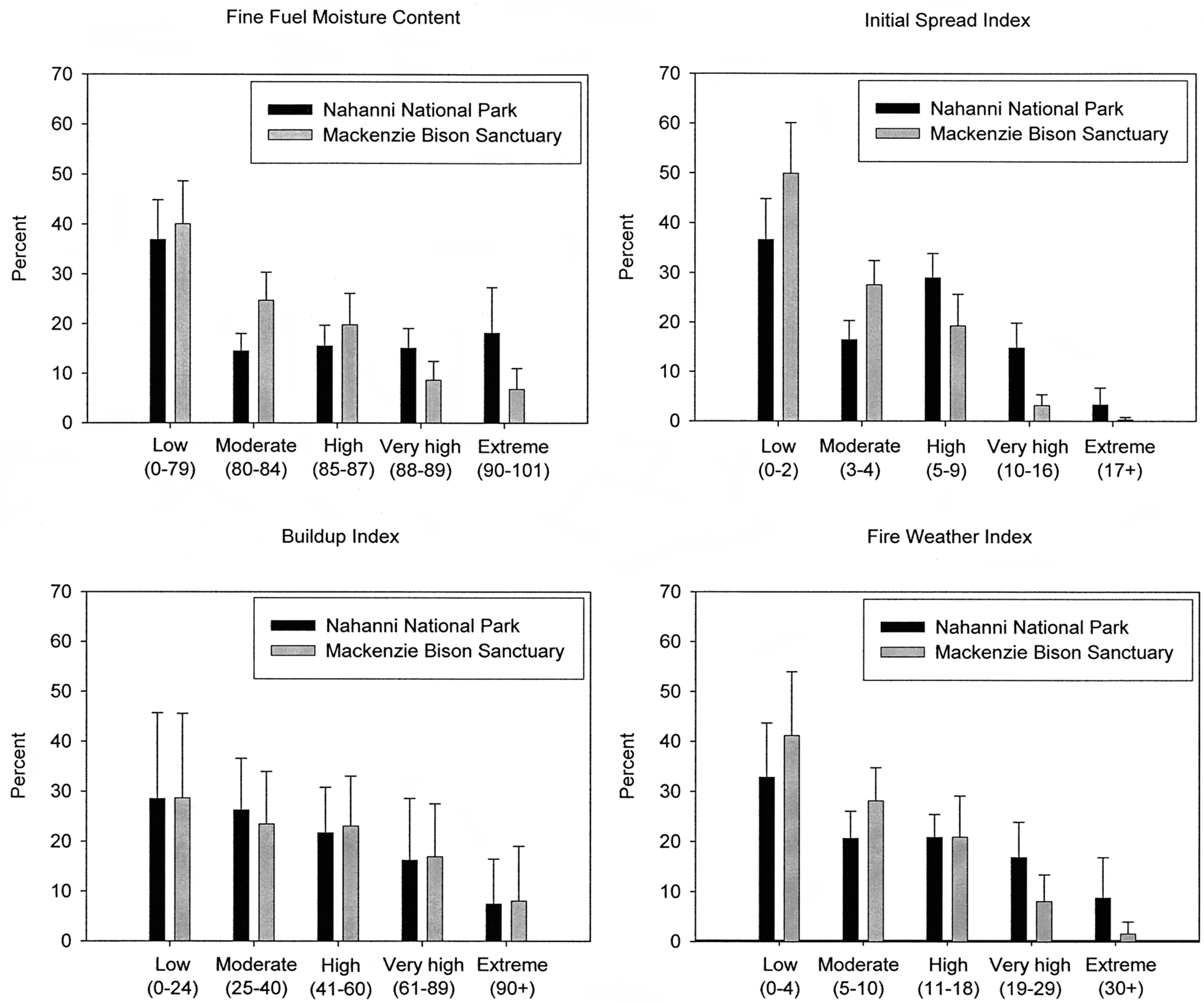

Figure 2. Frequency distribution (mean ± SD) of Fire Weather Index codes and indices for Nahanni National Park and the Mackenzie Bison Sanctuary, Northwest Territories.

and middle elevations. The Mackenzie Bison Sanctuary has a similar forest composition, with a slightly higher proportion of low-density coniferous (C1) fuel type, and slightly lower proportions of high-density (C2, C3, and C4) fuel types. The proportion of total landbase composed of the deciduous (D1) and various coniferous–deciduous (M1) fuel types is very similar to Nahanni National Park. Both study areas have a relatively large proportion of landbase in non-fuel vegetation classes, which are primarily wetlands, shrublands, and rock. Figure 3 compares the various fuel type proportions between Nahanni National Park and the Mackenzie Bison Sanctuary and indicates relatively small differences between the two study areas. The total vegetated area is 319,660 ha and 751,988 ha, respectively, for Nahanni National Park and the Mackenzie Bison Sanctuary.

Fire Scar Data

Without including jack pine and lodgepole pine OS data, fire scar data from Nahanni National Park indicated a weighted MFRI of 21.7 years associated with the period 1813 to 1974 (162 years). Using OS data the weighted MFRI was 28.3 years associated with the period 1731 to 1974 (244 years). These estimates should be considered conservative for this period because evidence of fire disappears through time (Van Wagner 1978). Three or more different sites were burned in 1907, 1915, 1925, 1937, 1940, and 1949 (Figure 4) and indicate relatively major fire years. Without OS data from jack pine, fire scar data for the Mackenzie Bison Sanctuary produced a weighted MFRI of 23.3 years for the period 1771 to 1977 (207 years). With OS data the weighted MFRI was 27.1 years for the period 1765 to 1977 (213 years). These

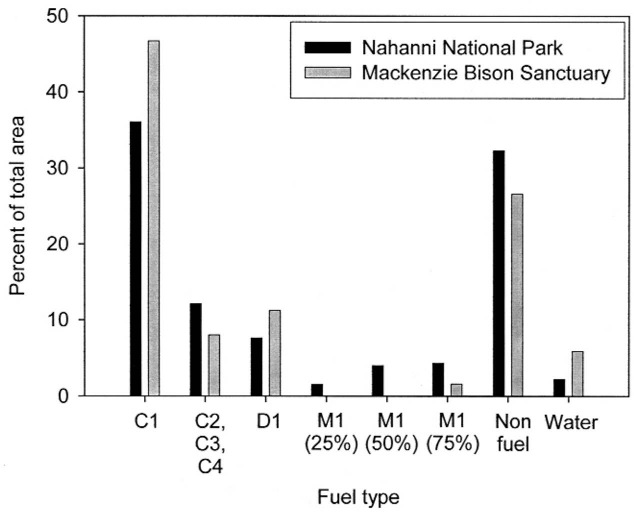

Figure 3. Fuel type distribution in Nahanni National Park and the Mackenzie Bison Sanctuary, Northwest Territories.

estimates should also be considered conservative. Major fire years occurred in 1878, 1916, 1927, 1930, 1939, 1942, 1946, and 1949 (Figure 4) when more than 10 different sites per year burned.

Large Fire Database

Analysis of the LFDB for the study areas produced conflicting results when compared to MFRIs from the fire scar data. Area burned during the period of 1959 to 1999 (41 years) indicated that about 11,494 ha burned in Nahanni National Park. This period had a total of 11 fires, 4 of which burned in 1983, and 3 of which (27%) had suppression action. Fire frequency is 0.084 large (>200 ha) fires/year per 100,000 ha. All fires were caused by lightning ignitions. Annual area burned for this period is 280 ha/year and corresponds to a percent AAB of 0.09. The fire cycle calculated from this percent AAB is 1,142 years. In the Mackenzie Bison Sanctuary, the area burned from 1959 to 1999 was 154,764 ha. This period had a total of 18 fires, 3 of which occurred in 1972 and 2 of which occurred in 1994. Three of these fires (17%) were human-caused ignitions, 14 fires (78%) were caused by lightning, and the cause of 1 fire was unknown. Finally, suppression action was applied to 10 of these fires (56%). Fire frequency is 0.056 large (>200 ha) fires/year per 100,000 ha. The AAB during the period is 3,775 ha/year and corresponds with a percent AAB of 0.50. The fire cycle calculated from the percent AAB is 199 years. The average fire size and standard deviations for the two study areas according to the LFDB are in Table 2.

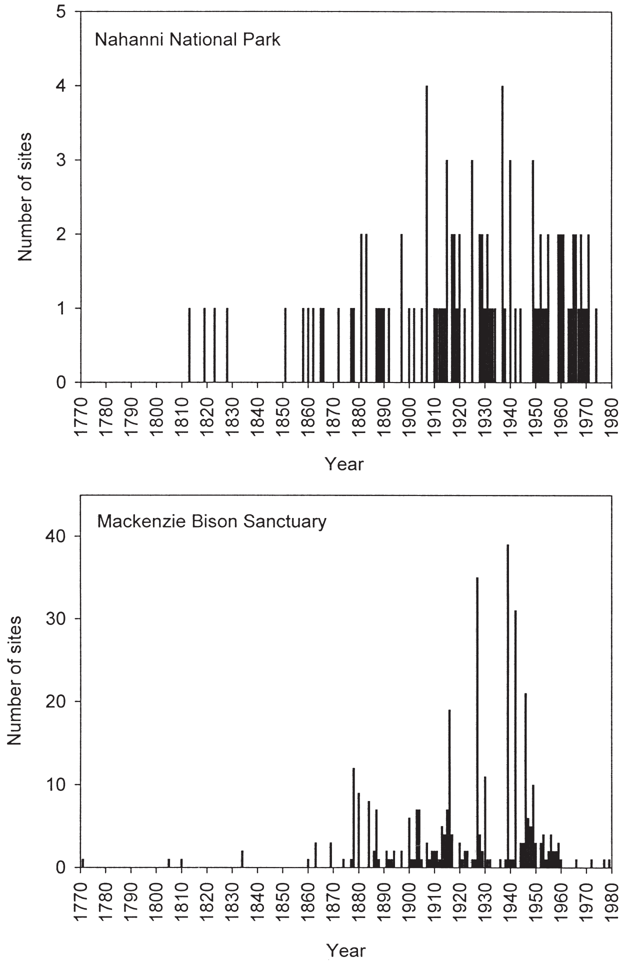

Figure 4. Frequency of fire scars among sample sites in Nahanni National Park and the Mackenzie Bison Sanctuary, Northwest Territories.

DISCUSSION

Comparisons of fire weather from the Watson Lake and Hay River weather stations indicate that Nahanni National Park is characterized by more severe fire weather than the Mackenzie Bison Sanctuary. The higher occurrence of days in the very high and extreme classes of the various FWI System codes and indices suggest that there is a higher ignition potential (FFMC), higher fire spread potential (ISI), and a higher overall fire intensity in Nahanni National Park (Van Wagner 1987). Fire weather in Nahanni National Park is subject to large variation because of the many complex variables in the mountainous fire environment, including fuel moistures and atmospheric characteristics that change according to aspect and elevation.

The SSR is calculated by averaging the Daily Severity Rating (DSR), which is derived from the FWI value of the FWI System, and provides a method of measuring the fire severity for an entire fire season

Table 2. Fire characteristics from the Large Fire Database for Nahanni National Park and the Mackenzie Bison Sanctuary, Northwest Territories, 1959–1999.

Study area	Forested area (ha)	Number of fires	Fire size characteristics	
			Average (ha)	SD (ha)
Nahanni National Park	319,660	11	1,149	954
Mackenzie Bison Sanctuary	751,988	18	7,806	13,767

(Van Wagner 1970). However, because the SSR is an average of the DSR it has the characteristic of offsetting higher DSR values with lower DSR values, and therefore does not identify fire seasons that may have had high fire weather severity in the beginning of the fire season and low fire weather severity in the end (or vice versa). The SSRs in years of fire activity according to the LFDB on average were not higher than years without fire activity. It is therefore possible that this could be partially explained by the inability of the SSR to detect seasonal variation in fire weather patterns. Analysis of individual FWI System parameters on fire start dates (according to the LFDB) discovered, by and large, that most fire start dates had FWI System values in the very high and extreme classes despite the geographic differences between the weather stations and the study areas. This indicates FWI System parameters were generally applicable over a large geographic area (within 100–200 km) given similar topography and land features (e.g., Great Slave Lake).

The fuels within Nahanni National Park and the Mackenzie Bison Sanctuary were very similar and therefore not considered important in explaining the differences in fire regime characteristics. However, differences in fuel continuity, as it is influenced by topography and elevation, can potentially play an important role in fire spread and size patterns and will be discussed later. Experimental fires have been conducted in the various coniferous and deciduous fuel types common to the study locations (Stocks 1987, 1989; Alexander and Sando 1989; Alexander et al. 1991; Quintilio et al. 1991). Coniferous fuels in the boreal forest typically burn at higher intensities than deciduous fuels. Most area burned in the Canadian boreal forest burns as high-intensity crown fires, though high variation in fire intensity within each fire is also common.

Estimates of MFRIs are subject to various interpretations. Ideally the weighted MFRI and fire cycle should be the same, despite the fundamental differences in the approach, methodology, and data used to calculate them (Baker and Ehle 2001). Mean fire return intervals are often calculated at a point without knowing the actual size of the fire that is being recorded (temporal). In contrast, the area of past fire events are most often used to estimate fire cycles (spatial). Theoretically, each unit of area within a study area will experience an average of 1 fire during a period equal to 1 fire cycle, though some units will experience more or less. The weighted MFRI provides a way to estimate the fire cycle without knowing actual fire sizes (Baker and Ehle 2001). Mean fire return interval estimates from fire scar data are subject to numerous sources of error including missed scars, incorrect dendrochronology, loss of fire scar evidence over time, fire events that do not leave scars, and often inappropriate sampling intensities over a large study area. However, estimating fire cycles from known fire areas provides a method that is able to avoid many of these sources of error.

Our study used composite MFRIs and we assumed that all fire scars at one sample site, even though they may not all be found on any single tree, had burned the entire site. This is an advantageous method in boreal forest because individual trees missing fire scars are likely common. Unfortunately, composite MFRIs are also biased because they become smaller as the study area becomes larger (Arno and Petersen 1983). Due to the various sources of bias and a low sampling intensity for fire scar analysis, the weighted MFRI may not be a reliable estimate of the fire cycle for the study areas.

Inclusion of OS data for calculation of composite MFRIs has not been a common method in many fire history studies because sporadic or delayed regeneration following fire makes determining the exact time since last fire difficult (Houston 1973). Lodgepole pine and jack pine are fire-adapted species and typically have a serotinous cone that requires heat to open. In mature jack pine and lodgepole pine stands, cone serotiny typically gives way to abundant and rapid colonization of burned sites (Horton 1956, Chrosciewicz 1988). Use of OS data from jack pine and lodgepole pine may not be as accurate as using fire

Table 3. Fire frequency studies in western Canada.

Area	General location	Fire frequency (yr)	Reference
Yoho National Park	SE British Columbia	60–300+[a]	Tymstra 1991
Kootenay National Park	SE British Columbia	130[a]	Masters 1989, 1990
Glacier National Park	SE British Columbia	110[b]	Johnson et al. 1990
Kananaskis Watershed	SW Alberta	90[b]	Johnson and Larsen 1991
Banff National Park	SW Alberta	216[b]	Rogeau 1996
Mount Assiniboine Provincial Park	SW Alberta and SE British Columbia	266[b]	Rogeau 1996
West-central Alberta	West-central Alberta	65[b]	Van Wagner 1978
Prince Albert National Park	Central Saskatchewan	25–645[b]	Weir 1996
Wood Buffalo National Park	NW Alberta, S. Northwest Territories	38–63[b]	Larsen 1994
East of Great Slave Lake	South-central Northwest Territories	36–102[c]	Johnson 1979
Kluane National Park	SW Yukon Territory	133–234[a]	Hawkes 1983

[a] Fire return interval reported.
[b] Fire cycle reported.
[c] Expected recurrence time reported.

scar data for dating fires; however, the additional interval provides more data and may outweigh the consequences of fire intervals being slightly shorter than they actually are. Baker and Ehle (2001) suggest that OS data should be included because it is the most ancient and often the longest interval in the fire history record.

Weighted MFRIs calculated from fire scar data for the two study areas are typically less than the MFRIs and fire cycles reported for other studies in western Canada (Table 3). Where applicable, MFRIs or fire cycles are reported for the period of time most similar to this study.

Mean fire return interval estimates from fire scar data are typically conservative because of the loss of fire evidence with time due to the increased probability of a second fire occurrence destroying previous fire evidence, as well as increased probability of non-fire-caused mortality of relic trees with time (Van Wagner 1978). Weighted MFRIs calculated for Nahanni National Park and the Mackenzie Bison Sanctuary from fire scar data are similar, despite the differences in fire weather severity. However, the number of sample sites providing fire evidence in any given year was surprisingly different. The Mackenzie Bison Sanctuary had many more sites for most fire years than Nahanni National Park. Differences are beyond the magnitude anticipated from the larger study area and higher sampling intensity associated with the Mackenzie Bison Sanctuary and indicates the influence of other variables associated with fire characteristics.

Area burned from 1959 to 1999 as calculated from the LFDB is a conservative estimate because only fires greater than 200 ha are included in the database, and the potential for undetected and unreported fires exists. Fire cycles estimated from the AAB according to the LFDB are much longer than the weighted MFRIs calculated by fire scar data, particularly in Nahanni National Park. According to the LFDB, from 1959 to 1999 the Mackenzie Bison Sanctuary had a lower number of fires per unit area than Nahanni National Park did. However, the average fire size in the Mackenzie Bison Sanctuary is about 7 times larger (Table 2). These fire characteristics provide an explanation for the differences in the number of sites with fire scars observed between the two study areas. Nahanni National Park is characterized by a larger number of smaller-sized fires than the Mackenzie Bison Sanctuary, which is characterized by a smaller number of larger-sized fires. These characteristics would permit the study areas to have a similar MFRI and percent AAB. The increased frequency of sites with fire scars in major fire years for the Mackenzie Bison Sanctuary is associated with its larger average fire size, which increases the probability of discovering fire scars from a given year at different sample sites.

Differences in the MFRIs estimated from fire scar data, and the fire cycles estimated from the LFDB could be associated with inconsistencies between the data sources and the study areas. First, comparison of

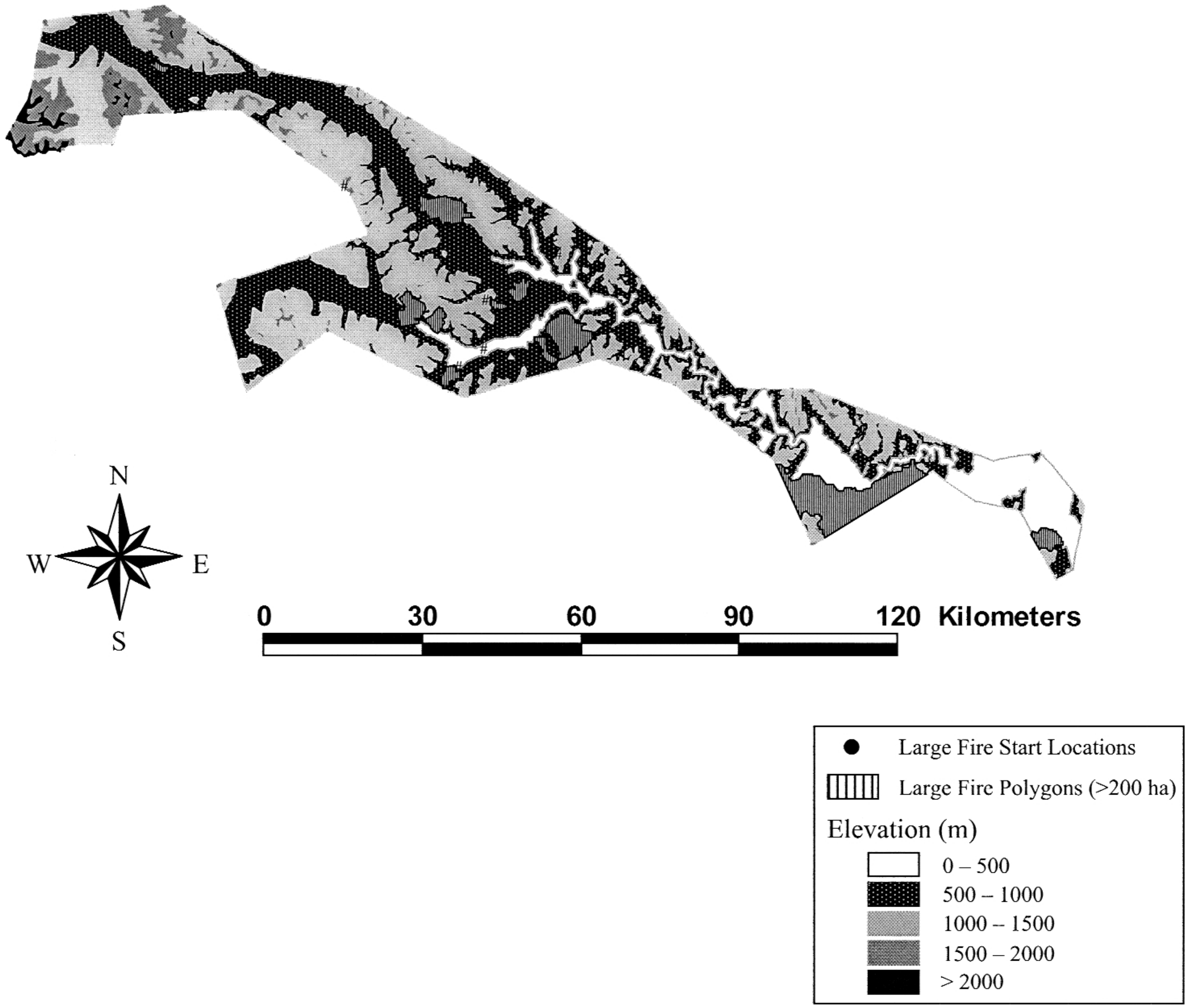

Figure 5. Elevation in Nahanni National Park, Northwest Territories, and large (<200 ha) fire locations.

the fire scar data and the LFDB is somewhat invalid because the two data sets correspond to different time periods. Flannigan et al. (1998) summarized numerous fire frequency studies in North America and northern Europe (including many of those discussed here) and reported that they all showed no change or a decrease in fire frequency in the 20th century. The authors suggest this anomaly may be explained by increased fire suppression effectiveness and precipitation since the Northern Hemisphere has experienced an increase in mean summer temperatures with the conclusion of the Little Ice Age (ca. 1850; Boden et al. 1990). These findings support the decrease in fire frequency found in both Nahanni National Park and the Mackenzie Bison Sanctuary using the LFDB (1959 to 1999), when compared to fire scar data (long term) for each study area. Study area size presents another potential problem in estimating fire return intervals and fire cycles. Johnson and Gutsell (1994) demonstrated the problem of large fires in comparatively small study areas. A large fire has the potential to skew the fire frequency distribution more severely in a small study area than in a large study area. As a rule of thumb, the largest fire or fire year should not have burned more than 33% of the study area. According to the LFDB (1959–1999) this rule was not broken in either study area by fires that started within their boundaries. However, analysis of the LFDB for all fires in the Northwest Territories between 1959 and 1999 indicate that 1.60% and 0.55% of all fire events (>200 ha) exceed the associated fire size limitation in Nahanni National Park and the Mackenzie Bison Sanctuary, respectively. Finally, the calculation of area burned from the LFDB assumed a fire point within the boundary of a study area had all of its area burned within the boundary of the study area. Therefore, if a fire advanced outside the study area, the area burned outside would be included in the AAB. Similarly, fire points outside the study area boundary were not included in the AAB, although the fire may have advanced into the study area. This was a necessary assumption because all fire boundaries were not available for this period. Given the small number of fires that started within the study area boundaries, a bias in either direction could cause significant deviations in the area burned as calculated by the LFDB.

Differences in average fire size in the two study areas could be related to topography. The effects of topography in mountainous areas have not been rigorously tested, although reductions in area burned and MFRI (Barrett et al. 1991) or older age class structure (Masters 1989) have been observed in areas of greater elevation relief compared to areas of moderate relief and/or lower elevation. Valley winds and slope winds have a significant effect on fire spread and can increase or decrease fire spread potential under various circumstances. However, fuel discontinuity caused by low-density fuels and bare ridge tops at high elevations undoubtedly limit fire size potential due to a fire's tendency to burn upslope. Comparison of the average number of fires per sampling site along an elevation gradient in Nahanni National Park failed to suggest that higher elevations had less fire activity. However, mapping of available fire polygons on elevation data suggests fire size is limited by mountaintops and bare ridges (Figure 5).

CONCLUSIONS

In most respects, the long-term fire regimes of Nahanni National Park and the Mackenzie Bison Sanctuary are quite similar despite their differences in geographic location, topography, and fire weather. Analysis of the FWI System codes and indices suggests high to extreme fire weather are more frequent in Nahanni National Park. However, elevation and aspect are likely a much stronger influence on fire weather, and therefore cause greater variation, than in the Mackenzie Bison Sanctuary. In both study areas, coarse-scale data indicate fuels are similar, though elevation gradients in Nahanni National Park potentially have an important influence in fuel continuity. Fire scar and stand origin data analysis from field sampling estimates long-term weighted MFRIs of approximately 25 years during the past 3 centuries in both study areas. In comparison, the LFDB estimates much longer fire cycles for a more recent period of time (1959 to 1999), based on a much smaller analysis period. Differences between MFRIs and fire cycles within each study area can be attributed to differences in the periods of analysis and methodological approach, and should provide valuable information to resource managers as to the effect more recent suppression policies and other anthropogenic influences have had on the fire regimes. Differences between the fire frequencies discovered during field sampling for fire scars in Nahanni National Park and the Mackenzie Bison Sanctuary are attributed to differences in the number of fires and the average fire sizes between the study areas. Ideally, information on fire regime characteristics will help provide a framework for prescribed fire programs directed to restore more natural disturbance patterns into the ecosystems.

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